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CONVERTING LIGNOCELLULOSIC BIOMASS TO HYDROCARBON FUELS

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CHE-136 EXAM PREVIEW

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Exam Preview:

1. The techno-economic analysis reported here uses nth-plant economics. The key assumption associated with nth-plant economics is that several plants using the same technology have already been built and are operating.
    a. True
    b. False
2. According to Section 3.2.1.1 of the reference material, the non-catalytic fast pyrolysis reactor outlet temperature is maintained at approximately ___°C.
    a. 250
    b. 350
    c. 500
    d. 750
3. According to the refence material, Area 800 has two process sub-areas for treating and recycling water discharges from the plant: a wastewater boiler, and a reverse osmosis unit for point treatment.
    a. True
    b. False
4. Using Table 1. Summary of nth-Plant Assumptions for Techno-Economic Analysis, what is the expected plant life that is used for the techno-economic analysis?
    a. 25 years
    b. 30 years
    c. 35 years
    d. 40 years

5. Using Figure 3. Chemical Engineering's Plant Cost Index data, which of the following years had the highest plant cost index?
    a. 1999
    b. 2000
    c. 2009
    d. 2008
6. According to the Area 600 section of the reference material, the steam turbine efficiencies are assumed to be __% and the generator mechanical efficiencies are assumed to be 97%.
    a. 75
    b. 78
    c. 80
    d. 85
7. According to the refence material, upgraded vapors from both in situ and ex situ configurations are quenched to condense and separate vapors from non-condensable gases.
    a. True
    b. False
8. With an expected 7,884 operating hours per year (90% on-stream factor/availability), the annual feedstock requirement is approximately 657,000 dry metric tonnes per year. The assumed on-stream factor allows approximately __ days of planned and unplanned downtime per year.
    a. 24
    b. 36
    c. 48
    d. 60
9. According to the reference material, the solids cooler consists of a vessel containing a series of ___-inch diameter A335 P91 tubes, and is sized based on the required heat duty and an assumed overall heat transfer coefficient of 31.7 Btu/hr-ft2-°F
    a. 1.0
    b. 1.5
    c. 2.5
    d. 3.0
10. Water losses from the cooling water system include evaporation, drift (water entrained in the cooling tower exhaust air), and tower basin blowdown. Drift losses were estimated to be 2.0% of the cooling water supply rate.
    a. True
    b. False

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Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbon Fuels

Thermochemical Research Pathways with *In Situ* and *Ex Situ* Upgrading of Fast Pyrolysis Vapors

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Harris Group Inc.

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Technical Report
NREL/TP-5100-62455
PNNL-23823
March 2015

Prepared for the U.S. Department of Energy Bioenergy Technologies Office

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Acronyms

ACCE	Aspen Capital Cost Estimator
ANL	Argonne National Laboratory
bbl	barrel
BETO	Bioenergy Technologies Office
BFW	boiler feed water
CE	*Chemical Engineering*
CFB	circulating fluidized bed
CFP	catalytic fast pyrolysis
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
COD	chemical oxygen demand
DCFROR	discounted cash flow rate of return
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPC	engineering, procurement, and construction
FCC	fluid catalytic cracking
FCI	fixed capital investment
FOB	freight on board
FP	fast pyrolysis
GGE	gallon gasoline equivalent
GHG	greenhouse gas
GJ	gigajoule
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
H_2S	hydrogen sulfide
HDS	hydrodesulfurization
HGF	hot gas filter
HHV	higher heating value
HP	high pressure
HT	hydrotreating
INL	Idaho National Laboratory
IRR	internal rate of return
ISBL	inside battery limits (of the plant)
kWh	kilowatt hour
LCA	life-cycle assessment
LCI	U.S. Life Cycle Inventory
LHV	lower heating value
LHSV	liquid hourly space velocity
LP	low pressure
MACRS	IRS Modified Accelerated Cost Recovery System
MFSP	minimum fuel selling price
MJ	megajoule
MM	million (e.g., MMBtu or $__MM)
MOC	material of construction
NG	natural gas
NO_2	nitrogen dioxide
NREL	National Renewable Energy Laboratory
OSBL	outside battery limits (of the plant)
PFD	process flow diagram
PNNL	Pacific Northwest National Laboratory
PSA	pressure swing adsorption
RO	reverse osmosis
RTO	regenerative thermal oxidizer
scf	standard cubic feet
SMR	steam methane reformer
SO_2	sulfur dioxide
TCI	total capital investment
TDC	total direct cost
TIC	total installed cost
TEA	techno-economic analysis
TPEC	total purchased equipment costs
VPU	vapor-phase upgrading
WGS	water gas shift
WHSV	weight hourly space velocity
WW	wastewater
WWT	wastewater treatment
ZnO	zinc oxide

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Executive Summary

This report was developed as part of the U.S. Department of Energy's Bioenergy Technologies Office's efforts to enable the development of technologies for the production of infrastructure-compatible, cost-competitive liquid hydrocarbon fuels from biomass. Specifically, this report details two conceptual designs based on *projected* product yields and quality improvements via catalyst development and process integration. It is expected that these research improvements will be made within the 2022 timeframe. The two conversion pathways detailed are (1) *in situ* and (2) *ex situ* upgrading of vapors produced from the fast pyrolysis of biomass. While the base case conceptual designs and underlying assumptions outline performance metrics for feasibility, it should be noted that these are only two of many other possibilities in this area of research. Other promising process design options emerging from the research will be considered for future techno-economic analysis.

Catalyst research and development, and the testing of catalysts in process-relevant equipment are the most important areas for the success of these two pathways. Some of the key objectives of catalyst development include the enabling of: (1) reduced coke and coke precursor formation, (2) reduced non-condensable species formation, (3) efficient hydrogen utilization, which ties into reduced aromatics in the product, reduced coke formation, and greater hydrodeoxygenation to allow higher carbon efficiency, (4) coupling (molecular combination) reactions to reduce the loss of smaller molecules to the gas phase and also enhance the formation of distillate range products, (5) attrition resistance of fluidizable catalysts, (6) catalyst maintenance and regeneration in fluidized and fixed bed configurations, and (7) catalyst longevity. It is expected that these developments will result in significant vapor quality improvements with reduced reactivity; upon condensation, the recovered organic phase can be hydroprocessed to fuel blendstocks at relatively less severe conditions compared to raw bio-oil from non-catalytic fast pyrolysis.

The conceptual process models for the two processes were developed using Aspen Plus. Based on the process models, n^{th}-plant process economics (in 2011 dollars) projecting minimum fuel selling prices (MFSP) were developed in Microsoft Excel using discounted cash flow rate of return analysis. Economic assumptions include a 30-year plant life, 40% equity financing with a 10% discount rate (internal rate of return), and the remaining 60% debt financed at 8% interest paid back over 10 years. Impacts of deviations from these financial assumptions are captured through sensitivity studies. Capital cost estimates for some of the key equipment were provided by Harris Group through vendor quotes or previously developed mechanical design tools. The plant size was assumed to be 2,000 dry metric tonnes per day using woody biomass feedstock cost. The feedstock is delivered with 10 wt % moisture, low ash (<1%), and nominal size of 2 mm to the throat of the reactor for $80/dry short ton per recent Idaho National Laboratory feedstock logistics design projections.

It should be noted that the base case processes assume a pressure of 120 psia (~8 bar), with hydrogen-enrichment of the fluidizing gases during fast pyrolysis and vapor upgrading. While this is assumed in the base cases, the ultimate decision about the operating pressure and fluidizing gas composition will be made based on their impacts on the economics. These impacts will be further quantified based on future experimental results. Table ES-1 shows key process conversion assumptions and metrics for both the *in situ* and *ex situ* upgrading cases, while the

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following Table ES-2 and Table ES-3 outline the economic summaries for the *in situ* and *ex situ* cases, respectively.

Both the *in situ* and *ex situ* conceptual designs, *using the underlying assumptions,* project MFSPs of less than $3.5/gallon gasoline equivalent (GGE) in 2022. The performance assumptions for the *ex situ* process were more aggressive with higher distillate (diesel-range) products. This was based on an assumption that more favorable reaction chemistry (such as hydrogenation, hydrodeoxygenation and coupling) can be made possible in a separate reactor where, unlike in an *in situ* upgrading reactor, one does not have to deal with catalyst mixing with biomass, char, and mineral matter/ash, which pose challenges to catalyst performance and maintenance. Natural gas was used for hydrogen production in the process model, but only when off-gases from the process were not sufficient to meet the needs; natural gas consumption is insignificant in both the *in situ* and *ex situ* 2022 base cases. Heat produced from the burning of char, coke, and off-gases is converted to electricity, with surplus electricity sold to the grid allowing a small reduction of less than 5¢/GGE in the MFSP.

There remain significant uncertainties in some of the assumptions which will be resolved with research progress and availability of more experimental data. Sensitivity analysis shows the impacts of many of the uncertainties on the projected costs, and opportunities for further cost reduction.

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Table ES-1. Key Process Metrics for the Proposed 2022 Target Cases

	In Situ	*Ex Situ*
Fast Pyrolysis Intermediate		
Gas Species – CO, CO_2, C_1-C_4 (wt % of dry biomass)	N/A*	13
Organics (wt % of dry biomass)	N/A*	64
Water (wt % of dry biomass)	N/A*	11
Char (wt % of dry biomass)	N/A*	12
Vapor Upgrading Product		
Gas (wt % of dry biomass)	23	23
Aqueous Phase (wt % of dry biomass)	29	30
Carbon Loss (% of C in biomass)	*2.1*	*1.3*
Organic Phase (wt % of dry biomass)	28	27
H/C Molar Ratio	*1.5*	*1.6*
Oxygen (wt % in organic phase)	*10.5*	*6.4*
Carbon Efficiency (%)	*44*	*44*
Solid Losses, Char + Coke (wt % of dry biomass)	12 + 8	12 + 8
Final Fuel Blendstock		
Yield (%, w/w dry biomass)	24	25
Hydroprocessing Carbon Efficiency (%, not including light dissolved gases in feed and product; assumed efficiency scaling by O content in organic liquid feed—higher efficiency for lower O)	91	94
Overall Carbon Efficiency (% of C in biomass)	40.4	41.5
Overall Carbon Efficiency (% of C in biomass + NG)	40.4	41.5
Total Product (GGE/dry U.S. ton)	75	78
Gasoline-Range Product (gallons/dry U.S. ton)	56	36
Diesel-Range Product (gallons/dry U.S. ton)	18	39
Gasoline/Diesel-Range Product (% GGE basis)	73/27	45/55
Oxygen Content in Cumulative Product (wt %)	0.5	0.4
Minimum Fuel Selling Price ($/GGE)	3.46	3.31
Natural Gas† and Electricity		
Natural Gas Energy Input (% of biomass, LHV basis)	0.1	0.2
Natural Gas Cost Contribution (¢/GGE)	0.1	0.2
Surplus Electricity Credit (¢/GGE)	4	3
Fuel Blendstock Production Efficiencies (various bases)		
Biomass Feedstock (%, LHV basis)	54	57
Biomass + Natural Gas† (%, LHV basis)	54	57
Biomass + Natural Gas† + Electricity (%, LHV basis, all electrical energy converted to heat)	56	57

*Not applicable for *in situ* case. †Negligible natural gas used in process designs.

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Table ES-2. Economic Summary for *In Situ* Base Case (2022 Target)

Process Engineering Analysis for Hydrocarbon Fuel Production via In Situ Upgrading of Fast Pyrolysis Vapors

Potential Research-Driven Pathway for Cost-Competitiveness by 2022
2,000 Dry Metric Tonnes Biomass per Day
All Values in 2011$

Minimum Fuel Selling Price (MFSP) **$3.37 /Gallon Gasoline Blendstock**
$3.85 /Gallon Diesel Blendstock
$3.46 /Gallon Gasoline Equivalent (GGE)

Gasoline Blendstock Production	40.4 MM Gal per Year	55.8 Gal per Dry US Ton Feedstock	
Diesel Blendstock Production	13.4 MM Gal per Year	18.5 Gal per Dry US Ton Feedstock	
Total Gasoline Equivalent Production	54.2 MM GGE per Year	74.9 GGE per Dry US Ton Feedstock	
Delivered Feedstock Cost	$80.00 per Dry U.S. Ton (Includes Capital Up to Throat of Pyrolyzer)		
Internal Rate of Return (After-Tax)	10.0%		
Equity Percent of Total Investment	40.0%		
On-Stream Factor	90.0%		

Capital Costs	
100: Feedstock (Additional Dryer & Blower Only)	$500,000
200: Fast Pyrolysis & Vapor Upgrading	$92,480,000
300: Pyrolysis Vapor Quench	$22,390,000
400: Hydroprocessing & Separation	$32,540,000
500: Hydrogen Plant	$70,640,000
600: Steam System & Power Generation	$52,450,000
700: Cooling Water & Other Utilities	$9,450,000
800: Water Management	$17,160,000
Total Installed Equipment Cost (TIC)	$297,610,000
Land (115 Acres at $14000 per Acre)	$1,600,000
Site Development	$14,790,000
(% of ISBL)	10.0%
Indirect Costs & Project Contingency	$194,990,000
(% of TIC)	65.5%
Fixed Capital Investment (FCI)	$519,960,000
Working Capital	$26,000,000
Total Capital Investment (TCI)	$545,960,000
Loan Interest Rate	8.0%
Loan Term (Years)	10
Total Installed Equipment Cost per Annual GGE	$5.49
Fixed Capital Investment per Annual GGE	$9.59
Plant Operating Hours per Year	7884
On-Stream Percentage	90.0%
Efficiencies	
Carbon Eff. to Organic Liquid after In Situ Upgrade	44%
Carbon Eff. for Hydroprocessing of Organic Liquid	91%
Carbon Eff. for Overall Process (Biomass to Fuel)	40.4%
Overall Plant Efficiency - HHV %	54.1%
Overall Plant Efficiency - LHV %	54.3%

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Operating Costs (¢ / GGE Product)	
Feedstock	106.9
Natural Gas	0.1
Catalysts	54.0
Sand	-
Other Raw Materials	1.1
Waste Disposal	1.8
Purchased Electricity	-
Fixed Costs	46.9
Electricity Coproduct Credit	(4.4)
Capital Depreciation	48.0
Average Income Tax	19.3
Average Return on Investment	72.5

Operating Costs ($ / Year)	
Feedstock	$57,940,000
Natural Gas	$100,000
Catalysts	$29,290,000
Sand	$0
Other Raw Materials	$610,000
Waste Disposal	$1,000,000
Purchased Electricity	$0
Fixed Costs	$25,410,000
Electricity Coproduct Credit	-$2,360,000
Capital Depreciation	$26,000,000
Average Income Tax	$10,480,000
Average Return on Investment	$39,300,000
Total Plant Electricity Usage (kW)	43,173
Electricity Produced on Site (kW)	48,291
Electricity Purchased from Grid (kW)	0
Electricity Sold to Grid (kW)	5,117
Plant Electricity Use (kWh /GGE)	6.28

Specific Operating Conditions		
Feed Rate	Dry Tonnes / Day	2,000
	Dry Tons / Day	2,205
Feedstock Cost	$/Dry Ton	$80.00
	$/Moisture+Ash Free Ton	$80.74

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Table ES-3. Economic Summary for *Ex Situ* Base Case (2022 Target)

Process Engineering Analysis for Hydrocarbon Fuel Production via Ex Situ Upgrading of Fast Pyrolysis Vapors

Potential Research-Driven Pathway for Cost-Competitiveness by 2022
2,000 Dry Metric Tonnes Biomass per Day
All Values in 2011$

Minimum Fuel Selling Price (MFSP) **$3.26 /Gallon Gasoline Blendstock**
$3.68 /Gallon Diesel Blendstock
$3.31 /Gallon Gasoline Equivalent (GGE)

Gasoline Blendstock Production	25.9 MM Gal per Year	35.7 Gal per Dry US Ton Feedstock	
Diesel Blendstock Production	27.9 MM Gal per Year	38.6 Gal per Dry US Ton Feedstock	
Total Gasoline Equivalent Production	56.5 MM GGE per Year	78.0 GGE per Dry US Ton Feedstock	
Delivered Feedstock Cost	$80.00 per Dry U.S. Ton (Includes Capital Up to Throat of Pyrolyzer)		
Internal Rate of Return (After-Tax)	10.0%		
Equity Percent of Total Investment	40.0%		
On-Stream Factor	90.0%		

Capital Costs	
100: Feedstock (Additional Dryer & Blower Only)	$430,000
200: Fast Pyrolysis & Vapor Upgrading	$126,940,000
300: Pyrolysis Vapor Quench	$24,220,000
400: Hydroprocessing & Separation	$29,110,000
500: Hydrogen Plant	$66,760,000
600: Steam System & Power Generation	$47,900,000
700: Cooling Water & Other Utilities	$9,280,000
800: Water Management	$12,910,000
Total Installed Equipment Cost (TIC)	$317,540,000
Land (115 Acres at $14000 per Acre)	$1,600,000
Site Development	$18,070,000
(% of ISBL)	10.0%
Indirect Costs & Project Contingency	$210,580,000
(% of TIC)	66.3%
Fixed Capital Investment (FCI)	$561,550,000
Working Capital	$28,080,000
Total Capital Investment (TCI)	$589,630,000
Loan Interest Rate	8.0%
Loan Term (Years)	10
Total Installed Equipment Cost per Annual GGE	$5.62
Fixed Capital Investment per Annual GGE	$9.94
Plant Operating Hours per Year	7884
On-Stream Percentage	90.0%
Efficiencies	
Carbon Eff. to Organic Liquid after Ex Situ Upgrade	44%
Carbon Eff. for Hydroprocessing of Organic Liquid	94%
Carbon Eff. for Overall Process (Biomass to Fuel)	41.5%
Overall Plant Efficiency - HHV %	56.4%
Overall Plant Efficiency - LHV %	56.6%

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Operating Costs (¢ / GGE Product)	
Feedstock	102.6
Natural Gas	0.2
Catalysts	36.2
Sand	0.5
Other Raw Materials	1.1
Waste Disposal	1.7
Purchased Electricity	-
Fixed Costs	47.7
Electricity Coproduct Credit	(2.6)
Capital Depreciation	49.7
Average Income Tax	19.8
Average Return on Investment	74.6

Operating Costs ($ / Year)	
Feedstock	$57,940,000
Natural Gas	$100,000
Catalysts	$20,430,000
Sand	$300,000
Other Raw Materials	$610,000
Waste Disposal	$930,000
Purchased Electricity	$0
Fixed Costs	$26,950,000
Electricity Coproduct Credit	-$1,480,000
Capital Depreciation	$28,080,000
Average Income Tax	$11,200,000
Average Return on Investment	$42,150,000
Total Plant Electricity Usage (kW)	41,046
Electricity Produced on Site (kW)	44,247
Electricity Purchased from Grid (kW)	0
Electricity Sold to Grid (kW)	3,201
Plant Electricity Use (kWh /GGE)	5.73

Specific Operating Conditions		
Feed Rate	Dry Tonnes / Day	2,000
	Dry Tons / Day	2,205
Feedstock Cost	$/Dry Ton	$80.00
	$/Moisture+Ash Free Ton	$80.74

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1 Introduction

1.1 Motivation and Background

Fast pyrolysis-based biomass conversion processes have the potential to offer high efficiencies for the production of liquid transportation fuels such as gasoline and diesel blendstocks, or petroleum refinery compatible intermediates for conversion to liquid fuels. The process involves rapid heating of biomass particles in the absence of air at approximately 500°C with the production of permanent gases, vapors including water, and solids including mineral matter and char. The liquid product fraction collected after the condensation of the vapors is also known as bio-oil or pyrolysis oil [1]. The attractiveness of such conversion lies in the yield of a significant proportion of products directly in the liquid phase.

However, challenges lie in the modification of the quality of the liquid product to make it compatible with the current transportation fuels infrastructure and end use vehicles, which are predominantly operated with liquid hydrocarbon fuels. The source of this challenge is inherent to biomass feedstocks which usually contain substantial quantities of oxygen (~40 wt % in wood). Fast pyrolysis of such feedstocks yields oxygenated compounds that can react easily, posing a variety of processing challenges. Catalytically reducing the oxygen content, during or immediately after fast pyrolysis *while the products are still in the vapor phase*, can ease downstream processing challenges and provide many of the benefits outlined in this design report.

Included in this report are descriptions of process models and assumptions for two related conversion pathways: (1) *in situ* (also referred to elsewhere as catalytic fast pyrolysis), where catalytic vapor upgrading happens within the fast pyrolysis reactor, and (2) *ex situ* (also referred to elsewhere as vapor phase upgrading), where catalytic vapor upgrading happens in a separate reactor following the fast pyrolysis reactor. An *in situ* system includes catalytic upgrading within the circulating fluidized bed fast pyrolysis reactor system. This has the potential to reduce capital costs by precluding the use of additional vapor phase upgrading reactors and potentially a hot gas filter (HGF) in an *ex situ* configuration. However, the catalyst needs to survive in a considerably more challenging environment in an *in situ* reactor because of mixing with other solids including inhibitory mineral matter, char, and biomass. These other solids impose challenges for maintaining physical and chemical integrity required for a functional catalyst. In an *ex situ* configuration the elimination of such detriments can allow more focus on the achievable chemistry rather than on the mitigation of impacts of other solids. It is to be noted that a hybrid of an *in situ* configuration using relatively inexpensive catalyst followed by *ex situ* upgrading reactors may also be economically justifiable.

The *in situ* and *ex situ* catalytic fast pyrolysis vapor upgrading processes were identified by the U.S. Department of Energy's (DOE) Bioenergy Technologies Office (BETO) as research pathways for enabling the production of cost-competitive liquid transportation fuels from biomass [2, 3]. It should be noted that although circulating catalyst in fluidized beds were used as the basis for the conceptual designs, research and development will also consider other catalysts, including those with noble metals, suitable for use in *ex situ* fixed bed systems. Such design variations will be captured in future techno-economic analysis (TEA) and will leverage experimental data as they become available. Overall, this report captures envisioned process performances to be achieved for cost-competiveness by 2022. Intermediate research targets

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leading up to 2022 were developed subsequently for publication in BETO's Multi-Year Program Plan, using key assumptions in this report as the foundation; those metrics will be updated annually with research realities, and necessary deviations from the current design basis.

Numerous experimental studies have been conducted in the area of fast pyrolysis vapor upgrading, particularly with zeolite catalysts, and most commonly with HZSM-5 [4, 5, 6, 7]. Figure 1 illustrates how better quality, reflected by lower oxygen content, follows an inverse trend with liquid product yield. Lower biomass to catalyst ratios, corresponding to higher catalyst activity, result in better product quality at the expense of yield; potential organic liquid yield is lost to gas phase products, water, and coke. Since both improved bio-oil quality and high yields are necessary for economic viability, significant catalyst improvements will be necessary to break out of the performance mold demonstrated by current catalysts. In this regard it should be noted that performance in continuous systems with regeneration may be significantly better than in batch systems [8]. Some discussion of catalysts and associated references are provided in Section 3.2.1.6.

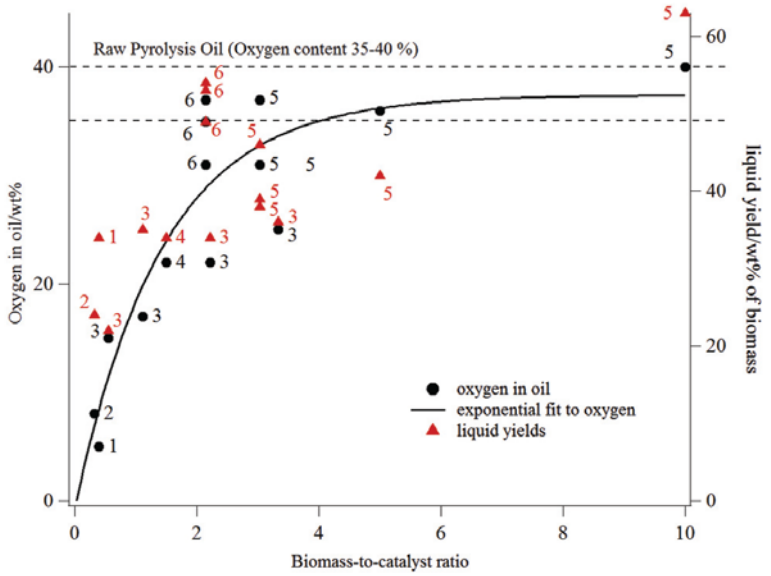

Figure 1. Literature results for yields and oxygen content in bio-oil after catalytic upgrading of fast pyrolysis vapors using HZSM-5 as a function of biomass-to-catalyst ratio. (Reproduced with permission from Mukarakate et al. [4].)

In this respect, modified zeolites and other families of catalysts [9] will need to be developed. Some of the key objectives of catalyst development include the enabling of: (1) reduced coke and coke precursor formation, (2) reduced non-condensable species formation, (3) efficient hydrogen utilization, which ties into reduced aromatics in the product, reduced coke formation, and greater hydrodeoxygenation to allow higher carbon efficiency, (4) coupling (molecular combination) reactions to reduce the loss of smaller molecules to the gas phase and also enhance the formation of distillate range products, (5) attrition resistance of fluidizable catalysts, (6) catalyst maintenance and regeneration in fluidized and fixed bed configurations, and (7) catalyst longevity. It is expected that these developments will result in significant vapor quality improvements with reduced reactivity; upon condensation the recovered organic phase can be

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hydroprocessed to fuel blendstocks at relatively less severe conditions compared to raw bio-oil from non-catalytic fast pyrolysis. Note that quality is a function of not only the oxygen content, but also the types of remaining oxygenated species and functional groups in the oil, e.g. acids are more detrimental than phenol.

Some hydrogen reactivity during vapor upgrading will be necessary for higher organic liquid yields; hydrogen reactivity will need to be facilitated by the inclusion of metals within catalyst formulations. In order to help hydrogen reactivity in the vapor phase, the proposed designs for both *in situ* and *ex situ* configurations operate at slightly elevated pressures and include hydrogen in the fluidizing gas, with the aim of maintaining a nominal hydrogen partial pressure of 72–95 psia (5–6.6 bar) at the various reactor inlets (fast pyrolysis, *in situ* catalytic fast pyrolysis, and *ex situ* vapor phase upgrading). This process design decision does not require significant modifications to the vessel thicknesses of refractory-lined fluidized reactors operated at near ambient pressures. This inference was based on a design-study by Worley and Yale [10] who concluded that the minimum vessel wall thicknesses necessary to maintain mechanical integrity during fabrication and handling would be consistent with wall thicknesses of vessels designed for 150 psia. That study is the basis for the cost of fluidized reactors in this report. It is important to distinguish this process from conventionally known biomass hydropyrolysis processes operated at significantly higher pressures of 300–525 psia (20–35 bar) and a temperature range of 350°C–480°C [11].

The conceptual designs in this report assume stand-alone plants for the production of gasoline- and diesel-range blendstocks. It may be possible to produce sufficiently upgraded intermediates acceptable to petroleum refiners for further processing immediately after pyrolysis vapor upgrading. In such cases, it may be possible to further reduce or eliminate the on-site hydroprocessing facilities assumed in this report. However, such configurations will only be feasible after careful scrutiny of product quality and buy-in from refiners regarding compatibility with refinery unit operations [12].

1.2 Techno-Economic Analysis Approach

The general approach used in the process design, process model, and economic analysis is depicted in Figure 2. This design report includes information from previously published reports including those by the National Renewable Energy Laboratory (NREL) and Pacific Northwest National Laboratory (PNNL), reviews of commercially available technologies, process modeling using Aspen Plus software, equipment cost estimation through vendor quotes and Aspen Capital Cost Estimator (ACCE) software, and discounted cash flow analysis. The techno-economic analysis ultimately provides a minimum fuel selling price (MFSP) based on the financial assumptions in Table 1.

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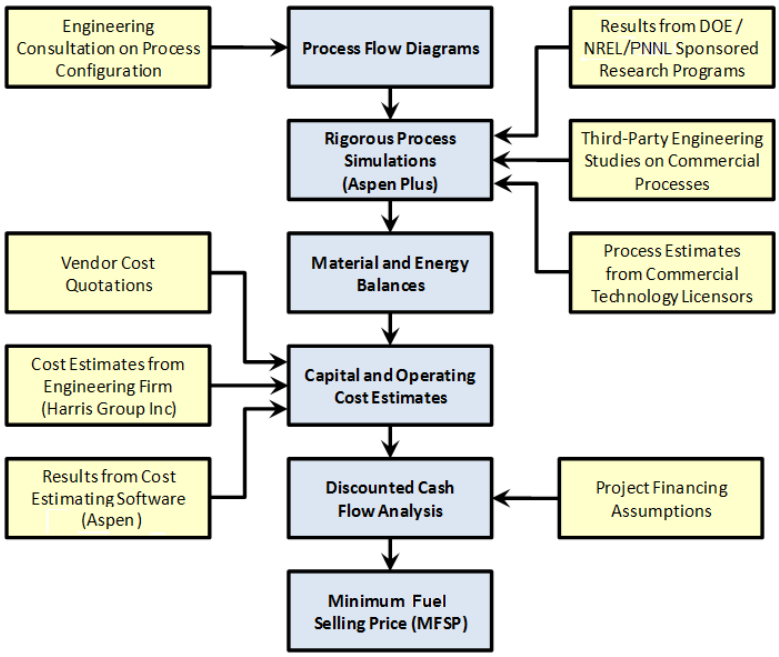

Figure 2. Approach for *in situ* and *ex situ* fast pyrolysis vapor upgrading process design and analysis

Aspen Plus Version 7.2 was used to develop mass and energy balances for the process. The plant operations are separated into eight major process areas:

- Area 100: Feed handling and drying
- Area 200: Fast pyrolysis and vapor upgrading
- Area 300: Pyrolysis vapor quench and product recovery
- Area 400: Hydroprocessing and product separation
- Area 500: Hydrogen plant
- Area 600: Steam system and power generation
- Area 700: Cooling water and other utilities
- Area 800: Wastewater management and recycle.

1.3 Definition of nth-Plant Economics

The techno-economic analysis reported here uses nth-plant economics. The key assumption associated with nth-plant economics is that several plants using the same technology have already been built and are operating. In other words, the assumption reflects a future in which a successful industry has been established with many operating plants. Because the techno-economic model is a tool used primarily for (1) studying new process technologies or (2) comparing integrated processes in order to comment on their relative economic impact, it is prudent to ignore artificial inflation of project costs associated with risk financing, longer start-

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ups, equipment overdesign, and other costs associated with pioneer plants, as these overshadow the real economic impact of advances in conversion science or process engineering research. At the very least, n^{th}-plant economics should help to provide justification and support for early technology adopters and pioneer plants about longer-term prospects.

Because equipment costs in this design report have been estimated explicitly, the n^{th}-plant assumptions apply primarily to the factored cost model used to determine the total capital investment from the purchased equipment cost and to the assumptions applied for plant financing. The n^{th}-plant assumption also applies to operating parameters, such as process uptime and start-up time. A summary of the n^{th}-plant assumptions applied in this report are listed in Table 1. These financial assumptions are consistent with assumptions used for other economic analyses done for DOE's Bioenergy Technologies Office, with some deviations to reflect the uniqueness of the current processes.

Table 1. Summary of n^{th}-Plant Assumptions for Techno-Economic Analysis

Description of Assumption	Assumed Value
Internal rate of return (IRR)	10%
Plant financing by equity/debt	40%/60% of total capital investment
Plant life	30 years
Income tax rate	35%
Interest rate for debt financing	8.0% annually
Term for debt financing	10 years
Working capital cost	5.0% of fixed capital investment (excluding land purchase cost)
Depreciation schedule	7-year MACRS schedule [13]
Steam plant depreciation	20-year MACRS schedule [13]
Construction period (spending schedule)	3 years (8% Y1, 60% Y2, 32% Y3)
Plant salvage value	No value
Start-up time	6 months
Revenue and costs during startup	Revenue = 50% of normal Variable costs = 75% of normal Fixed costs = 100% of normal
On-stream percentage after startup	90% (7,884 operating hours per year)

1.4 Estimation of Capital Costs

Capital costs were estimated using a variety of resources. For sub-processes that utilize well-developed technologies and can be purchased as modular packages (e.g., steam reforming unit and refrigeration), an overall package cost was used instead of the sum of costs for individual pieces of equipment. Costs for common process equipment (e.g., tanks, drums, pumps, and simple heat exchangers) were estimated using ACCE costing software. Fluidized bed equipment (e.g., fast pyrolysis and *in situ* and *ex situ* reactors) specific to this process was estimated by

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Harris Group using a mechanical design spreadsheet tool previously developed for gasifier costs [10]; design parameters were modified based on flow rates from the Aspen Plus process simulations and additional process inferences from mature fluid catalytic cracking (FCC) systems available in literature [14]. Hydroprocessing reactor costs were developed using ACCE, with some vendor quotes obtained by Harris Group used as supporting information. Some other major equipment costs, such as for the hydrogen compressors, were also obtained from vendors. Further details of equipment cost assumptions are provided under individual process areas in Section 3.

The original (base) purchased equipment costs reflect the base case for equipment size and cost year. Equipment sizes required for the process may vary from the original base case, requiring adjustment of the equipment costs. Instead of re-pricing equipment after minor changes in size, exponential scaling is applied to adjust the purchased equipment costs using Equation 1:

$$Scale\text{-}Up\ Equipment\ Cost\ =\ Base\ Equipment\ Cost\left(\frac{Scale\text{-}Up\ Capacity}{Base\ Capacity}\right)^{n} \qquad \text{(Eq. 1)}$$

The characteristic scaling exponent, n, is typically in the range of 0.6 to 0.7 for process equipment. The sizing parameters are based on a characteristic of the equipment related to production capacity, such as inlet flow for a process vessel or heat transfer duty for a heat exchanger. Equation 1 assumes that all other process parameters (pressure, temperature, etc.) remain constant relative to the base case. Scaling exponents were determined from the following sources:

- Vendors' estimates of scaling exponent or inference from vendor quotes when multiple quotes were available for equipment of various processing capacities
- Development of correlations by multiple estimates from the ACCE software
- Standard reference from published sources such as Garrett [15], Peters, Timmerhaus, and West [16], and Perry et al. [17].

When cost data were not available in 2011 dollars, costs were adjusted with *Chemical Engineering's* (CE) Plant Cost Index [18] using Equation 2:

$$Corrected\ Equipment\ Cost\ =\ Base\ Equipment\ Cost\left(\frac{2011\ Cost\ Index\ Value}{Base\ Year\ Cost\ Index\ Value}\right) \qquad \text{(Eq. 2)}$$

The CE indices used in this study are listed and plotted in Figure 3. The index data show a sharp increase after 2003 due to increases in global steel demand and a dip in 2009 due to the global recession. An intermediate 2014 index was used for 2014 corresponding to roughly the time when most of the recent cost quotes were obtained.

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Year	Index	Year	Index
1990	357.6	2003	402.0
1991	361.3	2004	444.2
1992	358.2	2005	468.2
1993	359.2	2006	499.6
1994	368.1	2007	525.4
1995	381.1	2008	575.4
1996	381.7	2009	521.9
1997	386.5	2010	550.8
1998	389.5	2011	585.7
1999	390.6	2012	584.6
2000	394.1	2013	567.3
2001	394.3	2014	573.9
2002	395.6	(Mid-Year)	

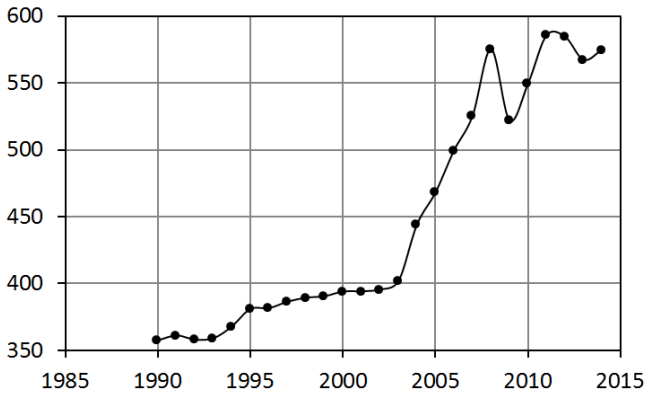

Figure 3. *Chemical Engineering's* Plant Cost Index data

Once the total purchased equipment costs (TPEC) were determined, scaled, and time-corrected, an equipment installation factor was applied to estimate the total installed cost (TIC) for the equipment or process unit including associated piping, instrumentation and controls, electrical systems, buildings, yard improvements, and direct labor per Equation 3, where $f_{Installation}$ is the installation factor:

$$Total\ Installed\ Cost\ (TIC) = f_{Installation} * Total\ Purchased\ Equipment\ Cost\ (TPEC) \quad \text{(Eq. 3)}$$

Where possible, specific installation factors from vendor quotes, ACCE, or published data [19] were applied to equipment or process units to estimate the TIC. Details for TPEC, installation factors, and TIC values for each process area are presented in Section 3.

Once the scaled TICs were determined, overhead and contingency factors were applied to determine a total capital investment (TCI) cost. The TCI, along with plant operating expenses, serves as the basis for the discounted cash flow analysis. The discounted cash flow analysis then yields the MFSP on a gallon gasoline equivalent (GGE) basis, a metric by which this conceptual process performance can be compared to alternate fuel production designs.

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2 Plant Design Basis

2.1 Feedstock and Plant Size

The dry basis elemental composition of the feedstock, shown in Table 2, is identical to previous NREL and PNNL design reports [20, 21]. The composition was originally assumed to come from pulpwood. Recent feedstock logistics work at the Idaho National Laboratory (INL) suggests that the use of blended material may be required to meet a cost target of $80/dry U.S. ton while still meeting these specifications [22]. For the purpose of this report, it is assumed that any blended material provided to meet this feedstock elemental composition will not adversely affect fast pyrolysis conversion efficiencies. Ongoing studies being conducted jointly by INL, NREL, and PNNL will provide experimental evidence of the impact of blended feedstocks on fast pyrolysis and gasification processes. Future TEA will be modified to reflect conversion impacts inferred from such studies.

Table 2. Ultimate Analysis of Woody Biomass Feedstock

Component	Weight % (Dry Basis [20, 21])
Carbon	50.94
Hydrogen	6.04
Nitrogen	0.17
Sulfur	0.03
Oxygen	41.90
Ash	0.92
Heating value[a] (Btu/lb)	8,601 HHV
	7,996 LHV

[a] Calculated using the Aspen Plus Boie correlation.

The current feedstock moisture specification is 10 wt %, unlike the previous studies [20, 21] where a moisture content of 30 wt % was assumed at the plant gate. The cost of the material provided to the fast pyrolysis reactor (for *ex situ*) or catalytic fast pyrolysis reactor (for *in situ*) is $80/dry U.S. ton [22]. This includes all feedstock logistics including the delivery of a nominal particle size of 2 mm into the reactors.

The design capacity for this study is 2,000 dry metric tonnes per day (2,205 dry tons per day), which matches that of previous design reports. With an expected 7,884 operating hours per year (90% on-stream factor/availability), the annual feedstock requirement is approximately 657,000 dry metric tonnes per year (724,000 dry tons per year). The assumed on-stream factor allows approximately 36 days of planned and unplanned downtime per year.

The delivered feedstock cost was estimated using INL's model. This cost of $80 per dry ton includes all capital costs, operating costs, and dry matter losses associated with feed delivery, drying, and handling as determined by INL. The only additional equipment included with the plant costs is a cross-flow dryer, which was included for warming up the feedstock using flue gas and allowing for drying contingency during the wet weather.

It should be noted that the term mineral matter is used throughout the text to refer to the inorganic content in the feedstock, while the term ash is used to refer to the residual inorganic product after the combustion of biomass.

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2.2 Process Overview

A block flow diagram of the current design is shown in Figure 4. A high level description of the conversion steps and their main purposes are presented below, with further details in Section 3.

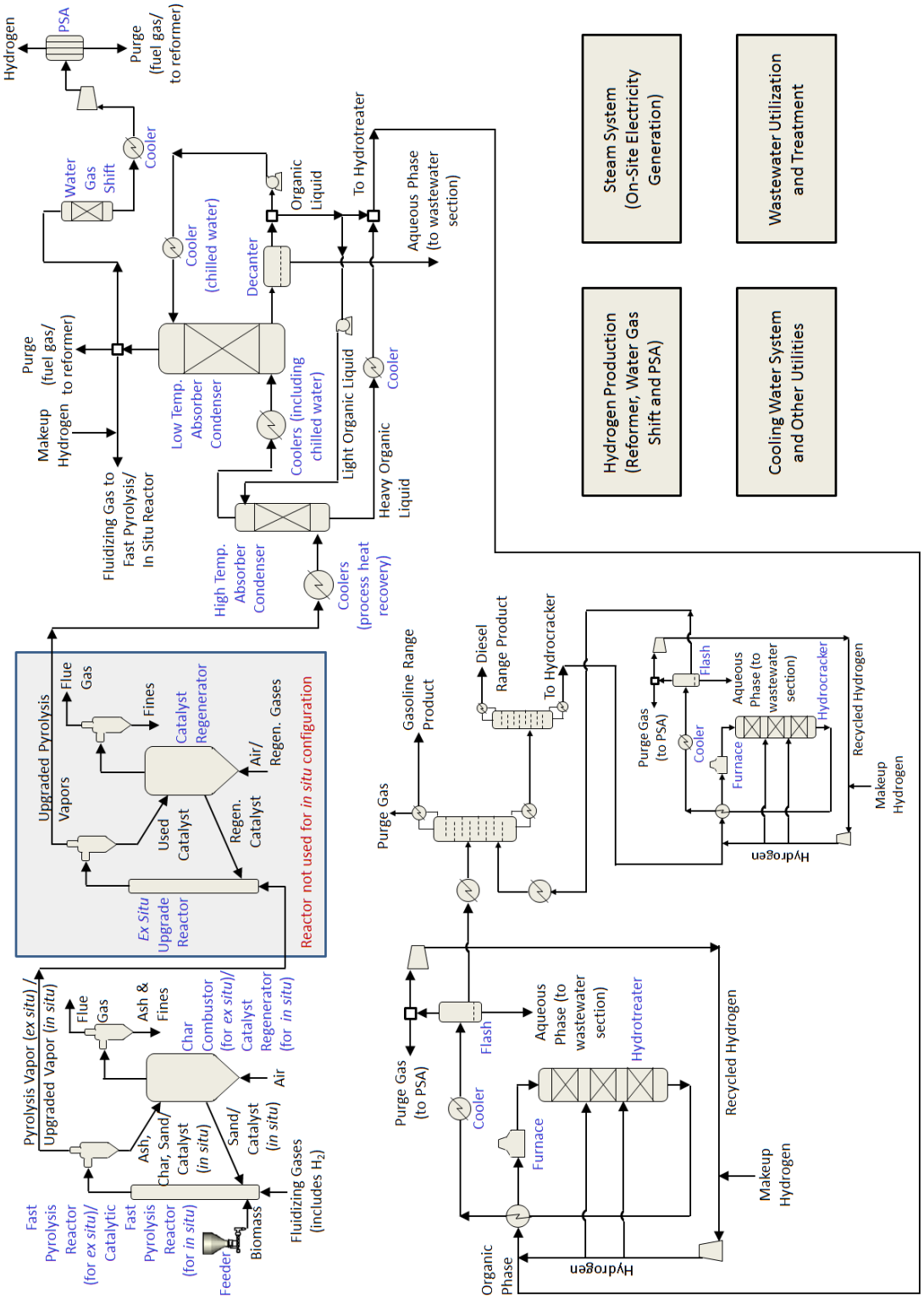

Figure 4. Simplified flow diagram for the conversion processes

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- *Feed handling and preparation.* The modeled biomass feedstock has an ultimate analysis shown in Table 2. The assumed moisture content is 10 wt %, with an ash content of <1% and nominally sized to 2 mm for the fast pyrolysis reactor. A cross-flow dryer is included in the system to allow warming up of the feed prior to feeding in to the reactor, using process waste heat. This also allows for contingencies during wet weather when additional feed drying may be necessary. The feedstock is delivered at $80/dry U.S. ton.
- *Fast pyrolysis with in situ or ex situ vapor upgrading.* The *in situ* configuration combines fast pyrolysis and catalytic vapor upgrading within the same reactor, while the *ex situ* configuration has a front end non-catalytic fast pyrolysis reactor followed by a separate *ex situ* catalytic vapor upgrading reactor system. The *ex situ* reactor is not exposed to biomass associated solids (biomass, char, and mineral matter) beyond the unintended entrainment of fine material such as attrited solids and some mineral matter/ash, making it a more benign environment for catalyst performance and maintenance. It is also possible for the *ex situ* reactor to have a fixed bed configuration. In this report, all three reactors, (1) non-catalytic fast pyrolysis, (2) catalytic fast pyrolysis or *in situ* upgrading, and (3) separate vapor phase upgrading or *ex situ* reactors, are dual circulating fluidized bed (CFB) systems. Each has an entrained flow reactor and a second fluidized bed combustor for char/coke combustion, similar to FCC reactors. In the *in situ* and *ex situ* catalytic systems the combustor also serves as a catalyst regenerator by burning off coke deposits. In the conceptual designs presented, all three reactors operate at 500°C (932°F) reactor outlet temperatures, with short residence times (<2 s), under approximately 72–95 psia (5–6.6 bar) of hydrogen partial pressure, and 120 psia (~8 bar) total pressure. The catalytic vapor upgrading step is designed to help reduce oxygen content in the produced bio-oil organic liquid fraction, making it less reactive and amenable to hydroprocessing under less severe conditions into fuel blendstocks. It should be noted that the above parameters are for one possible design, which are used for our base cases. The fluidizing gas composition and pressure assumed for the base case may be altered as benefits are analyzed with further catalyst development and experiments. Other design variations may include hot gas filters, fixed bed vapor phase upgrading reactor systems, and catalysts other than zeolites. Such changes can alter process conditions, including operating temperatures and catalyst regeneration protocols.
- *Pyrolysis vapor quench.* Upgraded vapors from both *in situ* and *ex situ* systems are quenched to separate vapors from non-condensable gases. The base case assumes that there will remain concerns about fouling of indirect heat exchange equipment during the condensation of the heavy fraction of the organic vapors. A first absorber/condenser is thus used to recover the heavy organic fraction after vapors are cooled to the stream's predicted dew point. The absorber/condenser is followed by indirect heat exchange to cool down the remaining vapor. This stream then enters a second absorber/condenser where a light organic phase and an aqueous phase are condensed from non-condensable gases. The organic fraction is sent for hydroprocessing, while the aqueous fraction is sent to wastewater treatment. The majority of the non-condensable gases are recycled to the fast pyrolysis reactor for fluidization. The remaining gas is used for hydrogen production via sour water gas shift and pressure swing adsorption (PSA). Economic impacts of the inability to use any indirect heat exchange for energy recovery from the hot upgraded

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vapors are discussed later in Section 5 as part of sensitivity analysis; equipment configuration modifications for such scenarios were not modeled in this study.

- *Hydroprocessing and product separation.* The organic liquid fraction is sent to a hydrotreater for deoxygenation and saturation of a portion of the products to reduce aromatic content. Note that the separation of the aqueous phase after the condensation of upgraded vapors reduces the liquid flow to the hydrotreater significantly. The hydrotreater is modeled with a specified inlet temperature of 375°C (707°F), and inlet pressures of 1,845 psia and 1,545 psia for the *in situ* and *ex situ* cases, respectively. The products are fractionated into gasoline and diesel boiling ranges. The heavier product is sent to a hydrocracking reactor with a specified inlet temperature of 392°C (738°F) and inlet pressure of 1,945 psia. Products from hydrocracking are also sent for fractionation to produce gasoline and diesel boiling range products.
- *Hydrogen production.* A fixed-bed steam methane reformer (SMR) package was used for hydrogen production. Natural gas was used only as a supplement for hydrogen production; in the base cases there is sufficient fuel gas available in the process to provide all the duty necessary to operate the reformer at high temperatures as well as produce required quantities of hydrogen. In the base cases negligible amounts of supplemental natural gas was used for both the *in situ* and *ex situ* cases (as shown in Table 13). The natural gas demand increases for sensitivity cases where higher liquid fuel product yields are assumed. The process design and costs [21] include sulfur removal from the fuel gases fed to the reformer, a water gas shift reactor for the enhancement of hydrogen production, and a subsequent PSA for hydrogen purification.
- *Heat and power.* A conventional steam cycle uses process heat to produce electricity. There is a significant amount of heat available in the process that needs to be managed efficiently to positively impact the economics. The significant sources of heat are the char and coke combustors, hot upgraded pyrolysis vapors (including fluidization gases), steam reformer flue gas, and reformed gas quench. In both the *in situ* and *ex situ* designs, excess electricity is available after consumption in the plant. This electricity is sold to the grid, and the credit reduces the MFSP.
- *Cooling water.* A cooling water system is included in the Aspen Plus model to determine the requirements of each cooling water heat exchanger within the biomass conversion process.
- *Wastewater management*. Wastewater from the vapor condensation section is sent to a reboiler system to generate steam for process use (sour water gas shift and steam reforming). However, to avoid fouling in the reboiler, not all the wastewater is evaporated. The carbon in the remaining wastewater after partial evaporation is approximately 25 wt %. This wastewater is sent to an aqueous regenerative thermal oxidizer (RTO) to eliminate the varied carbon species that may be present. The Aspen Plus process model predicts that the aqueous RTO is self-sustaining with some extra heat available from the combustion of the carbon remaining in the aqueous phase. The remaining wastewater is sent for conventional treatment. However, there remain significant opportunities to recover valuable products from the wastewater using processes such as aqueous phase reforming and biological upgrading; such processes are

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not considered in this design in order to focus on the core technology of *in situ* and *ex situ* fast pyrolysis vapor upgrading.

2.3 Aspen Plus Model

An Aspen Plus Version 7.2 simulation was used as the basis for this report. Since the products in pyrolysis are numerous and varied, only selected model compounds were used to represent the product slate. Additional hydrocarbon species were added to represent hydroprocessing products. Many of the desired molecular species in the desired boiling ranges for light and heavy fractions did not exist in Aspen Plus databanks and physical property parameters needed to be estimated. The biomass feedstock, ash, char, and coke were modeled as non-conventional components. Appendix F provides information about compounds selected to represent the process. The Peng-Robinson with Boston-Mathias modifications (PR-BM) equation of state was used throughout most of the process simulation. The ASME 1967 steam table correlations (STEAM-TA) were used for the steam cycle calculations.

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3 Process Design and Cost Estimation

The process design broadly consists of the following areas:

- Area 100: Feed handling and drying
- Area 200: Fast pyrolysis and vapor upgrading
- Area 300: Pyrolysis vapor quench and product recovery
- Area 400: Hydroprocessing and product separation
- Area 500: Hydrogen plant
- Area 600: Steam system and power generation
- Area 700: Cooling water and other utilities
- Area 800: Wastewater management and recycle.

The following sections present process overviews, design bases, and installed equipment cost estimations for each process area of the plant. Heat balance and pinch analysis are discussed separately in Section 3.10. Note that additional details of equipment costs and economics are provided in Appendices B and C. Detailed process flow diagrams and stream summaries are presented in Appendix G. Note that appendix name suffixes "-1" and "-2" are used when there are separate sets of information presented for the *in situ* and *ex situ* cases, respectively.

3.1 Area 100: Feed Handling and Drying

Feed handling and drying, as well as all other off-site logistics are described in detail in a recent INL report [22]. As mentioned in Section 2, INL's cost model for the material uses blended material. The blend constituents include pulpwood (45%), woody residues (32%), switchgrass (3%), and construction and demolition waste (20%). Further details are provided in the INL report [22]. The dry basis ultimate analysis of this blended material is similar to pulpwood. It is assumed that the biomass feedstock modeled will be provided at $80/dry U.S. ton to the throat of the reactor and will have similar conversion performance to pulpwood for the processes under consideration in this report. It *remains to be experimentally determined* whether this assumption is correct; INL, NREL, and PNNL are jointly working on this aspect. Table 2 shows the feedstock ultimate analysis used in this design. This ultimate analysis is used in the simulation for atomic balance closure. The moisture content of the material is 10 wt %, with a nominal particle size of 2 mm. The conceptual plant is modeled to consume 2,000 dry metric tonnes of biomass feedstock per day.

While all feedstock logistics including capital and energy requirements for drying and size reduction are included in the feedstock cost, an additional cross-flow dryer and a flue gas blower was added to the plant equipment list (the small power consumption for feed handling and drying shown in Table 15 and Table 16 are from these additional operations). The capital costs and installation factors are shown in Appendix B. This dryer was added to help warm up the biomass feedstock prior to feeding into the reactor. It will also help to control feedstock moisture content during wet weather. In both the *in situ* and *ex situ* process models the feedstock is warmed in the cross-flow dryer from 15.6°C (60°F) to 103.3°C (218°F) using flue gases from the combustors in the process.

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3.2 Area 200: Fast Pyrolysis and Vapor Upgrading

The following section presents an overview, basis for design, and cost estimates for construction of the fast pyrolysis, *in situ* catalytic fast pyrolysis, and *ex situ* vapor upgrading facilities.

3.2.1 Area 200 Overview

Figure 5 shows a simplified flow diagram for the fast pyrolysis and catalytic vapor upgrading equipment.

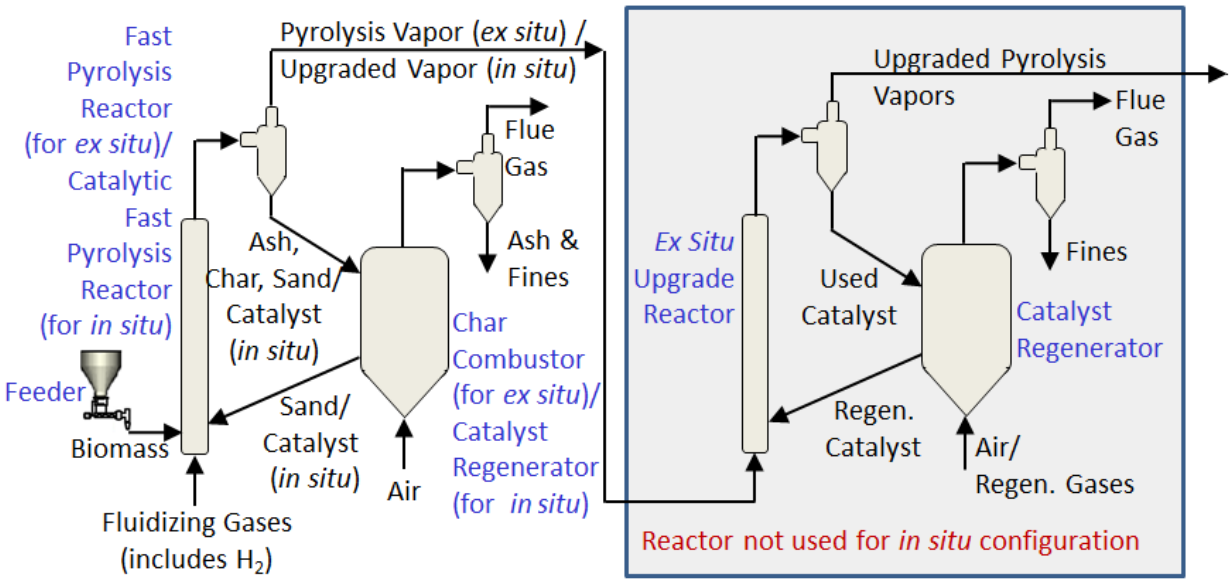

Figure 5. Simplified process flow diagram for fast pyrolysis and catalytic vapor upgrading

The *in situ* configuration combines fast pyrolysis and catalytic vapor upgrading within the same reactor, while the *ex situ* configuration has a front end non-catalytic fast pyrolysis reactor followed by a separate *ex situ* catalytic vapor phase upgrading reactor system. The *ex situ* reactor is not exposed to biomass associated solids (biomass, char, and mineral matter/ash) beyond unintended entrainment of fine material such as attrited solids and some mineral matter/ash mixed with char. It should be noted that much of the mineral matter/ash is mixed with the char that is removed by the cyclones after the non-catalytic fast pyrolysis reactor. This makes the *ex situ* configuration a more benign environment for catalyst performance and maintenance; some of the superior performance assumptions in this design for *ex situ* over *in situ* are based on this advantage. It is also possible for the *ex situ* reactor to have a fixed bed configuration, with a hot gas filter to remove fine solid material before the vapors from the fast pyrolysis reactor enter the *ex situ* upgrading reactor. In this report, all three reactors, (1) non-catalytic fast pyrolysis for the *ex situ* case, (2) catalytic fast pyrolysis or *in situ*, and (3) separate vapor phase upgrading or *ex situ* reactors, are CFB systems. A hot gas filter may also be an option for ensuring that all remaining entrained mineral matter/ash (even after two cyclones in the fast pyrolysis system) is eliminated prior to the *ex situ* CFB reactor; this is not considered in the base case, and any future inclusion will be based on benefits to catalyst maintenance assessed from experimental results. Each of the CFB systems has an entrained flow reactor and a second fluidized bed combustor for

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char/coke combustion, similar to FCC reactors. In the *in situ* and *ex situ* catalytic systems the combustor also serves as a catalyst regenerator by burning off coke deposits. The following paragraph focuses on the non-catalytic fast pyrolysis reactor and discusses some of the basis for the Aspen Plus model implementation, and equipment costs that needed to be taken into consideration [10]. Some of the key operating parameters and assumptions in our design are noted. Following this description of the non-catalytic system, variations introduced for the *in situ* and *ex situ* upgrading reactors are pointed out.

3.2.1.1 Fast Pyrolysis System

The non-catalytic fast pyrolysis reactor outlet temperature is maintained at approximately 500°C. The reactor is operated at approximately 120 psia (~8 bar) with a hydrogen partial pressure of approximately 72–95 psia (5–6.6 bar) in the inlet fluidizing gas. The riser reactor is sized for a residence time of less than 2 seconds, and velocity of 30 ft/s for design purposes. Hot sand returned from the combustor bed provides the heat necessary for the endothermic pyrolysis reactions. The reaction products include char and mineral matter in the solid phase along with vapors including water, as well as non-condensable light gases dominated by carbon monoxide (CO) and carbon dioxide (CO_2). Upon exiting the riser reactor, the solids consisting of sand and mineral matter mixed with char are separated from the vapors in two cyclones in series. These solids are returned to the combustor. The vapor products are sent to an *ex situ* upgrading reactor. The combustor is operated at nearly the same pressure as the reactor; 20% excess air is supplied to burn the char. The combustor is sized assuming a superficial velocity of 2.5 ft/s and a transport disengagement height of 19 feet [23]. The reactor and combustor capital costs are scaled based on actual gas volumetric flow rate; consequently there is a significant capital cost reduction predicted for higher operating pressures. The capital cost for the fast pyrolysis reactor and condensation train is comparable to the 2013 PNNL-led report [21] if the reactor and combustor are scaled using a higher volumetric flow rate at a lower pressure of 20 psia. Note that higher operating pressures assumed in this report also result in higher combustion-air compression costs, which is factored in the process model. The residual ash and finer particles are entrained in the flue gas and separated by two cyclones in series. The fines are sent for disposal and the flue gases go through a heat recovery train. Sand is heated during the combustion process. The hot sand is partially cooled in a solids-cooler to produce high pressure steam; this allows the sand returning to the pyrolysis reactor to have the thermal capacity to maintain 500°C at the exit of the fast pyrolysis reactor because pyrolysis is an endothermic process. A 1% heat loss on a lower heating value (LHV) of biomass basis is assumed, each in the combustor and the pyrolysis reactor. The sand flow is calculated within the constraints of delivering the right amount of heat to the pyrolyzer, while at the same time maintaining the combustor at a specified temperature of 720°C (1,328°F). The solids cooler consists of a vessel containing a series of 2.5-inch diameter A335 P91 tubes, and is sized based on the required heat duty and an assumed overall heat transfer coefficient of 31.7 Btu/hr-ft^2-°F [24]. The solids cooler price is scaled based on duty. All of the vessels and ducts are made of carbon steel with refractory lining, and were originally estimated based on a 150 psia design pressure [10]. Two parallel trains are proposed, each handling 1,000 dry metric tonnes per day of biomass, because of anticipated biomass feeding constraints into a single reactor.

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3.2.1.2 In Situ Upgrading System

The *in situ* catalytic fast pyrolysis reactor has a similar design as the system described above. In this case, the circulating solid is a catalyst instead of sand. A significant change occurs in the thermal balance and heat removal requirements due to the formation of coke that needs to be burned along with the char in the combustor bed. Hydrogen partial pressure in the fluidizing gas was chosen to be slightly higher (still within the 72–95 psia range), with the consideration that some additional pressure will be necessary for hydrogen reactivity in a more challenging *in situ* catalytic environment (compared to the *ex situ* case). The assumption of pressure will be revised later (approximately within the 25 psia to 120 psia range) based on experimental results for both the *in situ* and *ex situ* systems. The *in situ* reactor design is otherwise similar to the non-catalytic system. Catalyst circulation is calculated within the thermal constraints described for the non-catalytic fast pyrolysis reactor. The combustor temperature was lower at 650°C (1,202°F), based on constraints for HZSM-5 [25]. Two percent of the catalyst inventory is replenished per day; typical FCC replenishment rates are between 1% and 3% per day [26]. An additional 1.6% of the inventory is assumed to be replaced to account for attrition. It is expected that an equilibrium catalyst (E-Cat) with activity commensurate to conversion requirements will be established as the system is operated. Catalyst costs and related assumptions are based on FCC catalysts, using the rare earth metals lanthanum and cerium for catalyst stability. The $19,500/ton catalyst cost was in anticipation of the use of rare earth metals [27] and non-precious metals such as nickel for hydrogenation, in addition to a base catalyst cost [28]. As noted earlier, catalyst research will be key to the success of these conversion pathways, and these assumptions will be modified with advances in the research. Stripping steam is used in this reactor system and also in the *ex situ* upgrading reactor system to recover additional product from the catalyst surface. A design specification of 3 lbs of steam per 1,000 lbs of catalyst was used with a catalyst flux of 600 lb/min/ft^2 [14]. Cost of an additional vessel with structured 410SS packing internals was added for this purpose, and was sized assuming a height of 28 feet based on vendor estimates. The stripper is scaled based on catalyst flow rate, which is the primary variable affecting the vessel diameter.

3.2.1.3 Ex Situ Upgrading System

The *ex situ* system catalyst material assumptions are the same as for *in situ* systems. The catalyst replenishment rate was also assumed to be 2% of the inventory per day. In addition it is assumed that 1.6% of the inventory is added to the reactor system per day to account for attrition losses. The total replacement assumption of 3.6% of the inventory per day may be conservative; this leaves leeway for the future use of more expensive catalysts with lower replacement rates for the *in situ* and *ex situ* cases. The catalyst flow rate was fixed at 5 times the mass flow rate of dry biomass, which is lower than the corresponding value of 7.5 times for the *in situ* case, an assumption based on a more benign environment in the *ex situ* reactor. This is a parameter that can be adjusted in the simulation based on specific catalyst activity and performance. The heat balance in the *ex situ* reactor is significantly different because this system is expected to be exothermic (as also predicted by the Aspen Plus model) and an additional catalyst cooling step to 341°C (645°F) is necessary after the catalyst is regenerated at 650°C (1,202°F). While reactor design temperature in the base case is 500°C (932°F) at the outlet of the *ex situ* reactor, this temperature will likely be revised as experimental results become available. Also, there is no biomass feed into the *ex situ* vapor phase upgrading reactor because it follows a separate non-catalytic biomass fast pyrolysis reactor. Thus the *ex situ* reactor does not have the scale-up

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constraints associated with biomass feed; in this report we limited each CFB system with biomass feed to 1,000 dry metric tonnes/day capacity based on publicly available industrial fast pyrolysis reactor sizing information. Therefore, a single large *ex situ* reactor can process the entire vapor stream from 2x1,000 dry metric tonnes/day fast pyrolysis reactors. Note that this scale-up is the primary reason for the lower cost of the *ex situ* reactor compared to the other CFB reactor systems (with biomass feed) shown in Table 5. The total heat loss in the *ex situ* reactor was assumed to be 1% of the LHV of biomass (0.5% each in the reactor and catalyst regenerator). The use of a hot gas filter is not considered in the base case, although some discussion is provided with the sensitivity analysis presented in Section 5. The use of precious metals in catalysts, which may be feasible in fixed bed reactor systems, is also left for future consideration and analysis.

3.2.1.4 Comparison of In Situ and Ex Situ Upgrading

A summary of some of the key differences between the *in situ* and *ex situ* upgrading approaches are summarized in Table 3.

Table 3. Comparison of *In Situ* and *Ex Situ* Upgrading

In Situ	***Ex Situ***
Fluidized bed systems only	Fluidized or fixed bed; fixed bed systems can use precious metal catalysts. Coke formation needs to be minimized for the feasibility of fixed bed systems.
Lower capital because of single reactor	Higher capital because of separate *ex situ* upgrading reactor.
Hot gas filter (HGF) not required	HGF necessary for fixed bed systems, and maybe desirable for fluidized systems; HGF can result in additional yield losses.
Catalyst mixes with biomass, char, mineral matter/ash	Biomass, char, mineral matter/ash reduced or removed upstream of reactor.
Higher catalyst replacement requirement because of higher irreversible catalyst deactivation from inorganic material (e.g., alkali)	Lower catalyst replacement requirement because of the removal of inorganic matter upstream of the reactor (using cyclones and optionally a hot gas filter).
Operating conditions closely tied to fast pyrolysis conditions	Flexibility to operate at different conditions (e.g., temperature, contact time) compared to upstream fast pyrolysis reactor; this will allow optimizations for higher carbon efficiency, product selectivity, deactivation rates, etc.

3.2.1.5 Pressure and Hydrogen Assumptions

The conceptual designs presented in this report assume higher than atmospheric pressures and hydrogen-enriched fluidizing gases as described above (Table 4). While the primary consideration for proposing an elevated pressure was the potential benefit to the chemistry including hydrodeoxygenation, hydrogenation, and yield improvements, there are also advantages from a process economics standpoint based on the following:

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- Hydrogen partial pressure is below the embrittlement pressure for carbon steel as indicated by Nelson curves [29]. Based on this information it was not required to modify the proposed reactor materials of construction (refractory-lined carbon steel) for this conceptual process design.

- Capital costs are lower because of lower volumetric flow rates and smaller equipment.

- There is increased feasibility of using a hot gas filter in future variations of this design. Hot gas filter costs scale by the actual volumetric gas flow rate. The process can remain cost competitive even with the addition of a hot gas filter because of the lower volumetric flow rate at these slightly elevated pressures.

3.2.1.6 Catalysts

Catalyst research and development will be key for achieving the functionality and product yields targeted in this report for 2022. Zeolite-based catalysts have been used extensively for fast pyrolysis vapor upgrading [30, 31]. Experimental results using ZSM-5 and its variations are the most widely reported in the literature [8, 32, 33, 34, 35, 36, 37]. In this report we assumed the use of similar catalysts, with metal additives for hydrogen activity, and rare earth metal additives for stability, deployed in a circulating fluidized bed system.

It is understood that performance outlined with respect to hydrodeoxygenation, hydrogenation, and molecular combination (coupling) will require significant advances in catalysts. In addition, with further maturity of the research and product characterization, ring-opening chemistry will likely become very desirable; the optimal location for utilizing such chemistry in the process configuration will need to be determined, with the downstream hydroprocessing step being an option to consider. The conceptual processes outlined in this report are expected to be modified (in the 2017 timeframe) based on experimental results for the catalysts being developed. The use of noble metals in fixed bed reactors (preceded by a hot gas filter) during *ex situ* upgrading is another promising configuration. The use of bifunctional catalysts has been suggested for this vapor upgrading step [9]. Information about the chemistry and candidate catalysts for enhancing coupling reactions such as ketonization, aldol condensation, and hydroalkylation are also available in literature [9, 38]. The biggest challenge for the *ex situ* pathway is to accomplish and optimize the chemistry to desired products within an economically feasible number of steps, while also minimizing yield losses in each step, including during any associated hot gas filtration.

It will be important to reduce rates of irreversible catalyst deactivation to improve longevity and reduce replacement rates. Critical catalyst deactivation mechanisms are poisoning by inorganic impurities, structural changes that result from elevated temperatures during regeneration, and the presence of water and acids leading to physical degradation. By analogy with FCC systems, all components of the catalyst (active site, matrix, binder) will need to exhibit stability under process conditions.

3.2.2 Area 200 Design Basis

The design basis for the fast pyrolysis and catalytic vapor upgrading area is presented in Table 4. This basis reflects the overall plant capacity of 2,000 dry metric tonnes per day (2,205 dry tons per day). Product flow information is provided under Area 300. Detailed process flow diagrams

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and stream summaries are presented in Appendix G (A-201 in Appendix G-1 for *in situ*, and A-201 to A-203 in Appendix G-2 for *ex situ*).

Table 4. Design Basis for Fast Pyrolysis and Catalytic Vapor Upgrading

Configuration	*In Situ*	*Ex Situ*	
	Reactor for Fast Pyrolysis with *In Situ* Vapor Upgrading	Reactor for Non-Catalytic Fast Pyrolysis	Reactor for *Ex Situ* Vapor Upgrading
Reactor			
Parallel trains for reactor and combustor	2	2	1
Total biomass feed rate per train, dry metric tonnes/day	1,000	1,000	N/A
Biomass moisture (wt %)	10	10	N/A
Exit temperature, °C (°F)	500 (932)	500 (932)	500 (932)
Pressure, psia (bar)	121 (8.3)	121 (8.3)	117 (8.1)
Bed solids material	Catalyst (ZSM-5)	Sand	Catalyst (ZSM-5)
Bed solids inventory (ton)	115	120	77
Catalyst replacement (% of reactor system inventory/day)	2	N/A	2
Additional catalyst attrition (% of reactor system inventory/day)	1.6	N/A	1.6
Ratio of bed solids to dry biomass (w/w)	7.5	7.8	5.0
Number of cyclones per reactor	2	2	2
Stripping steam (lb/1,000 lb catalyst)	3	-	3
Fluidizing gases to dry biomass (w/w)	0.86	0.76	-
H_2 partial pressure in fluidizing gas, psia (bar)	86 (6)	93 (6.4)	72 (5.0)
Combustor/Regenerator			
Temperature, °C (°F)	650 (1,202)	720 (1,328)	650 (1,202)
Pressure, psia (bar)	117 (8.1)	117 (8.1)	113 (7.8)
Excess air (%)	20	20	20
Solids temperature before transfer to reactor, °C (°F)	650 (1,202)	720 (1,328)	341 (645)
No. of cyclones per combustor	2	2	2

3.2.3 Area 200 Equipment Cost Estimations

Capital costs for the equipment in this area were estimated by Harris Group. A previously developed spreadsheet tool for gasifier costs was leveraged for this exercise. Cost estimates from this tool were compared with order of magnitude estimates from technology vendors and documented in Appendix I of Worley et al. [10]. Of particular interest for this report, because of significant parallels to the three reactors in our design (as discussed in Section 3.2.1), is the CFB

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gasifier. The CFB gasifier estimation tool was used with the flow rates in the Aspen Plus model for developing cost estimates shown in Table 5. Another advantage of using the tool was its adaptability to add on estimates for additional vessels such as catalyst coolers and steam strippers, which were not originally built into the CFB gasifier configuration. The tool also provided estimates for the biomass feeder, which was not included into our economics because INL's feedstock logistics already includes biomass feeding within the $80/dry U.S. ton feedstock cost. Operating cost assumptions are shown in Section 4 and impacts on the overall economics are summarized in Appendix C.

Table 5. Capital Cost Estimates for the Fast Pyrolysis and Catalytic Vapor Upgrading Area

	TPEC (2011$k)	TIC (2011$k)
***In Situ* Configuration**		
Catalytic fast pyrolysis CFB reactor/regenerator	$28,558	$85,829
Heat integration	$2,524	$6,651
Area A200 subtotal	**$31,082**	**$92,480**
***Ex Situ* Configuration**		
Fast pyrolysis CFB reactor/combustor	$23,163	$71,847
Ex situ catalytic vapor upgrading reactor/regenerator	$14,835	$48,103
Heat integration	$2,653	$6,991
Area A200 subtotal	**$40,651**	**$126,941**

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3.3 Area 300: Pyrolysis Vapor Quench and Product Recovery

The following section presents an overview, basis for design, and cost estimates for upgraded pyrolysis vapor quench, product recovery and fluidizing gas recycle.

3.3.1 Area 300 Overview

Figure 6 is a simplified flow diagram showing the major equipment in this section.

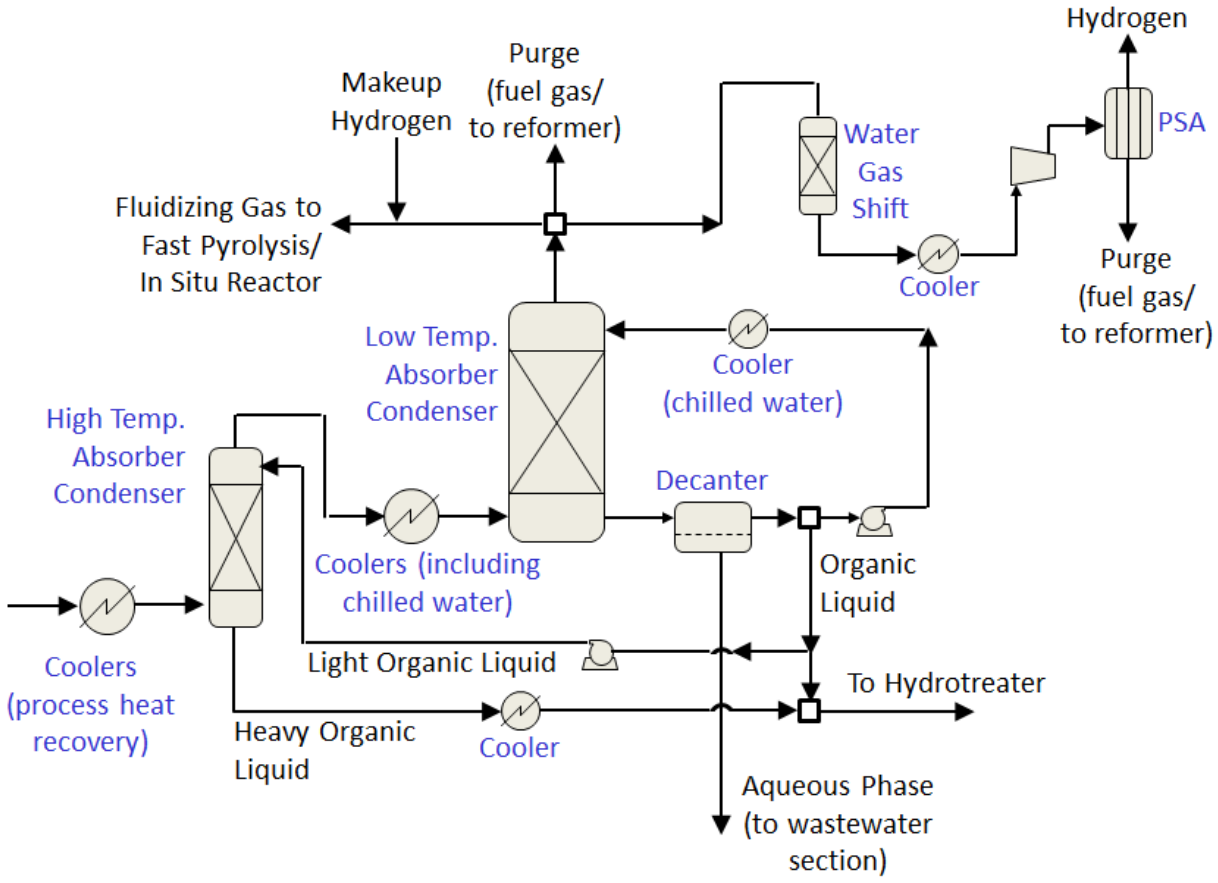

Figure 6. Simplified process flow diagram of pyrolysis vapor quench and product recovery

Upgraded vapors from both *in situ* and *ex situ* configurations are quenched to condense and separate vapors from non-condensable gases. Note that there is a significant proportion of non-condensable gases beyond those produced from the pyrolysis reactions. In particular, the gases are rich in hydrogen because of a deliberate attempt to create a hydrogen-rich atmosphere to favorably impact the chemistry. In addition, water constitutes a large fraction of the condensable vapors. The base case assumes that there will remain concerns about fouling of indirect heat exchange equipment during the condensation of the heavy fraction of the organic vapors. Heat is recovered via indirect heat exchange up to the dew point of the vapors, predicted to be 241°C (466°F). A first absorber/condenser is then used to recover the heavy organic fraction using a quench stream of recycled liquid consisting of the light organic fraction. Nearly 40 wt % of the organic product is condensed out and recovered at the bottom of the absorber/condenser. The

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overhead products exit at 176°C (348°F) and 181°C (358°F) for the *in situ* and *ex situ* cases, respectively, and enter an indirect heat exchanger train to cool down the remaining vapors. Process heat recovery, air cooling to 60°C (140°F), water cooling to 43.3°C (110°F) and chilled water cooling to 15.6°C (60°F) are used in sequence. This stream then enters a second absorber/condenser where a light organic phase and an aqueous phase are recovered as the bottoms product and separated by decantation. The recycled light organic product is chilled to 10°C (50°F) and used as the quench liquid. The light and heavy organic fractions are mixed and sent for hydroprocessing, while the aqueous fraction is sent to wastewater treatment. Filters are included for all three product streams (heavy organic, light organic, aqueous). Proper filtration to remove particulates from the organic phases is important for the maintenance of the downstream hydrotreating catalyst.

The non-condensable gases from the top of the absorber-condenser are split into (1) a purge stream (1%) to the reformer, (2) recycle to the fast pyrolysis reactor for fluidization (75% for *in situ* and 71% for *ex situ*), and (3) the balance sent to a sour water gas shift (WGS) reactor. The inlet temperature of the WGS reactor is 240°C (464°F) [39]. Steam for the WGS reactor is generated from the collected waste aqueous streams using a reboiler (discussed later under A800). The product from the WGS reactor is cooled and condensed water is sent to the wastewater section. The gases are then compressed to approximately 220 psia and cooled to 43.3°C (110°F) before being sent to a PSA unit with 84% hydrogen recovery at 99% purity. The PSA off-gases are sent to the reformer section for use either as fuel or reformer feed; this split is determined by the heat balance of the reformer system. The hydrogen is recycled back to the fast pyrolysis reactor (*ex situ* case) or the catalytic fast pyrolysis reactor (*in situ* case). In both the *in situ* and *ex situ* configurations, supplemental hydrogen is added to maintain the design H_2 partial pressure of approximately 72–95 psia in the fluidizing gas.

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3.3.2 Area 300 Design Basis

Table 6 summarizes the design basis and other key information for this area. Detailed process flow diagrams and stream summaries are presented in Appendix G (A-301 to A-304 in Appendix G-1 for *in situ*, and A-301 to A-305 in Appendix G-2 for *ex situ*).

Table 6. Design Basis for Pyrolysis Vapor Quench and Product Recovery

Configuration	*In Situ*	*Ex Situ*
Heavy fraction condenser-absorber		
Overhead temperature, °F	348	358
Pressure, psia	114	110
Feed rate, lb/h	329,131	310,342
Recycle liquid flow, lb/h	86,730	81,043
Vapor product, lb/h	396,315	371,714
Bottoms liquid product, lb/h	19,547	19,671
Light fraction condenser-absorber		
Feed temperature, °F	60	60
Overhead pressure, psia	101	97
Recycle liquid flow, lb/h	964,869	901,600
Vapor product, lb/h	199,763	182,444
Bottoms liquid flow, lb/h	1,161,420	1,090,871
Mole % H_2 overhead in gas	62%	68%
Aqueous phase		
Flow rate, lb/h	77,273	77,811
Mass percent C	2.6%	1.6%
Total organic phase (heavy + light)		
Flow rate, lb/h	52,053	50,051
Mass percent C, H, O	80%, 10%, 10%	83%, 11%, 6%
Water gas shift		
Feed gas flow rate, lb/h	48,356	51,621
Inlet temperature, °F	464	464
Outlet temperature, °F	663	637
Pressure, psia	88	86
Steam flow rate, lb/h	29,556	30,755
Temperature approach to equilibrium, °F	35	35
Wastewater (condensate), lb/h	19,648	20,736
Pressure swing adsorption (PSA)		
Inlet flow rate, lb/h	58,265	61,652
Inlet hydrogen mole %	67%	71%
Hydrogen recovery %	84%	84%
Hydrogen purity %	99%	99%
Hydrogen product stream, lb/h	5,462	7,032

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3.3.3 Area 300 Equipment Cost Estimations

Table 7 presents the capital cost summary for this area. Further capital cost details are available in Appendix B.

Table 7. Cost Estimate for Pyrolysis Vapor Quench and Product Recovery

	TPEC (2011$k)	TIC (2011$k)
***In Situ* Configuration**		
Product condensation and separation	$4,977	$8,542
Water gas shift and PSA	$5,312	$8,890
Heat integration	$1,881	$4,958
Area A300 subtotal	**$12,170**	**$22,390**
***Ex Situ* Configuration**		
Product condensation and separation	$5,071	$8,652
Water gas shift and PSA	$6,146	$10,286
Heat integration	$2,004	$5,282
Area A300 subtotal	**$13,221**	**$24,220**

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3.4 Area 400: Hydroprocessing and Product Separation

The following section presents an overview, basis for design, and cost estimates for the hydrotreating, hydrocracking, and product fractionation operations.

3.4.1 Area 400 Overview

Figure 7 presents a simplified process flow diagram for this area. Some equipment, including many heat exchangers, is not shown for simplicity.

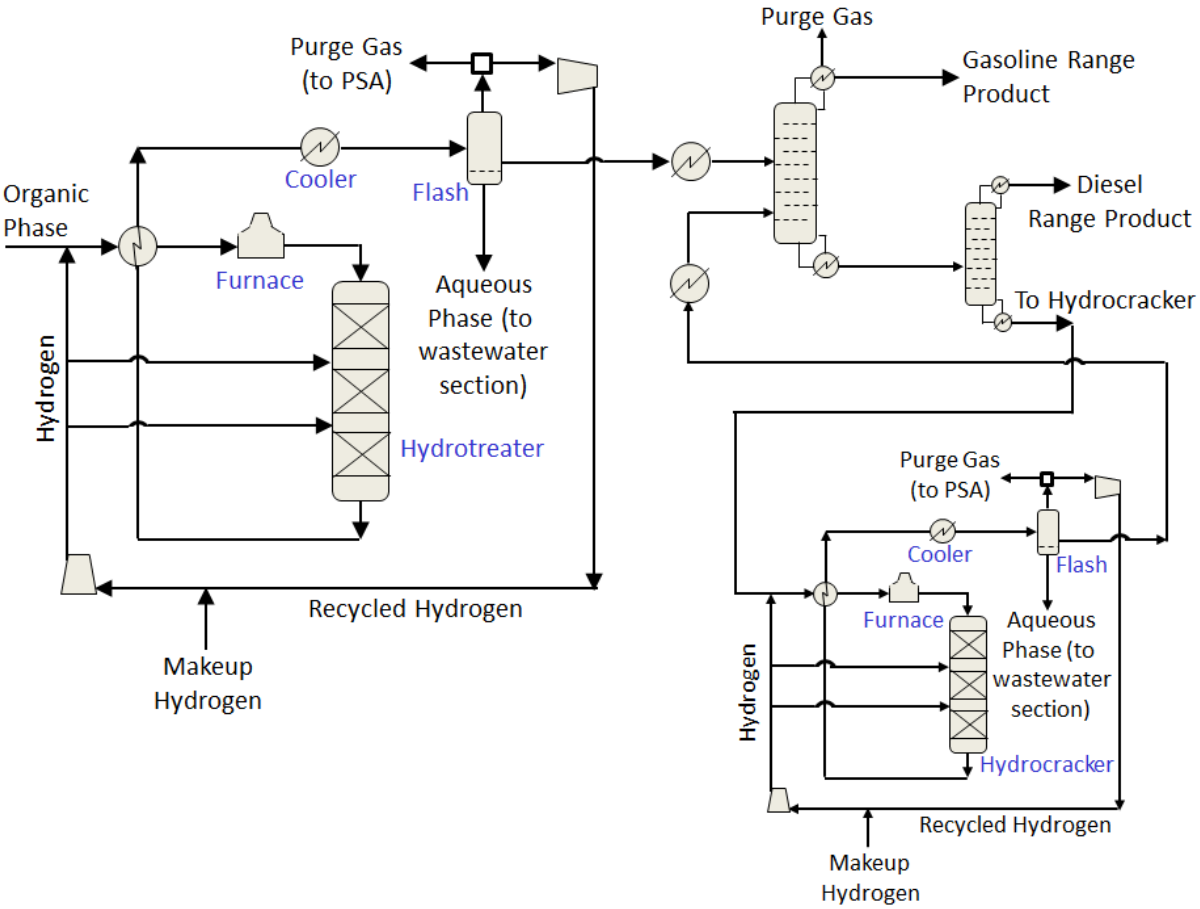

Figure 7. Simplified process flow diagram of the hydroprocessing and product separation area

The organic liquid fraction collected from the condensation of upgraded vapors in A300 is sent to a hydrotreater for further deoxygenation, as well as for saturating a portion of the products to reduce aromatic content. A sulfided CoMo catalyst is assumed for the hydrotreating reactor, although other catalysts may also be considered [40]. Note that the separation of the aqueous phase in A300 significantly reduces the liquid flow to the hydrotreater. The hydrotreater is modeled as a three-bed packed reactor with intermediate hydrogen quench to limit temperature rise in the reactor within 27.8°C (50°F). The organic liquid feed is mixed with 34% of the total hydrogen feed into the reactor. This feed is cross-exchanged with the hydrotreating reactor product for preheating the feed and cooling the reactor effluent. Following this a feed preheat furnace, designed for a 40°C (72°F) temperature rise, heats the feed to 375°C (707°F). The

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remaining 66% of the hydrogen is introduced in equal amounts (33% each) between the reactor beds. The inlet temperature for these hydrogen streams is 43.3°C (110°F). The reactor outlet, after cross-exchange with the reactor feed, is further cooled via process, air, and water exchangers in series. The products are then sent to a flash drum where the gas (mostly hydrogen) and liquid streams are separated. The aqueous portion of the liquid stream is separated via decantation and sent to the wastewater handling section (A800). The organic portion is sent for fractionation (discussed below). The gases are then recycled to the hydrotreating reactor after recompression. A portion of the gases are purged (19% for the *in situ* case and 12% for the *ex situ* case) to maintain less than 10 mole % impurities in the feed hydrogen. Makeup hydrogen is added to account for purge losses and hydrogen consumption in the reactor. The purge stream is fed directly to the PSA in Area 500. The total hydrogen feed to the reactor based on these design assumptions was 14,174 scf/bbl (4,133 scf/bbl makeup) for the *in situ* case and 9,161 scf/bbl (2,306 scf/bbl makeup) for the *ex situ* case. While there is a significant amount of information in literature about petroleum refinery hydrotreating and rules of thumb for hydrogen use, there is very little information about hydrotreating highly oxygenated products at scale; hence, we decided to use the logical steps dictated by the process operations and temperature control considerations outlined above to determine hydrogen consumption and recycle. An acid gas removal system for controlling hydrogen sulfide (H_2S) was not deemed necessary because of the low sulfur content in the biomass feedstock. PSA systems can be designed to handle low quantities of H_2S produced or sulfur introduced for maintenance of sulfided hydrotreating catalysts [41]. H_2S concentrations at the hydrotreater inlet in the model were ~100 ppm (*in situ* case) and ~170 ppm (*ex situ* case) on a mole basis, which should be capable of keeping the catalyst sulfided.

The hydrotreater inlet pressures for the *in situ* and *ex situ* cases were 1,845 psia and 1,545 psia, respectively. This decision was based on the premise that less severe hydrotreating will be necessary for the lower oxygen content product from the *ex situ* upgrading case. This assumption will require future experimental validation.

The product from the hydrotreater is sent for fractionation. The first column separates light gases and a gasoline boiling range fraction as its overhead product, with an off-gas stream purged and used as fuel. Note that products from hydrocracking are also fed to a lower section of this same column. The bottoms product from this column is sent to a second column where diesel boiling range product is recovered overhead. The heavier bottoms product is sent for hydrocracking; any products heavier than the distillate/diesel-range are recycled to extinction via hydrocracking.

The design of the hydrocracker follows the same logic outlined under the discussion for the hydrotreater. Note that the oxygen content of the organic liquid feed to the hydrocracker is assumed to be reduced to ~1% as a result of the previous hydrotreating operation. The catalyst is assumed to be crystalline silica-alumina based with rare earth metals and metals added for hydrogenation activity [42]. The hydrocracking inlet pressure was 1,945 psia, with a reactor inlet temperature of 392°C (738°F). The same limitations of a 27.8°C (50°F) temperature rise within the reactor and 10% impurity in the hydrogen feed were also assumed here. The hydrogen feed to the reactor was 16,347 scf/bbl (6,867 scf/bbl makeup) for the *in situ* case and 8,272 scf/bbl (3,091 scf/bbl makeup) for the *ex situ* case. Again, we relied on the simulated operational considerations mentioned above for a logical derivation of hydrogen consumption based on operational and temperature constraints.

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Process model flow information for the hydrotreater, hydrocracker, and fractionation columns is summarized in Table 8. Detailed process flow diagrams and stream summaries are presented in Appendix G (A-401 to A-403 in Appendix G-1 for *in situ*, and A-401 to A-404 in Appendix G-2 for *ex situ*). Note that an additional design specification was added to scale the carbon efficiency based on oxygen content of the feed material entering the hydrotreater. A linear scale was assumed with 85% carbon efficiency for ~20% oxygen content [43] and 98.5% carbon efficiency for negligible oxygen content as is usually the case in petroleum refineries (based on approximations from case studies outlined by Gary and Handwerk for petroleum refineries [42]). This is shown in Figure 8.

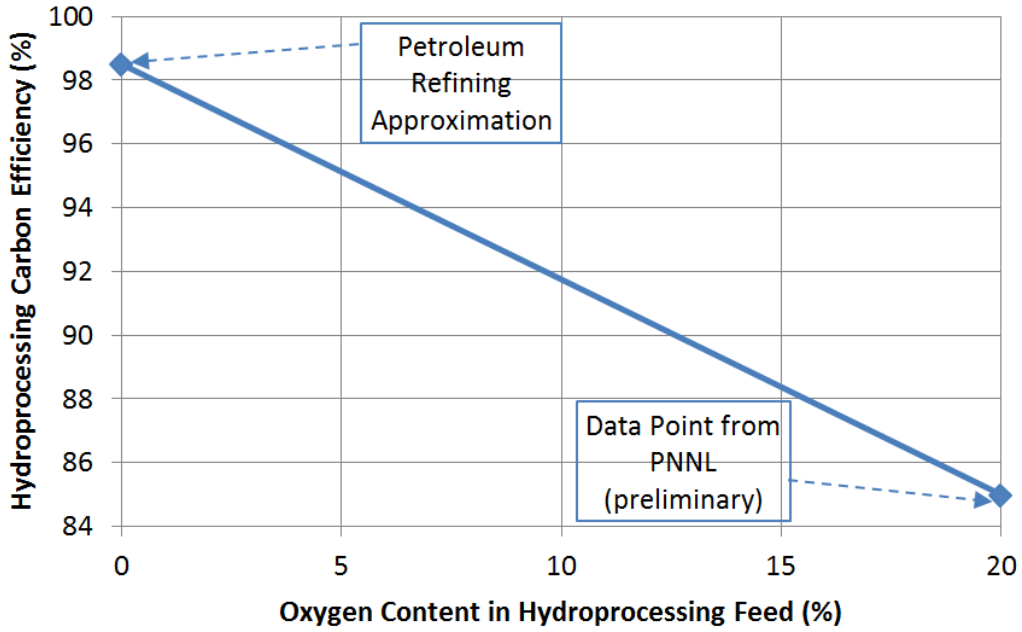

Figure 8. Assumed hydroprocessing carbon efficiency vs. oxygen content in organic liquid feed

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Table 8. Process Model Flow Information for A400

	In Situ	*Ex Situ*
Hydrotreater		
Liquid feed, lb/h	52,053	50,051
Liquid feed wt % C, H, O	80%, 10%, 10%	83%, 11%, 6%
Total hydrogen feed (pure H_2), lb/h	11,219	7,249
Hydrogen stream mole % purity	90%	90%
Makeup hydrogen (pure H_2), lb/h	3,274	1,824
Product gas (HP flash), lb/h	28,548	17,435
Product gas (HP flash) mole % hydrogen	87%	87%
Purge gas (HP flash), lb/h	5,327	2,061
Purge gas (LP flash), lb/h	870	787
Aqueous phase product, lb/h	4,696	2,912
Organic phase product, lb/h	45,023	46,446
Organic phase product wt % C,H,O	87%, 12%, 1%	86%, 13%, 1%
Hydrocracker		
Liquid feed, lb/h	8,833	16,654
Liquid feed wt % C, H, O	88%, 11%, 1%	88%, 11%, 1%
Total hydrogen feed (pure H_2), lb/h	2,154	2,109
Hydrogen stream mole % purity	90%	90%
Makeup hydrogen (pure H_2), lb/h	905	647
Product gas (HP flash), lb/h	5,487	4,353
Product gas (HP flash) mole % hydrogen	84%	87%
Purge gas (HP flash), lb/h	1,342	298
Purge gas (LP flash), lb/h	412	356
Aqueous phase product, lb/h	80	129
Organic phase product, lb/h	8,068	16,636
Organic phase product wt % C,H,O	85%, 15%, 0%	86%, 14%, 0%
Gasoline boiling range column		
Feed from hydrotreater, lb/h	45,023	46,446
Feed from hydrocracker, lb/h	8,068	16,636
Gasoline range product, lb/h	31,866	20,408
Light gases, lb/h	547	1,281
Bottoms flow to diesel column, lb/h	20,678	41,393
Diesel boiling range column		
Feed from gasoline-range column, lb/h	20,678	41,393
Diesel-range product, lb/h	11,845	24,739
Bottoms product to hydrocracker, lb/h	8,833	16,654
Overall efficiency		
Carbon efficiency %	91%	94%
Yield lb product/lb feed	0.84	0.90
Oxygen content in feed/product (wt %)	10.5%/0.5%	6.4%/0.4%

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3.4.2 Area 400 Design Basis

For our equipment design, we assumed a relatively high severity would be required in hydrotreating. In addition to higher temperature and pressure, higher severity is characterized by lower weight hourly space velocity (WHSV):

$$\text{WHSV} = \frac{\text{mass flow of feed}}{\text{mass of catalyst}}$$

We chose WHSV to avoid using liquid density predictions, which can sometimes be highly dependent on the model compounds and physical property methods chosen. We assumed 0.5 h^{-1} for hydrotreating and hydrocracking in our design, which is considered severe for most petroleum refining hydroprocessing operations. A WHSV of 0.5 h^{-1} usually translates to a lower liquid hourly space velocity (LHSV) for most feedstock and catalyst combinations with an example of such conversion provided by Elliott et al. [44]. Hydrotreating of raw bio-oil without vapor phase deoxygenation is expected to be even more severe (lower space velocity) as indicated by LHSV values in literature [21, 40, 45]. For a given feed rate, the WHSV determines the total mass of catalyst required. Given a catalyst density, the total reactor volume is also determined by WHSV. However, because of the relatively high pressure requirements as noted above, these hydrotreating reactors have relatively thick walls of 2–4 inches and are thus quite heavy. When we estimated the price of the hydrotreating reactors, we therefore specified adders within the cost estimation software for field fabrication.

The design basis for the hydrotreating and hydrocracking reactor systems are presented in Table 9 and Table 10. Note that the vessel length of 48 feet is not entirely catalyst-full. Reactor internals were assumed to occupy 33% of the reactor volume, and additionally a 70% overdesign was applied to bed length to accommodate catalyst deactivation over time [46, 47]. Included among the reactor internals are inlet distributors, catalyst supports, redistribution trays, quench distributors, and outlet collection. The design catalyst bed length was therefore 19 feet.

The hydrotreating and hydrocracking reactor products are cooled and flashed at two different pressures to separate the hydrocarbons from reaction water and unreacted hydrogen. A recycle compressor serves the higher-pressure flash (approximately 20 psi below reactor outlet) gas stream. Both the hydrotreating and hydrocracking reactors also have hydrogen makeup compressors to bring hydrogen from Area 500 up to reactor pressure. The specifications for the compressors are summarized in Table 11.

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Table 9. Design Basis Parameters for Hydrotreating Reactor

Process Parameters	*In Situ*	*Ex Situ*
Reactor inlet temperature, °C (°F)	375 (707)	375 (707)
Reactor outlet temperature, °C (°F)	403 (757)	403 (757)
Reactor pressure, psia	1,845	1,545
Reactor pressure drop, psi	30	30
Hydrogen inlet purity	90 mol%	90 mol%
Outlet hydrogen stream recycle/purge, %	81/19	88/12
Hydrogen feed (and makeup), scf/bbl HT feed	14,174 (4,133)	9,161 (2,306)
Chemical hydrogen consumption (lb/100 lb HT feed)	2.6	2.1
No. of internal beds per modeled reactor	3	3
Reactor Design Parameters		
Reactor length, ft	48	48
Reactor diameter, ft	10	10
Weight hourly space velocity, $hour^{-1}$	0.5	0.5
Catalyst density, lb/ft^3	78	78
Catalyst bed length overdesign	70%	70%
Reactor internals volume	33%	33%
Mass of catalyst (design), lb	122,520	112,000
Mass of catalyst (actual), lb	208,290	190,430
Material of construction	A204C with Inconel Cladding	

Table 10. Design Basis Parameters for Hydrocracking Reactor

Process Parameters	*In Situ*	*Ex Situ*
Reactor inlet temperature, °C (°F)	392 (738)	392 (738)
Reactor outlet temperature, °C (°F)	420 (788)	420 (788)
Reactor pressure, psia	1,945	1,945
Reactor pressure drop, psi	30	30
Hydrogen inlet purity	90 mol%	90 mol%
Outlet hydrogen stream recycle/purge, %	76/24	93/7
Hydrogen feed (and makeup), scf/bbl HC feed	16,347 (6,867)	8,272 (3,091)
Chemical hydrogen consumption (lb/100 lb HC feed)	5.4	3.1
No. of internal beds per modeled reactor	3	3
Reactor Design Parameters		
Reactor length, ft	48	48
Reactor diameter, ft	6.5	6.5
Weight hourly space velocity, $hour^{-1}$	0.5	0.5
Catalyst density, lb/ft^3	78	78
Catalyst bed length overdesign	70%	70%
Reactor internals volume	33%	33%
Mass of catalyst per reactor (design), lb	21,200	36,600
Mass of catalyst per reactor (actual), lb	36,060	62,200
Material of construction	A204C with Inconel Cladding	

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Table 11. Design Parameters for Hydrogen Compressors

Hydrotreating Recycle Compressor	
Service	Recycled unreacted hydrogen
Inlet pressure	1,793 psia (*in situ*)/1,493 psia (*ex situ*)
Outlet pressure	1,900 psia (*in situ*)/1,600 psia (*ex situ*)
Inlet mass flow	27,085 lb/h (*in situ*)/17,528 lb/h (*ex situ*)
Inlet molecular weight	2
Drive power source	Electric motor
Inter-stage cooling	Process, air, cooling water
Number of stages	1
Electrical consumption	176 kW (*in situ*)/134 kW (*ex situ*)
Hydrocracking Recycle Compressor	
Service	Recycled unreacted hydrogen
Inlet pressure	1,893 psia
Outlet pressure	2,000 psia
Inlet mass flow	5,214 lb/h (*in situ*)/4,819 lb/h (*ex situ*)
Inlet molecular weight	2
Drive power source	Electric motor
Inter-stage cooling	Process, air, cooling water
Number of stages	1
Electrical consumption	32 kW (*in situ*)/31 kW (*ex situ*)
Hydrotreating Makeup Compressor	
Service	Pipeline hydrogen
Inlet pressure	245 psia
Outlet pressure	1,795 psia (*in situ*)/1,495 psia (*ex situ*)
Inlet mass flow	3,865 lb/h (*in situ*)/2,154 lb/h (*ex situ*)
Inlet molecular weight	2
Drive power source	Electric motor
Inter-stage cooling	Process, air, cooling water
Number of stages	4
Electrical consumption	1,765 kW (*in situ*)/888 kW (*ex situ*)
Hydrocracking Makeup Compressor	
Service	Pipeline hydrogen
Inlet pressure	245 psia
Outlet pressure	1,995 psia
Inlet mass flow	1,068 lb/h (*in situ*)/764 lb/h (*ex situ*)
Inlet molecular weight	2
Drive power source	Electric motor
Inter-stage cooling	Process, air, cooling water
Number of stages	4
Electrical consumption	516 kW (*in situ*)/369 kW (*ex situ*)

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3.4.3 Area 400 Equipment Cost Estimations

The estimated purchased equipment costs and total installed costs for the hydroprocessing area were gathered from various sources, including technology licensors, industrial suppliers, published literature, and ACCE. The sources are listed in Appendix A.

Table 12 presents the equipment list and cost estimates for the hydroprocessing area of the plant.

Table 12. Cost Estimate for the Hydroprocessing Area

Equipment Description	*In Situ*		*Ex Situ*	
	TPEC (2011$k)	TIC (2011$k)	TPEC (2011$k)	TIC (2011$k)
Hydrotreating reactor	$8,351	$13,257	$6,213	$10,514
Hydrocracking reactor	$1,548	$3,274	$2,472	$5,116
Recycle and makeup compressors	$7,013	$11,221	$5,159	$8,254
Product separation columns	$1,105	$2,804	$1,287	$3,188
Heat integration	$754	$1,988	$772	$2,033
Area A400 subtotal	**$18,771**	**$32,544**	**$15,902**	**$29,106**

3.5 Area 500: Hydrogen Plant

The following section presents an overview, basis for design, and cost estimates for the steam reformer, water gas shift reactor, PSA, and associated equipment used for hydrogen production.

3.5.1 Area 500 Overview

A fixed-bed steam methane reformer package was used for hydrogen production. The small amount of natural gas feed (shown in Table 13) was used entirely for hydrogen production and fed to the reformer because there is sufficient fuel gas available in the process to provide all the heat duty necessary to run the reformer. The reformer was modeled as a Gibbs equilibrium reactor operating at 115 psia and 880°C (1,616°F) with a 30°C (54°F) approach to equilibrium. Steam is provided from a wastewater recycle boiler in Area 800. The product gases are quenched and sent to high temperature and low temperature shift reactors in series with intermediate heat exchange for temperature control. Following the reformer, the gases are cooled and condensate removed. The gases are then compressed to 278 psia for feeding to a PSA. The PSA design assumes 80% hydrogen recovery with 99% purity. Off-gases from the PSA are used as combustion fuel.

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3.5.2 Area 500 Design Basis

Table 13 summarizes the design basis for the equipment in the hydrogen plant, including the steam methane reformer, WGS reactor, and PSA unit. Detailed process flow diagrams and stream summaries are presented in Appendix G (A-501 to A-504 in Appendix G-1 for *in situ*, and A-501 to A-505 in Appendix G-2 for *ex situ*).

Table 13. Design Basis Parameters for Hydrogen Plant

Hydrogen Plant Design Parameters	
Hydrogen production rate	30.0 MMscfd (*in situ*)/27.4 MMscfd (*ex situ*)
Supplemental natural gas*	54 lb/h (*in situ*)/125 lb/h (*ex situ*)
Hydrogen outlet purity	99 mol %
Hydrogen outlet pressure	266 psia

*Negligible natural gas required because of the availability of fuel gas from the process.

3.5.3 Area 500 Equipment Cost Estimations

For consistency, the hydrogen plant cost was derived from the same sources and methodology cited in the 2013 design report led by PNNL [21]. The report documented equipment costs for a large hydrogen plant producing 44.5 million scf/day of hydrogen. The costs were reported as a package, including the sulfur guard bed, pre-reformer, SMR, WGS, PSA, compressors, and heat integration. The total cost was entered into our model and scaled to the required hydrogen production rates shown above using the same scaling law as in the 2013 report [21]. Table 14 shows the major costs in the hydrogen plant area.

Table 14. Cost Estimate for Hydrogen Production Area

Equipment Description	*In Situ*		*Ex Situ*	
	TPEC (2011$k)	TIC (2011$k)	TPEC (2011$k)	TIC (2011$k)
SMR, WGS, PSA package	$28,968	$55,330	$27,368	$52,267
Pyrolysis off-gas compressor to SMR	$4,447	$7,159	$4,219	$6,799
Additional heat integration	$3,093	$8,152	$2,920	$7,696
Area A500 subtotal	**$36,508**	**$70,640**	**$34,507**	**$66,762**

3.6 Area 600: Steam System and Power Generation

The following section presents an overview, basis for design, and cost estimates for construction of the steam system and power generation facilities.

3.6.1 Area 600 Overview

A conventional steam cycle uses process heat to produce electricity. There is a significant amount of heat available in the process that needs to be managed efficiently to positively impact the economics. The big sources of heat are the char and coke combustors, upgraded pyrolysis vapors (including fluidization gases) cooling, steam reformer flue gas, and reformed gas quench. In both the *in situ* and *ex situ* designs there is excess electricity available after all consumption in the plant is met. This electricity is sold to the grid and reduces the MFSP by 4¢/GGE and

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3¢/GGE for the *in situ* and *ex situ* cases, respectively. Excess heat available for power generation was determined by conducting an overall plant heat balance. The heat balance assumptions are checked for thermodynamic viability by drawing heating and cooling curves for pinch analysis and ensuring there is no crossover between the curves. Electricity is generated using two steam turbines, with intermediate reheat. Pre-heaters, steam generators, and super-heaters are integrated within the process design to generate the steam from boiler feed water (BFW). Process condensate is recycled to the steam cycle, de-gassed, treated, and combined with makeup water.

The steam turbine efficiencies are assumed to be 75% and the generator mechanical efficiencies are assumed to be 97%. The first stage turbine drops the steam pressure from 1,321 psia to 350 psia. The second stage turbine drops the pressure from 345 psia to 3.5 psia. The steam inlets to both turbine stages are preheated to 1,000°F.

Low pressure (3.5 psia) steam exhaust from the turbine is cooled by exchanging heat with other process streams and is condensed in an air-cooled condenser. While an air-cooled exchanger is considerably more expensive than a water cooler, it has the advantage of reducing water consumption through evaporation in the cooling towers and was preferred in this design for sustainability considerations. A condensate collection tank gathers the condensate returns from indirect heat exchange along with the steam turbine condensate. The condensate from the collection tank is treated in the hot condensate polishing unit, mixed with treated makeup water, and sent to the condensate surge tank. From the surge tank, the water is pumped, heated to the saturation temperature, and sent to the deaerator to remove any dissolved gases from the water. The water from the deaerator is pumped to a pressure of 1,351 psia and then pre-heated to its saturation (bubble point) temperature using a series of exchangers. Steam is generated by heat exchange with hot streams in the process. This saturated steam is collected in the steam drum. To prevent buildup of solids, water is periodically discharged from the steam drum (also known as blowdown). Saturated steam from the steam drum is superheated with another series of exchangers to 538°C (1,000°F) before it goes to the steam turbine. Detailed process flow diagrams and stream summaries are presented in Appendix G (A-601 to A-603 in Appendix G-1 for *in situ*, and A-601 to A-605 in Appendix G-2 for *ex situ*).

The Aspen Plus model increases or decreases the boiler feed water flow rate through the steam cycle in order to close the heat balance. The control system in the plant will function in a similar fashion by controlling the flow rate of boiler feed water makeup to the steam system in order to maintain levels in the deaerator and steam drum.

All compressors, pumps, fans, etc., utilize electric motor drives and are modeled and quoted accordingly. An allowance of ~4 MW of excess power is specified to account for miscellaneous usage which may not be accounted for in the simulation and general electric needs (such as lights and computers).

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3.6.2 Area 600 Design Basis

Table 15 and Table 16 present summaries of the power requirements for each area for the *in situ* and *ex situ* cases, respectively. Excess electricity is sold to the grid.

Table 15. Plant Power Requirements for *In Situ* Case

Plant Area	Generated (kW)	Consumed (kW)
Feed handling and drying[a]		387
Pyrolysis		22,619
Condensation and product separation		3,500
Hydroprocessing		2,951
Hydrogen production and management		6,083
Steam system and power generation	48,291	1,588
Cooling water and other utilities		324
Wastewater management		1,798
Miscellaneous		3,925
Balance to grid		5,117
Plant totals	**48,291**	**48,291**

[a] Power costs for all feed handling, and for drying outside the plant, are included in the feedstock cost provided by INL. The small power consumption shown for this area reflects usage for a cross-flow dryer and flue gas blower.

Table 16. Plant Power Requirements for *Ex Situ* Case

Plant Area	Generated (kW)	Consumed (kW)
Feed handling and drying[a]		298
Pyrolysis		22,783
Condensation and product separation		3,914
Hydroprocessing		1,811
Hydrogen production and management		5,875
Steam system and power generation	44,247	1,461
Cooling water and other utilities		327
Wastewater management		846
Miscellaneous		3,731
Balance to grid		3,201
Plant totals	**44,247**	**44,247**

[a] Power costs for all feed handling, and for drying outside the plant, are included in the feedstock cost provided by INL. The small power consumption shown for this area reflects usage for a cross-flow dryer and flue gas blower.

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3.6.3 Area 600 Equipment Cost Estimations

Table 17 presents the equipment list and cost estimates for the steam system and power generation area of the plant.

Table 17. Cost Estimate for Steam System and Power Generation Area

Equipment Description	*In Situ*		*Ex Situ*	
	TPEC (2011$k)	TIC (2011$k)	TPEC (2011$k)	TIC (2011$k)
Power generation and associated equipment	$26,183	$44,237	$23,875	$40,579
Heat integration	$3,116	$8,212	$2,776	$7,316
Area A600 subtotal	**$29,300**	**$52,449**	**$26,651**	**$47,895**

3.7 Area 700: Cooling Water and Other Utilities

The following section presents an overview, basis for design, and cost estimates for construction of the cooling water facilities and other plant utility equipment.

3.7.1 Area 700 Overview

Equipment list for this area is included in Appendix B. Detailed process flow diagrams and stream summaries are presented in Appendix G (A-701 to A-703 in Appendix G-1 for *in situ*, and A-701 to A-703 in Appendix G-2 for *ex situ*). A mechanical draft cooling tower (M-701) provides cooling water to several heat exchangers in the plant. The tower utilizes fans to force air through circulated water.

An instrument air system is included to provide compressed air for both service and instruments. The system consists of an air compressor (K-701), dryer (S-701), and receiver (T-701). The instrument air is delivered at a pressure of 115 psia and a moisture dew point of -40°C (-40°F), and it is oil free.

Other miscellaneous items that are taken into account in the design include the following:

- Firewater storage tank (T-702) and firewater pump (P-702) for fire emergencies
- Diesel tank (T-703) and diesel pump (P-703) to fuel the front loaders
- Ammonia storage tank (T-704), ammonia pump (P-704), BFW chemical storage tank (T-708), and BFW chemical pump (P-707) for boiler feed water treatment
- Caustic (NaOH) storage tank (T-705) and pump (P-705)

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3.7.2 Area 700 Design Basis

Table 18 summarizes the design basis parameters for the plant's cooling water system.

Table 18. Design Basis for Cooling Water System

Cooling Water System Design Parameters	
Cooling water supply temperature (T_S)	90°F
Cooling water return temperature (T_R)	110°F
Losses from evaporation (F_{EVAP})	$0.00085 * F_S * (T_R - T_S)$
Losses from drift	$0.002 * F_S$
Cycles of concentration (C)	5
Required blowdown	$F_{EVAP}/(C - 1)$
Cooling water makeup pressure	14.7 psia
Cooling water makeup temperature	60°F

Note: Fs = Cooling water supply rate in gallons per minute.

Water losses from the cooling water system include evaporation, drift (water entrained in the cooling tower exhaust air), and tower basin blowdown. Drift losses were estimated to be 0.2% of the cooling water supply rate. Evaporation losses and blowdown were calculated based on information and equations in Perry et al. [17] (as shown in Table 18).

3.7.3 Area 700 Cost Estimation

Table 19 presents the equipment list and cost estimates for the cooling water and other utilities area of the plant.

Table 19. Cost Estimate for Cooling Water and Other Utilities Area

Equipment Description	*In Situ*		*Ex Situ*	
	TPEC (2011$k)	TIC (2011$k)	TPEC (2011$k)	TIC (2011$k)
Cooling water and other utilities	$4,712	$9,450	$4,633	$9,277
Area A700 subtotal	**$4,712**	**$9,450**	**$4,633**	**$9,277**

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3.8 Area 800: Wastewater Management and Recycle

Area 800 has three process sub-areas for treating and recycling water discharges from the plant: a wastewater boiler, a regenerative thermal oxidizer, and a reverse osmosis unit for point treatment. The majority of the soluble carbon is found in the aqueous phase of the pyrolysis quench loop in Area 300. This stream, with a significantly smaller makeup of clean recycled water is sent to a waste heat boiler system to first generate steam for process use in the sour water gas shift reactor in Area 300. Any H_2S present in the wastewater is expected to be stripped out of the water during this step. A following boiler generates steam for the reformer; small proportions of carbon species are also part of the steam and are expected to be utilized in the pre-reformer/reformer system for hydrogen production. Creating steam from the quench water serves to recycle some of the volatile carbon species back to the process, and also to concentrate the remaining soluble species like phenol. To avoid fouling in the boiler, not all the wastewater is evaporated.

The remaining wastewater, after the partial evaporation, has a chemical oxygen demand (COD) of 68 wt % for the *in situ* case and 71 wt % for the *ex situ* case. Most of this COD is from varied oxygenated organic species and are modeled using surrogate compounds such as phenol and benzenediol. These compounds are toxic to typical microbial consortia used in wastewater treatment. Therefore the concentrated wastewater cannot be treated by digestion without significant re-dilution, so it is sent to an aqueous regenerative thermal oxidizer to eliminate the remaining carbon species that may be present. A high-level schematic of such a system is shown on the website of Gulf Coast Environmental Systems [48]. The RTO essentially strips the wastewater into an excess of preheated air, and the resultant vapor is passed through hot ceramic blocks. The operation is cyclical with at least two sets of high heat capacity ceramic blocks. The ceramic blocks are heated by combustion products. Upon switching of the cycle these hot blocks preheat the inlet air, moisture, and carbonaceous matter; at this time the other set(s) of ceramic blocks are heated by combustion products. The preheated feed enters a combustion zone where supplemental fuel, such as natural gas, may be provided. Our Aspen Plus model of this sub-system predicts that the carbon content concentrated in the aqueous stream from the boiler has more than sufficient carbon and hydrogen to sustain the combustion and no supplemental fuel is necessary. The combustion zone is modeled as a reactor with complete oxidation of carbon (to CO_2) and hydrogen at 820°C (1,508°F), in the presence of significant excess air (amount of air decided by the lower explosive limits of organic species). We acknowledge that an RTO has not specifically been applied for the type of process described here; however, we are aware that such equipment is currently in service at ethylene plants to treat cracking furnace quench water, a system with similarities to ours. Detailed process flow diagrams and stream summaries for our design are presented in Appendix G (A-801 to A-804 in Appendix G-1 for *in situ*, and A-801 to A-805 in Appendix G-2 for *ex situ*).

An on-site reverse osmosis (RO) unit is specified for point treatment and recycle of streams with low contamination. These include the cooling tower blowdown, water knockout from the PSA compressor in Area 300, and the flue gas scrubber effluent from Area 100. We assume that 75% of the water can be recovered and recycled to the flue gas scrubber, Area 600 boiler, and cooling tower to offset the total water demand for the process. The remaining 25% is collected for treatment, along with the hydroprocessing water knockout streams, which were considered unsuitable for the boiler and RTO due to nitrogen (ammonia) content. While we did not perform

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a detailed design for an on-site wastewater treatment plant, it is expected that such treatment will entail demineralization of the RO retentate streams and probably activated sludge denitrification of the hydroprocessing water, followed by aerobic digestion and polishing. Anaerobic digestion is not likely to be economical due to the low remaining COD. We estimated an operating cost charge for wastewater using the aggregate CAPEX+OPEX cost contribution of the detailed wastewater facility designed for the 2011 biochemical ethanol design report [49]. At $0.022/gal wastewater, this conservatively estimated cost of treating the relatively less contaminated streams from the pyrolysis plant is a factor of 10 higher than the value cited in Peters and Timmerhaus [16] for treatment of boiler blowdown streams.

Table 20 summarizes the water balance for the plant. The consumptive water demand for the process is 0.76 gal/GGE for the *in situ* process and 0.70 gal/GGE for the *ex situ* process. Along with uncertainties surrounding the choice of equipment in Area 800, we note that there could also be significant opportunities to recover valuable products from the wastewater using processes such as aqueous phase reforming or biological upgrading. These research areas are not considered in this design in order to focus on the core technology of *in situ* and *ex situ* vapor phase upgrading.

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Table 20. Pyrolysis Plant Water Balance

Area	Stream	Source/Destination	*In Situ*	*Ex Situ*	
A100	Scrubber Water	Input	30,000	30,000	lb/h
	To Flue Gas	Loss	7,640	6,571	lb/h
	Scrubber Blowdown	To Point Treatment	22,360	23,429	lb/h
	COD		*0*	*0*	*lb/h*
A200	Catalyst Steam Stripper	From Boiler A800	4,151	2,756	lb/h
A300	Aqueous Phase	To Boiler A800	74,271	75,955	lb/h
	COD		*5,490*	*3,457*	*lb/h*
	WGS Steam Demand	From Boiler A800	29,430	30,663	lb/h
	PSA Water Knockout	To Point Treatment	19,552	20,658	lb/h
	COD		*187*	*128*	*lb/h*
A400	Hydrotreating HP Aq Phase	To Full Treatment	4,660	2,877	lb/h
	COD		*1*	*0*	*lb/h*
	Hydrocracking Aq Phase	To Full Treatment	80	129	lb/h
	COD		*0*	*0*	*lb/h*
A500	Reformer Steam Demand	From Boiler A800	40,842	45,491	lb/h
	PSA Water Knockout	To Boiler A800	13,979	15,786	lb/h
	COD		*0*	*0*	*lb/h*
A600	Makeup	Input	7,064	6,473	lb/h
	Makeup Chemicals (In Model)	Input	2	2	lb/h
	Steam Drum Knockout	To Cooling Tower Basin	7,067	6,475	lb/h
A700	Steam Drum Knockout	From A600	7,067	6,475	lb/h
	Makeup	Input	52,033	53,446	lb/h
	Blowdown	To Point Treatment	10,788	10,937	lb/h
	Drift	Loss	5,162	5,237	lb/h
	Evaporation	Loss	43,150	43,747	lb/h
A800	*Boiler*				
	BFW Makeup		0	1,926	lb/h
	Total Boiler Feed	To Boiler A800	74,271	77,881	lb/h
	COD		*5,490*	*3,457*	*lb/h*
	Process Steam Generated	To SMR+WGS	70,272	76,154	lb/h
	Remaining to RTO	Loss	3,999	1,727	lb/h
	COD		*0*	*0*	*lb/h*
	Point Treatment				
	Total Water for Treatment	75% Recovered	66,679	70,810	lb/h
	Water Recycled	Offsets Inputs	50,009	53,107	lb/h
	Remainder	To Full Treatment	16,670	17,702	lb/h
	Full Treatment				
	Total	Loss	21,410	20,708	lb/h
	COD		*1*	*0*	*lb/h*
	Total Water Makeup		93,251	94,603	lb/h
	Net Water Makeup		43,242	41,495	lb/h
	Net Water Makeup (Annual)		41.0	39.3	MMgal/y
	Water Usage		0.76	0.70	gal/GGE
	Liq Water Emission		21,410	20,708	lb/h
	Liq Water Emission (Annual)		20.3	19.6	MMgal/y

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3.8.1 Area 800 Cost Estimation

Table 21 presents the equipment list and cost estimates for the wastewater treatment and recycle area. The RTO capital cost was based on estimates in a report from the U.S. Environmental Protection Agency (EPA) [50].

Table 21. Cost Estimate for Wastewater Management Area

Equipment Description	*In Situ*		*Ex Situ*	
	TPEC (2011$k)	TIC (2011$k)	TPEC (2011$k)	TIC (2011$k)
Wastewater boiler and ancillaries	$139	$631	$162	$661
Regenerative thermal oxidizer and ancillaries	$4,938	$11,295	$3,112	$7,118
Reverse osmosis and clarifier skid	$1,022	$2,248	$1,032	$2,264
Heat integration	$1,132	$2,982	$1,090	$2,871
Area A800 subtotal	**$7,230**	**$17,156**	**$5,395**	**$12.915**

3.9 Additional Process Design Information

Table 22 contains additional information used in the Aspen Plus model and design basis. For those interested, any deviations in the pressure drop assumptions can be found in the stream tables (Appendix G).

Table 22. Utility and Miscellaneous Design Information

Item	Design Information
Ambient air conditions [a,b,c]	Pressure: 14.7 psia $T_{dry\ bulb}$: 90°F $T_{wet\ bulb}$: 80°F Air composition (mol %): N_2: 75.7% O_2: 20.3% Ar: 0.9% CO_2: 0.03% H_2O: 3.1%
Pressure drop allowance	Air pre-heat exchangers = 1 psi Heat exchangers = 5 psi, 2 psi in vapor condensation train

[a] In the GPSA *Engineering Data Book* [51], see Table 11.4 for typical design values for dry bulb and wet bulb temperature by geography. Selected values would cover summertime conditions for most lower 48 states.
[b] In Weast [52], see F-172 for composition of dry air. Nitrogen value is adjusted slightly to force mole fraction closure using only nitrogen gas (N_2), oxygen (O_2), argon (Ar), and carbon dioxide (CO_2) as air components.
[c] In Perry et al. [17], see psychrometric chart, Figure 12-2, for moisture content of air.

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3.10 Pinch Analysis

While an energy balance was performed within the Aspen Plus process simulation, it was also necessary to ensure that there was no temperature crossover when the assumption was made that the cold process streams can be heated using the available heat in hot process streams. A pinch analysis was performed to show the temperatures at which hot and cold duties are available.

The concept of pinch technology offers a systematic approach for optimizing energy integration in process design. Temperature and heat flow (Q) data were gathered for the hot process streams (streams cooled in the process), cold process streams (streams heated in the process), and utility streams like steam, flue gas, and cooling water. A composite curve, a graphical presentation of stream temperature and heat flow (Q) data, was constructed for the hot and cold process streams. These two curves are shifted so that they touch at the pinch point. From this shifted graph, a grand composite curve is constructed that plots the difference in heat flow between the hot and cold composite curves as a function of temperature.

The total hot duty equals the total cold duty, as the Aspen Plus model is designed to adjust the water flow rate through the steam cycle until the heat balance in the system is closed. The minimum vertical distance between the curves is ΔT_{min}, which is theoretically the smallest approach temperature in the exchanger network. For the *in situ* case, the upper and lower pinch temperatures are 310.9°F and 288.3°F, respectively, resulting in ΔT_{min} of 22.6°F. For the *ex situ* case, the upper and lower pinch temperatures are 309.9°F and 285.0°F, respectively, resulting in ΔT_{min} of 24.9°F. Figure 9 and Figure 10 show those curves for the *in situ* and *ex situ* cases. The figures demonstrate the feasibility of developing a network based on the current process models (since there is no crossover). A complete heat exchange network is provided for the *ex situ* case in Appendix H. The total heat exchanger network costs for the *in situ* and sensitivity cases (Figure 15) were factored from the *ex situ* base case using total duties, and a scaling exponent of 0.65. Since heat exchangers span the various process areas, heat exchanger network costs were distributed among the various areas based on duties from respective areas. The process flow diagrams in Appendix G-2 for the *ex situ* case include information from the heat exchanger network design shown in Appendix H.

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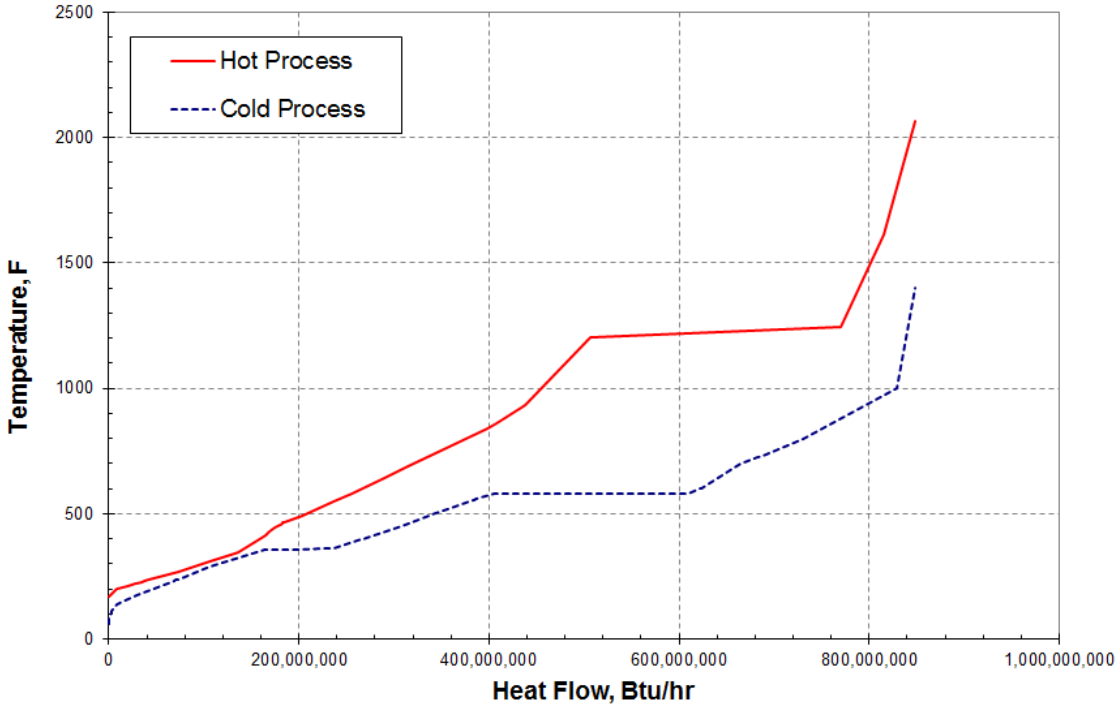

Figure 9. Pinch analysis composite curve for the *in situ* case

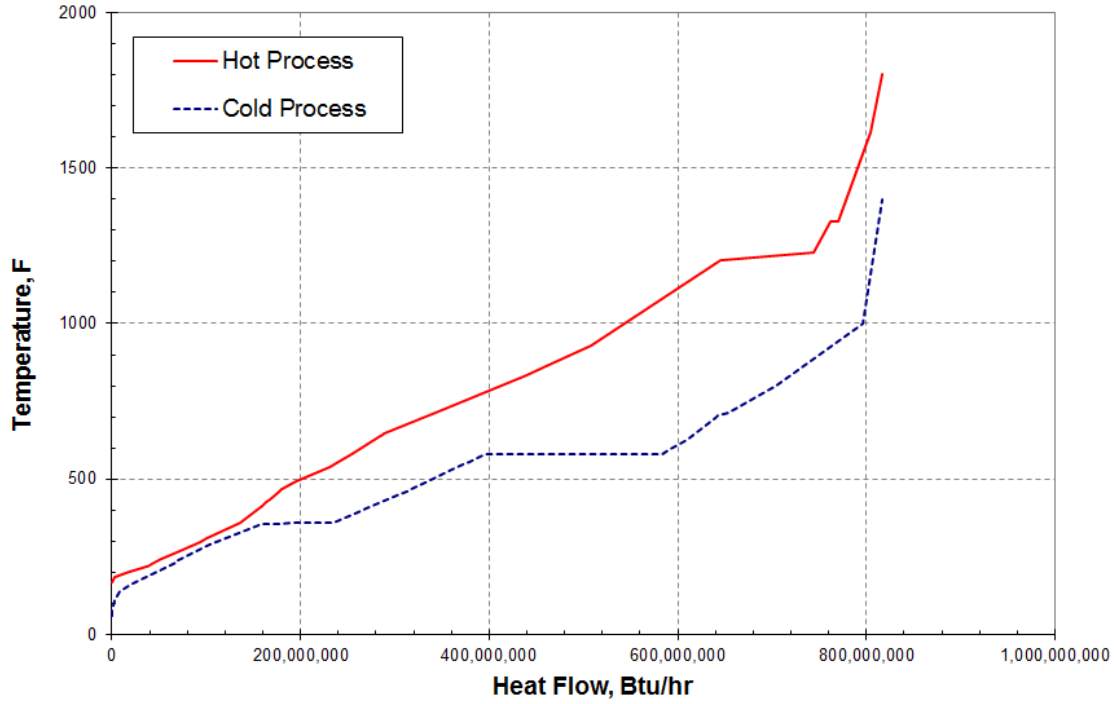

Figure 10. Pinch analysis composite curve for the *ex situ* case

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3.11 Energy Balance

Energy integration is important to the overall economics and efficiency of the process. Therefore a detailed understanding of how and where the energy is utilized and recovered is required. Detailed energy balances around the major process areas were derived using data from the Aspen Plus simulation. Comparing the process energy inputs and outputs allows the energy efficiency of the process to be quantified. Tracing energy transfer between process areas also makes it possible to identify potential improvements to the energy efficiency.

This design for pyrolysis and upgrading of cellulosic biomass was constructed with the goal of utilization of heating values of solid (char and coke) and gaseous (off-gases) products within the process, with the export of excess electricity using any extra energy available. Relative to the energy in biomass, an insignificant amount of natural gas input is added to supplement process gases in the steam reformer for hydrogen production. The small amount of natural gas was introduced to maintain the process model in a state where natural gas could be introduced in the model to study sensitivity cases. Unreacted light-ends from pyrolysis are combusted to produce steam and electricity for the plant. On balance, the pyrolysis process requires no electricity from the grid and exports electricity instead.

The distribution of the total energy content in the feed is shown in Figure 11. The basis for these pie charts is the total energy in the dry portion of the feed (approximately 1,470 MMBtu/h) and the total energy in the small natural gas co-feed to the process (2 MMBtu/h for *in situ*, 3 MMBtu/h for *ex situ*). Figure 11 shows that >50% of the LHV is recovered as fuel-range hydrocarbon products in both cases. Another 1% is further exported as saleable surplus electricity. A significant amount (~35%) is lost through electricity-driven air-cooled exchangers, and the remainder of the energy is lost to the plant surroundings. Further optimization of the heat integration network can be evaluated if it is felt as necessary in the future.

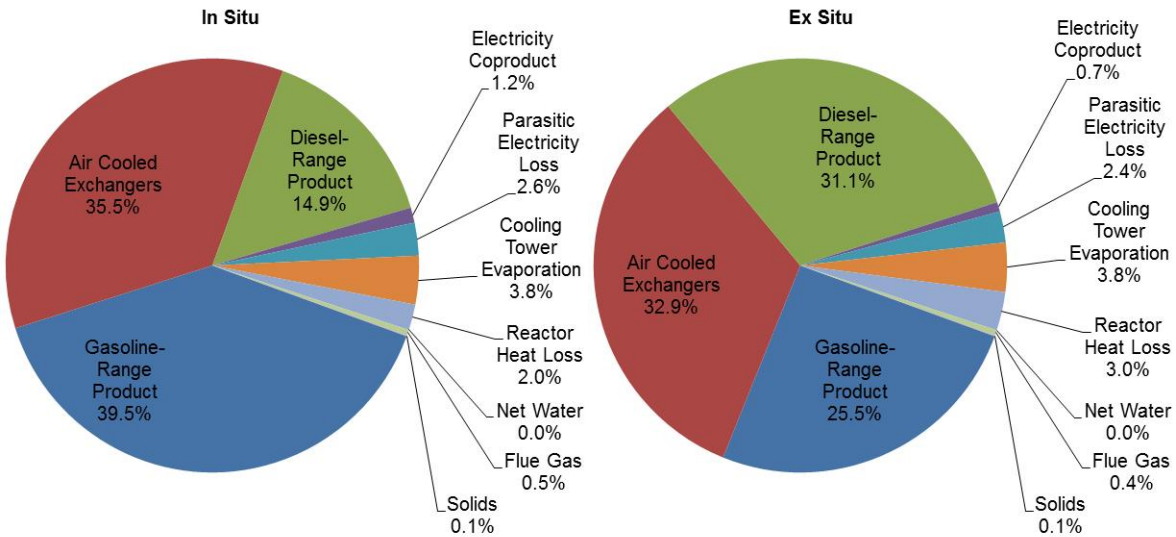

Figure 11. Overall energy balance (basis: LHV of wood + natural gas). Values rounded to nearest tenth.

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3.12 Sustainability Metrics

An important aspect of evaluating biofuel processes is the quantification of life-cycle resource consumption and environmental emissions. Life-cycle assessment (LCA) provides a framework from which the environmental sustainability of a given process may be quantified and assessed. This section presents the salient sustainability metrics of the current conceptual process at the conversion stage. Direct biorefinery emissions (i.e., CO_2, NO_2, and SO_2), water consumption, and other process-related metrics were derived from the conversion process model described above.

SimaPro v. 8.02 software [53] was used to develop and link units quantifying life-cycle impacts. Greenhouse gas (GHG) basis values for natural gas (NG) and the U.S. average electricity mix from the grid were applied consistently with the basis from Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model software; this includes GHG emission factors of 3.25 kg CO_2e/kg NG (LHV) and 0.65 kg CO_2e/kWh grid electricity [54]. Likewise, the basis from GREET was also applied for non-renewable (fossil) energy consumption values of 52.1 MJ/kg (LHV) natural gas and 7.5 MJ/kWh grid electricity [54]. All other process input/output inventory estimates were derived from Ecoinvent v.2.0 [55] and the U.S. Life Cycle Inventory (LCI) [56] processes to fill the data gaps. The Ecoinvent processes were modified to reflect U.S. conditions and the U.S. LCI processes were adapted to account for embodied emissions and fossil energy usage. The material and energy flows of the conversion step capture the impacts of input raw materials, and outputs, such as emissions, wastes, and coproducts as predicted by the process model, as shown in Table 23 for the *in situ* case and Table 24 for the *ex situ* case.

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Table 23. Material and Energy Flows for the *In Situ* Case

	Production Rate		
Products	lb/hr	gal/hr	MMBtu/hr (LHV)
Gasoline fuel	31,866	4,978	579
Diesel fuel	11,845	1,885	219
Byproducts	kW		
Excess electricity	5,117		
Resource Consumption	**Flow Rate**	**Per Gal Gasoline**	**Per MMBtu**
	lb/hr	lb/gal	lb/MMBtu
Blended woody biomass (wet)	204,131	41.01	352.35
Blended woody biomass (dry)	183,718	36.91	317.12
Sand makeup	0	0.00	0.00
Natural gas	54	0.01	0.09
Zeolite catalyst	344	0.07	0.59
Hydrotreating catalyst	15	0.00	0.03
Hydrocracking catalyst	2	0.00	0.00
50 wt % caustic	291	0.06	0.50
Net water makeup	43,242	8.69	74.64
Boiler feed water chemicals	2	0.00	0.00
Cooling tower chemicals	1	2.01E-04	0.00
No. 2 diesel fuel	71	0.01	0.12
Waste Streams	lb/hr	lb/gal	lb/MMBtu
Solids purge from fluidized bed reactors	2,555	0.51	4.41
Wastewater	21,410	4.30	36.96
Air Emissions	lb/hr	lb/gal	lb/MMBtu
CO2 (Fossil)	147	0.03	0.25
CO2 (Biogenic)	204,428	41.07	352.86
CH4	0	0.00	0.00
CO	0	0.00	0.00
NO2	13	0.00	0.02
SO2	106	0.02	0.18
H2O	105,471	21.19	182.05
H2S	0	0.00	0.00

Note: Small quantities of HDS catalyst and ZnO used before steam reforming not shown.

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Table 24. Material and Energy Flows for the *Ex Situ* Case

	Production Rate		
Products	lb/hr	gal/hr	MMBtu/hr (LHV)
Gasoline fuel	20,408	3,236	375
Diesel fuel	24,739	3,930	456
Byproducts	kW		
Excess electricity	3,201		
Resource Consumption	**Flow Rate**	**Per Gal Gasoline**	**Per MMBtu**
	lb/hr	lb/gal	lb/MMBtu
Blended woody biomass (wet)	204,131	63.07	544.03
Blended woody biomass (dry)	183,718	56.77	489.63
Sand makeup	158	0.05	0.42
Natural gas	125	0.04	0.33
Zeolite catalyst	229	0.07	0.61
Hydrotreating catalyst	16	0.00	0.04
Hydrocracking catalyst	4	0.00	0.01
50 wt % caustic	294	0.09	0.78
Net water makeup	41,495	12.82	110.59
Boiler feed water chemicals	2	0.00	0.01
Cooling tower chemicals	1	3.09E-04	0.00
No. 2 diesel fuel	71	0.02	0.19
Waste Streams	lb/hr	lb/gal	lb/MMBtu
Solids purge from fluidized bed reactors	2,335	0.72	6.22
Wastewater	20,708	6.40	55.19
Air Emissions	lb/hr	lb/gal	lb/MMBtu
CO2 (Fossil)	342	0.11	0.91
CO2 (Biogenic)	200,605	61.98	534.64
CH4	0	0.00	0.00
CO	0	0.00	0.00
NO2	17	0.01	0.04
SO2	107	0.03	0.29
H2O	98,451	30.42	262.38
H2S	0	0.00	0.00

Note: Small quantities of HDS catalyst and ZnO before steam reforming not shown.

In addition to primary fuel production, the process also produces an excess amount of electricity as coproduct. It is assumed that the excess electricity would be sold to the grid translating to coproduct credits for avoided GHG emissions and fossil energy consumption. This exported electricity is treated as an avoided product using the product displacement method [57]. Coproduct displacement (also termed system boundary expansion) is based on the concept of displacing the existing product with the new product. The excess electricity coproduct displaces an equivalent amount of grid electricity, thus avoiding a significant amount of GHG emissions as

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well as fossil energy consumption, assuming an average U.S. electricity grid mixture. The GHG and fossil energy consumption credits attributed to the displacement of an average U.S. electricity grid mixture is 0.65 kg CO_2e/kWh and 7.5 MJ/kWh, respectively, as defined by GREET [54]. However, it is not clear whether power companies would be willing to buy the excess electricity generated from cellulosic biorefinery. Thus, a second scenario assumed that the excess electricity would not be sold to the grid and thus there were no coproduct credits for avoided GHG emissions and fossil energy consumption. Table 25 lists the SimaPro database processes used for the GHG calculations.

Table 25. SimaPro Processes Used for Conversion Process Inputs

Key Inputs	SimaPro Processes
Electricity	GREET
Natural gas	GREET
Sand makeup	Silica sand, at plant/DE WITH US ELECTRICITY U
Zeolite catalyst	Zeolite, powder, at plant/RER WITH US ELECTRICITY U
Hydrotreating catalyst	Zeolite, powder, at plant/RER WITH US ELECTRICITY U
Hydrocracking catalyst	Zeolite, powder, at plant/RER WITH US ELECTRICITY U
ZnO bed material	Zeolite, powder, at plant/RER WITH US ELECTRICITY U
HDS catalyst before reformer	Zeolite, powder, at plant/RER WITH US ELECTRICITY U
Steam reforming catalyst	Zeolite, powder, at plant/RER WITH US ELECTRICITY U
Shift catalyst	Zeolite, powder, at plant/RER WITH US ELECTRICITY U
PSA adsorbent	Zeolite, powder, at plant/RER WITH US ELECTRICITY U
50 wt % caustic	Sodium hydroxide, 50% in H2O, production mix, at plant/RER WITH US ELECTRICITY U
Net water makeup	Water, process, unspecified natural origin/kg
Boiler feed water chemicals	Sodium hydroxide, 50% in H2O, production mix, at plant/RER WITH US ELECTRICITY U; Sulphite, at plant/RER WITH US ELECTRICITY U, Hydrochloric acid, 30% in H2O, at plant/RER WITH US ELECTRICITY U
Cooling tower chemicals	Chemicals in organic, at plant/GLO WITH US ELECTRICITY U

On an energy basis and with electricity credits, the GHG emissions at the conversion stage for the *in situ* and *ex situ* cases are *negative* 2.6 g CO_2e/MJ and *negative* 1.2 g CO_2e/MJ, respectively. However, without electricity credits, the GHG emissions are higher, 1.3 and 1.2 g CO_2e/MJ for the *in situ* and *ex situ* cases, respectively. Similarly, the fossil energy consumption for the case with electricity credits are *negative* 0.03 MJ/MJ and *negative* 0.01 MJ/MJ for the *in situ* and *ex situ* cases, respectively. Without electricity coproduct displacement credits, the fossil energy consumptions for both the *in situ* and *ex situ* cases are 0.02 MJ/MJ. The electricity coproduct displacement credits are only relevant to the GHG emissions and fossil energy consumption assessment and not to other metrics in Table 26. The contributions of individual inputs to the total conversion stage GHG are shown in Figure 12.

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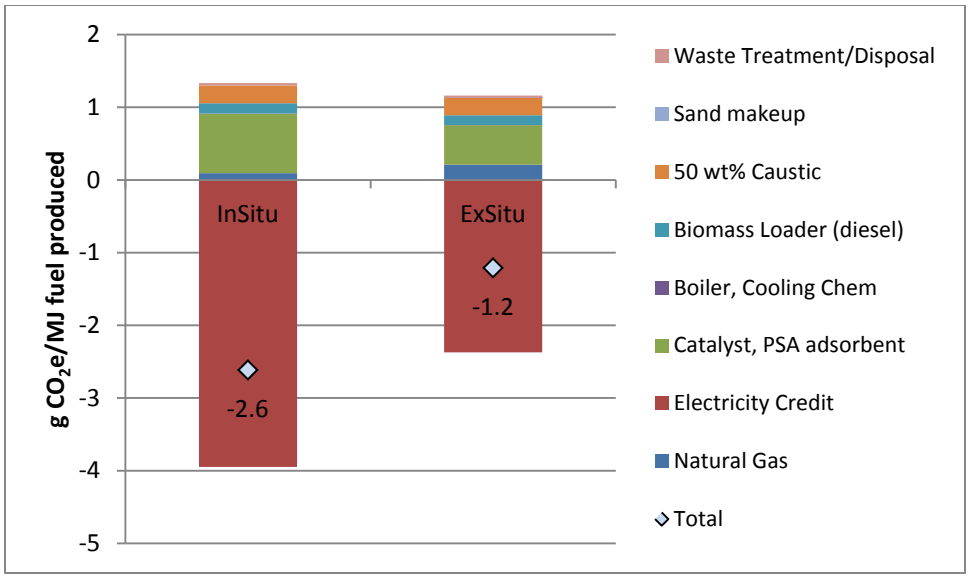

Figure 12. Contributing processes to conversion GHGs for catalytic pyrolysis pathways

In addition to GHG emissions and fossil energy consumption discussed above, water consumption (i.e., net water use during the biorefinery operation), total fuel efficiency (yield), and carbon-to-fuel efficiency are also reported in Table 26.

Biorefinery net water consumption includes, but is not limited to, water that is incorporated into the product and evaporation directly from process operations or indirectly from cooling and heating processes (e.g., cooling tower evaporative losses), but it does not include water that is directly returned to surface water or groundwater (such as blowdown). The net consumption for the *in situ* and *ex situ* cases are 468 and 449 m^3/day, respectively. The total fuel yield is 74.9 GGE per dry ton for the *in situ* case and 78.0 GGE per dry ton for the *ex situ* case. The corresponding carbon-to-fuel efficiency for the *in situ* and *ex situ* cases are determined to be 40.4% and 41.5%, respectively, calculated strictly as a ratio of carbon in the liquid fuel products relative to carbon in the biomass feedstock.

Table 26. Summary of Sustainability Metrics for the *In Situ* and *Ex Situ* Cases

Design Cases:	***In Situ***		***Ex Situ***	
Electricity credit	Yes	No	Yes	No
GHG emissions (g CO_2e/MJ)	-2.6	1.3	-1.2	1.2
Net fossil energy consumption (MJ/MJ)	-0.03	0.02	-0.01	0.02
Water consumption (m^3/day)	470		450	
Water consumption (gal/GGE fuel)	0.75		0.69	
Total fuel yield (GGE/dry ton)	74.9		78.0	
Carbon-to-fuel efficiency (C in fuel/C in biomass)	40.4%		41.5%	
Wastewater generation (m^3/day)	233		225	
Wastewater generation (gal/GGE)	0.37		0.35	

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The analysis was expanded to estimate the full life-cycle GHG emissions for fuels produced from the projected 2017 model feedstock, a blend of pulpwood (45%), wood residues (32%), switchgrass (3%), and construction and demolition waste (20%) [22]. Full life-cycle GHGs for gasoline fuel from the 2017 model feedstock are estimated at 9.2 g CO_2e/MJ and 10.2 g CO_2e/MJ for the *in situ* and *ex situ* cases, respectively. This corresponds to GHG reductions relative to the 2005 petroleum baseline GHGs (93.08 g CO_2e/MJ) [58] of 90% and 89% for the *in situ* and *ex situ* cases, respectively. The underlying assumptions and detailed results for the full life-cycle GHG analysis are given in Appendix E. While this analysis provides a preliminary estimate of GHG reduction associated with this biofuel, it is important to note that the EPA conducts its own LCA to make final determination of fuel qualification under the Renewable Fuel Standard 2. In addition, Argonne National Laboratory will provide more detailed LCA for these pathways in the future.

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4 Process Economics

The following section describes how the process model, detailed design, and cost estimation discussed so far is used to determine the economics of fuel production. The analysis is based entirely on estimated equipment costs and regular construction and project management costs associated with building a plant of this kind. The analysis does not take into account any policy factors such as carbon credits, subsidies, or mandates.

The TCI is first computed using a comprehensive list of mechanical equipment in the plant and its expected construction and project costs. Variable and fixed operating costs associated with plant operation and maintenance are determined next. With these estimated costs, a discounted cash flow analysis is used to determine an MFSP that resolves to a net present value of zero for the entire project at some assumed nonzero discount rate, also referred to in this report as the internal rate of return (IRR). In other words, given the production rates determined in the process model, fuel from the plant must be sold at its MFSP in order for the project to return the specified IRR and no more. This section describes the calculations and assumptions made in completing the discounted cash flow analysis.

4.1 Total Capital Investment

The following discussion summarizes the purchased and installed equipment costs presented in Section 3 and describes how the total installed costs for the plant serve as the basis for determining the total capital investment. As previously discussed, the equipment costs for each plant area were derived from various sources including equipment suppliers and licensors, cost estimates from Harris Group, published literature, and Aspen Capital Cost Estimator software. The sum of all items on a bare-equipment, freight on board (FOB) basis is the total purchased equipment cost. The installation cost for the bare equipment is estimated by applying installation factors to each piece of equipment. For those equipment costs estimated in ACCE, we used the installation factor implied by ACCE (total direct cost/equipment cost). For line items quoted as a package or drawn from other references (for example, the steam methane reformer), the installation factor implied in the source was used. Any remaining missing installation factors were determined as described in the 2011 NREL design report for biochemical ethanol [49], which used a table of installation factors by equipment type found in Walas [19], plus 0.3 to account for instrumentation, which NREL determined was deliberately excluded from these factors. See Appendix B for a complete listing of the equipment, along with its purchased and installed costs. Table 27 presents a summary of TPEC, aggregate installation factors ($f_{install}$), and TIC for each area of the plant.

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Table 27. General Cost Factors in Determining Total Installed Equipment Costs

		In Situ			*Ex Situ*		
Area	**Process Description**	**TPEC (MM$)**	**$f_{install}$**	**TIC (MM$)**	**TPEC (MM$)**	**$f_{install}$**	**TIC (MM$)**
100	Feed handling and drying[a]	0.3	1.96	0.5	0.2	1.97	0.4
200	Fast pyrolysis and vapor upgrading	31.1	2.98	92.5	40.7	3.12	126.9
300	Pyrolysis vapor quench and product recovery	12.2	1.84	22.4	13.2	1.83	24.2
400	Hydroprocessing and product separation	18.8	1.73	32.5	15.9	1.83	29.1
500	Hydrogen plant	36.5	1.93	70.6	34.5	1.93	66.8
600	Steam system and power generation	29.3	1.79	52.4	26.7	1.80	47.9
700	Cooling water and other utilities	4.7	2.01	9.4	4.6	2.00	9.3
800	Wastewater management and recycle	7.2	2.37	17.2	5.4	2.39	12.9
ISBL	**(Areas 100–400)**	**62.3**	**2.38**	**147.9**	**70.0**	**2.58**	**180.7**
OSBL	**(Areas 500–800)**	**77.7**	**1.93**	**149.7**	**71.2**	**1.92**	**136.8**
Total		**140.0**	**2.13**	**297.6**	**141.2**	**2.25**	**317.5**

[a] Most investment costs for feed handling and drying are included in the per-unit woody feedstock price. This cost is for a secondary biomass dryer that serves to recover heat.

The sum of equipment purchases and installation/construction costs is defined as the total direct cost (TDC). Indirect capital costs are non-construction costs typically associated with project management and engineering, procurement, and construction (EPC) services. Indirect costs are estimated with factors on the TDC as shown in Table 28. The sum of direct and indirect costs is defined as the fixed capital investment (FCI). Finally, working capital is determined to be 5% of the FCI. The sum of FCI and working capital is the TCI. Table 29 presents a summary of these capital quantities for the *in situ* and *ex situ* pyrolysis processes described in this report.

Table 28. Cost Factors for Indirect Costs

Indirect Costs	**% of TDC***
Prorated expenses	10.0
Home office and construction fees	20.0
Field expenses	10.0
Project contingency	10.0
Other costs (start-up and permits)	10.0
Total Indirect Costs	**60.0**

* Excluding land purchase cost.

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Table 29. Project Cost Worksheet

		In Situ	*Ex Situ*
Total purch. equipment cost (TPEC)		**$140,030,000**	**$141,180,000**
Installation factor		2.125	2.249
Total installed cost (TIC)		**$297,610,000**	**$317,540,000**
Other direct costs			
Land (not depreciated)		$1,610,000	$1,610,000
Warehouse	4.0% of ISBL	$5,920,000	$7,230,000
Site development	10.0% of ISBL	$14,790,000	$18,070,000
Additional piping	4.5% of ISBL	$6,660,000	$8,130,000
Total direct costs (TDC)		**$324,980,000**	**$350,970,000**
Indirect costs	% of TDC (ex land)		
Prorated expenses	10.0%	$32,500,000	$35,100,000
Home office and construction fees	20.0%	$65,000,000	$70,190,000
Field expenses	10.0%	$32,500,000	$35,100,000
Project contingency	10.0%	$32,500,000	$35,100,000
Other costs (start-up and permits)	10.0%	$32,500,000	$35,100,000
Total indirect costs	**60.0%**	**$194,990,000**	**$210,580,000**
Fixed capital investment (FCI)		**$519,960,000**	**$561,550,000**
Working capital	5.0% of FCI (ex land)	$26,000,000	$28,080,000
Total capital investment (TCI)		**$545,960,000**	**$589,630,000**
TCI/TPEC		3.899	4.177
FCI Lang Factor = FCI/ISBL TPEC		8.349	8.023
TCI Lang Factor = TCI/ISBL TPEC		8.766	8.424

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4.2 Variable Operating Costs

Variable operating costs, which include raw materials, waste handling charges, and by-product credits, are incurred only when the process is operating. Quantities of raw materials used and wastes produced were determined using the Aspen Plus material balance. Table 30 summarizes the basis for variable operating costs considered in this analysis. A detailed summary of variable plant operating costs is presented in Appendix C on a per-year and per-GGE basis.

Table 30. Summary of Variable Operating Costs

Variable	Information and Operating Cost (cost year in parentheses)
Fluidized bed media	For fast pyrolysis, the bed medium is sand. In catalytic fast pyrolysis (*in situ*) and vapor-phase upgrading (*ex situ*), the medium is assumed to be a zeolite catalyst. Initial fill then a total replacement rate of 3.6 wt % of circulation per day for both the *in situ* and *ex situ* cases. Sand price: $45.74/ton (2011) [59]; initial fill, then makeup for attrition. Zeolite price: $19,500/ton (2011); estimated cost based on modifications, such as to include rare earth [27] and non-precious metals like nickel (Ni) up to 5 wt %.
Hydrotreating and hydrocracking catalysts	To determine the amount of catalyst inventory, the hydroprocessors were sized for a WHSV of 0.5/h based on the expected hydroprocessing severity. Initial fill is then replaced every 2 years. Price: $20/lb (2011) based on NREL calculations using metals pricing and costs for manufacturing processes, and some buffer for modifications.
Steam methane reformer catalysts	Based on a literature value of price per unit hydrogen produced. Price: $7.80/ton hydrogen (2011) [60].
Natural gas	Purchased from pipeline for feed to steam methane reformer for hydrogen production. Price: $239/ton ($5/MMBtu) (2011).
Solids disposal	Price: $33/tonne (1998) [16].
Diesel fuel	Usage: 10 gal/h plant-wide use. 2012 price projection: $21.29/MMBtu (2009) [61] = $2.86/gal at 0.85 specific gravity.
Water makeup	Price: $0.22/tonne (2001) [17] = $0.20/ton.
Chemicals	Boiler feed water chemicals – Price: $75/MM lb blowdown (2014 vendor estimate). Cooling tower chemicals – Price: $33.84/yr per ton of cooling capacity (2014 vendor estimate). Caustic – Price: $150/dry ton (2010) [49].
Wastewater	Most wastewater is cleaned using an RO system and recycled. Additional treatment is assumed for the balance. Price: $0.022/gallon (2011). Based on Humbird et al. [49].

Note: Costs shown were updated to 2011 dollars using an inorganic cost index [62].
Values used: 1998 = 148.7; 2001 = 158.4; 2010 = 233.9.; 2011 = 249.3, 2014 = 280.2 (extrapolated).

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4.3 Fixed Operating Costs

Fixed operating costs, which include employee salaries and benefits, overhead, plant maintenance costs, insurance, and taxes (other than income taxes), are generally incurred in full whether or not the plant is producing at full capacity. Table 31 lists the expected number of employees for the plant and their associated salaries. The salaries listed do not include benefits, so a general overhead factor is applied, as shown in Table 32, along with fixed costs for insurance, taxes, and general plant maintenance, such as security, janitorial services, and communications. A detailed summary of fixed plant operating costs is presented in Appendix C.

Table 31. Salary Costs for Plant Employees

Position Title	Salary (2007)	Number of Positions	Total Cost* (2011)
Plant manager	$147,000	1	$161,362
Plant engineer	$70,000	1	$76,389
Maintenance supervisor	$57,000	1	$62,569
Laboratory manager	$56,000	1	$61,471
Shift supervisor	$48,000	5	$263,448
Lab technician	$40,000	2	$87,816
Maintenance technician	$40,000	16	$702,527
Shift operators	$48,000	20	$1,053,790
Yard employees	$28,000	12	$368,827
Clerks and secretaries	$36,000	3	$118,551
Total salaries (2011$/yr)			**$2,960,000**

* Additional 10% escalation to costs indicated in this column, as shown in Table 32,

Note: Labor costs are indexed, if necessary, to values from the U.S. Bureau of Labor Statistics (http://data.bls.gov/cgi-bin/srgate CEU3232500008).

Table 32. Fixed Operating Costs

Cost Item	Factor	*In Situ*	*Ex Situ*
Salaries (plus 10% escalation)		$3,250,000	$3,250,000
Benefits and overhead	90.0% of total salaries (after adding 10%)	$2,922,000	$2,922,000
Maintenance	3.0% of fixed capital investment (FCI*)	$15,599,000	$16,847,000
Insurance and taxes	0.7% of fixed capital investment (FCI*)	$3,640,000	$3,931,000
Total fixed operating costs (2011$/yr)		**$25,410,000**	**$26,950,000**

* Percentages of FCI exclude land purchase cost.

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4.4 Discounted Cash Flow Analysis and the Minimum Fuel Selling Price

Once the capital and operating costs are determined, an MFSP is determined using a discounted cash flow rate of return (DCFROR) analysis. The general methodology used is the same as that applied in previous NREL design reports [20, 49], with the small distinction that we normalize all fuel products from the plant (gasoline and diesel) by lower heating value to give a single gasoline-equivalent product. The discounted cash flow analysis determines the minimum selling price of a gallon of this gasoline-equivalent product, which yields a net present value of zero for the project. The financial parameters used to compute the net present value are as follows.

Discount Rate/IRR

For this analysis, the cash flow discount rate was set to an internal rate of return of 10% on equity finance.

Equity Financing

For this analysis, it was assumed that the plant would be 40% equity financed. The terms of the loan on the remaining 60% debt were taken to be 8% interest for 10 years. The principal is taken out in stages over the 3-year construction period. Interest on the loan is paid during this period, but principal is not paid back. (This implies that cash flow comes from a parent company until the plant starts up.)

Depreciation

Capital depreciation is computed according to the IRS Modified Accelerated Cost Recovery System (MACRS). The bulk of the plant capital is depreciated over a 7-year recovery period. Because the plant described here is a net exporter of electricity, the steam plant and power generation equipment is depreciated over a 20-year recovery period, according to the IRS.

Taxes

The federal corporate tax rate used in our analysis is 35%. Income tax is averaged over the plant life and that average is calculated on a per-GGE basis. The amount of income tax to be paid varies annually with changes in the volume of product produced and the allowable depreciation deduction. In fact, no income tax is paid in the first 8 years of operation because depreciation and loan interest deductions are greater than the net income. State taxes are not considered, primarily because the location of the plant has not been determined and tax rates vary from state to state (from 0% to 12%).

Construction Time

The construction time was taken to be 24 months. Twelve months are added before construction for planning and engineering.

Start-Up Time

Startup was taken to be 25% of the construction time, or 6 months in this case. It is assumed that the plant achieves 50% production during the start-up period while incurring 75% of variable expenses and 100% of fixed expenses.

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Lifetime

The plant and all equipment is assumed to have a 30-year life. No salvage value is assumed at the end of 30 years.

Working Capital

Working capital was taken to be 5% of the fixed capital investment.

4.5 Value of Hydrocarbon Fuel Products From Biomass Pyrolysis

The results of the cash flow analyses for the base *in situ* and *ex situ* cases are summarized in Table 33. As noted above, gasoline and diesel are normalized by lower heating value to represent a single gasoline-equivalent product and MFSP. To re-obtain individual selling prices for gasoline and diesel, the MFSP per GGE is ratioed back to these products by lower heating value. The densities of the blendstocks were assumed to be those of U.S. conventional gasoline (2,819 grams/gallon or 6.215 lb/gallon) and diesel fuels (3,167 grams/gallon or 6.982 lb/gallon) [63].

Table 33. Projected Selling Prices of Hydrocarbon Fuels From Biomass Pyrolysis

	In Situ	***Ex Situ***
Lower heating value for gasoline-range products from pyrolysis (simulation result)	112.988 Btu/gal	114,267 Btu/gal
Lower heating value for diesel-range products from pyrolysis (simulation result)	129,006 Btu/gal	128,779 Btu/gal
Calculated gasoline-equivalent MFSP	**$3.46/GGE**	**$3.31/GGE**
Calculated actual MFSP for gasoline-range products	**$3.37/gal**	**$3.26/gal**
Calculated actual MFSP for diesel-range products	**$3.85/gal**	**$3.68/gal**
Gasoline lower heating value for normalization		*116,090 Btu/gal*

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5 Process Economics Summary and Sensitivity Analysis

The contribution of individual areas toward the MFSP on a $/GGE basis are shown in Figure 13 for the *in situ* case and Figure 14 for the *ex situ* case. Additional summary tables with a detailed breakdown of costs are shown in the Executive Summary and not repeated here.

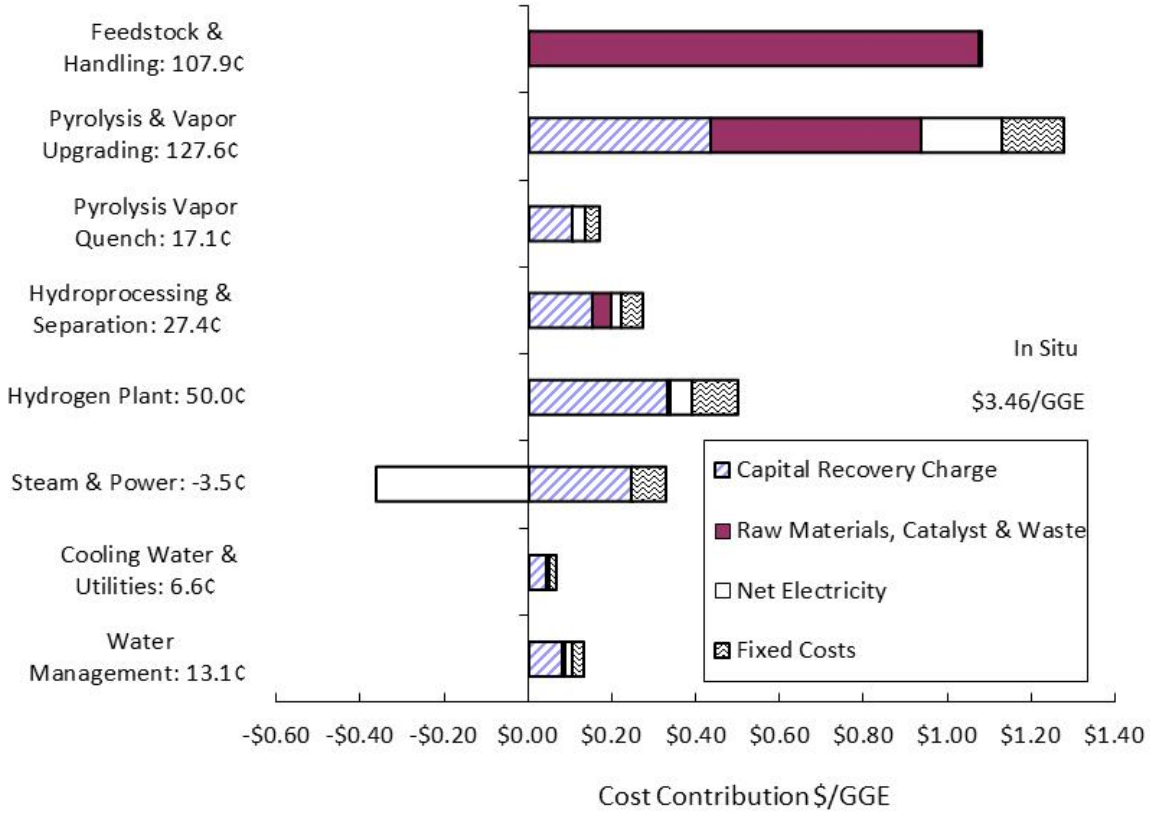

Figure 13. Cost contribution details from each process area for the *in situ* 2022 target case

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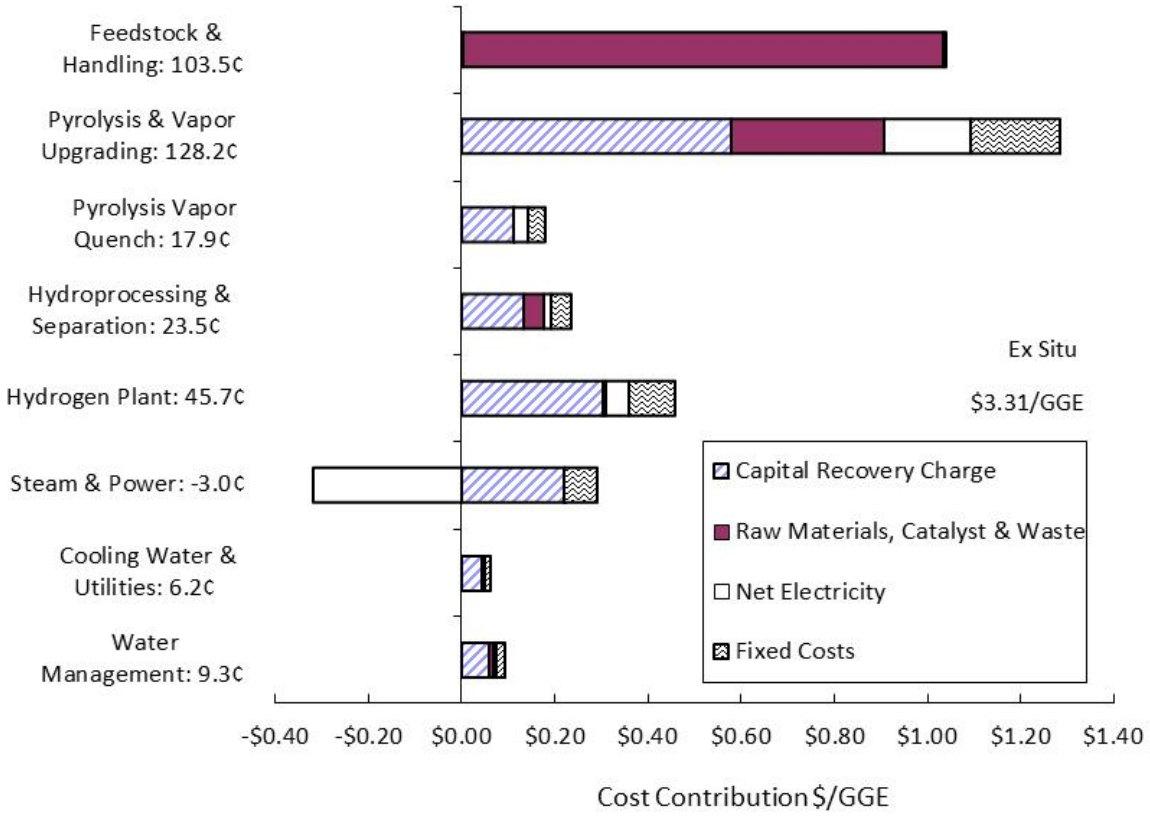

Figure 14. Cost contribution details from each process area for the *ex situ* 2022 target case

Since the design basis for the *in situ* and *ex situ* cases were similar, except for the fast pyrolysis and vapor upgrading reactors, it is not surprising that they show similar cost distribution trends. The key points to be noted are:

1. The higher capital cost due to separate fast pyrolysis and vapor upgrading reactors in the *ex situ* case (versus a single combined reactor in the *in situ* case) is offset by the lower catalyst replacement rate in the *ex situ* case. The assumed rate is 2% of the inventory per day for both the *in situ* and *ex situ* cases, with an additional 1.6% added to account for attrition. The catalyst to biomass ratio is 7.5 for the *in situ* case compared to 5 for the *ex situ* case, which results in a higher *in situ* catalyst inventory, hence higher calculated losses.
2. The slightly higher hydroprocessing cost for the *in situ* case is primarily due to the higher oxygen content assumed in the organic liquid after vapor upgrading; hydrogen consumption and the hydrogen plant cost is also higher for the same reason.
3. Wastewater management costs are higher for the *in situ* case because of the assumption of higher carbon loss to the aqueous phase as a result of higher oxygen content in the organic liquid from *in situ* vapor upgrading.

While these are some of the key differences, there are other underlying differences within the process model and costs, as was noted in the tables comparing the two base cases throughout this report.

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As previously pointed out, the *in situ* and *ex situ* base cases are two of many possible scenarios for cost competiveness of these pathways through research focused primarily on catalyst development, and demonstration of credible process integration and scale-up. Significant uncertainties remain to be resolved through experimental corroboration. Thus, it is important to show the impacts of variations in some of the key underlying assumptions through sensitivity studies. Sensitivity scenarios for the *ex situ* case are summarized in Figure 15. Similar parameter variations for the *in situ* case are expected to follow the trends shown for the *ex situ* case.

Note that each sensitivity scenario in Figure 15 has an associated deviation value from the base case MFSP of $3.31/GGE. The sensitivity scenarios are discussed in the following sections. The case numbers in the text refer to the numbers shown in the labels of Figure 15. This being a tornado chart, the results are sorted by the magnitudes of impacts on the MFSP.

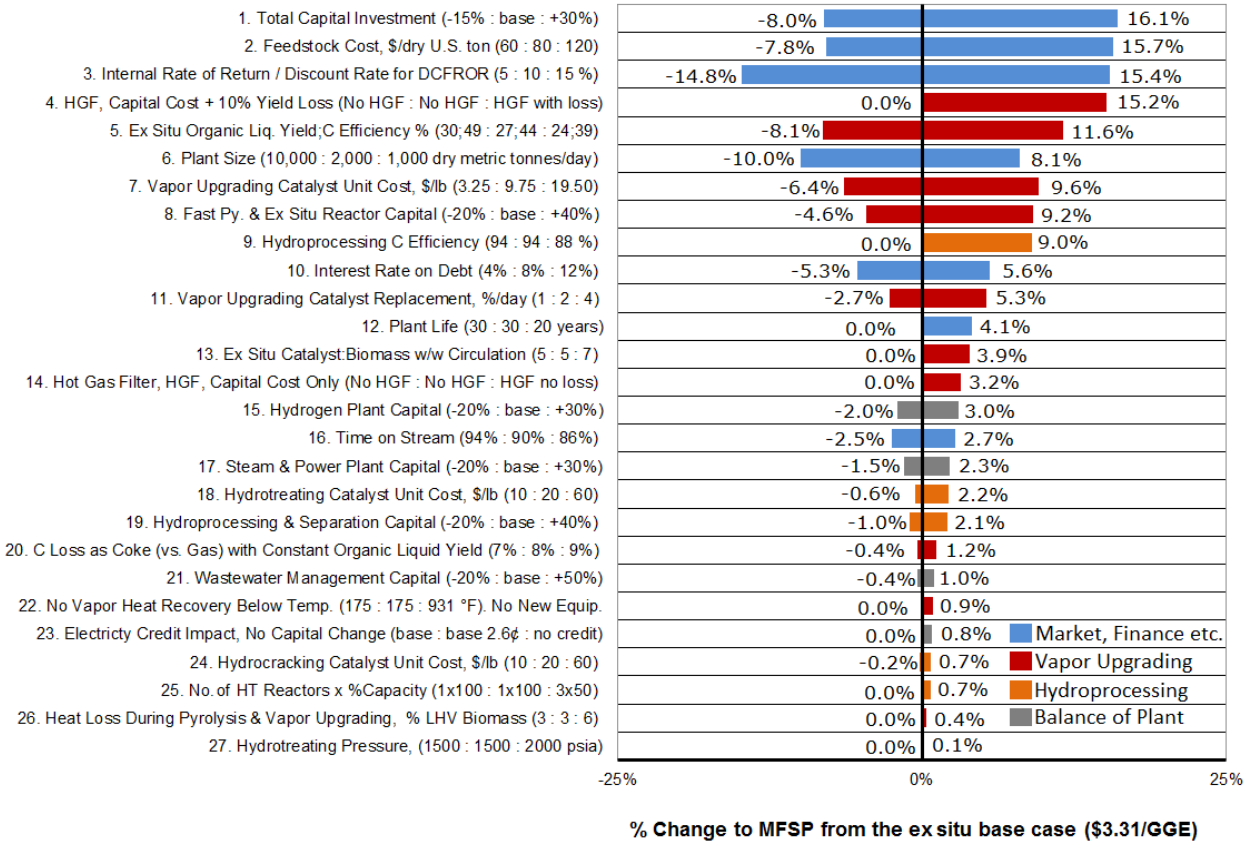

Figure 15. Results of sensitivity analyses for the *ex situ* case

5.1 Market, Financial, and Overall Assumptions

Variations in the TCI, shown in Case 1 of Figure 15, can have significant impacts on the MFSP. In this context it should be noted that some of the *major* equipment costs were derived from estimations based on similar equipment, or from costs derived from mechanical design tools. Variation in capital costs during an actual installation is potentially the biggest reason for changes in the TCI. A 30% increase in the TCI can increase the *ex situ* base case MFSP of $3.31/GGE by 16.1%.

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Case 3 shows that assuming a higher discount rate for DCFROR (also referred to here as the internal rate of return), of 15% instead of 10% can have a similar impact of 15.4% on the MFSP. Similarly, Case 10 shows the impact of assuming a higher interest rate.

Feedstock cost, which is shown as a significant contributor to the MFSP, can have a big impact as shown in Case 2. Increasing the feedstock cost from $80/dry U.S. ton to $120/dry U.S ton increased the MFSP by 15.7%. There is ongoing work at INL and other institutions toward enabling the provision of feedstock at $80/dry U.S. ton while meeting quality specifications. Some of their work is focused on improvements in feedstock logistics, and ways to soften market forces by expanding the feedstock pool to a wider range of blended material as mentioned earlier. The effects of blended material on product yields will be experimentally studied as part of ongoing research.

Case 6 shows the impact of a larger plant size, with feedstock available at the same price. This shows that the MFSP based on current assumptions can be significantly reduced to approximately $3/GGE by scaling up. The impact can be significantly larger if the assumed 1,000 dry metric tonnes/day/reactor constraint imposed on the fast pyrolysis reactor is lifted and larger reactors can be designed. Additional references discuss economies of scale and refinery integration [64] and biorefinery sizing [65] as potential approaches toward cost reduction.

Assuming a plant life of 20 years instead of 30 years increases the MFSP by 4.1% as shown in Case 12. Case 16 shows that the assumption of 86% plant on-stream factor (versus 90% in the base case) results in an increase of 2.7% in the MFSP.

5.2 Fast Pyrolysis and Catalytic Vapor Upgrading

The estimated impacts on the MFSP from the inclusion of a hot gas filter in the process are shown in Cases 4 and 14. A hot gas filter may be necessary even in the *ex situ* system if cyclones are inadequate for sufficiently removing mineral matter/ash from the vapor stream to prevent detrimental impacts on the catalyst. The capital cost of the HGF was scaled using the actual vapor flow rate in the process model, starting from original equipment cost estimates obtained for a near atmospheric system. The 120 psia system pressure (versus near atmospheric pressure) in the fast pyrolysis and vapor upgrading sections helped reduce gas volumes and reduce the capital impact of the HGF; the MFSP increased by 3.2%, as shown in Case 14. However, yield losses have not been quantified in a process configuration similar to that assumed in this process design. Assuming an organic liquid product yield loss of 10% due to cracking and coking leads to a higher (15.2%) impact on the MFSP as shown in Case 4.

A 40% increase in the reactor capital in the *ex situ* case leads to an increase of 9.2% to the MFSP (Case 8). Organic liquid yield after vapor upgrading is key to the process economics as indicated by an 11.6% increase in the MFSP from a 10% drop in yield (Case 5).

The impacts of higher catalyst replacements rates, higher catalyst to biomass ratios, and higher catalyst costs on the MFSP are captured in Cases 11, 13, and 7, respectively.

Heat recovery from upgraded vapors can have impacts on process efficiencies and design. The impact of lower efficiency (without accounting for the likely inclusion of new equipment in addition to those in the base case) is shown in Case 22. It reflects the scenario when no heat can

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be recovered from the hot upgraded vapors between 931°F and 466°F. The beginning temperature for vapor condensation using the model compounds in the simulation is 466°F; it is assumed in the base case that indirect exchange can be used to recover heat from 931°F to 466°F.

From an economic standpoint, Case 20 shows that losing carbon as gas is preferable over loss as coke. There are larger process operation and design implications of lower coke formation, especially if fixed bed vapor upgrading systems are used, and if regeneration protocols include reactor cycle times for offline regeneration.

Case 26 shows that there is a small impact of higher heat losses in the system. This is primarily due to a lower electricity credit.

5.3 Hydroprocessing

The catalytic vapor upgrading reduces the dependency on downstream hydroprocessing of condensed organic liquid. As a result the impacts on variations in this section are relatively smaller than those in the fast pyrolysis and catalytic vapor upgrading sections. As mentioned earlier (Figure 8), carbon efficiency of organic liquid feed to fractionated liquid products was assumed to scale linearly based on the oxygen content, assuming 85% efficiency for 20% oxygen content feed and 98.5% efficiency for feed with negligible oxygen content. Assumption of 88% carbon efficiency, versus 94% carbon efficiency in the *ex situ* case, results in a 9% increase in the MFSP, as shown in Case 9.

A 40% increase in hydroprocessing and separations area capital leads to a 2.1% increase in the MFSP (Case 19) using the underlying capital cost assumptions mentioned previously.

The impacts of hydrotreating and hydrocracking catalyst unit costs and hydrotreater operating pressure are shown in Cases 18, 24, and 27, respectively. Case 25 shows that using three hydrotreating reactors with 50% capacity each, to enable more frequent catalyst maintenance operations, adds 0.7% to the MFSP.

5.4 Other Operations and Overall Plant

Case 23 shows the impact of the electricity credit of 2.6¢ in the base case on the MFSP. It is to be noted that unlike in a syngas conversion process, non-condensable carbonaceous products are not recoverable as liquid products in this process. Unless there are other local consumers of the excess heat available in the process (due to the formation of char, coke, and non-condensable fuel gases), electricity production is the logical way to capture this thermal energy.

The impacts of hydrogen plant, steam plant, and wastewater treatment capital costs on the MFSP are shown in Cases 15, 17, and 21, respectively.

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6 Conclusions

This analysis lays out conceptual process designs for *in situ* and *ex situ* upgrading of fast pyrolysis vapors for the production of significantly deoxygenated bio-oil intermediate, with further hydroprocessing of the bio-oil to produce hydrocarbon fuel blendstocks that can be cost-competitive with petroleum-derived sources; this is contingent on the research helping achieve the performance goals (for 2022) outlined in this report. Advances in catalysts will be necessary to improve the quality and yields of the bio-oil intermediate for the success of this conversion pathway. Targeted catalyst development should enable bio-oil yield improvements by reducing losses to coke and non-condensable gases, quality improvements via hydrodeoxygenation and hydrogenation, and increased diesel-range products via molecular combination (coupling) in the vapor phase. Higher diesel-range products are targeted for the *ex situ* process because more favorable reaction chemistry (coupling reactions) is possible in a separate reactor where, unlike in an *in situ* upgrading reactor, one does not have to deal with catalyst detriments such as biomass, char, and mineral matter/ash. The catalysts developed for both the *in situ* and *ex situ* cases need to be cost-justifiable with respect to maintenance, materials used, and reactor designs that are compatible with catalyst performance; the *ex situ* case can have added options such as the use of fixed bed reactors following a hot gas filter.

The improvements outlined are targeted for the 2022 timeframe; new understanding and learnings from research will require adjustments to the conceptual design in the coming years. While near-term developments (2017 timeframe) will likely enable yield improvements and deoxygenation, longer-term developments are expected to allow further hydrodeoxygenation and hydrogenation of the bio-oil intermediate, as well as coupling reactions for the production of a higher proportion of diesel-range molecules. In addition, further understanding of the bio-oil intermediate will lead to the optimization of downstream hydroprocessing. Valorization of carbon in the aqueous phase (separated from the bio-oil) can also be made feasible via research.

Techno-economic analysis in the near-term will identify and study process variations to encompass a wider range of research for these conversion pathways. Continued assessments of the state of technology based on research results, and re-evaluations of the feasibility of targets will be critical in the coming years. Characterization of products and intermediates and the understanding of their compatibility with the existing petroleum refining infrastructure will be important for optimal integration and deployment of products. Characterization will become more feasible and meaningful after some progress in the research, and the availability of larger volumes of products from experimental reactors.

While the target cases with underlying assumptions project MFSPs below $3.5/GGE, further improvements and cost reductions to $3/GGE are possible, as shown in the sensitivity analysis. Significant impacts identified in the sensitivity cases include economies of larger scales, lower catalyst costs through catalyst longevity and lower unit costs, and higher product yields.

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7 Future TEA Work

This design reflects metrics for one possible base case each for the *in situ* and *ex situ* fast pyrolysis vapor upgrading pathways. This work will evolve with more understanding and experimental knowledge during the course of the research. Areas for further studies, among others, include the following:

- Research of other process configurations, including the use of a hot gas filter, fixed bed vapor upgrading reactors, and different catalysts.
- Inclusion of further understanding of compounds and their physical properties, including further speciation and phase equilibrium. This will lead to more predictive process models.
- Experimental development of reaction kinetics information. This can facilitate development of reactor models (with scale-up prediction capabilities) for use in TEA work.
- Impact of feedstock variability on yields.
- Refinement of equipment cost estimates through further understanding of the specifics of feasible conversion processes.
- Providing updated state of technology information based on experimental data and reassessment of technical targets for cost-competitiveness.
- Refinery integration and details of inclusion of products into the current infrastructure based on experimental information.

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Appendix A. Equipment Description and Design Basis Summary

NREL's Process Engineering Team has compiled information on the equipment in the benchmark model. The compilation contains information about the cost, reference year, scaling factor, scaling characteristic, design information, and back-up cost referencing. The information is stored in the economic spreadsheet portion of the model.

The following table summarizes the important fields of information contained in the spreadsheet model. A partial listing of the information is attached for each piece of equipment. Additional information from the spreadsheet model is presented in Appendix B.

Equipment number:[a,b]	Unique identifier, the first letter indicates the equipment type and the first number represents the process area, e.g., P-601 is a pump in Area 600
Equipment name:[a,b]	Descriptive name of the piece of equipment
Equipment category:[a]	Code indicating the general type of equipment, e.g., PUMP
Equipment type:[a]	Code indicating the specific type of equipment, e.g., CENTRIFUGAL for a pump
Equipment description:[a]	Short description of the size or characteristics of the piece of equipment, e.g., 20 gpm, 82 ft head for a pump
Number required:[b]	Number of duplicate pieces of equipment needed
Number spares:[b]	Number of on-line spares
Original equip. cost:[b]	Equipment cost
Source/reference:[a]	Source of the equipment cost, e.g., Aspen Capital Cost Estimator or vendor quotation
Base year:[b]	Year in which the cost estimate is based
Design flow:[b]	Value of the scaling stream or variable used to obtain the base cost of the equipment
Actual flow:[b]	Value of the actual stream from model used to derive size ratio relative to design flow
Size ratio:[b]	Actual flow/Design flow
Units:[b]	Units of the scaling stream or variable, e.g., LB/HR, MMBtu/HR
Installation factor:[b]	Value of the installation factor. Installed Cost = Base Cost x Installation Factor
Scaling exponent:[b]	Value of the exponential scaling equation
MOC:[a]	Material of construction
Notes:	Any other important information about the design or cost

[a] These fields are listed for all pieces of equipment in Appendix A.
[b] These fields are part of the equipment cost listing in Appendix B.

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Equip ID	Equipment Name	Equipment Category	Equipment Type	Design Pressure (psig)	Design Temp (F)	MOC	Sizing Information			Source/Reference
C-101	Hopper Feeder	CONVEYOR	VIBRATING-FEEDER			CS	Included in per unit cost of feedstock			Idaho National Lab
C-102	Screener Feeder Conveyor	CONVEYOR	BELT			CS	Included in per unit cost of feedstock			Idaho National Lab
C-103	Radial Stacker Conveyor	CONVEYOR	BELT			CS	Included in per unit cost of feedstock			Idaho National Lab
C-104	Dryer Feed Screw Conveyor	CONVEYOR	SCREW			CS	Included in per unit cost of feedstock			Idaho National Lab
C-105	Biomass Feed Screw Conveyor	CONVEYOR	SCREW			CS	Included in per unit cost of feedstock			Idaho National Lab
K-101	Flue Gas Blower	FAN	CENTRIFUGAL			CS	60,000 cfm 15" H2O 204 hp			ACCE V8.4
M-101	Hydraulic Truck Dump with Scale	SCALE	TRUCK-SCALE			CS	Included in per unit cost of feedstock			Idaho National Lab
M-102	Hammermill	MISC	SIZE REDUCER			CS	Included in per unit cost of feedstock			Idaho National Lab
M-103	Front End Loaders	VEHICLE	LOADER			CS	Included in per unit cost of feedstock			Idaho National Lab
M-104	Cross Flow Pellet Dryer	MISC	DRYER			CS	50 ton/h 5% moisture reduction			Idaho National Lab
S-101	Magnetic Head Pulley	SEPARATOR	MAGNET			CS	Included in per unit cost of feedstock			Idaho National Lab
S-102	Vibratory Conveyor	SEPARATOR	SCREEN			CS	Included in per unit cost of feedstock			Idaho National Lab
T-101	Dump Hopper	TANK	LIVE-BTM-BIN			CS	Included in per unit cost of feedstock			Idaho National Lab
T-102	Hammermill surge bin	TANK	LIVE-BTM-BIN			CS	Included in per unit cost of feedstock			Idaho National Lab
T-103	Dryer Feed Bin	TANK	LIVE-BTM-BIN			CS	Included in per unit cost of feedstock			Idaho National Lab
T-104	Dried Biomass Hopper	TANK	VERTICAL-VESSEL			CS	Included in per unit cost of feedstock			Idaho National Lab
T-105	Lock Hopper	TANK	VERTICAL-VESSEL			CS	Included in per unit cost of feedstock			Idaho National Lab
T-106	Feed Hopper	TANK	VERTICAL-VESSEL			CS	Included in per unit cost of feedstock			Idaho National Lab
A100	Pinch Exchanger CAPEX									
Area A100: Feed Handling & Drying ↑										
C-212	Fines purge cooler	CONVEYOR	SCREW			CS				HGI FCC Costing Sheet
K-211	Fluidizing gas recycle compressor	COMPRESSOR	RECIPROCATING			SS	2-stage reciprocating	3648 hp		Vendor quote via HGI
K-212	Combustor air compressor	COMPRESSOR	CENTRIFUGAL			SS	Multi-stage oil-free	10,000 hp		Vendor quote via HGI
R-211	Fluidized Bed Reactor	REACTOR	FLUIDIZED BED	105	930	Refractory	1,000 tpd biomass	20,375 ACFM gas prod	7.8 lb media/lb	HGI FCC Costing Sheet
R-212	Char Combustor	REACTOR	FLUIDIZED BED	105	1200	Refractory	718,690 lb/h solids	12,000 ACFM gas prod		HGI FCC Costing Sheet
R-212C	Sand Cooler	HEAT EXCH	SOLIDS COOLER	105	1200	Refractory	3.7 MMBtu/h			HGI FCC Costing Sheet
S-211	Primary Cyclone	SEPARATOR	CYCLONE	105	930	CS	20,375 ACFM gas prod	718,690 lb/h solids	99.9% reject	HGI FCC Costing Sheet
S-212	Secondary Cyclone	SEPARATOR	CYCLONE	105	930	CS	20,375 ACFM gas prod	720 lb/h solids	99.9% reject	HGI FCC Costing Sheet
S-213	Char Combustor Primary Cyclone	SEPARATOR	CYCLONE	105	1200	CS	12,000 ACFM gas prod	718,690 lb/h solids	99.9% reject	HGI FCC Costing Sheet
S-214	Char Combustor Secondary Cyclone	SEPARATOR	CYCLONE	105	1200	CS	12,000 ACFM gas prod	720 lb/h solids	99.9% reject	HGI FCC Costing Sheet
T-211	Bed Media Bin	VESSEL	PRESSURE STORAGE	105	650	CS				HGI FCC Costing Sheet
T-212	Depleted bed media and ash storage bin	MISC	ROLL-OFF DISPOSAL	0	300	CS				HGI FCC Costing Sheet
T-217	Char combustor bed media feed bin	VESSEL	PRESSURE STORAGE	105	650	CS				HGI FCC Costing Sheet
A211	Pinch Exchanger CAPEX									ACCE V7.2
Area A211: Ex Situ Fast Pyrolysis ↑										
C-202	Fines purge cooler	CONVEYOR	SCREW			CS				HGI FCC Costing Sheet
K-201	Fluidizing gas recycle compressor	COMPRESSOR	RECIPROCATING			SS	2-stage reciprocating	3648 hp		Vendor quote via HGI
K-202	Combustor air compressor	COMPRESSOR	CENTRIFUGAL			SS	Multi-stage oil-free	10,000 hp		Vendor quote via HGI
R-201	Catalytic Fluidized Bed Reactor	REACTOR	FLUIDIZED BED	105	930	Refractory	1,000 tpd biomass	20,424 ACFM gas prod	7.8 lb media/lb	HGI FCC Costing Sheet
R-202	Char Combustor	REACTOR	FLUIDIZED BED	105	1200	Refractory	727,725 lb/h solids	20,000 ACFM gas prod		HGI FCC Costing Sheet
R-202C	Catalyst Cooler	HEAT EXCH	SOLIDS COOLER	105	1200	Refractory	128 MMBtu/h			HGI FCC Costing Sheet
S-201	Primary Cyclone	SEPARATOR	CYCLONE	105	930	CS	20,424 ACFM gas prod	712,880 lb/h solids	99.9% reject	HGI FCC Costing Sheet
S-202	Secondary Cyclone	SEPARATOR	CYCLONE	105	930	CS	21,341 ACFM gas prod	720 lb/h solids	99.9% reject	HGI FCC Costing Sheet
S-203	Char Combustor Primary Cyclone	SEPARATOR	CYCLONE	105	1200	CS	20,000 ACFM gas prod	713,000 lb/h solids	99.9% reject	HGI FCC Costing Sheet
S-204	Char Combustor Secondary Cyclone	SEPARATOR	CYCLONE	105	1200	CS	20,000 ACFM gas prod	720 lb/h solids	99.9% reject	HGI FCC Costing Sheet
T-201	Catalyst steam stripper	VESSEL	PRESSURE STORAGE	105	650	CS	1 min cat res. time	3 lb steam/1000 lb catalyst		HGI FCC Costing Sheet
T-202	Depleted catalyst and ash storage bin	MISC	ROLL-OFF DISPOSAL	0	300	CS				HGI FCC Costing Sheet
T-207	Catalyst feed bin	VESSEL	PRESSURE STORAGE	105	650	CS				HGI FCC Costing Sheet
A201	Pinch Exchanger CAPEX									ACCE V7.2
Area A201: In Situ Catalytic Fast Pyrolysis ↑										
M-251	Hot Gas Filter package	SEPARATOR	FILTER	20	950		94500 ACFH 7400 lb/h solids			Pall Corporation
Area A251: Hot Gas Filter ↑										
C-262	Fines purge cooler	CONVEYOR	SCREW			CS				HGI FCC Costing Sheet
K-262	Regenerator air compressor	COMPRESSOR	CENTRIFUGAL			SS	Multi-stage oil-free	10,000 hp		Vendor quote via HGI
R-261	Catalytic Fluidized Bed Reactor	REACTOR	FLUIDIZED BED	105	930	Refractory	2,000 tpd biomass equiv	42,200 ACFM gas prod	5.0 lb media/lb	HGI FCC Costing Sheet
R-262	Catalyst Regenerator	REACTOR	FLUIDIZED BED	105	1200	Refractory	918,760 lb/h solids	10,200 ACFM gas prod		HGI FCC Costing Sheet
R-262C	Catalyst Cooler	HEAT EXCH	SOLIDS COOLER	105	1200	Refractory	272 MMBtu/h total for R-262C and R-262C-1			HGI FCC Costing Sheet
R-262C1	Catalyst cooler (secondary, included)	HEAT EXCH	SOLIDS COOLER	105	1200	Refractory	Cost included with R-262C			HGI FCC Costing Sheet
S-261	Primary Cyclone	SEPARATOR	CYCLONE	105	930	CS	42,200 ACFM gas prod	918,760 lb/h solids	99.9% reject	HGI FCC Costing Sheet
S-262	Secondary Cyclone	SEPARATOR	CYCLONE	105	930	CS	42,200 ACFM gas prod	920 lb/h solids	99.9% reject	HGI FCC Costing Sheet
S-263	Char Combustor Primary Cyclone	SEPARATOR	CYCLONE	105	1200	CS	18,000 ACFM gas prod	918,760 lb/h solids	99.9% reject	HGI FCC Costing Sheet
S-264	Char Combustor Secondary Cyclone	SEPARATOR	CYCLONE	105	1200	CS	18,000 ACFM gas prod	920 lb/h solids	99.9% reject	HGI FCC Costing Sheet
T-261	Catalyst steam stripper	VESSEL	PRESSURE STORAGE	105	650	CS	1 min cat res. time	3 lb steam/1000 lb catalyst		HGI FCC Costing Sheet
T-262	Depleted catalyst and ash storage bin	MISC	ROLL-OFF DISPOSAL	0	300	CS				HGI FCC Costing Sheet
T-267	Catalyst feed bin	VESSEL	PRESSURE STORAGE	105	650	CS				HGI FCC Costing Sheet
A261	Pinch Exchanger CAPEX									ACCE V7.2
R-261	VPU Fixed Bed Reactor	VESSEL	VERTICAL PRESSURE	130	1000	CS+Inconel	17' Ø 48' T-T	+20% internals		ACCE V8.4
A261	Pinch Exchanger CAPEX									ACCE V7.2
Area A261: Ex Situ Vapor Phase Upgrading ↑										

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Equip ID	Equipment Name	Equipment Category	Equipment Type	Design Pressure (psig)	Design Temp (F)	MOC	Sizing Information				Source/Reference
D-301	Heavy Fraction Condenser Absorber	VESSEL	TRAYED TOWER	120	500	316SS	12' Ø	70' T-T	14 trays	sieve	ACCE V8.4
D-302	Light Fraction Condenser Absorber	VESSEL	TRAYED TOWER	100	120	316SS	13' Ø	70' T-T	20 trays	sieve	ACCE V8.4
H-313	D-301 Vapor ACHE	HEAT EXCH	AIR COOLED	130		316SS	15,000 sq ft	45' tubes	3 bays x 15'	2 fan/bay	ACCE V8.4
H-314	D-302 Feed Cooler	HEAT EXCH	SHELL & TUBE	150	190	316SS	5,000 sq ft	Shell 43" Ø	20' L	955 X 1" tubes	ACCE V8.4
H-315	D-302 Feed/overhead exchanger	HEAT EXCH	SHELL & TUBE	110		316SS	18,500 sq ft	Shell 42" Ø	23' L	884 X 1" tubes 4 shells	ACCE V8.4
H-316	D-302 Liquid feed chiller	HEAT EXCH	SHELL & TUBE	150	190	316SS	3,650 sq ft	Shell 36" Ø	20' L	698 X 1" tubes	ACCE V8.4
H-320	Heavy fraction ACHE	HEAT EXCH	AIR COOLED	130		316SS	70 sq ft	5' tubes	1 bays x 2'	2 fan/bay	ACCE V8.4
H-320A	Heavy fraction cooler	HEAT EXCH	SHELL & TUBE	2085	190	SS Clad CS	343 sq ft	Shell 14"Ø	16' L	82 X 1" tubes	H-463C
H-326	D-302 Quench circulation chiller	HEAT EXCH	PLATE & FRAME	200	200	316SS	7,500 sq ft	486 plates			ACCE V8.4
P-318	D-301 Bottoms pump	PUMP	CENTRIFUGAL	125	250	316SS	56 gpm	75' head			ACCE V8.4
P-323	Circulation filter charge pump	PUMP	CENTRIFUGAL	135	250	316SS	2655 gpm	69' head			ACCE V8.4
P-329	Aqueous filter charge pump	PUMP	CENTRIFUGAL	125	250	316SS	182 gpm	30' head			ACCE V8.4
P-331	Organic product pump	PUMP	CENTRIFUGAL	125	250	316SS	124 gpm	30' head			ACCE V8.4
P-332	Quench recycle pump	PUMP	CENTRIFUGAL	125	250	316SS	215 gpm	9' head			ACCE V8.4
S-319	D-301 Bottoms filter	FILTER	CARTRIDGE			316SS	52 gpm				ACCE V8.4
S-322	D-302 Bottoms decanter	VESSEL	HORIZ LL SEP	110	150	316SS	11' Ø	35' T-T	+20% internals		ACCE V8.4
S-324	Quench circulation filter	FILTER	TUBULAR			316SS	2340 gpm	60 Mesh			ACCE V8.4
S-329	Aqueous phase filter	FILTER	TUBULAR			316SS	182 gpm	400 Mesh			ACCE V8.4
T-328	Organic product surge tank	VESSEL	VERTICAL PRESSURE	125	250	316SS	5' Ø	14' T-T			ACCE V8.4
T-332	D-301 Circulation surge tank	VESSEL	VERTICAL PRESSURE	125	250	316SS	5' Ø	14' T-T			T-328
A310	Pinch exchanger CAPEX										ACCE V7.2
Area A310: Product Condensation and Separation ↑											
H-373	Post-WGS ACHE	HEAT EXCH	AIR COOLED	150		316SS	1252 sq ft	24' tubes	1 bays x 8'	2 fan/bay	ACCE V8.4
H-374	Post-WGS cooler	HEAT EXCH	SHELL & TUBE	150	140	316SS	1188 sq ft	Shell 21"Ø	20' L	227 X 1" tubes	ACCE V8.4
K-390	PSA compressor: multistage	COMPRESSOR	RECIPROCATING			SS	2-stage reciprocating		3648 hp		Vendor quote via HGI
M-385	PSA	MISC	MISC								Vendor quote via HGI
P-377	Compressor condensate pump	PUMP	CENTRIFUGAL	125	250	316SS	56 gpm	30' head			P-318
R-365	High-temperature WGS	VESSEL	VERTICAL PRESSURE	450	1000	316SS	12' Ø	24' T-T	+20% internals		ACCE V8.4
S-385	PSA Compressor suction KO	VESSEL	VERTICAL PRESSURE	135	150	316SS	5' Ø	7.5' T-T			ACCE V8.4
S-386	PSA Compr disch KO	VESSEL	VERTICAL PRESSURE	280	160	316SS	4' Ø	7' T-T			ACCE V8.4
T-377	Compressor condensate tank	VESSEL	VERTICAL PRESSURE	125	250	316SS	5' Ø	14' T-T			T-328
A360	Pinch exchanger CAPEX										ACCE V7.2
Area A360: Hydrogen Recycle and WGS ↑											
H-410	Feed-effluent exchanger	HEAT EXCH	SHELL & TUBE	1910	650	316SS	2636 sq ft	Shell 32"Ø	23' L	504 X 1" tubes	ACCE V8.4
H-411	Feed furnace	HEAT EXCH	BOX FURNACE	1930	650	316SS	2.21 MMBtu/h		208 CFM gas		ACCE V8.4
H-413A	HT product ACHE	HEAT EXCH	AIR COOLED	150		316SS	432 sq ft	14' tubes	1 bays x 4'	2 fan/bay	ACCE V8.4
H-413C	HT product cooler	HEAT EXCH	SHELL & TUBE	2085	190	316SS	589 sq ft	Shell 18"Ø	16' L	141 X 1" tubes	ACCE V8.4
H-444	Quench hydrogen stage 2 cooler	HEAT EXCH	SHELL & TUBE	1650	650	316SS	57 sq ft	Shell 8"Ø	8' L	29 X 1" tubes	ACCE V8.4
H-445	Quench hydrogen stage 3 cooler	HEAT EXCH	SHELL & TUBE	1650	650	316SS	57 sq ft	Shell 8"Ø	8' L	29 X 1" tubes	H-444
K-412	Hydrogen makeup compressor	COMPRESSOR	RECIPROCATING				1,050 hp	4-stage recip			Vendor quote via HGI
K-442	Hydrogen recycle compressor	COMPRESSOR	RECIPROCATING				146 hp	single stage recip			Vendor quote via HGI
P-410	HT feed pump	PUMP	DIAPHRAGM		90	316SS	135 gpm	5275' head			ACCE V8.4
R-410	Hydrotreater, 1000 psi	VESSEL	VERTICAL PRESSURE	1130	850	CS+Inconel	10' Ø	48' T-T	+60% internals		ACCE V8.4
R-410	Hydrotreater, 1500 psi	VESSEL	VERTICAL PRESSURE	1640	850	CS+Inconel	10' Ø	48' T-T	+60% internals		ACCE V8.4
R-410	Hydrotreater, 2000 psi	VESSEL	VERTICAL PRESSURE	2070	850	CS+Inconel	10' Ø	48' T-T	+60% internals		ACCE V8.4
S-410	Vapor KO drum	VESSEL	VERTICAL PRESSURE	120	250	316SS	4.5' Ø	10' T-T			ACCE V8.4
S-411	HP HT effluent flash: 3 phase	VESSEL	HORIZ LL SEP	2025	160	316SS	3' Ø	10' T-T	+20% internals		ACCE V8.4
S-412	LP HT effluent flash: 3 phase	VESSEL	HORIZ LL SEP	70	170	316SS	4' Ø	13' T-T	+10% internals		ACCE V8.4
A410	Pinch exchanger CAPEX										ACCE V7.2
Area A410: Whole Oil Hydroprocessing ↑											
D-450	Gasoline column	VESSEL	TRAYED TOWER	35	650	316SS	7.5' Ø	64' T-T	26 trays	sieve	ACCE V8.4
D-451	Diesel column	VESSEL	TRAYED TOWER	35	800	316SS	3.5' Ø	64' T-T	26 trays	sieve	ACCE V8.4
H-450C	D-450 Condenser (startup)	HEAT EXCH	SHELL & TUBE	60	250	316SS	821 sq ft	Shell 18"Ø	20' L	157 X 1" tubes	ACCE V8.4
H-450R	D-450 Reboiler (startup)	HEAT EXCH	SHELL & TUBE	60	250	316SS	980 sq ft	Shell 30"Ø	25' L	94 X 1" tubes	ACCE V8.4
H-451C	D-451 Condenser (startup)	HEAT EXCH	SHELL & TUBE	150	190	316SS	72 sq ft	Shell 18"Ø	20' L	28 X 1" tubes	ACCE V8.4
H-451R	D-451 Reboiler (startup)	HEAT EXCH	SHELL & TUBE	60	250	316SS	980 sq ft	Shell 30"Ø	25' L	94 X 1" tubes	H-450R
H-454	Gasoline product cooler	HEAT EXCH	SHELL & TUBE	150	250	CS	589 sq ft	Shell 18"Ø	16' L	141 X 1" tubes	ACCE V8.4
H-457A	Diesel product ACHE	HEAT EXCH	AIR COOLED	150		CS	41 sq ft	10' tubes	1 bays x 1'	2 fan/bay	ACCE V8.4
H-457C	Diesel Product Cooler	HEAT EXCH	SHELL & TUBE	150	250	CS	58 sq ft	Shell 8"Ø	8' L	28 X 1" tubes	ACCE V8.4
H-459	D-450 Overhead vapor cooler	HEAT EXCH	SHELL & TUBE	150	250	CS	12 sq ft	Shell 4"Ø	8' L	6 X 1" tubes	ACCE V8.4
P-450	D-450 Reflux pump	PUMP	CENTRIFUGAL	35	250	316SS	253 gpm	225' head			ACCE V8.4
P-451	D-451 Reflux pump	PUMP	CENTRIFUGAL	35	250	316SS	108 gpm	225' head			ACCE V8.4
S-450	D-450 Overhead accumulator	VESSEL	HORIZ PRESSURE	35	250	316SS	4.5' Ø	13.5' T-T			ACCE V8.4
S-451	D-451 Overhead accumulator	VESSEL	HORIZ PRESSURE	35	400	316SS	3.5' Ø	10.5' T-T			ACCE V8.4
A450	Pinch exchanger CAPEX										ACCE V7.2
Area A450: Oil Fractionation ↑											

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Equip ID	Equipment Name	Equipment Category	Equipment Type	Design Pressure (psig)	Design Temp (F)	MOC	Sizing Information				Source/Reference
H-460	Feed-effluent exchanger	HEAT EXCH	SHELL & TUBE	2390	650	CS	276 sq ft	Shell 14"Ø	18' L	66 X 1" tubes	ACCE V8.4
H-461	Feed furnace	HEAT EXCH	BOX FURNACE	2100	750	316SS	0.68 MMBtu/h		48 CFM gas		ACCE V8.4
H-463A	HC product ACHE	HEAT EXCH	AIR COOLED	150		CS	243 sq ft	10' tubes	1 bays x 3'	2 fan/bay	ACCE V8.4
H-463C	HC product Cooler	HEAT EXCH	SHELL & TUBE	2085	190	SS Clad CS	343 sq ft	Shell 14"Ø	16' L	82 X 1" tubes	ACCE V8.4
H-494	Quench hydrogen stage 2 cooler	HEAT EXCH	SHELL & TUBE	1650	650	316SS	57 sq ft	Shell 8"Ø	8' L	29 X 1" tubes	H-444
H-495	Quench hydrogen stage 3 cooler	HEAT EXCH	SHELL & TUBE	1650	650	316SS	57 sq ft	Shell 8"Ø	8' L	29 X 1" tubes	H-444
K-462	Hydrogen makeup compressor	COMPRESSOR	RECIPROCATING				1,050 hp	4-stage recip			Vendor quote via HGI
K-492	Hydrogen recycle compressor	COMPRESSOR	RECIPROCATING				146 hp	single stage recip			Vendor quote via HGI
P-460	HC feed pump	PUMP	DIAPHRAGM		90	316SS	135 gpm	5275' head			P-410
R-460	Hydrocracker	VESSEL	VERTICAL PRESSURE	2070	850	CS+Inconel	6.5' Ø	48' T-T	+60% internals		ACCE V8.4
S-460	Vapor KO drum	VESSEL	VERTICAL PRESSURE	120	250	316SS	4.5' Ø	10' T-T			S-410
S-461	HP effluent flash: 3 phase	VESSEL	HORIZ LL SEP	2025	160	316SS	3' Ø	10' T-T	+20% internals		ACCE V8.4
S-462	LP effluent flash	VESSEL	HORIZ LL SEP	70	170	316SS	1' Ø	7' T-T			ACCE V8.4
A460	Pinch exchanger CAPEX										ACCE V7.2
Area A460: Hydrocracking ↑											
H-568A	WGS Effluent ACHE	HEAT EXCH	AIR COOLED	150		CS	1392 sq ft	24' tubes	1 bays x 8'	2 fan/bay	ACCE V8.4
H-568C	WGS Effluent cooler	HEAT EXCH	SHELL & TUBE	60	250	CS	1281 sq ft	Shell 22"Ø	20' L	245 X 1" tubes	ACCE V8.4
K-511	Pyrolysis offgas compressor to reformer	COMPRESSOR	RECIPROCATING			SS	2-stage reciprocating		3648 hp		K-211
K-545	Reformer combustor air blower	INCLUDED									
K-580	PSA Compressor multistage	INCLUDED									
M-575	PSA	INCLUDED									
P-576	Compressor condensate pump	PUMP	CENTRIFUGAL	125	250	316SS	56 gpm	30' head			P-318
R-530	Steam reformer package (PNNL)	MISC	PACKAGE UNIT								23053
R-565	WGS reactor	INCLUDED									
R-566	LTS reactor	VESSEL	VERTICAL PRESSURE	450	1000	316SS	12' Ø	24' T-T	+20% internals		R-365
S-575	Compressor suction KO drum	INCLUDED									
S-586	PSA Compressor discharge KO drum	INCLUDED									
T-576	Compressor condensate tank	VESSEL	VERTICAL PRESSURE	125	250	316SS	4.5' Ø	14' T-T			T-328
A500	Pinch exchanger CAPEX										ACCE V7.2
Area A500: Hydrogen Plant ↑											
H-601	Steam turbine condenser	HEAT EXCH	AIR COOLED				58.25 MMBtu/h per module				SPX Cooling
H-603	Blowdown cooler	HEAT EXCH	Shell and tube	50		CS	0.4 MMBtu/Hr; LMTD = 15 F; U = 100 Btu/hr-ft^2-F; Area = 265 Ft^2; U-Tube				51400 Icarus 2006.5
M-601	BFW EDI+polishing	MISC	PACKAGE UNIT				Quote from 51400 (RO+EDI+polish) with RO removed				51400 Siemens
M-602A	Steam turbine generator Stage 1	GENERATOR	STEAM-TURBINE			CS	Vendor quotation for 30.14 MW system. Excludes steam turbine condenser.				Shin Nippon
M-602B	Steam turbine generator Stage 2	GENERATOR	STEAM-TURBINE			CS	Vendor quotation for 30.14 MW system. Excludes steam turbine condenser.				Shin Nippon
M-603	Startup boiler	MISC	PACKAGE UNIT			CS	40,000 lb/h (half of A800 steam at 2,000 TPD)				ACCE V8.4
P-601	Makeup pump	PUMP	CENTRIFUGAL			CS	160 gpm	35' head			51400 Icarus 2006.5
P-602	Condensate pump	PUMP	CENTRIFUGAL			CS	500 gpm	60' head			51400 Icarus 2006.5
P-603	EDI pump	PUMP	CENTRIFUGAL			CS	500 gpm	60' head			51400 Icarus 2006.5
P-604	Boiler feed water pump	PUMP	POS-DISPLACEMENT			CS	1050 gpm	3340' head			51400 Icarus 2006.5
P-605	Condensate collection pump	PUMP	CENTRIFUGAL			CS	500 gpm	60' head			P-603
S-601	Blowdown flash drum	VESSEL	VERTICAL PRESSURE	1500		CS	Liquid 30 gpm; 10 Minute Residence Time; Vessel Volume = 900 gal				51400 Icarus 2006.5
T-601	Condensate collection tank	VESSEL	VERTICAL PRESSURE			CS	Liquid 1,000 gpm; 5 minute Residence Time; Liquid Volume = 5,000 gal				51400 Icarus 2006.5
T-602	Condensate surge tank	TANK	HORIZONTAL-VESSEL			CS	Liquid 1,000 gpm; 5 minute Residence Time; Liquid Volume = 5,000 gal				51400 Icarus 2006.5
T-603	Deaerator	TANK	HORIZONTAL-VESSEL	50		CS	Liquid 1,050 gpm; 10 Minute Residence Time; Vessel Volume = 21,000 gal				51400 Icarus 2006.5
T-603A	Deaerator packed column	COLUMN	PACKED COLUMN			CS	Inside Diameter = 2 ft; Height = 10 ft; Packing Height = 8 ft				51400 Icarus 2006.5
T-605	Steam drum	TANK	HORIZONTAL-VESSEL			CS	Horizontal Drum; < 100% of Critical Velocity; Diameter = 5' T-T Length = 20'				51400 Icarus 2006.5
T-606	Steam turbine condensate tank	VESSEL	VERTICAL PRESSURE			CS	Liquid 1,000 gpm; 5 minute Residence Time; Liquid Volume = 5,000 gal				T-601
A600	Pinch exchanger CAPEX										ACCE V7.2
Area A600: Steam System & Power Generation ↑											

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Equip ID	Equipment Name	Equipment Category	Equipment Type	Design Pressure (psig)	Design Temp (F)	MOC	Sizing Information	Source/Reference
K-701	Plant air compressor	COMPRESSOR	RECIPROCATING			CS	Flow Rate = 450 CFM; Outlet Pressure = 125 PSIG	51400 Icarus 2006.5
M-701	Cooling tower system	COOLNG TWR	INDUCED-DRAFT			FIBERGLASS	15,000 gpm, 110 °F Cooling Tower Inlet Temperature	Cooling Tower Depot
M-702	Hydraulic truck dump with scale	SCALE	TRUCK-SCALE			CS	Hydraulic Truck Dumper with Scale	Vendor Quotation
M-703	Flue gas scrubber	MISC	VERTICAL-VESSEL			SS304	Scrubber costs from TurboSonic. Quotation basis = $160,000/ACFM	TurboSonic
M-704	Flue gas stack	MISC	MISC			CS	Base Diameter = 72 inches; Stack Height = 200 ft	51400 Icarus 2006.5
M-708	Chilled water system	CHILLER	CENTRIFUGAL			CS	2,350 Ton	Trane
M-710	Product loading rack	MISC	MISC					Estimate
P-701	Cooling water pump	PUMP	CENTRIFUGAL			CS	18620 gpm 185' head	51400 Icarus 2006.5
P-702	Firewater pump	PUMP	CENTRIFUGAL			CS	2500 gpm 120' head	51400 Icarus 2006.5
P-703	Diesel pump	PUMP	CENTRIFUGAL			CS	5 gpm 150' head	51400 Icarus 2006.5
P-704	Ammonia pump	PUMP	CENTRIFUGAL			CS	1 gpm 150' head	51400 Icarus 2006.5
P-705	Caustic pump	PUMP	CENTRIFUGAL			CS	0.5 gpm 10' head	51400 Icarus 2006.5
P-707	BFW chemical pump	PUMP	CENTRIFUGAL			CS	1 gpm 150' head	51400 Icarus 2006.5
P-708	Flue gas scrubber circulation pump	PUMP	CENTRIFUGAL			CS	1010 gpm 60' head	51400 Icarus 2006.5
P-790	Gasoline product pump	PUMP	CENTRIFUGAL	35	250	316SS	108 gpm 225' head	P-450
P-792	Diesel product pump	PUMP	CENTRIFUGAL	35	250	316SS	108 gpm 225' head	P-450
S-701	Instrument air dryer	DRYER	PACKAGE UNIT			CS	400 SCFM Dewpt -40F	Richardson (51400)
T-701	Plant air receiver	TANK	VERTICAL-VESSEL	200		CS	1000 gal	51400 Icarus 2006.5
T-702	Firewater storage tank	TANK	FLAT-BTM-STORAGE	0.5		CS	600,000 gal flat roof	51400 Icarus 2006.5
T-703	Purchased diesel storage tank	TANK	FLAT-BTM-STORAGE	0.5		CS	12,000 gal floating roof	51400 Icarus 2006.5
T-704	Ammonia storage tank	TANK	HORIZ-STORAGE	350		CS	560 gal	51400 Icarus 2006.5
T-705	Caustic storage tank	TANK	FLAT-BTM-STORAGE	0.5		CS	5,400 gal flat roof	51400 Icarus 2006.5
T-708	BFW chemical storage tank	TANK	HORIZ-STORAGE	10		SS316	400 gal	51400 Icarus 2006.5
T-790	Gasoline product storage tanks	VESSEL	STORAGE	15	250	CS	47' Ø 40' H 500,000 gal	ACCE V8.4
T-792	Diesel product storage tank	VESSEL	STORAGE	15	250	CS	47' Ø 40' H 500,000 gal	T-790
Area A700: Cooling Water & Other Utilities ↑								
H-840	RTO Feed/Effluent exchanger	MISC	MISC				Included with RTO	
K-831	RTO blower	FAN	CENTRIFUGAL					
M-805	Clarifier	SEPARATOR	CLARIFIER				1.4 Ft / Hr Rise Rate; 40' Diameter x 12' Height	51400 M-705
M-806	Belt press	MISC	MISC					51400 M-706
M-807	Sand filter	MISC	MISC					51400 M-707
M-833	Aqueous regenerative thermal oxidizer	MISC	MISC			Refractory	$100 /SCFM	EPA Guideline
M-861	Reverse osmosis unit	MISC	MISC				15 gal/ft2/day	HGI 9/21/14
P-801	Clarifier overflow pump	PUMP	CENTRIFUGAL	35	250	CS	50 gpm 40' head	ACCE V8.4
P-809	Slurry pump	PUMP	CENTRIFUGAL	45		CS	2 gpm 10' head	51400 Icarus 2006.5
P-810	Boiler charge pump	PUMP	CENTRIFUGAL	170	250	CS	200 gpm 160' head	ACCE V8.4
P-812	Condensate Pump	PUMP	CENTRIFUGAL	155	400	CS	140 gpm 20' head	ACCE V8.4
P-814	Boiler charge pump	PUMP	CENTRIFUGAL	160	400	CS	145 gpm 5' head	ACCE V8.4
P-815	Boiler makeup pump	PUMP	CENTRIFUGAL	170	70	CS	5 gpm 400' head	ACCE V8.4
P-822	Concentrated waste water pump	PUMP	CENTRIFUGAL	150	400	304SS	7 gpm 20' head	ACCE V8.4
P-860	RO Feed pump	PUMP	CENTRIFUGAL	85	250	CS	185 gpm 170' head	ACCE V8.4
P-866	Clean water pump	PUMP	CENTRIFUGAL	40	250	CS	140 gpm 50' head	ACCE V8.4
T-801	Clarifier overflow tank	VESSEL	STORAGE	15	250	CS	17' Ø 32' H 50,000 gal	ACCE V8.4
T-809	Slurry tank	VESSEL	STORAGE	15	250	CS	17' Ø 32' H 50,000 gal	T-801
T-810	Boiler Feed Tank	VESSEL	VERTICAL PRESSURE	110	250	CS	5' Ø 15' T-T	ACCE V8.4
T-812	Steam drum	VESSEL	VERTICAL PRESSURE	160	410	CS	4.5' Ø 14' T-T	ACCE V8.4
T-814	Boiler feed tank	VESSEL	VERTICAL PRESSURE	160	400	CS	4.5' Ø 14' T-T	ACCE V8.4
T-822	Steam drum	VESSEL	VERTICAL PRESSURE	160	410	CS	4' Ø 12' T-T	ACCE V8.4
T-860	RO Feed tank	VESSEL	STORAGE	15	250	CS	21.5' Ø 9.5' H	ACCE V8.4
T-866	Clean water tank	VESSEL	STORAGE	15	250	CS	42' Ø 19' H	ACCE V8.4
A800	Pinch exchanger CAPEX							ACCE V7.2
Area A800: Water Management ↑								

NOTES

ACCE	Aspen Capital Cost Estimator
HGI	Harris Group
51400	2011 NREL mixed alcohols report
23053	2013 PNNL Pyrolysis report

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Appendix B-1. Individual Equipment Cost Summary (*In Situ* Case)

ENGINEERING-PDH.COM
| CHE-136 |
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Equip ID	Required	Spares	Equipment Name	Design Flow (per unit)	Design Flow (total)	Actual Flow (total)	Units	Size Ratio	Original Equip Cost (per unit)	Base Year	Total Orig Equip Cost (Req+Spare) in Base Year	Scaling Exp.	Scaled Cost in Base Year	Install Factor	Installed Cost in Base Year	Installed Cost in 2011$	Scaled Uninstalled Cost in 2011$
C-101			Hopper Feeder						INCLUDED								
C-102			Screener Feeder Conveyor						INCLUDED								
C-103			Radial Stacker Conveyor						INCLUDED								
C-104			Dryer Feed Screw Conveyor						INCLUDED								
C-105			Biomass Feed Screw Conveyor						INCLUDED								
K-101	3		Flue Gas Blower	204	612	502	hp	0.82	$59,300	2013	$177,900	0.78	$152,406	1.94	$295,046	$304,616	$157,349
M-101			Hydraulic Truck Dump with Scale						INCLUDED								
M-102			Hammermill						INCLUDED								
M-103			Front End Loaders						INCLUDED								
M-104	2		Cross Flow Pellet Dryer	102,066	204,131	204,131	lb/h	1.00	$50,000	2011	$100,000	0.80	$100,000	2.00	$200,000	$200,000	$100,000
S-101			Magnetic Head Pulley						INCLUDED								
S-102			Vibratory Conveyor						INCLUDED								
T-101			Dump Hopper						INCLUDED								
T-102			Hammermill surge bin						INCLUDED								
T-103			Dryer Feed Bin						INCLUDED								
T-104			Dried Biomass Hopper						INCLUDED								
T-105			Lock Hopper						INCLUDED								
T-106			Feed Hopper						INCLUDED								
A100	1		Pinch Exchanger CAPEX							2008	$0		$0	2.64	$0	$0	$0
Area A100: Feed Handling & Drying ↑											**$277,900**		**$252,406**	**1.96**	**$495,047**	**$504,616**	**$257,350**
C-202	2		Fines purge cooler														
K-201	2		Fluidizing gas recycle compressor	3,648	7,296	2,259	hp	0.31	$4,700,000	2014	$9,400,000	0.90	$3,272,282	1.60	$5,235,650	$5,343,301	$3,339,563
K-202	2		Combustor air compressor	10,000	20,000	25,042	hp	1.25	$2,600,000	2014	$5,200,000	0.78	$6,196,626	1.60	$9,914,602	$10,118,457	$6,324,036
R-201	2		Catalytic Fluidized Bed Reactor	1,225,468	2,450,936	2,285,891	ACFH	0.93	$3,889,900	2011	$7,779,800	0.50	$7,513,290	4.01	$30,128,295	$30,128,295	$7,513,290
R-202	2		Char Combustor	1,199,076	2,398,152	2,386,324	ACFH	1.00	$3,152,459	2011	$6,304,918	0.50	$6,289,351	3.97	$24,963,814	$24,963,814	$6,289,351
R-202C	2		Catalyst Cooler	127,815,673	255,631,346	258,621,302	Btu/h	1.01	$1,793,235	2011	$3,586,470	0.80	$3,619,990	3.00	$10,859,970	$10,859,970	$3,619,990
S-201	2		Primary Cyclone						INCLUDED								
S-202	2		Secondary Cyclone						INCLUDED								
S-203	0		Char Combustor Primary Cyclone						INCLUDED								
S-204	0		Char Combustor Secondary Cyclone						INCLUDED								
T-201	2		Catalyst steam stripper	2,139	4,278	4,151	lb/h	0.97	$742,538	2011	$1,485,076	0.30	$1,471,731	3.00	$4,415,194	$4,415,194	$1,471,731
T-202	0		Depleted catalyst and ash storage bin						INCLUDED								
T-207	0		Catalyst feed bin						INCLUDED								
A201	1		Pinch Exchanger CAPEX							2008	$2,479,203		$2,479,203	2.64	$6,533,610	$6,650,565	$2,523,583
Area A201: In Situ Catalytic Fast Pyrolysis ↑											**$36,235,467**		**$30,842,473**	**2.98**	**$92,051,135**	**$92,479,596**	**$31,081,544**
D-301	1		Heavy Fraction Condenser Absorber		12.0	11.5	ft	0.91	$1,085,800	2013	$1,085,800	0.60	$1,026,955	1.40	$1,436,489	$1,483,080	$1,060,264
D-302	1		Light Fraction Condenser Absorber		13.0	12.8	ft	0.96	$1,085,300	2013	$1,085,300	0.60	$1,061,899	1.33	$1,407,875	$1,453,539	$1,096,341
H-313	1		D-301 Vapor ACHE		61,000,000	73,704,854	Btu/h	1.21	$578,900	2013	$578,900	0.60	$648,490	1.32	$854,385	$882,096	$669,523
H-314	1		D-302 Feed Cooler		12,067,840	11,873,657	Btu/h	0.98	$172,000	2013	$172,000	0.70	$170,058	2.03	$344,862	$356,047	$175,574
H-315	1		D-302 Feed/overhead exchanger		4,850,345	4,515,958	Btu/h	0.93	$758,400	2013	$758,400	0.70	$721,410	1.52	$1,097,050	$1,132,632	$744,809
H-316	1		D-302 Liquid feed chiller		10,138,754	10,271,256	Btu/h	1.01	$132,400	2013	$132,400	0.70	$133,609	2.33	$311,519	$321,622	$137,942
H-320	1		Heavy fraction ACHE		280,000	278,343	Btu/h	0.99	$33,300	2013	$33,300	0.60	$33,182	2.42	$80,413	$83,021	$34,258
H-326	1	1	D-302 Quench circulation chiller		13,087,000	13,478,244	Btu/h	1.03	$78,300	2013	$156,600	0.70	$159,863	4.63	$740,922	$764,953	$165,048
P-318	1	1	D-301 Bottoms pump		56.0	51	gpm	0.92	$5,800	2013	$11,600	0.80	$10,822	4.38	$47,395	$48,932	$11,173
P-323	1	1	Circulation filter charge pump		41	43	hp	1.05	$25,400	2013	$50,800	0.80	$52,656	4.61	$242,963	$250,843	$54,364
P-329	1	1	Aqueous filter charge pump		182.0	179	gpm	0.99	$7,500	2013	$15,000	0.80	$14,822	4.20	$62,254	$64,273	$15,303
P-331	1	1	Organic product pump		124.0	121	gpm	0.97	$6,500	2013	$13,000	0.80	$12,708	4.63	$58,846	$60,754	$13,120
P-332	1	1	Quench recycle pump		0.53	0.55	hp	1.04	$7,800	2013	$15,600	0.80	$16,125	4.88	$78,766	$81,321	$16,648
S-319	1	1	D-301 Bottoms filter		52	47	gpm	0.91	$14,600	2013	$29,200	0.80	$27,138	1.84	$50,000	$51,622	$28,018
S-322	1		D-302 Bottoms decanter		1,013,050	1,084,143	lb/h	1.07	$294,700	2013	$294,700	0.70	$309,029	1.82	$562,900	$581,158	$319,052
S-324	2	1	Quench circulation filter		2,340.0	2,432	gpm	1.04	$83,100	2013	$249,300	0.80	$257,122	1.71	$439,676	$453,937	$265,462
S-329	1	1	Aqueous phase filter		182.0	179	gpm	0.99	$26,500	2013	$53,000	0.80	$52,372	1.77	$92,689	$95,695	$54,071
T-328	1		Organic product surge tank		1,000	967	ACFH	0.97	$48,000	2013	$48,000	0.70	$46,878	3.24	$151,962	$156,890	$48,398
T-332	1		D-301 Circulation surge tank		1,000	1,561	ACFH	1.56	$48,000	2013	$48,000	0.70	$65,554	3.24	$212,504	$219,397	$67,680
A310	1		Pinch exchanger CAPEX							2008	$1,411,745		$1,411,745	2.64	$3,720,465	$3,787,064	$1,437,016
Area A310: Product Condensation and Separation ↑											**$6,242,645**		**$6,232,437**	**1.92**	**$11,993,934**	**$12,328,877**	**$6,414,064**
H-373	1		Post-WGS ACHE		5,160,000	11,767,420	Btu/h	2.28	$88,300	2013	$88,300	0.60	$144,804	1.71	$248,282	$256,335	$149,500
H-374	1		Post-WGS cooler		2,929,000	3,038,996	Btu/h	1.04	$45,600	2013	$45,600	0.70	$46,792	4.05	$189,426	$195,570	$48,310
K-390	1		PSA compressor: multistage		3,648	2,506	hp	0.69	$4,700,000	2014	$4,700,000	0.90	$3,352,616	1.60	$5,364,186	$5,474,479	$3,421,550
M-385	1		PSA		5,218	5,462	lb/h	1.05	$975,000	2013	$975,000	0.60	$1,002,124	1.80	$1,803,823	$1,862,329	$1,034,627
P-377	1	1	Compressor condensate pump		56.0	47	gpm	0.83	$5,800	2013	$11,600	0.80	$10,035	4.38	$43,946	$45,372	$10,360
R-365	1		High-temperature WGS		354,424	77,912	lb/h	0.22	$1,243,000	2013	$1,243,000	0.60	$500,865	1.42	$709,512	$732,525	$517,110
S-385	1		PSA Compressor suction KO		288,000	308,258	ACFH	1.07	$44,900	2013	$44,900	0.70	$47,088	2.00	$94,176	$97,231	$48,615
S-386	1		PSA Compr disch KO		103,650	110,914	ACFH	1.07	$52,500	2013	$52,500	0.70	$55,049	2.56	$141,031	$145,605	$56,835
T-377	1		Compressor condensate tank		1,000	375	ACFH	0.37	$48,000	2013	$48,000	0.70	$24,148	3.24	$78,279	$80,818	$24,931
A360	1		Pinch exchanger CAPEX							2008	$436,413		$436,413	2.64	$1,150,109	$1,170,696	$444,225
Area A360: Hydrogen Recycle and WGS ↑											**$7,645,313**		**$5,619,934**	**1.75**	**$9,822,769**	**$10,060,958**	**$5,756,064**

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Equip ID	Required	Spares	Equipment Name	Design Flow (per unit)	Design Flow (total)	Actual Flow (total)	Units	Size Ratio	Original Equip Cost (per unit)	Base Year	Total Orig Equip Cost (Req+Spare) in Base Year	Scaling Exp.	Scaled Cost in Base Year	Install Factor	Installed Cost in Base Year	Installed Cost in 2011$	Scaled Uninstalled Cost in 2011$
H-410	1		Feed-effluent exchanger		22,846,147	27,103,960	Btu/h	1.19	$542,500	2013	$542,500	0.70	$611,440	2.23	$1,360,946	$1,405,088	$631,271
H-411	1		Feed furnace		2,210,000	2,515,037	Btu/h	1.14	$263,800	2013	$263,800	0.60	$285,080	1.31	$373,802	$385,926	$294,326
H-413A	1		HT product ACHE		1,780,000	2,877,173	Btu/h	1.62	$44,800	2013	$44,800	0.60	$59,759	1.93	$115,517	$119,264	$61,698
H-413C	1		HT product cooler		1,452,000	2,344,968	Btu/h	1.61	$63,900	2013	$63,900	0.70	$89,376	3.20	$286,031	$295,308	$92,275
H-444	1		Quench hydrogen stage 2 cooler		215,000	311,172	Btu/h	1.45	$21,500	2013	$21,500	0.70	$27,850	7.10	$197,803	$204,218	$28,754
H-445	1		Quench hydrogen stage 3 cooler		215,000	311,172	Btu/h	1.45	$21,500	2013	$21,500	0.70	$27,850	7.10	$197,803	$204,218	$28,754
K-412	1		Hydrogen makeup compressor		1,051	2,367	hp	2.25	$1,890,000	2014	$1,890,000	0.64	$3,178,074	1.60	$5,084,919	$5,189,470	$3,243,419
K-442	1		Hydrogen recycle compressor		146	236	hp	1.62	$1,200,000	2014	$1,200,000	0.90	$1,848,080	1.60	$2,956,928	$3,017,726	$1,886,079
P-410	1	1	HT feed pump		135.0	121	gpm	0.89	$43,200	2013	$86,400	0.80	$78,903	3.58	$282,189	$291,341	$81,462
R-410	1		Hydrotreater, 2000 psi	55,000	55,000	61,262	lb/h	1.11	$6,045,800	2013	$6,045,800	1.00	$6,734,094	1.43	$9,603,362	$9,914,841	$6,952,509
S-410	1		Vapor KO drum		56,193	52,053	lb/h	0.93	$48,500	2013	$48,500	0.70	$45,970	3.45	$158,573	$163,716	$47,461
S-411	1		HP HT effluent flash: 3 phase		8,028	19,791	ACFH	2.47	$373,800	2013	$373,800	0.70	$702,970	2.05	$1,443,551	$1,490,372	$725,770
S-412	1		LP HT effluent flash: 3 phase		9,494	6,961	ACFH	0.73	$45,200	2013	$45,200	0.70	$36,373	4.99	$181,462	$187,348	$37,553
A410	1		Pinch exchanger CAPEX							2008	$212,784		$212,784	2.64	$560,763	$570,801	$216,593
Area A410: Whole Oil Hydroprocessing ↑											**$10,317,984**		**$13,327,163**	**1.61**	**$21,442,703**	**$22,034,550**	**$13,696,651**
D-450	1		Gasoline column		52,557	45,023	lb/h	0.86	$491,900	2013	$491,900	0.70	$441,410	1.69	$745,704	$769,890	$455,727
D-451	1		Diesel column		23,368	20,678	lb/h	0.88	$297,900	2013	$297,900	0.70	$273,459	1.91	$521,398	$538,309	$282,328
H-450C	1		D-450 Condenser (startup)		16,444,000	13,989,118	Btu/h	0.85	$34,700	2013	$34,700	0.70	$30,987	4.58	$141,897	$146,499	$31,992
H-450R	1		D-450 Reboiler (startup)		6,951,000	6,554,290	Btu/h	0.94	$50,500	2013	$50,500	0.70	$48,465	2.83	$137,045	$141,490	$50,037
H-451C	1		D-451 Condenser (startup)		3,050,000	3,161,779	Btu/h	1.04	$13,200	2013	$13,200	0.70	$13,537	6.66	$90,143	$93,067	$13,976
H-451R	1		D-451 Reboiler (startup)		6,951,000	2,871,306	Btu/h	0.41	$50,500	2013	$50,500	0.70	$27,197	2.83	$76,904	$79,399	$28,079
H-454	1		Gasoline product cooler		1,731,000	1,346,878	Btu/h	0.78	$22,400	2013	$22,400	0.70	$18,792	4.04	$75,923	$78,385	$19,401
H-457A	1		Diesel product ACHE		170,000	0	Btu/h	0.00	$29,700	2013	$29,700	0.60	$0	2.34	$0	$0	$0
H-457C	1		Diesel Product Cooler		316,000	359,610	Btu/h	1.14	$10,300	2013	$10,300	0.70	$11,276	5.63	$63,493	$65,553	$11,641
H-459	1		D-450 Overhead vapor cooler		54,900	72,347	Btu/h	1.32	$7,900	2013	$7,900	0.70	$9,583	6.30	$60,412	$62,371	$9,894
P-450	1	1	D-450 Reflux pump		7,190,000	13,989,118	Btu/h	1.95	$9,400	2013	$18,800	0.80	$32,019	4.31	$137,954	$142,428	$33,057
P-451	1	1	D-451 Reflux pump		7,436,000	3,161,779	Btu/h	0.43	$7,400	2013	$14,800	0.80	$7,467	3.96	$29,565	$30,523	$7,709
S-450	1	1	D-450 Overhead accumulator		7,190,000	13,989,118	Btu/h	1.95	$39,100	2013	$78,200	0.70	$124,609	4.01	$499,392	$515,590	$128,651
S-451	1	1	D-451 Overhead accumulator		7,436,000	3,161,779	Btu/h	0.43	$28,600	2013	$57,200	0.70	$31,435	4.34	$136,291	$140,711	$32,454
A450	1		Pinch exchanger CAPEX							2008	$448,752		$448,752	2.64	$1,182,626	$1,203,796	$456,785
Area A450: Oil Fractionation ↑											**$1,626,752**		**$1,518,986**	**2.57**	**$3,898,746**	**$4,008,011**	**$1,561,731**
H-460	1		Feed-effluent exchanger		1,395,356	1,489,635	Btu/h	1.07	$134,600	2013	$134,600	0.70	$140,903	3.37	$475,156	$490,568	$145,473
H-461	1		Feed furnace		680,000	447,147	Btu/h	0.66	$142,800	2013	$142,800	0.60	$111,043	1.52	$168,898	$174,376	$114,645
H-463A	1		HC product ACHE		1,000,000	471,298	Btu/h	0.47	$38,000	2013	$38,000	0.60	$24,197	2.05	$49,667	$51,278	$24,982
H-463C	1		HC product Cooler		845,500	395,651	Btu/h	0.47	$45,300	2013	$45,300	0.70	$26,622	3.23	$85,918	$88,705	$27,485
H-494	1		Quench hydrogen stage 2 cooler		215,000	66,371	Btu/h	0.31	$21,500	2013	$21,500	0.70	$9,443	7.10	$67,068	$69,243	$9,749
H-495	1		Quench hydrogen stage 3 cooler		215,000	66,371	Btu/h	0.31	$21,500	2013	$21,500	0.70	$9,443	7.10	$67,068	$69,243	$9,749
K-462	1		Hydrogen makeup compressor		1,051	692	hp	0.66	$1,890,000	2014	$1,890,000	0.64	$1,446,333	1.60	$2,314,132	$2,361,713	$1,476,071
K-492	1		Hydrogen recycle compressor		146	43	hp	0.29	$1,200,000	2014	$1,200,000	0.90	$399,269	1.60	$638,830	$651,965	$407,478
P-460	1	1	HC feed pump		135.0	29	gpm	0.22	$43,200	2013	$86,400	0.80	$25,568	3.58	$91,442	$94,408	$26,398
R-460	1		Hydrocracker	24,000	24,000	10,606	lb/h	0.44	$2,615,800	2013	$2,615,800	1.00	$1,155,933	1.97	$2,273,288	$2,347,021	$1,193,425
S-460	1		Vapor KO drum		56,193	8,833	lb/h	0.16	$48,500	2013	$48,500	0.70	$13,281	3.45	$45,813	$47,299	$13,712
S-461	1		HP effluent flash: 3 phase		8,257	3,224	ACFH	0.39	$223,900	2013	$223,900	0.70	$115,927	2.15	$249,303	$257,389	$119,687
S-462	1		LP effluent flash		2,520	2,529	ACFH	1.00	$8,100	2013	$8,100	0.70	$8,121	8.99	$72,990	$75,358	$8,385
A460	1		Pinch exchanger CAPEX							2008	$79,483		$79,483	2.64	$209,466	$213,215	$80,905
Area A460: Hydrocracking ↑											**$6,421,283**		**$3,424,663**	**1.85**	**$6,333,885**	**$6,501,214**	**$3,512,672**
H-568A	1		WGS Effluent ACHE		5,740,000	12,089,601	Btu/h	2.11	$76,300	2013	$76,300	0.60	$119,296	1.63	$194,031	$200,325	$123,165
H-568C	1		WGS Effluent cooler		3,159,000	3,083,763	Btu/h	0.98	$32,600	2013	$32,600	0.70	$32,055	3.60	$115,239	$118,977	$33,094
K-511	1		Pyrolysis offgas compressor to reformer		3,648	3,186	hp	0.87	$4,700,000	2014	$4,700,000	0.60	$4,333,528	1.60	$6,933,645	$7,076,208	$4,422,630
K-545	1		Reformer combustor air blower						INCLUDED								
K-580	1		PSA Compressor multistage						INCLUDED								
M-575	1		PSA						INCLUDED								
P-576	1		Compressor condensate pump		50.0	33	gpm	0.67	$5,800	2013	$5,800	0.80	$4,191	4.38	$18,352	$18,948	$4,327
R-530	1		Steam reformer package (PNNL)		49,000,000	29,956,484	SCFD	0.61	$66,875,000	2007	$34,830,729	0.65	$25,296,134	1.92	$48,568,578	$54,142,779	$28,199,364
R-565	1		WGS reactor						INCLUDED								
R-566	1		LTS reactor		354,424	103,323	lb/h	0.29	$1,243,000	2013	$1,243,000	0.60	$593,302	1.42	$840,456	$867,715	$612,546
S-575	1		Compressor suction KO drum						INCLUDED								
S-586	1		PSA Compressor discharge KO drum						INCLUDED								
T-576	1		Compressor condensate tank		1,000	267	ACFH	0.27	$48,000	2013	$48,000	0.70	$19,054	3.24	$61,768	$63,771	$19,672
A500			Pinch exchanger CAPEX							2008	$3,038,752		$3,038,752	2.64	$8,008,226	$8,151,578	$3,093,148
Area A500: Hydrogen Plant ↑											**$43,975,181**		**$33,436,312**	**1.94**	**$64,740,295**	**$70,640,300**	**$36,507,945**

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Equip ID	Required	Spares	Equipment Name	Design Flow (per unit)	Design Flow (total)	Actual Flow (total)	Units	Size Ratio	Original Equip Cost (per unit)	Base Year	Total Orig Equip Cost (Req+Spare) in Base Year	Scaling Exp.	Scaled Cost in Base Year	Install Factor	Installed Cost in Base Year	Installed Cost in 2011$	Scaled Uninstalled Cost in 2011$
H-601	1		Steam turbine condenser		1.00	7.00	Btu/h	7.00	$1,300,000	2010	$1,300,000	1.00	$9,100,000	1.40	$12,740,000	$13,547,237	$9,676,598
H-603	1		Blowdown cooler		381,671	421,230	Btu/h	1.10	$16,780	2007	$16,780	0.65	$17,891	4.32	$77,300	$86,171	$19,944
M-601	1		BFW EDI+polishing		300,000	353,336	lb/h	1.18	$1,325,000	2010	$1,325,000	0.60	$1,461,692	2.00	$2,923,384	$3,108,616	$1,554,308
M-602A	1		Steam turbine generator Stage 1		-40,418	-17,228	hp	0.43	$7,700,000	2010	$7,700,000	0.70	$4,238,925	1.80	$7,630,066	$8,113,525	$4,507,514
M-602B	1		Steam turbine generator Stage 2		-40,418	-47,530	hp	1.18	$7,700,000	2010	$7,700,000	0.70	$8,625,126	1.80	$15,525,228	$16,508,943	$9,171,635
M-603	1		Startup boiler		204,131	204,131	lb/h	1.00	$275,500	2013	$275,500	0.60	$275,500	1.69	$466,519	$481,650	$284,436
P-601	1	1	Makeup pump		80,411	7,064	lb/h	0.09	$6,528	2007	$13,056	0.30	$6,294	4.72	$29,697	$33,105	$7,017
P-602	1	1	Condensate pump		247,010	353,336	lb/h	1.43	$9,810	2007	$19,620	0.30	$21,844	4.61	$100,649	$112,201	$24,352
P-603	1	1	EDI pump		247,010	353,336	lb/h	1.43	$9,810	2007	$19,620	0.30	$21,844	4.61	$100,649	$112,201	$24,352
P-604	1	1	Boiler feed water pump		494,622	353,336	lb/h	0.71	$304,578	2007	$609,156	0.30	$550,684	1.35	$744,906	$830,399	$613,886
P-605	1	1	Condensate collection pump		247,010	353,336	lb/h	1.43	$9,810	2007	$19,620	0.30	$21,844	4.61	$100,649	$112,201	$24,352
S-601	1		Blowdown flash drum		9,892	7,067	lb/h	0.71	$47,205	2007	$47,205	0.65	$37,934	3.41	$129,542	$144,410	$42,288
T-601	1		Condensate collection tank		500,400	353,336	lb/h	0.71	$28,505	2007	$28,505	0.65	$22,735	6.83	$155,286	$173,108	$25,344
T-602	1		Condensate surge tank		500,400	353,336	lb/h	0.71	$27,704	2007	$27,704	0.65	$22,096	6.51	$143,881	$160,394	$24,632
T-603	1		Deaerator		494,619	353,336	lb/h	0.71	$53,299	2007	$53,299	0.65	$42,832	5.07	$217,056	$241,967	$47,747
T-603A	1		Deaerator packed column		494,619	353,336	lb/h	0.71	$18,405	2007	$18,405	0.65	$14,790	5.18	$76,584	$85,374	$16,488
T-605	1		Steam drum		494,622	353,338	lb/h	0.71	$104,100	2007	$104,100	0.65	$83,656	2.28	$190,536	$212,404	$93,257
T-606	1		Steam turbine condensate tank		500,400	353,336	lb/h	0.71	28,505	2007	$28,505	0.65	$22,735	6.83	$155,286	$173,108	$25,344
A600			Pinch exchanger CAPEX							2008	$3,061,423		$3,061,423	2.64	$8,067,973	$8,212,394	$3,116,225
Area A600: Steam System & Power Generation ↑											**$22,367,498**		**$27,649,848**	**1.79**	**$49,575,189**	**$52,449,407**	**$29,299,717**
K-701	2	1	Plant air compressor		262,454	204,131	lb/h	0.78	$87,922	2007	$263,766	0.30	$244,611	1.57	$383,656	$427,688	$272,685
M-701	1		Cooling tower system		7,506,000	2,581,093	lb/h	0.34	$260,852	2010	$260,852	0.78	$113,444	2.47	$280,207	$297,962	$120,632
M-702	1		Hydraulic truck dump with scale		367,437	204,131	lb/h	0.56	$80,000	1998	$80,000	0.60	$56,225	2.47	$138,875	$208,829	$84,546
M-703	1		Flue gas scrubber		489,600	890,764	lb/h	1.82	$436,250	2010	$436,250	0.65	$643,701	2.47	$1,589,942	$1,690,684	$684,488
M-704	1		Flue gas stack		939,119	890,764	lb/h	0.95	$169,187	2007	$169,187	0.65	$163,472	1.30	$212,376	$236,750	$182,234
M-708	1		Chilled water system		28,200,000	23,749,500	Btu/h	0.84	$637,500	2011	$637,500	0.60	$575,074	1.80	$1,035,132	$1,035,132	$575,074
M-710	1		Product loading rack		1	1			$25,000	2011	$25,000	1.00	$25,000	2.47	$61,750	$61,750	$25,000
P-701	1	1	Cooling water pump		7,001,377	2,581,093	lb/h	0.37	$239,375	2007	$478,750	0.30	$354,891	2.14	$759,522	$846,692	$395,622
P-702	1	1	Firewater pump		262,454	204,131	lb/h	0.78	$23,043	2007	$46,086	0.30	$42,739	3.70	$158,025	$176,162	$47,644
P-703	1	1	Diesel pump		262,454	204,131	lb/h	0.78	$3,842	2007	$7,684	0.30	$7,126	5.39	$38,393	$42,800	$7,944
P-704	1	1	Ammonia pump		262,454	204,131	lb/h	0.78	$3,842	2007	$7,684	0.30	$7,126	5.21	$37,095	$41,353	$7,944
P-705	1	1	Caustic pump		1	1			$4,906	2007	$9,812	0.30	$9,812	4.30	$42,200	$47,043	$10,938
P-707	1	1	BFW chemical pump		262,454	204,131	lb/h	0.78	$3,842	2007	$7,684	0.30	$7,126	5.21	$37,095	$41,353	$7,944
P-708	1	1	Flue gas scrubber circulation pump		489,600	890,764	lb/h	1.82	$12,510	2007	$25,020	0.30	$29,941	4.12	$123,258	$137,404	$33,377
P-790	1	1	Gasoline product pump		108.0	84	gpm	0.78	$7,400	2013	$14,800	0.80	$12,077	3.96	$47,817	$49,368	$12,468
P-792	1	1	Diesel product pump		108.0	33	gpm	0.31	$7,400	2013	$14,800	0.80	$5,797	3.96	$22,954	$23,699	$5,985
S-701	1	1	Instrument air dryer		262,454	204,131	lb/h	0.78	$8,349	2002	$16,698	0.60	$14,361	2.47	$35,471	$52,516	$21,262
T-701	1		Plant air receiver		262,454	204,131	lb/h	0.78	$21,005	2007	$21,005	0.65	$17,839	5.44	$97,074	$108,215	$19,887
T-702	1		Firewater storage tank		262,454	204,131	lb/h	0.78	$229,900	2007	$229,900	0.65	$195,252	1.46	$285,447	$318,207	$217,661
T-703	1		Purchased diesel storage tank		262,454	204,131	lb/h	0.78	$104,674	2007	$104,674	0.65	$88,899	1.35	$119,665	$133,399	$99,102
T-704	1		Ammonia storage tank		262,454	204,131	lb/h	0.78	$15,704	2007	$15,704	0.65	$13,337	5.39	$71,850	$80,096	$14,868
T-705	1		Caustic storage tank		262,454	204,131	lb/h	0.78	$16,005	2007	$16,005	0.65	$13,593	3.01	$40,936	$45,634	$15,153
T-708	1		BFW chemical storage tank		262,454	204,131	lb/h	0.78	$22,004	2007	$22,004	0.65	$18,688	6.70	$125,186	$139,553	$20,833
T-790	1	1	Gasoline product storage tanks		50	84	gpm	1.68	$442,700	2013	$885,400	0.70	$885,400	1.75	$1,553,400	$1,603,784	$914,117
T-792	1	1	Diesel product storage tank		50	33	gpm	0.67	$442,700	2013	$885,400	0.70	$885,400	1.75	$1,553,400	$1,603,784	$914,117
Area A700: Cooling Water & Other Utilities ↑											**$4,681,665**		**$4,430,930**	**2.00**	**$8,850,727**	**$9,449,857**	**$4,711,524**

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Equip ID	Required	Spares	Equipment Name	Design Flow (per unit)	Design Flow (total)	Actual Flow (total)	Units	Size Ratio	Original Equip Cost (per unit)	Base Year	Total Orig Equip Cost (Req+Spare) in Base Year	Scaling Exp.	Scaled Cost in Base Year	Install Factor	Installed Cost in Base Year	Installed Cost in 2011$	Scaled Uninstalled Cost in 2011$
H-840	1		RTO Feed/Effluent exchanger						INCLUDED								
K-831	1		RTO blower		900	2,222	hp	2.47	$360,420	2009	$360,420	0.60	$619,845	1.60	$991,752	$1,112,989	$695,618
M-805	1		Clarifier		220	220			$96,221	2007	$96,221	0.65	$96,221	2.41	$232,300	$258,961	$107,264
M-806	1		Belt press		1	1			$135,000	2010	$135,000	0.65	$135,000	2.47	$333,450	$354,578	$143,554
M-807	1		Sand filter		265	265			$120,400	2010	$120,400	0.65	$120,400	2.47	$297,388	$316,231	$128,029
M-833	1		Aqueous regenerative thermal oxidizer		18,500	38,359	SCFM	2.07	$1,850,000	2002	$1,850,000	0.60	$2,865,414	2.40	$6,876,994	$10,181,637	$4,242,349
M-861	1		Reverse osmosis unit		197,000	66,679	lb/h	0.34	$350,000	2012	$350,000	0.70	$163,958	1.15	$188,552	$188,907	$164,267
P-801	1	1	Clarifier overflow pump		50	53	gpm	1.06	$4,500	2013	$9,000	0.80	$9,394	4.38	$41,126	$42,460	$9,699
P-809	1	1	Slurry pump		1	1			$3,242	2007	$3,242	0.80	$3,242	3.10	$10,050	$11,204	$3,614
P-810	1	1	Boiler charge pump		200	179	gpm	0.90	$6,500	2013	$13,000	0.80	$11,912	4.14	$49,298	$50,897	$12,298
P-812	1	1	Condensate Pump		140	127	gpm	0.91	$5,100	2013	$10,200	0.80	$9,422	4.59	$43,229	$44,631	$9,727
P-814	1	1	Boiler charge pump		145	128	gpm	0.88	$5,100	2013	$10,200	0.80	$9,204	4.59	$42,231	$43,600	$9,503
P-815	1	1	Boiler makeup pump		5	0	gpm	0.00	$14,700	2013	$29,400	0.80	$0	1.84	$0	$0	$0
P-822	1	1	Concentrated waste water pump		7	14	gpm	2.05	$4,900	2013	$9,800	0.80	$17,375	4.31	$74,821	$77,248	$17,939
P-860	1	1	RO Feed pump		185	160	gpm	0.87	$6,400	2013	$12,800	0.80	$11,402	3.84	$43,828	$45,250	$11,772
P-866	1	1	Clean water pump		140	120	gpm	0.86	$5,200	2013	$5,200	0.80	$4,596	4.35	$19,977	$20,624	$4,745
T-801	1		Clarifier overflow tank		1	1		1.00	$85,800	2013	$85,800	0.65	$85,800	2.27	$195,000	$201,325	$88,583
T-809	1		Slurry tank		1	1		1.00	$85,800	2013	$85,800	0.65	$85,800	2.27	$195,000	$201,325	$88,583
T-810	1		Boiler Feed Tank		200	179	gpm	0.90	$24,600	2013	$24,600	0.70	$22,789	4.49	$102,365	$105,685	$23,528
T-812	1		Steam drum		100,800	96,797	ACFH	0.96	$24,400	2013	$24,400	0.70	$23,718	4.46	$105,854	$109,288	$24,487
T-814	1		Boiler feed tank		145	128	gpm	0.88	$24,400	2013	$24,400	0.70	$22,302	4.46	$99,538	$102,766	$23,026
T-822	1		Steam drum		156,000	140,136	ACFH	0.90	$19,400	2013	$19,400	0.70	$17,997	5.23	$94,066	$97,117	$18,581
T-860	1		RO Feed tank		185	160	gpm	0.87	$76,000	2013	$76,000	0.70	$68,687	2.24	$153,643	$158,626	$70,915
T-866	1		Clean water tank		140	120	gpm	0.86	$194,200	2013	$194,200	0.70	$194,200	2.23	$434,000	$448,077	$200,499
A800	1		Pinch exchanger CAPEX							2008	$1,111,734		$1,111,734	2.64	$2,929,827	$2,982,272	$1,131,635
Area A800: Water Management ↑											**$4,661,217**		**$5,710,414**	**2.37**	**$13,554,287**	**$17,155,696**	**$7,230,214**
Plant Total											**$144,452,905**		**$132,445,567**	**2.13**	**$282,758,716**	**$297,613,083**	**$140,029,476**

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Appendix B-2. Individual Equipment Cost Summary (*Ex Situ* Case)

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Equip ID	Required	Spares	Switch	Equipment Name	Design Flow (per unit)	Design Flow (total)	Actual Flow (total)	Units	Size Ratio	Original Equip Cost (per unit)	Base Year	Total Orig Equip Cost (Req+Spare) in Base Year	Scaling Exp.	Scaled Cost in Base Year	Install Factor	Installed Cost in Base Year	Installed Cost in 2011$	Scaled Uninstalled Cost in 2011$
C-101				Hopper Feeder						INCLUDED								
C-102				Screener Feeder Conveyor						INCLUDED								
C-103				Radial Stacker Conveyor						INCLUDED								
C-104				Dryer Feed Screw Conveyor						INCLUDED								
C-105				Biomass Feed Screw Conveyor						INCLUDED								
K-101	2		on	Flue Gas Blower	204	408	383	hp	0.94	$59,300	2013	$118,600	0.78	$112,835	1.94	$218,439	$225,524	$116,495
M-101				Hydraulic Truck Dump with Scale						INCLUDED								
M-102				Hammermill						INCLUDED								
M-103				Front End Loaders						INCLUDED								
M-104	2		ON	Cross Flow Pellet Dryer	102,066	204,131	204,131	lb/h	1.00	$50,000	2011	$100,000	0.80	$100,000	2.00	$200,000	$200,000	$100,000
S-101				Magnetic Head Pulley						INCLUDED								
S-102				Vibratory Conveyor						INCLUDED								
T-101				Dump Hopper						INCLUDED								
T-102				Hammermill surge bin						INCLUDED								
T-103				Dryer Feed Bin						INCLUDED								
T-104				Dried Biomass Hopper						INCLUDED								
T-105				Lock Hopper						INCLUDED								
T-106				Feed Hopper						INCLUDED								
A100	1		on	Pinch Exchanger CAPEX							2008	$0		$0	2.64	$0	$0	$0
Area A100: Feed Handling & Drying ↑												**$218,600**		**$212,835**	**1.97**	**$418,440**	**$425,525**	**$216,495**
C-212	2		FP	Fines purge cooler						INCLUDED								
K-211	2		FP	Fluidizing gas recycle compressor	3,648	7,296	2,887	hp	0.40	$4,700,000	2014	$9,400,000	0.90	$4,081,188	1.60	$6,529,901	$6,664,163	$4,165,102
K-212	2		FP	Combustor air compressor	10,000	20,000	13,584	hp	0.68	$2,600,000	2014	$5,200,000	0.78	$3,845,515	1.60	$6,152,824	$6,279,333	$3,924,583
R-211	2		FP	Fluidized Bed Reactor	1,222,474	2,444,948	2,433,724	ACFH	1.00	$3,449,500	2011	$6,899,000	0.50	$6,883,146	4.01	$27,601,417	$27,601,417	$6,883,146
R-212	2		FP	Char Combustor	719,240	1,438,480	1,429,542	ACFH	0.99	$3,483,784	2011	$6,967,568	0.50	$6,945,888	3.97	$27,569,756	$27,569,756	$6,945,888
R-212C	2		FP	Sand Cooler	3,671,901	7,343,802	7,323,460	Btu/h	1.00	$623,441	2011	$1,246,882	0.80	$1,244,118	3.00	$3,732,355	$3,732,355	$1,244,118
S-211	2		FP	Primary Cyclone						INCLUDED								
S-212	2		FP	Secondary Cyclone						INCLUDED								
S-213	2		FP	Char Combustor Primary Cyclone						INCLUDED								
S-214	2		FP	Char Combustor Secondary Cyclone						INCLUDED								
T-211	2		FP	Bed Media Bin						INCLUDED								
T-212	2		FP	Depleted bed media and ash storage bin						INCLUDED								
T-217	2		FP	Char combustor bed media feed bin						INCLUDED								
A211	1		FP	Pinch Exchanger CAPEX							2008	$1,841,846		$1,841,846	2.64	$4,853,940	$4,940,828	$1,874,816
Area A211: Ex Situ Fast Pyrolysis ↑												**$31,555,296**		**$24,841,702**	**3.08**	**$76,440,192**	**$76,787,851**	**$25,037,654**
C-262	1		VPU	Fines purge cooler						INCLUDED								
K-262	1		VPU	Regenerator air compressor	10,000	10,000	11,036	hp	1.10	$2,600,000	2014	$2,600,000	0.78	$2,807,856	1.60	$4,492,569	$4,584,941	$2,865,588
R-261	1		VPU	Catalytic Fluidized Bed Reactor	2,534,057	2,534,057	2,526,198	lb/h	1.00	$3,818,400	2011	$3,818,400	0.50	$3,812,474	3.97	$15,132,548	$15,132,548	$3,812,474
R-262	1		VPU	Catalyst Regenerator	1,084,318	1,084,318	1,088,654	ACFH	1.00	$4,207,313	2011	$4,207,313	0.50	$4,215,716	3.93	$16,561,186	$16,561,186	$4,215,716
R-262C	1		VPU	Catalyst Cooler	272,000,000	272,000,000	240,298,657	Btu/h	0.88	$3,968,900	2011	$3,968,900	0.80	$3,594,315	3.00	$10,782,944	$10,782,944	$3,594,315
R-262C1	1		VPU	Catalyst cooler (secondary, included)			147,367,743	Btu/h										
S-261	1		VPU	Primary Cyclone						INCLUDED								
S-262	1		VPU	Secondary Cyclone						INCLUDED								
S-263	1		VPU	Char Combustor Primary Cyclone						INCLUDED								
S-264	1		VPU	Char Combustor Secondary Cyclone						INCLUDED								
T-261	1		VPU	Catalyst steam stripper	2,756	2,756	2,756	lb/h	1.00	$347,005	2011	$347,005	0.30	$346,999	3.00	$1,040,997	$1,040,997	$346,999
T-262	1		VPU	Depleted catalyst and ash storage bin						INCLUDED								
T-267	1		VPU	Catalyst feed bin						INCLUDED								
A261	1		VPU	Pinch Exchanger CAPEX							2008	$764,272		$764,272	2.64	$2,014,136	$2,050,190	$777,953
R-261	2	1	FBVPU	VPU Fixed Bed Reactor	161,200	322,400	0	lb/h	0.00	$3,841,800	2013	$0	0.70	$0	1.21	$0	$0	$0
A261	1		FBVPU	Pinch Exchanger CAPEX							2008	$0		$0	2.64	$0	$0	$0
Area A261: Ex Situ Vapor Phase Upgrading ↑												**$15,705,890**		**$15,541,632**	**3.22**	**$50,024,382**	**$50,152,808**	**$15,613,046**

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Equip ID	Required	Spares	Equipment Name	Design Flow (per unit)	Design Flow (total)	Actual Flow (total)	Units	Size Ratio	Original Equip Cost (per unit)	Base Year	Total Orig Equip Cost (Req+Spare) in Base Year	Scaling Exp.	Scaled Cost in Base Year	Install Factor	Installed Cost in Base Year	Installed Cost in 2011$	Scaled Uninstalled Cost in 2011$
D-301	1		Heavy Fraction Condenser Absorber		12.0	12.1	ft	1.02	$1,085,800	2013	$1,085,800	0.60	$1,096,648	1.40	$1,533,974	$1,583,728	$1,132,217
D-302	1		Light Fraction Condenser Absorber		13.0	12.7	ft	0.95	$1,085,300	2013	$1,085,300	0.60	$1,051,451	1.33	$1,394,022	$1,439,236	$1,085,554
H-313	1		D-301 Vapor ACHE		61,000,000	77,484,946	Btu/h	1.27	$578,900	2013	$578,900	0.60	$668,246	1.32	$880,413	$908,968	$689,920
H-314	1		D-302 Feed Cooler		12,067,840	11,973,851	Btu/h	0.99	$172,000	2013	$172,000	0.70	$171,061	2.03	$346,896	$358,148	$176,609
H-315	1		D-302 Feed/overhead exchanger		4,850,345	4,850,345	Btu/h	1.00	$758,400	2013	$758,400	0.70	$758,400	1.52	$1,153,300	$1,190,707	$782,998
H-316	1		D-302 Liquid feed chiller		10,138,754	10,138,689	Btu/h	1.00	$132,400	2013	$132,400	0.70	$132,399	2.33	$308,699	$318,711	$136,694
H-320	1		Heavy fraction ACHE		280,000	284,155	Btu/h	1.01	$33,300	2013	$33,300	0.60	$33,596	2.42	$81,416	$84,057	$34,685
H-326	1	1	D-302 Quench circulation chiller		13,087,000	13,088,111	Btu/h	1.00	$78,300	2013	$156,600	0.70	$156,609	4.63	$725,843	$749,385	$161,689
P-318	1	1	D-301 Bottoms pump		56.0	56	gpm	1.00	$5,800	2013	$11,600	0.80	$11,588	4.38	$50,748	$52,394	$11,964
P-323	1	1	Circulation filter charge pump		41	41	hp	1.01	$25,400	2013	$50,800	0.80	$51,124	4.61	$235,896	$243,548	$52,782
P-329	1	1	Aqueous filter charge pump		182.0	182	gpm	1.00	$7,500	2013	$15,000	0.80	$14,990	4.20	$62,956	$64,998	$15,476
P-331	1	1	Organic product pump		124.0	122	gpm	0.98	$6,500	2013	$13,000	0.80	$12,831	4.63	$59,416	$61,343	$13,247
P-332	1	1	Quench recycle pump		0.53	0.53	hp	1.01	$7,800	2013	$15,600	0.80	$15,716	4.88	$76,768	$79,257	$16,226
S-319	1	1	D-301 Bottoms filter		52	52	gpm	0.99	$14,600	2013	$29,200	0.80	$29,056	1.84	$53,535	$55,271	$29,998
S-322	1		D-302 Bottoms decanter		1,013,050	1,013,055	lb/h	1.00	$294,700	2013	$294,700	0.70	$294,701	1.82	$536,802	$554,213	$304,259
S-324	2	1	Quench circulation filter		2,340.0	2,338	gpm	1.00	$83,100	2013	$249,300	0.80	$249,131	1.71	$426,010	$439,828	$257,211
S-329	1	1	Aqueous phase filter		182.0	182	gpm	1.00	$26,500	2013	$53,000	0.80	$52,963	1.77	$93,735	$96,775	$54,681
T-328	1		Organic product surge tank		1,000	978	ACFH	0.98	$48,000	2013	$48,000	0.70	$47,274	3.24	$153,248	$158,219	$48,808
T-332	1		D-301 Circulation surge tank		1,000	1,500	ACFH	1.50	$48,000	2013	$48,000	0.70	$63,768	3.24	$206,715	$213,419	$65,836
A310	1		Pinch exchanger CAPEX							2008	$1,447,138		$1,447,138	2.64	$3,813,738	$3,882,006	$1,473,042
Area A310: Product Condensation and Separation ↑											**$6,278,038**		**$6,358,689**	**1.92**	**$12,194,129**	**$12,534,210**	**$6,543,897**
H-373	1		Post-WGS ACHE		5,160,000	9,374,326	Btu/h	1.82	$88,300	2013	$88,300	0.60	$126,338	1.71	$216,621	$223,647	$130,436
H-374	1		Post-WGS cooler		2,929,000	3,641,754	Btu/h	1.24	$45,600	2013	$45,600	0.70	$53,110	4.05	$215,003	$221,977	$54,833
K-390	1		PSA compressor: multistage		3,648	3,031	hp	0.83	$4,700,000	2014	$4,700,000	0.90	$3,978,374	1.60	$6,365,399	$6,496,278	$4,060,174
M-385	1		PSA		5,218	7,032	lb/h	1.35	$975,000	2013	$975,000	0.60	$1,166,164	1.80	$2,099,096	$2,167,179	$1,203,988
P-377	1	1	Compressor condensate pump		56.0	49	gpm	0.88	$5,800	2013	$11,600	0.80	$10,478	4.38	$45,887	$47,375	$10,818
R-365	1		High-temperature WGS		354,424	82,376	lb/h	0.23	$1,243,000	2013	$1,243,000	0.60	$517,890	1.42	$733,628	$757,423	$534,687
S-385	1		PSA Compressor suction KO		288,000	391,976	ACFH	1.36	$44,900	2013	$44,900	0.70	$55,713	2.00	$111,425	$115,039	$57,520
S-386	1		PSA Compr disch KO		103,650	141,872	ACFH	1.37	$52,500	2013	$52,500	0.70	$65,402	2.56	$167,553	$172,987	$67,523
T-377	1		Compressor condensate tank		1,000	396	ACFH	0.40	$48,000	2013	$48,000	0.70	$25,078	3.24	$81,295	$83,931	$25,891
A360	1		Pinch exchanger CAPEX							2008	$522,045		$522,045	2.64	$1,375,780	$1,400,408	$531,390
Area A360: Hydrogen Recycle and WGS ↑											**$7,730,945**		**$6,520,592**	**1.75**	**$11,411,687**	**$11,686,244**	**$6,677,260**
H-410	1		Feed-effluent exchanger		22,846,147	22,846,148	Btu/h	1.00	$542,500	2013	$542,500	0.70	$542,500	2.23	$1,207,500	$1,246,665	$560,096
H-411	1		Feed furnace		2,210,000	2,209,486	Btu/h	1.00	$263,800	2013	$263,800	0.60	$263,763	1.31	$345,852	$357,069	$272,318
H-413A	1		HT product ACHE		1,780,000	2,075,079	Btu/h	1.17	$44,800	2013	$44,800	0.60	$49,119	1.93	$94,948	$98,028	$50,712
H-413C	1		HT product cooler		1,452,000	1,707,068	Btu/h	1.18	$63,900	2013	$63,900	0.70	$71,565	3.20	$229,030	$236,458	$73,886
H-444	1		Quench hydrogen stage 2 cooler		215,000	214,948	Btu/h	1.00	$21,500	2013	$21,500	0.70	$21,496	7.10	$152,674	$157,626	$22,194
H-445	1		Quench hydrogen stage 3 cooler		215,000	214,948	Btu/h	1.00	$21,500	2013	$21,500	0.70	$21,496	7.10	$152,674	$157,626	$22,194
K-412	1		Hydrogen makeup compressor		1,051	1,191	hp	1.13	$1,890,000	2014	$1,890,000	0.64	$2,047,681	1.60	$3,276,290	$3,343,654	$2,089,784
K-442	1		Hydrogen recycle compressor		146	180	hp	1.23	$1,200,000	2014	$1,200,000	0.90	$1,449,203	1.60	$2,318,724	$2,366,400	$1,479,000
P-410	1	1	HT feed pump		135.0	122	gpm	0.90	$43,200	2013	$86,400	0.80	$79,667	3.58	$284,920	$294,161	$82,251
R-410	1		Hydrotreater, 1500 psi	55,000	55,000	56,010	lb/h	1.02	$4,775,000	2013	$4,775,000	1.00	$4,862,715	1.53	$7,438,070	$7,679,319	$5,020,434
S-410	1		Vapor KO drum		56,193	50,051	lb/h	0.89	$48,500	2013	$48,500	0.70	$44,725	3.45	$154,279	$159,283	$46,176
S-411	1		HP HT effluent flash: 3 phase		8,028	14,710	ACFH	1.83	$373,800	2013	$373,800	0.70	$571,135	2.05	$1,172,828	$1,210,868	$589,659
S-412	1		LP HT effluent flash: 3 phase		9,494	5,752	ACFH	0.61	$45,200	2013	$45,200	0.70	$31,825	4.99	$158,774	$163,924	$32,857
A410	1		Pinch exchanger CAPEX							2008	$159,918		$159,918	2.64	$421,442	$428,987	$162,781
Area A410: Whole Oil Hydroprocessing ↑											**$8,994,318**		**$9,674,309**	**1.67**	**$16,200,506**	**$16,653,402**	**$9,944,245**
D-450	1		Gasoline column		52,557	46,446	lb/h	0.88	$491,900	2013	$491,900	0.70	$451,124	1.69	$762,115	$786,833	$465,756
D-451	1		Diesel column		23,368	41,393	lb/h	1.77	$297,900	2013	$297,900	0.70	$444,514	1.91	$847,545	$875,035	$458,931
H-450C	1		D-450 Condenser (startup)		16,444,000	7,190,523	Btu/h	0.44	$34,700	2013	$34,700	0.70	$19,447	4.58	$89,054	$91,942	$20,078
H-450R	1		D-450 Reboiler (startup)		6,951,000	5,072,974	Btu/h	0.73	$50,500	2013	$50,500	0.70	$40,508	2.83	$114,546	$118,261	$41,822
H-451C	1		D-451 Condenser (startup)		3,050,000	7,436,530	Btu/h	2.44	$13,200	2013	$13,200	0.70	$24,633	6.66	$164,036	$169,356	$25,432
H-451R	1		D-451 Reboiler (startup)		6,951,000	6,062,749	Btu/h	0.87	$50,500	2013	$50,500	0.70	$45,891	2.83	$129,767	$133,976	$47,379
H-454	1		Gasoline product cooler		1,731,000	897,375	Btu/h	0.52	$22,400	2013	$22,400	0.70	$14,142	4.04	$57,138	$58,991	$14,601
H-457A	1		Diesel product ACHE		170,000	0	Btu/h	0.00	$29,700	2013	$29,700	0.60	$0	2.34	$0	$0	$0
H-457C	1		Diesel Product Cooler		316,000	738,813	Btu/h	2.34	$10,300	2013	$10,300	0.70	$18,665	5.63	$105,104	$108,513	$19,270
H-459	1		D-450 Overhead vapor cooler		54,900	188,200	Btu/h	3.43	$7,900	2013	$7,900	0.70	$18,714	6.30	$117,968	$121,794	$19,321
P-450	1	1	D-450 Reflux pump		7,190,000	7,190,523	Btu/h	1.00	$9,400	2013	$18,800	0.80	$18,801	4.31	$81,005	$83,632	$19,411
P-451	1	1	D-451 Reflux pump		7,436,000	7,436,530	Btu/h	1.00	$7,400	2013	$14,800	0.80	$14,801	3.96	$58,603	$60,504	$15,281
S-450	1	1	D-450 Overhead accumulator		7,190,000	7,190,523	Btu/h	1.00	$39,100	2013	$78,200	0.70	$78,204	4.01	$313,416	$323,581	$80,740
S-451	1	1	D-451 Overhead accumulator		7,436,000	7,436,530	Btu/h	1.00	$28,600	2013	$57,200	0.70	$57,203	4.34	$248,012	$256,056	$59,058
A450	1		Pinch exchanger CAPEX							2008	$482,593		$482,593	2.64	$1,271,810	$1,294,576	$491,232
Area A450: Oil Fractionation ↑											**$1,660,593**		**$1,729,240**	**2.52**	**$4,360,117**	**$4,483,051**	**$1,778,313**

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Equip ID	Required	Spares	Equipment Name	Design Flow (per unit)	Design Flow (total)	Actual Flow (total)	Units	Size Ratio	Original Equip Cost (per unit)	Base Year	Total Orig Equip Cost (Req+Spare) in Base Year	Scaling Exp.	Scaled Cost in Base Year	Install Factor	Installed Cost in Base Year	Installed Cost in 2011$	Scaled Uninstalled Cost in 2011$
H-460	1		Feed-effluent exchanger		1,395,356	1,395,356	Btu/h	1.00	$134,600	2013	$134,600	0.70	$134,600	3.37	$453,900	$468,622	$138,966
H-461	1		Feed furnace		680,000	678,232	Btu/h	1.00	$142,800	2013	$142,800	0.60	$142,577	1.52	$216,861	$223,895	$147,202
H-463A	1		HC product ACHE		1,000,000	573,607	Btu/h	0.57	$38,000	2013	$38,000	0.60	$27,224	2.05	$55,881	$57,693	$28,107
H-463C	1		HC product Cooler		845,500	477,916	Btu/h	0.57	$45,300	2013	$45,300	0.70	$30,385	3.23	$98,065	$101,246	$31,371
H-494	1		Quench hydrogen stage 2 cooler		215,000	57,559	Btu/h	0.27	$21,500	2013	$21,500	0.70	$8,547	7.10	$60,703	$62,672	$8,824
H-495	1		Quench hydrogen stage 3 cooler		215,000	57,559	Btu/h	0.27	$21,500	2013	$21,500	0.70	$8,547	7.10	$60,703	$62,672	$8,824
K-462	1		Hydrogen makeup compressor		1,051	495	hp	0.47	$1,890,000	2014	$1,890,000	0.64	$1,166,697	1.60	$1,866,716	$1,905,098	$1,190,686
K-492	1		Hydrogen recycle compressor		146	42	hp	0.29	$1,200,000	2014	$1,200,000	0.90	$391,259	1.60	$626,014	$638,886	$399,304
P-460	1	1	HC feed pump		135.0	56	gpm	0.42	$43,200	2013	$86,400	0.80	$42,912	3.58	$153,471	$158,449	$44,304
R-460	1		Hydrocracker	24,000	24,000	18,293	lb/h	0.76	$2,615,800	2013	$2,615,800	1.00	$1,993,762	1.97	$3,920,984	$4,048,158	$2,058,428
S-460	1		Vapor KO drum		56,193	16,654	lb/h	0.30	$48,500	2013	$48,500	0.70	$20,703	3.45	$71,414	$73,731	$21,374
S-461	1		HP effluent flash: 3 phase		8,257	3,011	ACFH	0.36	$223,900	2013	$223,900	0.70	$110,515	2.15	$237,664	$245,372	$114,099
S-462	1		LP effluent flash		2,520	2,851	ACFH	1.13	$8,100	2013	$8,100	0.70	$8,831	8.99	$79,366	$81,941	$9,117
A460	1		Pinch exchanger CAPEX							2008	$115,488		$115,488	2.64	$304,354	$309,802	$117,555
Area A460: Hydrocracking ↑											**$6,457,288**		**$4,067,448**	**1.91**	**$7,752,196**	**$7,969,614**	**$4,179,196**
H-568A	1		WGS Effluent ACHE		5,740,000	8,349,471	Btu/h	1.45	$76,300	2013	$76,300	0.60	$95,537	1.63	$155,389	$160,429	$98,636
H-568C	1		WGS Effluent cooler		3,159,000	3,275,594	Btu/h	1.04	$32,600	2013	$32,600	0.70	$33,438	3.60	$120,211	$124,110	$34,522
K-511	1		Pyrolysis offgas compressor to reformer		3,648	2,915	hp	0.80	$4,700,000	2014	$4,700,000	0.60	$4,108,302	1.60	$6,573,282	$6,708,436	$4,192,773
K-545	1		Reformer combustor air blower						INCLUDED								
K-580	1		PSA Compressor multistage						INCLUDED								
M-575	1		PSA						INCLUDED								
P-576	1		Compressor condensate pump		50.0	38	gpm	0.75	$5,800	2013	$5,800	0.80	$4,619	4.38	$20,227	$20,883	$4,769
R-530	1		Steam reformer package (PNNL)		49,000,000	27,420,513	SCFD	0.56	$66,875,000	2007	$34,830,729	0.65	$23,882,745	1.92	$45,854,870	$51,117,619	$26,623,760
R-565	1		WGS reactor						INCLUDED								
R-566	1		LTS reactor		354,424	102,802	lb/h	0.29	$1,243,000	2013	$1,243,000	0.60	$591,504	1.42	$837,908	$865,085	$610,689
S-575	1		Compressor suction KO drum						INCLUDED								
S-586	1		PSA Compressor discharge KO drum						INCLUDED								
T-576	1		Compressor condensate tank		1,000	302	ACFH	0.30	$48,000	2013	$48,000	0.70	$20,747	3.24	$67,255	$69,436	$21,420
A500			Pinch exchanger CAPEX							2008	$2,868,877		$2,868,877	2.64	$7,560,543	$7,695,881	$2,920,232
Area A500: Hydrogen Plant ↑											**$43,805,306**		**$31,605,768**	**1.94**	**$61,189,686**	**$66,761,881**	**$34,506,800**
H-601	1		Steam turbine condenser		1.00	6.00	Btu/h	6.00	$1,300,000	2010	$1,300,000	1.00	$7,800,000	1.40	$10,920,000	$11,611,917	$8,294,227
H-603	1		Blowdown cooler		381,671	385,956	Btu/h	1.01	$16,780	2007	$16,780	0.65	$16,902	4.32	$73,028	$81,409	$18,842
M-601	1		BFW EDI+polishing		300,000	323,747	Btu/h	1.08	$1,325,000	2010	$1,325,000	0.60	$1,386,968	2.00	$2,773,937	$2,949,700	$1,474,850
M-602A	1		Steam turbine generator Stage 1		-40,418	-15,786	hp	0.39	$7,700,000	2010	$7,700,000	0.70	$3,987,202	1.80	$7,176,964	$7,631,713	$4,239,841
M-602B	1		Steam turbine generator Stage 2		-40,418	-43,550	hp	1.08	$7,700,000	2010	$7,700,000	0.70	$8,112,934	1.80	$14,603,282	$15,528,581	$8,626,989
M-603	1		Startup boiler		204,131	204,131	lb/h	1.00	$275,500	2013	$275,500	0.60	$275,500	1.69	$466,519	$481,650	$284,436
P-601	1	1	Makeup pump		80,411	6,473	lb/h	0.08	$6,528	2007	$13,056	0.30	$6,131	4.72	$28,928	$32,248	$6,835
P-602	1	1	Condensate pump		247,010	323,747	lb/h	1.31	$9,810	2007	$19,620	0.30	$21,279	4.61	$98,043	$109,295	$23,721
P-603	1	1	EDI pump		247,010	323,747	lb/h	1.31	$9,810	2007	$19,620	0.30	$21,279	4.61	$98,043	$109,295	$23,721
P-604	1	1	Boiler feed water pump		494,622	323,747	lb/h	0.65	$304,578	2007	$609,156	0.30	$536,424	1.35	$725,616	$808,895	$597,989
P-605	1	1	Condensate collection pump		247,010	323,747	lb/h	1.31	$9,810	2007	$19,620	0.30	$21,279	4.61	$98,043	$109,295	$23,721
S-601	1		Blowdown flash drum		9,892	6,475	lb/h	0.65	$47,205	2007	$47,205	0.65	$35,838	3.41	$122,384	$136,429	$39,951
T-601	1		Condensate collection tank		500,400	323,747	lb/h	0.65	$28,505	2007	$28,505	0.65	$21,478	6.83	$146,704	$163,542	$23,943
T-602	1		Condensate surge tank		500,400	323,747	lb/h	0.65	$27,704	2007	$27,704	0.65	$20,875	6.51	$135,930	$151,530	$23,270
T-603	1		Deaerator		494,619	323,747	lb/h	0.65	$53,299	2007	$53,299	0.65	$40,465	5.07	$205,061	$228,595	$45,109
T-603A	1		Deaerator packed column		494,619	323,747	lb/h	0.65	$18,405	2007	$18,405	0.65	$13,973	5.18	$72,352	$80,656	$15,577
T-605	1		Steam drum		494,622	323,749	lb/h	0.65	$104,100	2007	$104,100	0.65	$79,033	2.28	$180,007	$200,666	$88,104
T-606	1		Steam turbine condensate tank		500,400	323,747	lb/h	0.65	28,505	2007	$28,505	0.65	$21,478	6.83	$146,704	$163,542	$23,943
A600			Pinch exchanger CAPEX							2008	$2,727,447		$2,727,447	2.64	$7,187,822	$7,316,488	$2,776,270
Area A600: Steam System & Power Generation ↑											**$22,033,522**		**$25,146,486**	**1.80**	**$45,259,365**	**$47,895,448**	**$26,651,339**

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Equip ID	Required	Spares	Equipment Name	Design Flow (per unit)	Design Flow (total)	Actual Flow (total)	Units	Size Ratio	Original Equip Cost (per unit)	Base Year	Total Orig Equip Cost (Req+Spare) in Base Year	Scaling Exp.	Scaled Cost in Base Year	Install Factor	Installed Cost in Base Year	Installed Cost in 2011$	Scaled Uninstalled Cost in 2011$
K-701	2	1	Plant air compressor		262,454	204,131	lb/h	0.78	$87,922	2007	$263,766	0.30	$244,611	1.57	$383,656	$427,688	$272,685
M-701	1		Cooling tower system		7,506,000	2,618,485	lb/h	0.35	$260,852	2010	$260,852	0.78	$114,724	2.47	$283,368	$301,323	$121,993
M-702	1		Hydraulic truck dump with scale		367,437	204,131	lb/h	0.56	$80,000	1998	$80,000	0.60	$56,225	2.47	$138,875	$208,829	$84,546
M-703	1		Flue gas scrubber		489,600	777,008	lb/h	1.59	$436,250	2010	$436,250	0.65	$589,000	2.47	$1,454,829	$1,547,010	$626,320
M-704	1		Flue gas stack		939,119	777,008	lb/h	0.83	$169,187	2007	$169,187	0.65	$149,581	1.30	$194,328	$216,631	$166,748
M-708	1		Chilled water system		28,200,000	23,226,800	Btu/h	0.82	$637,500	2011	$637,500	0.60	$567,446	1.80	$1,021,402	$1,021,402	$567,446
M-710	1		Product loading rack		1	1			$25,000	2011	$25,000	1.00	$25,000	2.47	$61,750	$61,750	$25,000
P-701	1	1	Cooling water pump		7,001,377	2,618,485	lb/h	0.37	$239,375	2007	$478,750	0.30	$356,426	2.14	$762,806	$850,354	$397,332
P-702	1	1	Firewater pump		262,454	204,131	lb/h	0.78	$23,043	2007	$46,086	0.30	$42,739	3.70	$158,025	$176,162	$47,644
P-703	1	1	Diesel pump		262,454	204,131	lb/h	0.78	$3,842	2007	$7,684	0.30	$7,126	5.39	$38,393	$42,800	$7,944
P-704	1	1	Ammonia pump		262,454	204,131	lb/h	0.78	$3,842	2007	$7,684	0.30	$7,126	5.21	$37,095	$41,353	$7,944
P-705	1	1	Caustic pump		1	1			$4,906	2007	$9,812	0.30	$9,812	4.30	$42,200	$47,043	$10,938
P-707	1	1	BFW chemical pump		262,454	204,131	lb/h	0.78	$3,842	2007	$7,684	0.30	$7,126	5.21	$37,095	$41,353	$7,944
P-708	1	1	Flue gas scrubber circulation pump		489,600	777,008	lb/h	1.59	$12,510	2007	$25,020	0.30	$28,738	4.12	$118,308	$131,886	$32,037
P-790	1	1	Gasoline product pump		108.0	54	gpm	0.50	$7,400	2013	$14,800	0.80	$8,463	3.96	$33,508	$34,595	$8,737
P-792	1	1	Diesel product pump		108.0	69	gpm	0.63	$7,400	2013	$14,800	0.80	$10,287	3.96	$40,730	$42,051	$10,620
S-701	1	1	Instrument air dryer		262,454	204,131	lb/h	0.78	$8,349	2002	$16,698	0.60	$14,361	2.47	$35,471	$52,516	$21,262
T-701	1		Plant air receiver		262,454	204,131	lb/h	0.78	$21,005	2007	$21,005	0.65	$17,839	5.44	$97,074	$108,215	$19,887
T-702	1		Firewater storage tank		262,454	204,131	lb/h	0.78	$229,900	2007	$229,900	0.65	$195,252	1.46	$285,447	$318,207	$217,661
T-703	1		Purchased diesel storage tank		262,454	204,131	lb/h	0.78	$104,674	2007	$104,674	0.65	$88,899	1.35	$119,665	$133,399	$99,102
T-704	1		Ammonia storage tank		262,454	204,131	lb/h	0.78	$15,704	2007	$15,704	0.65	$13,337	5.39	$71,850	$80,096	$14,868
T-705	1		Caustic storage tank		262,454	204,131	lb/h	0.78	$16,005	2007	$16,005	0.65	$13,593	3.01	$40,936	$45,634	$15,153
T-708	1		BFW chemical storage tank		262,454	204,131	lb/h	0.78	$22,004	2007	$22,004	0.65	$18,688	6.70	$125,186	$139,553	$20,833
T-790	1	1	Gasoline product storage tanks		50	54	gpm	1.07	$442,700	2013	$885,400	0.70	$885,400	1.75	$1,553,400	$1,603,784	$914,117
T-792	1	1	Diesel product storage tank		50	69	gpm	1.37	$442,700	2013	$885,400	0.70	$885,400	1.75	$1,553,400	$1,603,784	$914,117
Area A700: Cooling Water & Other Utilities ↑											**$4,681,665**		**$4,357,197**	**1.99**	**$8,688,798**	**$9,277,418**	**$4,632,878**
H-840	1		RTO Feed/Effluent exchanger						INCLUDED								
K-831	1		RTO blower		900	1,032	hp	1.15	$360,420	2009	$360,420	0.60	$391,180	1.60	$625,888	$702,400	$439,000
M-805	1		Clarifier		220	220			$96,221	2007	$96,221	0.65	$96,221	2.41	$232,300	$258,961	$107,264
M-806	1		Belt press		1	1			$135,000	2010	$135,000	0.65	$135,000	2.47	$333,450	$354,578	$143,554
M-807	1		Sand filter		265	265			$120,400	2010	$120,400	0.65	$120,400	2.47	$297,388	$316,231	$128,029
M-833	1		Aqueous regenerative thermal oxidizer		18,500	17,765	SCFM	0.96	$1,850,000	2002	$1,850,000	0.60	$1,805,560	2.40	$4,333,344	$6,415,672	$2,673,197
M-861	1		Reverse osmosis unit		197,000	70,810	lb/h	0.36	$350,000	2012	$350,000	0.70	$171,005	1.15	$196,655	$197,025	$171,326
P-801	1	1	Clarifier overflow pump		50	51	gpm	1.01	$4,500	2013	$9,000	0.80	$9,078	4.38	$39,742	$41,031	$9,373
P-809	1	1	Slurry pump		1	1			$3,242	2007	$3,242	0.80	$3,242	3.10	$10,050	$11,204	$3,614
P-810	1	1	Boiler charge pump		200	182	gpm	0.91	$6,500	2013	$13,000	0.80	$12,047	4.14	$49,854	$51,471	$12,437
P-812	1	1	Condensate Pump		140	126	gpm	0.90	$5,100	2013	$10,200	0.80	$9,392	4.59	$43,094	$44,491	$9,697
P-814	1	1	Boiler charge pump		145	132	gpm	0.91	$5,100	2013	$10,200	0.80	$9,434	4.59	$43,287	$44,691	$9,740
P-815	1	1	Boiler makeup pump		5	5	gpm	0.90	$14,700	2013	$29,400	0.80	$27,048	1.84	$49,863	$51,481	$27,925
P-822	1	1	Concentrated waste water pump		7	6	gpm	0.90	$4,900	2013	$9,800	0.80	$9,001	4.31	$38,759	$40,016	$9,293
P-860	1	1	RO Feed pump		185	170	gpm	0.92	$6,400	2013	$12,800	0.80	$11,949	3.84	$45,931	$47,420	$12,337
P-866	1	1	Clean water pump		140	127	gpm	0.91	$5,200	2013	$5,200	0.80	$4,820	4.35	$20,949	$21,629	$4,977
T-801	1		Clarifier overflow tank		1	1		1.00	$85,800	2013	$85,800	0.65	$85,800	2.27	$195,000	$201,325	$88,583
T-809	1		Slurry tank		1	1		1.00	$85,800	2013	$85,800	0.65	$85,800	2.27	$195,000	$201,325	$88,583
T-810	1		Boiler Feed Tank		200	182	gpm	0.91	$24,600	2013	$24,600	0.70	$23,014	4.49	$103,375	$106,728	$23,760
T-812	1		Steam drum		100,800	100,789	ACFH	1.00	$24,400	2013	$24,400	0.70	$24,398	4.46	$108,891	$112,423	$25,189
T-814	1		Boiler feed tank		145	132	gpm	0.91	$24,400	2013	$24,400	0.70	$22,789	4.46	$101,712	$105,011	$23,529
T-822	1		Steam drum		156,000	156,173	ACFH	1.00	$19,400	2013	$19,400	0.70	$19,415	5.23	$101,478	$104,770	$20,045
T-860	1		RO Feed tank		185	170	gpm	0.92	$76,000	2013	$76,000	0.70	$71,562	2.24	$160,074	$165,265	$73,883
T-866	1		Clean water tank		140	127	gpm	0.91	$194,200	2013	$194,200	0.70	$194,200	2.23	$434,000	$448,077	$200,499
A800	1		Pinch exchanger CAPEX							2008	$1,070,377		$1,070,377	2.64	$2,820,835	$2,871,329	$1,089,537
Area A800: Water Management ↑											**$4,619,860**		**$4,412,732**	**2.40**	**$10,580,920**	**$12,914,554**	**$5,395,370**
Plant Total											**$153,741,320**		**$134,468,631**	**2.26**	**$304,520,418**	**$317,542,004**	**$141,176,492**

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Appendix C-1. Discounted Cash Flow Rate of Return and Operating Cost Summary (*In Situ* Case)

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Year		-2	-1	0	1	2	3	4	5	6	7	8	9	10
Fixed Capital Investment		$18,248,867	$124,791,506	$66,555,470										
Working Capital				$25,998,230										
Loan Payment					$46,494,036	$46,494,036	$46,494,036	$46,494,036	$46,494,036	$46,494,036	$46,494,036	$46,494,036	$46,494,036	$46,494,036
Loan Interest Payment		$1,996,664	$16,971,645	$24,958,301	$24,958,301	$23,235,442	$21,374,755	$19,365,212	$17,194,907	$14,850,976	$12,319,532	$9,585,571	$6,632,894	$3,444,003
Loan Principal		$24,958,301	$212,145,560	$311,978,765	$290,443,030	$267,184,437	$242,065,156	$214,936,332	$185,637,203	$153,994,144	$119,819,640	$82,911,175	$43,050,033	$0
Fuel Product Sales					$140,774,123	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830
Byproduct Credit					$1,770,680	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907
Total Annual Sales					$142,544,803	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737
Annual Manufacturing Cost														
Raw Materials					$50,695,237	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413
Catalyst Costs		$0	$0	$0	$7,433,882	$298,198	$5,185,172	$298,198	$5,185,172	$298,198	$5,185,172	$298,198	$5,185,172	$298,198
Other Variable Costs					$24,612,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001
Fixed Operating Costs					$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303
Total Product Cost					$108,147,424	$111,769,916	$116,656,890	$111,769,916	$116,656,890	$111,769,916	$116,656,890	$111,769,916	$116,656,890	$111,769,916
Annual Depreciation														
General Plant % Depreciation					14.3%	24.5%	17.5%	12.5%	8.9%	8.9%	8.9%	4.5%		
General Plant Depreciation					$58,755,822	$100,694,896	$71,913,178	$51,354,808	$36,717,249	$36,676,132	$36,717,249	$18,338,066		
General Plant Remaining					$352,411,579	$251,716,683	$179,803,504	$128,448,696	$91,731,447	$55,055,315	$18,338,066	$0		
Steam Plant % Depreciation					3.75%	7.22%	6.68%	6.18%	5.71%	5.29%	4.89%	4.52%	4.46%	4.46%
Steam Plant Depreciation					$4,079,895	$7,854,070	$7,264,390	$6,720,403	$6,215,584	$5,749,932	$5,318,007	$4,919,810	$4,854,531	$4,853,443
Steam Plant Remaining					$104,717,312	$96,863,241	$89,598,852	$82,878,448	$76,662,864	$70,912,932	$65,594,924	$60,675,114	$55,820,583	$50,967,140
Total Depreciation					$62,835,717	$108,548,967	$79,177,568	$58,075,212	$42,932,833	$42,426,065	$42,035,256	$23,257,876	$4,854,531	$4,853,443
Net Revenue					-$53,396,639	-$53,494,588	-$27,149,476	$849,397	$13,275,107	$21,012,780	$19,048,059	$45,446,374	$61,915,422	$69,992,375
Losses Forward						-$53,396,639	-$106,891,227	-$134,040,703	-$133,191,306	-$119,916,198	-$98,903,418	-$79,855,358	-$34,408,984	$0
Taxable Income					-$53,396,639	-$106,891,227	-$134,040,703	-$133,191,306	-$119,916,198	-$98,903,418	-$79,855,358	-$34,408,984	$27,506,438	$69,992,375
Income Tax					$0	$0	$0	$0	$0	$0	$0	$0	$9,627,253	$24,497,331
Annual Cash Income					-$12,096,657	$31,795,785	$26,908,811	$31,795,785	$26,908,811	$31,795,785	$26,908,811	$31,795,785	$17,281,558	$7,298,454
Discount Factor		1.210	1.100	1.000	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386
Annual Present Value	$296,366,372				-$10,996,961	$26,277,509	$20,216,988	$21,716,949	$16,708,255	$17,947,892	$13,808,475	$14,832,969	$7,329,068	$2,813,870
Total Capital Investment + Interest		$24,497,093	$155,939,466	$117,512,001										
Net Present Worth				$0										

Year	11	12	13	14	15	16	17	18	19	20
Fixed Capital Investment										
Working Capital										
Loan Payment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Loan Interest Payment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Loan Principal	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Fuel Product Sales	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830
Byproduct Credit	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907
Total Annual Sales	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737
Annual Manufacturing Cost										
Raw Materials	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413
Catalyst Costs	$5,185,172	$298,198	$5,185,172	$298,198	$5,185,172	$298,198	$5,185,172	$298,198	$5,185,172	$298,198
Other Variable Costs	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001
Fixed Operating Costs	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303
Total Product Cost	$116,656,890	$111,769,916	$116,656,890	$111,769,916	$116,656,890	$111,769,916	$116,656,890	$111,769,916	$116,656,890	$111,769,916
Annual Depreciation										
General Plant % Depreciation										
General Plant Depreciation										
General Plant Remaining										
Steam Plant % Depreciation	4.46%	4.46%	4.46%	4.46%	4.46%	4.46%	4.46%	4.46%	4.46%	4.46%
Steam Plant Depreciation	$4,854,531	$4,853,443	$4,854,531	$4,853,443	$4,854,531	$4,853,443	$4,854,531	$4,853,443	$4,854,531	$4,853,443
Steam Plant Remaining	$46,112,608	$41,259,165	$36,404,633	$31,551,190	$26,696,659	$21,843,215	$16,988,684	$12,135,240	$7,280,709	$2,427,266
Total Depreciation	$4,854,531	$4,853,443	$4,854,531	$4,853,443	$4,854,531	$4,853,443	$4,854,531	$4,853,443	$4,854,531	$4,853,443
Net Revenue	$68,548,316	$73,436,378	$68,548,316	$73,436,378	$68,548,316	$73,436,378	$68,548,316	$73,436,378	$68,548,316	$73,436,378
Losses Forward	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Taxable Income	$68,548,316	$73,436,378	$68,548,316	$73,436,378	$68,548,316	$73,436,378	$68,548,316	$73,436,378	$68,548,316	$73,436,378
Income Tax	$23,991,911	$25,702,732	$23,991,911	$25,702,732	$23,991,911	$25,702,732	$23,991,911	$25,702,732	$23,991,911	$25,702,732
Annual Cash Income	$49,410,937	$52,587,089	$49,410,937	$52,587,089	$49,410,937	$52,587,089	$49,410,937	$52,587,089	$49,410,937	$52,587,089
Discount Factor	0.350	0.319	0.290	0.263	0.239	0.218	0.198	0.180	0.164	0.149
Annual Present Value	$17,318,232	$16,755,867	$14,312,588	$13,847,824	$11,828,585	$11,444,483	$9,775,690	$9,458,250	$8,079,083	$7,816,736
Total Capital Investment + Interest										
Net Present Worth										

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DCFROR Worksheet										
Year	21	22	23	24	25	26	27	28	29	30
Fixed Capital Investment										
Working Capital										-$27,608,230
Loan Payment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Loan Interest Payment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Loan Principal	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Fuel Product Sales	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830	$187,698,830
Byproduct Credit	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907	$2,360,907
Total Annual Sales	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737	$190,059,737
Annual Manufacturing Cost										
Raw Materials	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413
Catalyst Costs	$5,185,172	$298,198	$5,185,172	$298,198	$5,185,172	$298,198	$5,185,172	$298,198	$5,185,172	$298,198
Other Variable Costs	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001	$28,128,001
Fixed Operating Costs	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303	$25,406,303
Total Product Cost	$116,656,890	$111,769,916	$116,656,890	$111,769,916	$116,656,890	$111,769,916	$116,656,890	$111,769,916	$116,656,890	$111,769,916
Annual Depreciation										
General Plant % Depreciation										
General Plant Depreciation										
General Plant Remaining										
Steam Plant % Depreciation	2.23%									
Steam Plant Depreciation	$2,427,266									
Steam Plant Remaining	$0									
Total Depreciation	$2,427,266									
Net Revenue	$70,975,582	$78,289,821	$73,402,847	$78,289,821	$73,402,847	$78,289,821	$73,402,847	$78,289,821	$73,402,847	$78,289,821
Losses Forward	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Taxable Income	$70,975,582	$78,289,821	$73,402,847	$78,289,821	$73,402,847	$78,289,821	$73,402,847	$78,289,821	$73,402,847	$78,289,821
Income Tax	$24,841,454	$27,401,437	$25,690,997	$27,401,437	$25,690,997	$27,401,437	$25,690,997	$27,401,437	$25,690,997	$27,401,437
Annual Cash Income	$48,561,394	$50,888,384	$47,711,851	$50,888,384	$47,711,851	$50,888,384	$47,711,851	$50,888,384	$47,711,851	$50,888,384
Discount Factor	0.135	0.123	0.112	0.102	0.092	0.084	0.076	0.069	0.063	0.057
Annual Present Value	$6,562,129	$6,251,433	$5,328,372	$5,166,474	$4,403,613	$4,269,813	$3,639,349	$3,528,771	$3,007,727	$2,916,340
Total Capital Investment + Interest										-$1,582,188
Net Present Worth										

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Operating Cost Summary — In Situ

Raw Material	Scaling Flow		Quoted Price		Year of Price Quote	2011 Cost	2011 Cost ($/h)	2011 Cost (MM$/yr)	2011 Cost (¢/GGE)
Variable Operating Costs									
Feedstock, Catalyst & Chemicals									
Feedstock - Wood Chips	102	US ton/h	$ 72.00	/US ton	2011	$ 72.00	7,348.73	57.937	106.88
Sand Makeup	-	lb/h	$ 0.21	/lb	2011	$ 0.21	-	-	-
VPU Zeolite Catalyst	-	lb/h	$ 9.75	/lb	2011	$ 9.75	-	-	-
CFP Zeolite Catalyst	344	lb/h	$ 9.75	/lb	2011	$ 9.75	3,358.11	26.475	48.84
Natural Gas to SMR	54	lb/h	$ 0.12	/lb	2011	$ 0.12	6.40	0.050	0.09
50 wt% Caustic	291	lb/h	$ 0.08	/lb	2010	$ 0.08	23.27	0.183	0.34
Boiler Chemicals	7,067	lb/h blowdn	$ 75.00	/MM lb	2014	$ 66.73	0.47	0.004	0.01
Cooling Tower Chemicals	4,627	ton cool	$ 33.84	/ton cool/yr	2014	$ 30.11	17.67	0.139	0.26
Regeneration Gas: FP	-	lb/h	$ 0.12	/lb	2011	$ 0.12	-	-	-
Regeneration Gas: CFP	0	lb/h	$ 0.12	/lb	2011	$ 0.12	0.00	0.000	0.00
Regeneration Gas: VPU	-	lb/h	$ 0.12	/lb	2011	$ 0.12	-	-	-
Net Water Makeup	43,242	lb/h	$ 0.20	/ton	2001	$ 0.31	6.79	0.054	0.10
Diesel Fuel	71	lb/h	$ 0.40	/lb	2011	$ 0.40	28.56	0.225	0.42
Subtotal							**10,790.01**	**85.068**	**156.93**
Waste Streams									
FP Purge	-	lb/h	$ 0.016	/lb	1998	$ 0.027	-	-	-
CFP Purge	2,512	lb/h	$ 0.016	/lb	1998	$ 0.027	68.77	0.542	1.00
VPU Purge	-	lb/h	$ 0.016	/lb	1998	$ 0.027	-	-	-
Quench Filter Solids	43	lb/h	$ 0.016	/lb	1998	$ 0.027	1.16	0.009	0.02
WWT Cost	21,410	lb/h	$ 0.003	/lb	2011	$ 0.003	56.52	0.446	0.82
Subtotal							**126.46**	**0.997**	**1.84**
Coproduct Credits									
Electricity	5,117	kW	$ 0.0585	/kWh	2011	$ 0.059	(299)	(2.36)	(4.36)
Subtotal							**(299.46)**	**(2.36)**	**(4.36)**
Total Variable Operating Costs							**10,617.01**	**83.705**	**154.41**
Fixed Operating Costs									
	2007 Salary	**# Positions**	**2011 Cost**		**2011 Hourly Wage**				
Plant Manager	$ 147,000	1	$ 161,362		$ 70.67				
Plant Engineer	$ 70,000	1	$ 76,839		$ 33.65				
Maintenance Supr	$ 57,000	1	$ 62,569		$ 27.40				
Lab Manager	$ 56,000	1	$ 61,471		$ 26.92				
Shift Supervisor	$ 48,000	5	$ 263,448		$ 23.08				
Lab Technician	$ 40,000	2	$ 87,816		$ 19.23				
Maintenance Tech	$ 40,000	16	$ 702,527		$ 19.23				
Shift Operators	$ 48,000	20	$ 1,053,790		$ 23.08				
Yard Employees	$ 28,000	12	$ 368,827		$ 13.46				
Clerks & Secretaries	$ 36,000	3	$ 118,551		$ 17.31				
Total Salaries		**62**	**$ 2,957,199**					**3.246**	**5.99**
					Avg Salary (w/ Benefits)				
Overhead and Benefits	x Supervison =	90.0%	$2,921,501		$45.59	per Hour		2.922	5.39
Maintenance	% of FCI =	3.0%	$15,598,938		$94,818	per Year		15.599	28.78
Insurance & Taxes	% of FCI =	0.7%	$3,639,752					3.640	6.71
Total Fixed Operating Costs								**25.406**	**46.87**
Total Operating Costs								**109.111**	**201.28**
Annual Capital Charge								**91.514**	**168.82**

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Appendix C-2. Discounted Cash Flow Rate of Return and Operating Cost Summary (*Ex Situ* Case)

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Year		-2	-1	0	1	2	3	4	5	6	7	8	9	10
Fixed Capital Investment		$19,579,672	$134,772,539	$71,878,688										
Working Capital				$28,077,612										
Loan Payment					$50,212,707	$50,212,707	$50,212,707	$50,212,707	$50,212,707	$50,212,707	$50,212,707	$50,212,707	$50,212,707	$50,212,707
Loan Interest Payment		$2,156,361	$18,329,065	$26,954,508	$26,954,508	$25,093,852	$23,084,344	$20,914,075	$18,570,184	$16,038,782	$13,304,868	$10,352,241	$7,163,404	$3,719,460
Loan Principal		$26,954,508	$229,113,317	$336,931,348	$313,673,150	$288,554,295	$261,425,932	$232,127,300	$200,484,777	$166,310,853	$129,403,015	$89,542,549	$46,493,247	$0
Fuel Product Sales					$140,387,007	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676
Byproduct Credit					$1,107,466	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621
Total Annual Sales					$141,494,473	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297
Annual Manufacturing Cost														
Raw Materials					$50,695,237	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413
Catalyst Costs		$0	$0	$0	$6,868,000	$272,954	$5,325,566	$272,954	$5,325,566	$272,954	$5,325,566	$272,954	$5,325,566	$272,954
Other Variable Costs					$17,056,575	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229
Fixed Operating Costs					$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046
Total Product Cost					$101,564,858	$104,648,642	$109,701,254	$104,648,642	$109,701,254	$104,648,642	$109,701,254	$104,648,642	$109,701,254	$104,648,642
Annual Depreciation														
General Plant % Depreciation					14.3%	24.5%	17.5%	12.5%	8.9%	8.9%	8.9%	4.5%		
General Plant Depreciation					$65,096,988	$111,562,298	$79,674,340	$56,897,227	$40,679,923	$40,634,369	$40,679,923	$20,317,184		
General Plant Remaining					$390,445,265	$278,882,967	$199,208,627	$142,311,400	$101,631,477	$60,997,108	$20,317,184	$0		
Steam Plant % Depreciation					3.75%	7.22%	6.68%	6.18%	5.71%	5.29%	4.89%	4.52%	4.46%	4.46%
Steam Plant Depreciation					$3,975,375	$7,652,862	$7,078,287	$6,548,237	$6,056,351	$5,602,628	$5,181,769	$4,793,772	$4,730,166	$4,729,106
Steam Plant Remaining					$102,034,620	$94,381,758	$87,303,471	$80,755,234	$74,698,883	$69,096,254	$63,914,486	$59,120,714	$54,390,548	$49,661,442
Total Depreciation					$69,072,363	$119,215,159	$86,752,627	$63,445,465	$46,736,274	$46,236,997	$45,861,692	$25,110,956	$4,730,166	$4,729,106
Net Revenue					-$56,097,255	-$60,298,356	-$30,878,928	-$348,884	$13,651,585	$21,734,876	$19,791,483	$48,547,458	$67,064,473	$75,562,090
Losses Forward						-$56,097,255	-$116,395,611	-$147,274,539	-$147,623,423	-$133,971,839	-$112,236,963	-$92,445,480	-$43,898,022	$0
Taxable Income					-$56,097,255	-$116,395,611	-$147,274,539	-$147,623,423	-$133,971,839	-$112,236,963	-$92,445,480	-$43,898,022	$23,166,451	$75,562,090
Income Tax					$0	$0	$0	$0	$0	$0	$0	$0	$8,108,258	$26,446,731
Annual Cash Income					-$10,283,092	$33,797,949	$28,745,336	$33,797,949	$28,745,336	$33,797,949	$28,745,336	$33,797,949	$20,637,078	$7,351,217
Discount Factor		1.210	1.100	1.000	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386
Annual Present Value	$319,921,818				-$9,348,265	$27,932,189	$21,596,797	$23,084,454	$17,848,592	$19,078,061	$14,750,903	$15,766,993	$8,752,136	$2,834,213
Total Capital Investment + Interest		$26,300,599	$168,411,765	$126,910,808										
Net Present Worth				$0										

Year	11	12	13	14	15	16	17	18	19	20
Fixed Capital Investment										
Working Capital										
Loan Payment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Loan Interest Payment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Loan Principal	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Fuel Product Sales	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676
Byproduct Credit	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621
Total Annual Sales	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297
Annual Manufacturing Cost										
Raw Materials	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413
Catalyst Costs	$5,325,566	$272,954	$5,325,566	$272,954	$5,325,566	$272,954	$5,325,566	$272,954	$5,325,566	$272,954
Other Variable Costs	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229
Fixed Operating Costs	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046
Total Product Cost	$109,701,254	$104,648,642	$109,701,254	$104,648,642	$109,701,254	$104,648,642	$109,701,254	$104,648,642	$109,701,254	$104,648,642
Annual Depreciation										
General Plant % Depreciation										
General Plant Depreciation										
General Plant Remaining										
Steam Plant % Depreciation	4.46%	4.46%	4.46%	4.46%	4.46%	4.46%	4.46%	4.46%	4.46%	4.46%
Steam Plant Depreciation	$4,730,166	$4,729,106	$4,730,166	$4,729,106	$4,730,166	$4,729,106	$4,730,166	$4,729,106	$4,730,166	$4,729,106
Steam Plant Remaining	$44,931,276	$40,202,170	$35,472,004	$30,742,898	$26,012,732	$21,283,627	$16,553,461	$11,824,355	$7,094,189	$2,365,083
Total Depreciation	$4,730,166	$4,729,106	$4,730,166	$4,729,106	$4,730,166	$4,729,106	$4,730,166	$4,729,106	$4,730,166	$4,729,106
Net Revenue	$74,227,877	$79,281,549	$74,227,877	$79,281,549	$74,227,877	$79,281,549	$74,227,877	$79,281,549	$74,227,877	$79,281,549
Losses Forward	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Taxable Income	$74,227,877	$79,281,549	$74,227,877	$79,281,549	$74,227,877	$79,281,549	$74,227,877	$79,281,549	$74,227,877	$79,281,549
Income Tax	$25,979,757	$27,748,542	$25,979,757	$27,748,542	$25,979,757	$27,748,542	$25,979,757	$27,748,542	$25,979,757	$27,748,542
Annual Cash Income	$52,978,286	$56,262,113	$52,978,286	$56,262,113	$52,978,286	$56,262,113	$52,978,286	$56,262,113	$52,978,286	$56,262,113
Discount Factor	0.350	0.319	0.290	0.263	0.239	0.218	0.198	0.180	0.164	0.149
Annual Present Value	$18,568,566	$17,926,843	$15,345,922	$14,815,573	$12,682,580	$12,244,275	$10,481,471	$10,119,236	$8,662,373	$8,363,005
Total Capital Investment + Interest										
Net Present Worth										

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Year	21	22	23	24	25	26	27	28	29	30
Fixed Capital Investment										-$29,687,612
Working Capital										
Loan Payment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Loan Interest Payment	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Loan Principal	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Fuel Product Sales	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676	$187,182,676
Byproduct Credit	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621	$1,476,621
Total Annual Sales	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297	$188,659,297
Annual Manufacturing Cost										
Raw Materials	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413	$57,937,413
Catalyst Costs	$5,325,566	$272,954	$5,325,566	$272,954	$5,325,566	$272,954	$5,325,566	$272,954	$5,325,566	$272,954
Other Variable Costs	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229	$19,493,229
Fixed Operating Costs	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046	$26,945,046
Total Product Cost	$109,701,254	$104,648,642	$109,701,254	$104,648,642	$109,701,254	$104,648,642	$109,701,254	$104,648,642	$109,701,254	$104,648,642
Annual Depreciation										
General Plant % Depreciation										
General Plant Depreciation										
General Plant Remaining										
Steam Plant % Depreciation	2.23%									
Steam Plant Depreciation	$2,365,083									
Steam Plant Remaining	$0									
Total Depreciation	$2,365,083									
Net Revenue	$76,592,960	$84,010,655	$78,958,043	$84,010,655	$78,958,043	$84,010,655	$78,958,043	$84,010,655	$78,958,043	$84,010,655
Losses Forward	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Taxable Income	$76,592,960	$84,010,655	$78,958,043	$84,010,655	$78,958,043	$84,010,655	$78,958,043	$84,010,655	$78,958,043	$84,010,655
Income Tax	$26,807,536	$29,403,729	$27,635,315	$29,403,729	$27,635,315	$29,403,729	$27,635,315	$29,403,729	$27,635,315	$29,403,729
Annual Cash Income	$52,150,507	$54,606,926	$51,322,728	$54,606,926	$51,322,728	$54,606,926	$51,322,728	$54,606,926	$51,322,728	$54,606,926
Discount Factor	0.135	0.123	0.112	0.102	0.092	0.084	0.076	0.069	0.063	0.057
Annual Present Value	$7,047,128	$6,708,241	$5,731,628	$5,544,001	$4,736,882	$4,581,819	$3,914,779	$3,786,627	$3,235,354	$3,129,444
Total Capital Investment + Interest										-$1,701,354
Net Present Worth										

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Operating Cost Summary — Ex Situ

Raw Material	Scaling Flow		Quoted Price		Year of Price Quote	2011 Cost	2011 Cost ($/h)	2011 Cost (MM$/yr)	2011 Cost (¢/GGE)
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Variable Operating Costs									
Feedstock, Catalyst & Chemicals									
Feedstock - Wood Chips	102	US ton/h	$ 72.00	/US ton	2011	$ 72.00	7,348.73	57.937	102.60
Sand Makeup	158	lb/h	$ 0.21	/lb	2011	$ 0.21	32.79	0.259	0.46
VPU Zeolite Catalyst	229	lb/h	$ 9.75	/lb	2011	$ 9.75	2,229.26	17.576	31.12
CFP Zeolite Catalyst	-	lb/h	$ 9.75	/lb	2011	$ 9.75	-	-	-
Natural Gas to SMR	125	lb/h	$ 0.12	/lb	2011	$ 0.12	14.88	0.117	0.21
50 wt% Caustic	294	lb/h	$ 0.08	/lb	2010	$ 0.08	23.54	0.186	0.33
Boiler Chemicals	6,475	lb/h blowdn	$ 75.00	/MM lb	2014	$ 66.73	0.43	0.003	0.01
Cooling Tower Chemicals	4,694	ton cool	$ 33.84	/ton cool/yr	2014	$ 30.11	17.93	0.141	0.25
Regeneration Gas: FP	0	lb/h	$ 0.12	/lb	2011	$ 0.12	0.00	0.000	0.00
Regeneration Gas: CFP	-	lb/h	$ 0.12	/lb	2011	$ 0.12	-	-	-
Regeneration Gas: VPU	0	lb/h	$ 0.12	/lb	2011	$ 0.12	0.00	0.000	0.00
Net Water Makeup	41,495	lb/h	$ 0.20	/ton	2001	$ 0.31	6.52	0.051	0.09
Diesel Fuel	71	lb/h	$ 0.40	/lb	2011	$ 0.40	28.56	0.225	0.40
Subtotal							**9,702.64**	**76.496**	**135.46**
Waste Streams									
FP Purge	2,038	lb/h	$ 0.016	/lb	1998	$ 0.027	55.78	0.440	0.78
CFP Purge	-	lb/h	$ 0.016	/lb	1998	$ 0.027	-	-	-
VPU Purge	262	lb/h	$ 0.016	/lb	1998	$ 0.027	7.17	0.056	0.10
Quench Filter Solids	36	lb/h	$ 0.016	/lb	1998	$ 0.027	0.98	0.008	0.01
WWT Cost	20,708	lb/h	$ 0.003	/lb	2011	$ 0.003	54.67	0.431	0.76
Subtotal							**118.59**	**0.935**	**1.66**
Coproduct Credits									
Electricity	3,201	kW	$ 0.0585	/kWh	2011	$ 0.059	(187)	(1.48)	(2.61)
Subtotal							**(187.29)**	**(1.48)**	**(2.61)**
Total Variable Operating Costs							**9,633.94**	**75.954**	**134.50**
Fixed Operating Costs									
	2007 Salary	**# Positions**	**2011 Cost**		**2011 Hourly Wage**				
Plant Manager	$ 147,000	1	$ 161,362		$ 70.67				
Plant Engineer	$ 70,000	1	$ 76,839		$ 33.65				
Maintenance Supr	$ 57,000	1	$ 62,569		$ 27.40				
Lab Manager	$ 56,000	1	$ 61,471		$ 26.92				
Shift Supervisor	$ 48,000	5	$ 263,448		$ 23.08				
Lab Technician	$ 40,000	2	$ 87,816		$ 19.23				
Maintenance Tech	$ 40,000	16	$ 702,527		$ 19.23				
Shift Operators	$ 48,000	20	$ 1,053,790		$ 23.08				
Yard Employees	$ 28,000	12	$ 368,827		$ 13.46				
Clerks & Secretaries	$ 36,000	3	$ 118,551		$ 17.31				
Total Salaries		**62**	**$ 2,957,199**					**3.246**	**5.75**
					Avg Salary (w/ Benefits)				
Overhead and Benefits	Labor & Supervison =	90.0%	$2,921,501		$45.59	per Hour		2.922	5.17
Maintenance	% of FCI =	3.0%	$16,846,567		$94,818	per Year		16.847	29.83
Insurance & Taxes	% of FCI =	0.7%	$3,930,866					3.931	6.96
Total Fixed Operating Costs								**26.945**	**47.72**
Total Operating Costs								**102.899**	**182.22**
Annual Capital Charge								**98.833**	**175.02**

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Appendix D-1. Process Parameter and Operating Summary (*In Situ* Case)

Process Parameters and Operation Summary — **In Situ**

FEEDSTOCK		
Biomass total	204,131	lb/h
Feed Moisture	10%	wt
Moisture flow	20,413	lb/h
Dry feed rate	183,718	lb/h
Feedstock %C	50.9%	dry wt
Feedstock %H	6.0%	dry wt
Feedstock %O	41.9%	dry wt
Feedstock %S	0.0%	dry wt
Feedstock %N	0.2%	dry wt
Feedstock %Ash	0.9%	dry wt
Specific LHV	7,989	Btu/lb
Specific HHV	8,578	Btu/lb
PYROLYSIS MAIN CFB		
Reactor		
Parallel trains (reactor+combustor)	2	
Biomass feed per train	1000	dry MT/day
Biomass moisture	10%	wt%
Temperature	500°C	932°F
Pressure	121 psia	8.3 bar
Bed solids material	Catalyst (ZSM-5)	
Bed solids inventory	115	ton
Catalyst makeup (% rxr inventory)	2.00%	
Ratio of bed solids to dry biomass	6.8	w/w
Number of cyclones per reactor	2	
Stripping steam	3.0	lb/1000 lb cat
Fluidizing gases to dry biomass	0.77	w/w
H2 partial pressure in fluidizing gas	86 psia	5.9 bar
Combustor/Regenerator		
Temperature	650°C	1202°F
Pressure	117 psia	8.1 bar
Excess air (%)	20%	
Upstream solids temperature	650°C	1202°F
No. of cyclones per combustor	2	
VAPOR PHASE UPGRADING CFB		
Reactor		
Parallel trains (reactor+combustor)	N/A	
Biomass feed per train	N/A	dry MT/day
Biomass moisture	10%	wt%
Temperature	N/A	N/A
Pressure	N/A	N/A
Bed solids material	N/A	
Bed solids inventory	N/A	ton
Catalyst makeup (% rxr inventory)	N/A	
Ratio of bed solids to dry biomass	N/A	w/w
Number of cyclones per reactor	2	
Stripping steam	N/A	lb/1000 lb cat
Fluidizing gases to dry biomass	N/A	
H2 partial pressure in fluidizing gas	N/A	N/A
Combustor/Regenerator		
Temperature	N/A	N/A
Pressure	N/A	N/A
Excess air (%)	20%	
Upstream solids temperature	N/A	N/A
No. of cyclones per combustor	2	
UPGRADED PRODUCT COMPOSITION		
Hydrogen incorporated	1.3%	wt% dry BM
Gas	22.9%	wt% dry BM
Aqueous	28.7%	wt% dry BM
Organic	28.3%	wt% dry BM
Coke	8.1%	wt% dry BM
Char	12.0%	wt% dry BM
Net Water	27.3%	wt% dry BM

VAPOR QUENCH		
Heavy Fraction condenser-absorber		
Temperature	348	°F
Pressure	114	psia
Feed rate	329,131	lb/h
Recycle liquid flow	86,730	lb/h
Vapor product	396,315	lb/h
Bottoms liquid flow	19,547	lb/h
Light fraction condenser-absorber		
Temperature	60	°F
Pressure	101	psia
Recycle liquid flow	964,869	lb/h
Vapor product	199,763	lb/h
Bottoms liquid flow	1,161,420	lb/h
Mole % H_2 overhead	62%	
Total aqueous phase		
Flow	77,273	lb/h
wt% carbon	2.6%	
% carbon loss to aq phase	2.1%	
Total organic phase		
Flow	52,053	lb/h
wt% C	80%	
wt% H	10%	
wt% O	10%	
organic H/C	1.47	
carbon eff to organic phs	44%	
HYDROGEN RECYCLE		
Water gas shift		
Gas flow rate	48,356	lb/h
Inlet temperature	464	°F
Outlet temperature	663	°F
Pressure	88	psia
Steam flow rate	29,556	lb/h
Temperature approach	35	°F
Wastewater (condensate)	19,648	lb/h
Pressure swing adsorption (PSA)		
Inlet flow rate	58,265	lb/h
Inlet hydrogen mole %	67%	
Hydrogen recovery %	84%	
Hydrogen purity %	99%	
Hydrogen product stream	5,462	lb/h
HYDROPROCESSING		
Hydrotreater		
Pressure	1,815	psia
Liquid feed	52,053	lb/h
Liquid feed C, H, O	80%, 10%, 10%	wt%
Total H2 feed (pure)	11,229	lb/h
H2 purity	90%	mol%
Makeup H2 (pure)	3,274	lb/h
Product gas (HP flash)	28,548	lb/h
Product gas (HP flash) H2	87%	mol%
Purge gas (HP flash)	5,327	lb/h
Purge gas (LP flash)	870	lb/h
Aqueous phase product	4,696	lb/h
Organic phase product	45,023	lb/h
Organic phase C,H,O	87%, 12%, 1%	wt%
Hydrocracker		
Liquid feed	8,833	lb/h
Liquid feed C, H, O	88%, 11%, 1%	wt%
Total H2 feed (pure)	2,154	lb/h
H2 purity	90%	mol%
Makeup H2 (pure)	905	lb/h
Product gas (HP flash)	5,487	lb/h
Product gas (HP flash) H2	84%	mol%
Purge gas (HP flash)	1,342	lb/h
Purge gas (LP flash)	412	lb/h
Aqueous phase product	80	lb/h
Organic phase producth	8,068	lb/h
Organic phase C,H,O	85%, 15%, 0%	wt%

SEPARATION		
Gasoline column		
Feed from hydrotreater	45,023	lb/h
Feed from hydrocracker	8,068	lb/h
Gasoline range product	31,866	lb/h
Light gases	547	lb/h
Bottoms to diesel column	20,678	lb/h
Diesel column		
Feed from gasoline column	20,678	lb/h
Diesel-range product	11,845	lb/h
Bottoms to hydrocracker	8,833	lb/h
Overall hydroprocess efficiency		
Carbon efficiency %	91%	
Yield lb product/lb feed	84%	
Oxygen content in feed/product	10.5%, 0.5%	wt%
HYDROTREATING RECYCLE COMPRESSOR		
Inlet pressure	1793	psia
Outlet pressure	1900	psia
Inlet mass flow	27085	lb/h
Inlet molecular weight	2	
Electrical consumption	176	kW
HYDROCRACKING RECYCLE COMPRESSOR		
Inlet pressure	1893	psia
Outlet pressure	2000	psia
Inlet mass flow	5214	lb/h
Inlet molecular weight	2	
Electrical consumption	32	kW
HYDROTREATING MAKEUP COMPRESSOR		
Inlet pressure	245	psia
Outlet pressure	1795	psia
Inlet mass flow	3865	lb/h
Inlet molecular weight	2	
Electrical consumption	1765	kW
HYDROCRACKING MAKEUP COMPRESSOR		
Inlet pressure	245	psia
Outlet pressure	1995	psia
Inlet mass flow	1068	lb/h
Inlet molecular weight	2	
Electrical consumption	516	kW
HYDROGEN PLANT		
Hydrogen production rate	29956483.7	MMscfd
Supplemental natural gas	54	lb/h
Hydrogen outlet purity	99	mol%
Hydrogen outlet pressure	266	psia
Hydrogen Balance		
Pyrolysis Reactor Makeup	8,288	lb/h
Hydrotreating Makeup	3,865	lb/h
Hydrocracking Makeup	1,068	lb/h
Total consumed	13,221	lb/h
Produced from recycle PSA	5,462	lb/h
Produced from reformer	7,759	lb/h
Total produced	13,221	lb/h
STEAM SYSTEM		
HP Turbine Brake Power	-17228	hp
IP Turbine Brake Power	-21952	hp
LP Turbine Brake Power	-25578	hp

POWER SUMMARY (kW)	GENERATED	CONSUMED
Feed handling and drying		387
Pyrolysis		22,619
Condensation & separation		3,500
Hydroprocessing		2,951
Hydrogen production		6,083
Steam & power	48,291	1,588
Cooling water & utilities		324
Wastewater management		1,798
Miscellaneous		3,925
Balance to grid		5,117
Plant totals	48,291	48,291
HEAT INTEGRATION		
Total Pinch Duty	848	MMBtu/h

FUEL PRODUCTION			
Gasoline	density	6.215	lb/gal (1)
	Oxygen content	0.69%	wt%
	production	31,866	lb/h
		251.2	MMlb/yr
	actual volume	123,060	gal/day
		40.4	MMgal/yr
		55.8	gal/dry ton
	HHV (Aspen)	19,422	Btu/lb
		120,705	Btu/gal
	HHV equiv volume	39.2	MMGGE/yr
		54.2	GGE/dry ton
	LHV (Aspen)	18,180	Btu/lb
		112,988	Btu/gal
	LHV Vol Equiv	39.3	MMGGE/yr
		54.3	GGE/dry ton
Diesel	density	6.982	lb/gal (1)
	Oxygen content	0.00%	wt%
	production	11,845	lb/h
		93.4	MMlb/yr
	actual volume	40,716	gal/day
		13.4	MMgal/yr
		18.5	gal/dry ton
	HHV (Aspen)	19,792	Btu/lb
		138,185	Btu/gal
	HHV equiv volume	14.86	MMGGE/yr
		20.5	GGE/dry ton
	LHV (Aspen)	18,477	Btu/lb
		129,006	Btu/gal
	LHV Vol Equiv	14.86	MMGGE/yr
		20.5	GGE/dry ton
Total	production	43,711	lb/h
		344.6	MMlb/yr
	actual volume	53.8	MMgal/yr
		163,776	gal/day
		74.3	gal/dry ton
	HHV equiv volume	54.1	MMGGE/yy
	LHV equiv volume	54.2	MMGGE/yr
	% Gasoline	73%	
	% Diesel	27%	

THEORETICAL PRODUCTION		
total HHV	1577	MMbtu/h
HHV Theo. Volume	13,066	gge/h
HHV Theo. Yield	142	gal/ton

ENERGY EFFICIENCY	LHV	HHV
Inputs (MMBtu/h)		
Feedstock	1,468	1,576
Natural Gas	1	1
Outputs (MMBtu/h)		
Gasoline product	579	619
Diesel product	219	234
Electricity product	17	17
Fuel/Biomass Effic.	54.4%	54.1%
Fuel/(Biomass+NG)	54.3%	54.1%
(Fuel+Elec)/(Biomass+NG)	55.5%	55.2%

CARBON EFFICIENCY		
Fuel yield, mass basis	23.8%	wt% dry BM
Fuel/Biomass Effic.	40.4%	
Fuel/(Biomass+NG) Effic.	40.4%	

(1) From: http://cta.ornl.gov/bedb/appendix_a/Lower_and_Higher_Heating_Values_of_Gas_Liquid_and_Solid_Fuels.pdf
Conventional gasoline 2,819 grams/gallon = 6.214831 lb/gal
US conventional diesel 3,167 grams/gallon = 6.98204 lb/gal

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Appendix D-2. Process Parameter and Operating Summary (*Ex Situ* Case)

Process Parameters and Operation Summary — **Ex Situ**

FEEDSTOCK		
Biomass total	204,131	lb/h
Feed Moisture	10%	wt
Moisture flow	20,413	lb/h
Dry feed rate	183,718	lb/h
Feedstock %C	50.9%	dry wt
Feedstock %H	6.0%	dry wt
Feedstock %O	41.9%	dry wt
Feedstock %S	0.0%	dry wt
Feedstock %N	0.2%	dry wt
Feedstock %Ash	0.9%	dry wt
Specific LHV	7,989	Btu/lb
Specific HHV	8,578	Btu/lb
PYROLYSIS MAIN CFB		
Reactor		
Parallel trains (reactor+combustor)	2	
Biomass feed per train	1000	dry MT/day
Biomass moisture	10%	wt%
Temperature	500°C	932°F
Pressure	121 psia	8.3 bar
Bed solids material	Sand	
Bed solids inventory	120	ton
Catalyst makeup (% rxr inventory)	N/A	
Ratio of bed solids to dry biomass	7.0	w/w
Number of cyclones per reactor	2	
Stripping steam	N/A	lb/1000 lb cat
Fluidizing gases to dry biomass	0.69	w/w
H2 partial pressure in fluidizing gas	93 psia	6.4 bar
Combustor/Regenerator		
Temperature	720°C	1328°F
Pressure	117 psia	8.1 bar
Excess air (%)	20%	
Upstream solids temperature	720°C	1328°F
No. of cyclones per combustor	2	
VAPOR PHASE UPGRADING CFB		
Reactor		
Parallel trains (reactor+combustor)	1	
Biomass feed per train	2000	dry MT/day
Biomass moisture	10%	wt%
Temperature	500°C	932°F
Pressure	119 psia	8.2 bar
Bed solids material	st (ZSM-5)	
Bed solids inventory	77	ton
Catalyst makeup (% rxr inventory)	2.00%	
Ratio of bed solids to dry biomass	4.5	w/w
Number of cyclones per reactor	2	
Stripping steam	3.0	lb/1000 lb cat
Fluidizing gases to dry biomass	N/A	
H2 partial pressure in fluidizing gas	73 psia	5.1 bar
Combustor/Regenerator		
Temperature	650°C	1202°F
Pressure	113 psia	7.8 bar
Excess air (%)	20%	
Upstream solids temperature	341°C	645°F
No. of cyclones per combustor	2	
UPGRADED PRODUCT COMPOSITION		
Hydrogen incorporated	1.8%	wt% dry BM
Gas	23.0%	wt% dry BM
Aqueous	29.7%	wt% dry BM
Organic	27.2%	wt% dry BM
Coke	8.0%	wt% dry BM
Char	12.0%	wt% dry BM
Net Water	28.9%	wt% dry BM

VAPOR QUENCH		
Heavy Fraction condenser-absorber		
Temperature	358	°F
Pressure	110	psia
Feed rate	310,342	lb/h
Recycle liquid flow	81,043	lb/h
Vapor product	371,714	lb/h
Bottoms liquid flow	19,671	lb/h
Light fraction condenser-absorber		
Temperature	60	°F
Pressure	97	psia
Recycle liquid flow	901,601	lb/h
Vapor product	182,444	lb/h
Bottoms liquid flow	1,090,871	lb/h
Mole % H_2 overhead	68%	
Total aqueous phase		
Flow	77,811	lb/h
wt% carbon	1.6%	
% carbon loss to aq phase	1.3%	
Total organic phase		
Flow	50,051	lb/h
wt% C	83%	
wt% H	11%	
wt% O	6%	
organic H/C	1.57	
carbon eff to organic phs	44%	
HYDROGEN RECYCLE		
Water gas shift		
Gas flow rate	51,621	lb/h
Inlet temperature	464	°F
Outlet temperature	637	°F
Pressure	84	psia
Steam flow rate	30,755	lb/h
Temperature approach	35	°F
Wastewater (condensate)	20,723	lb/h
Pressure swing adsorption (PSA)		
Inlet flow rate	61,652	lb/h
Inlet hydrogen mole %	71%	
Hydrogen recovery %	84%	
Hydrogen purity %	99%	
Hydrogen product stream	7,032	lb/h
HYDROPROCESSING		
Hydrotreater		
Pressure	1,515	psia
Liquid feed	50,051	lb/h
Liquid feed C, H, O	83%, 11%, 6%	wt%
Total H2 feed (pure)	7,249	lb/h
H2 purity	90%	mol%
Makeup H2 (pure)	1,825	lb/h
Product gas (HP flash)	17,435	lb/h
Product gas (HP flash) H2	87%	mol%
Purge gas (HP flash)	2,061	lb/h
Purge gas (LP flash)	787	lb/h
Aqueous phase product	2,912	lb/h
Organic phase product	46,446	lb/h
Organic phase C,H,O	87%, 13%, 1%	wt%
Hydrocracker		
Liquid feed	16,654	lb/h
Liquid feed C, H, O	88%, 11%, 1%	wt%
Total H2 feed (pure)	2,109	lb/h
H2 purity	90%	mol%
Makeup H2 (pure)	647	lb/h
Product gas (HP flash)	4,353	lb/h
Product gas (HP flash) H2	87%	mol%
Purge gas (HP flash)	298	lb/h
Purge gas (LP flash)	356	lb/h
Aqueous phase product	129	lb/h
Organic phase producth	16,636	lb/h
Organic phase C,H,O	86%, 14%, 0%	wt%

SEPARATION		
Gasoline column		
Feed from hydrotreater	46,446	lb/h
Feed from hydrocracker	16,636	lb/h
Gasoline range product	20,408	lb/h
Light gases	1,281	lb/h
Bottoms to diesel column	41,393	lb/h
Diesel column		
Feed from gasoline column	41,393	lb/h
Diesel-range product	24,739	lb/h
Bottoms to hydrocracker	16,654	lb/h
Overall hydroprocess efficiency		
Carbon efficiency %	94%	
Yield lb product/lb feed	90%	
Oxygen content in feed/product	6.4%, 0.4%	wt%
HYDROTREATING RECYCLE COMPRESSOR		
Inlet pressure	1493	psia
Outlet pressure	1600	psia
Inlet mass flow	17528	lb/h
Inlet molecular weight	2	
Electrical consumption	134	kW
HYDROCRACKING RECYCLE COMPRESSOR		
Inlet pressure	1893	psia
Outlet pressure	2000	psia
Inlet mass flow	4819	lb/h
Inlet molecular weight	2	
Electrical consumption	31	kW
HYDROTREATING MAKEUP COMPRESSOR		
Inlet pressure	245	psia
Outlet pressure	1495	psia
Inlet mass flow	2154	lb/h
Inlet molecular weight	2	
Electrical consumption	888	kW
HYDROCRACKING MAKEUP COMPRESSOR		
Inlet pressure	245	psia
Outlet pressure	1995	psia
Inlet mass flow	764	lb/h
Inlet molecular weight	2	
Electrical consumption	369	kW
HYDROGEN PLANT		
Hydrogen production rate	27420512.8	MMscfd
Supplemental natural gas	125	lb/h
Hydrogen outlet purity	99	mol%
Hydrogen outlet pressure	266	psia
Hydrogen Balance		
Pyrolysis Reactor Makeup	11,217	lb/h
Hydrotreating Makeup	2,154	lb/h
Hydrocracking Makeup	764	lb/h
Total consumed	14,134	lb/h
Produced from recycle PSA	7,032	lb/h
Produced from reformer	7,102	lb/h
Total produced	14,134	lb/h
STEAM SYSTEM		
HP Turbine Brake Power	-15786	hp
IP Turbine Brake Power	-20114	hp
LP Turbine Brake Power	-23436	hp

POWER SUMMARY (kW)	GENERATED	CONSUMED
Feed handling and drying		298
Pyrolysis		22,783
Condensation & separation		3,914
Hydroprocessing		1,811
Hydrogen production		5,875
Steam & power	44,247	1,461
Cooling water & utilities		327
Wastewater management		846
Miscellaneous		3,731
Balance to grid		3,201
Plant totals	44,247	44,247
HEAT INTEGRATION		
Total Pinch Duty	816	MMBtu/h

FUEL PRODUCTION			
Gasoline	density	6.215	lb/gal (1)
	Oxygen content	0.78%	wt%
	production	20,408	lb/h
		160.9	MMlb/yr
	actual volume	78,809	gal/day
		25.9	MMgal/yr
		35.7	gal/dry ton
	HHV (Aspen)	19,719	Btu/lb
		122,549	Btu/gal
	HHV equiv volume	25.5	MMGGE/yr
		35.2	GGE/dry ton
	LHV (Aspen)	18,386	Btu/lb
		114,267	Btu/gal
	LHV Vol Equiv	25.5	MMGGE/yr
		35.2	GGE/dry ton
Diesel	density	6.982	lb/gal (1)
	Oxygen content	0.00%	wt%
	production	24,739	lb/h
		195.0	MMlb/yr
	actual volume	85,037	gal/day
		27.9	MMgal/yr
		38.6	gal/dry ton
	HHV (Aspen)	19,752	Btu/lb
		137,910	Btu/gal
	HHV equiv volume	30.98	MMGGE/yr
		42.8	GGE/dry ton
	LHV (Aspen)	18,444	Btu/lb
		128,779	Btu/gal
	LHV Vol Equiv	30.99	MMGGE/yr
		42.8	GGE/dry ton
Total	production	45,146	lb/h
		355.9	MMlb/yr
	actual volume	53.8	MMgal/yr
		163,846	gal/day
		74.3	gal/dry ton
	HHV equiv volume	56.5	MMGGE/yy
	LHV equiv volume	56.5	MMGGE/yr
	% Gasoline	45%	
	% Diesel	55%	

THEORETICAL PRODUCTION		
total HHV	1579	MMbtu/h
HHV Theo. Volume	12,882	gge/h
HHV Theo. Yield	140	gal/ton

ENERGY EFFICIENCY	LHV	HHV
Inputs (MMBtu/h)		
Feedstock	1,468	1,576
Natural Gas	2	3
Outputs (MMBtu/h)		
Gasoline product	375	402
Diesel product	456	489
Electricity product	11	11
Fuel/Biomass Effic.	56.7%	56.5%
Fuel/(Biomass+NG)	56.6%	56.4%
(Fuel+Elec)/(Biomass+NG)	57.3%	57.1%

CARBON EFFICIENCY		
Fuel yield, mass basis	24.6%	wt% dry BM
Fuel/Biomass Effic.	41.5%	
Fuel/(Biomass+NG) Effic.	41.5%	

(1) From: http://cta.ornl.gov/bedb/appendix_a/Lower_and_Higher_Heating_Values_of_Gas_Liquid_and_Solid_Fuels.pdf
Conventional gasoline 2,819 grams/gallon = 6.214831 lb/gal
US conventional diesel 3,167 grams/gallon = 6.98204 lb/gal

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Appendix E. Assumptions and Analysis for Full Life-Cycle GHG Emissions

To provide an initial estimate of life-cycle fuel GHGs associated with this conversion pathway, a preliminary life-cycle GHG analysis was performed for fuel produced via the *in situ* and e*x situ* catalytic pyrolysis pathways using the model 2017 blended feedstock (45% pulpwood, 32% wood residues, 3% switchgrass, and 20% construction and demolition waste). The data and sources used for each of the life-cycle stages are described in the following paragraphs, along with the results of the analysis.

Feedstock Crop Establishment and Growing

For the production of the purpose-grown bioenergy crops, pulpwood and switchgrass, emissions calculations from the GREET 2014 model (GREET 2014) were aggregated and used in the SimaPro fuel life-cycle model. Poplar was used to represent pulpwood in the feedstock blend. Switchgrass and poplar farming emissions were taken from the "EtOH" worksheet in the GREET model. Information on the development of GREET crop production parameters from Wang et al. (2013) was used to subtract the harvesting energy (which is accounted for in the next stage) from the GREET model total farming energy values in order to calculate emissions for only the establishment and growing phase of farming operations. Table E-1 shows the total farming energy assumed in GREET (including harvesting) and the estimated energy value for establishment and growing operations ("Farming Energy Excluding Harvesting" in Table E-1) used in this analysis.

Table E-1. Farming Energy Values from GREET and Modified for this Analysis

	GREET Farming Energy (including harvesting), Btu/dry ton	Farming Energy Excluding Harvesting (estimated from GREET), Btu/dry ton
Switchgrass*	201,995 (92.8% diesel;7.2% electricity)	56,870 (100% diesel)
Poplar	219,200 (100% diesel)	20,496 (100% diesel)

*Values include 14% dry matter loss.

The overall emissions from crop establishment and growing operations including fertilizer and herbicide application for switchgrass and poplar estimated from the GREET model data are 107,434 g CO_2-e/dry ton and 40,056 g CO_2-e/dry ton, respectively. For the production of the remaining feedstocks, wood residues, and construction/demolition waste, it is assumed that these are strictly waste products. As such, their life cycle begins at the waste pile and they do not receive any energy or GHG burdens from the upstream processes from which they are generated.

Feedstock Harvesting, Preprocessing, and Transportation

Jacobson et al. (2014) has estimated the GHG emissions associated with the logistics required for production of a conversion reactor-ready 2017 design case feedstock blend at 75.91 kg CO_2-e/dry ton. This value includes energy and emissions associated with harvesting of purpose-grown crops (pulpwood, switchgrass), collection of waste (wood residues, construction and demolition waste), preprocessing and handling required at the landing, centralized feedstock processing

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facility (depot) and the biorefinery, and transportation of biomass from the landing to the depot and from the depot to the biorefinery. About 70% of the feedstock logistics GHGs stems from preprocessing of the feedstock materials. The 2017 feedstock supply chain design incorporates several research advances that will significantly reduce energy use and cost compared to the current state of technology. More detail on the individual process steps and associated energy requirements for the feedstock supply system can be found in the recent design report published by INL (Jacobson et al. 2014). The aggregated value of 75.91 kg CO_2-e/dry ton of conversion plant feedstock was used in the SimaPro model for calculation of the full fuel lifecycle emissions.

Conversion

The inventory for the conversion stages of the life cycle are listed in Table 23 and Table 24. Assumptions for the conversion stage processes are given in Section 3.12.

Fuel Distribution and Consumption

Emissions associated with fuel distribution to the end user (fuel transportation and operation of storage tanks and fueling stations) are modeled using an EcoInvent database (2010) process ("petrol, unleaded, at refinery/kg/RER/U"). Emissions of biogenic methane and N_2O from combustion of gasoline and diesel fuel in a vehicle are adapted from GREET (2014).

Life Cycle GHG Results

Figure E-1 shows the full life-cycle GHGs for gasoline and diesel fuel via the catalytic pyrolysis and upgrading pathways (including electricity credits). For the *in situ* case, emissions are estimated at 9.2 g CO_2e/MJ for gasoline and 9.3 g CO_2e/MJ for diesel. Relative to the 2005 petroleum baseline GHGs (93.08 g CO_2e/MJ for gasoline and 91.94 g CO_2e/MJ for diesel) (EPA 2010), this is a GHG reduction of 90% and 89% for gasoline and diesel, respectively. For the *ex situ* case, emissions are estimated at 10.2 g CO_2e/MJ for gasoline and 10.3 g CO_2e/MJ for diesel, corresponding to a GHG reduction of 89% for both fuels. This preliminary analysis suggests that these fuels would meet the Energy Independence and Security Act Renewable Fuel Standard cellulosic biofuel definition (60% GHG reduction); however, final qualification is made by the EPA based on their own analysis and determination. In addition, through collaboration with Argonne National Laboratory, conversion energy and materials inventory from this work will be integrated into the GREET model for more detailed analyses.

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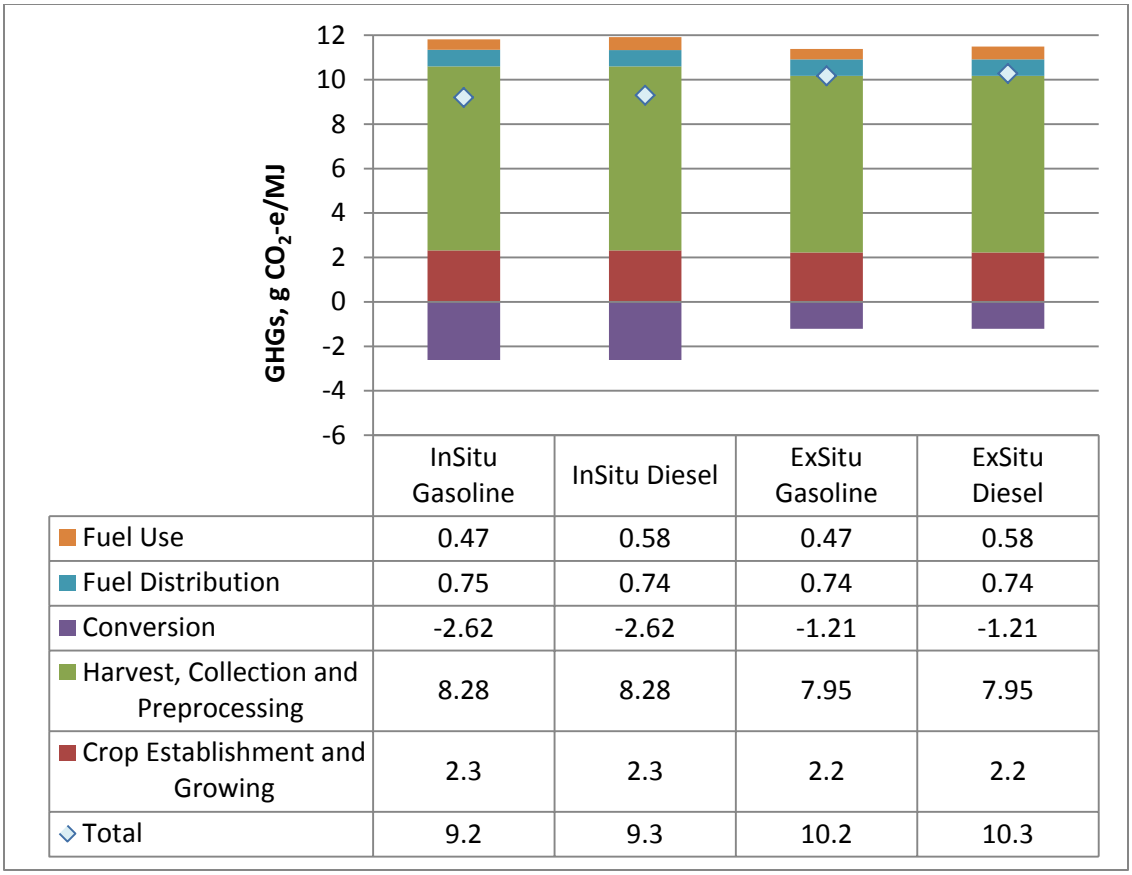

	InSitu Gasoline	InSitu Diesel	ExSitu Gasoline	ExSitu Diesel
Fuel Use	0.47	0.58	0.47	0.58
Fuel Distribution	0.75	0.74	0.74	0.74
Conversion	-2.62	-2.62	-1.21	-1.21
Harvest, Collection and Preprocessing	8.28	8.28	7.95	7.95
Crop Establishment and Growing	2.3	2.3	2.2	2.2
Total	9.2	9.3	10.2	10.3

Figure E-1. Life-cycle GHG emissions for fuels from catalytic pyrolysis using the INL 2017 blended feedstock (45% pulpwood, 32% wood residues, 3% switchgrass, and 20% construction and demolition waste) (Jacobson 2014)

Appendix E References

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Appendix F. Compounds in Aspen Plus Simulation

This appendix provides information about compounds selected to represent the process in Aspen Plus. Note that these are model compounds used to represent a much more numerous and varied set that actually occurs in systems such as these.

Table F-1. Compounds in Aspen Plus Simulation

Argon	1,2-Benzenediol	1-Naphthalenol
Nitrogen	Hydroxymethylfurfural	Coniferyl Aldehyde
Oxygen	2,5-dimethylfuran	Tetralin
SO2	Methyl Cyclopentenone	Isoeugenol
NO2	Hydroxymethylcyclopentenone	Decalin
Hydrogen	Cyclohexanone	2,5-Dimethyloctane
Ammonia	Levoglucosan	1-Methyl naphthalene
H2S	1-Hexanal	1-methyl decahydronaphthene
Water	Dimethoxytetrahydrofuran	Dibenzothiophene
Carbon Monoxide	Cyclohexane	Biphenyl
Carbon Dioxide	N-Hexane	5-hexyl-O-cresol
Methane	Hexanol	n-Heptylcyclohexane
Methanol	Toluene	C14H20-N35
Formic Acid	2-Methylphenol	C14H24-N5
Glyoxal	3-Methyl-phenol	3,5-Dimethyldodecane
Ethylene	Guaiacol	C15H26-N4
Acetaldehyde	Methyl-Cyclohexane	6,8-Dimethyltridecane
Hydroxyacetaldehyde	2-Methylhexane	1,4-Dimethyl-Phenanthrene
Acetic Acid	VinylPhenol	N-Cetane
Ethane	O-Xylene	C18H26O
Propylene	Ethylbenzne	C18H28
1-Hydroxy-2-propanone	2,3-Dimethyl-phenol	C21H26O2
Propionic Acid	2,6-dimethoxyphenol	C21H34
Propane	Vanillyl alcohol	C22H28O2
Furan	2,4,6-Trimethylpyridine	Carbon
1-Butene	Cis-1,2-dimethyl cyclohexane	Sulfur
Tetrahydrofuran	Trans-1,2-dimethylcyclohexane	Sand/Catalyst Solids
N-Butane	Ethylcyclohexane	Ash
Furfural	4-Methylheptane	Wood
2-methylfuran	2-Methyl-Benzofuran	Char
Furfuryl Alcohol	Indane	Coke
n-Pentane	2-methoxy-4-vinylphenol	
Pentenone	Syringaldehyde	
Benzene	n-Propylbenzene	
Phenol	Naphthalene	

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Table F-2. Structures of Compounds Identified by Formula

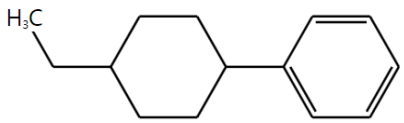
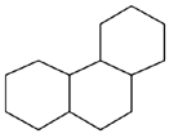
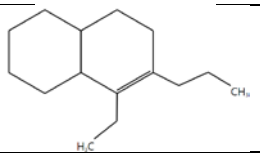
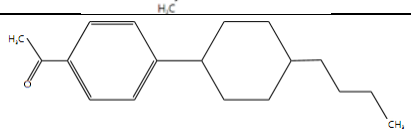
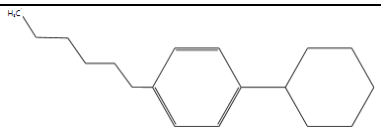
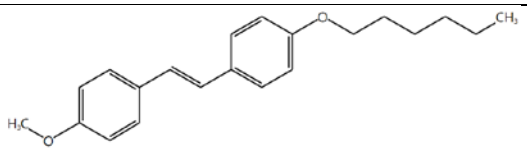
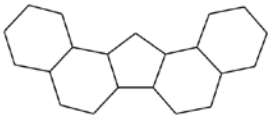
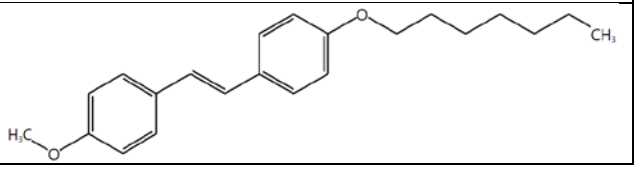
C14H20-N35	
C14H24-N5	
C15H26-N4	
C18H26O	
C18H28	
C21H26O2	
C21H34	
C22H28O2	

Table F-3. Ultimate Analysis of Non-Conventional Components

	Char	Coke
Ash	7.67	0
Carbon	69.07	96.06
Hydrogen	4.66	0
Nitrogen	1.24	0
Chlorine	0	0
Sulfur	0.19	0
Oxygen	17.16	3.94

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Appendix G-1. Process Flow Diagrams and Stream Summary for the *In Situ* Case

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M-101
HYDRAULIC TRUCK
DUMP WITH SCALE

T-101
DUMP HOPPER

C-101
HOPPER FEEDER

C-102
SCREENER FEEDER
CONVEYOR

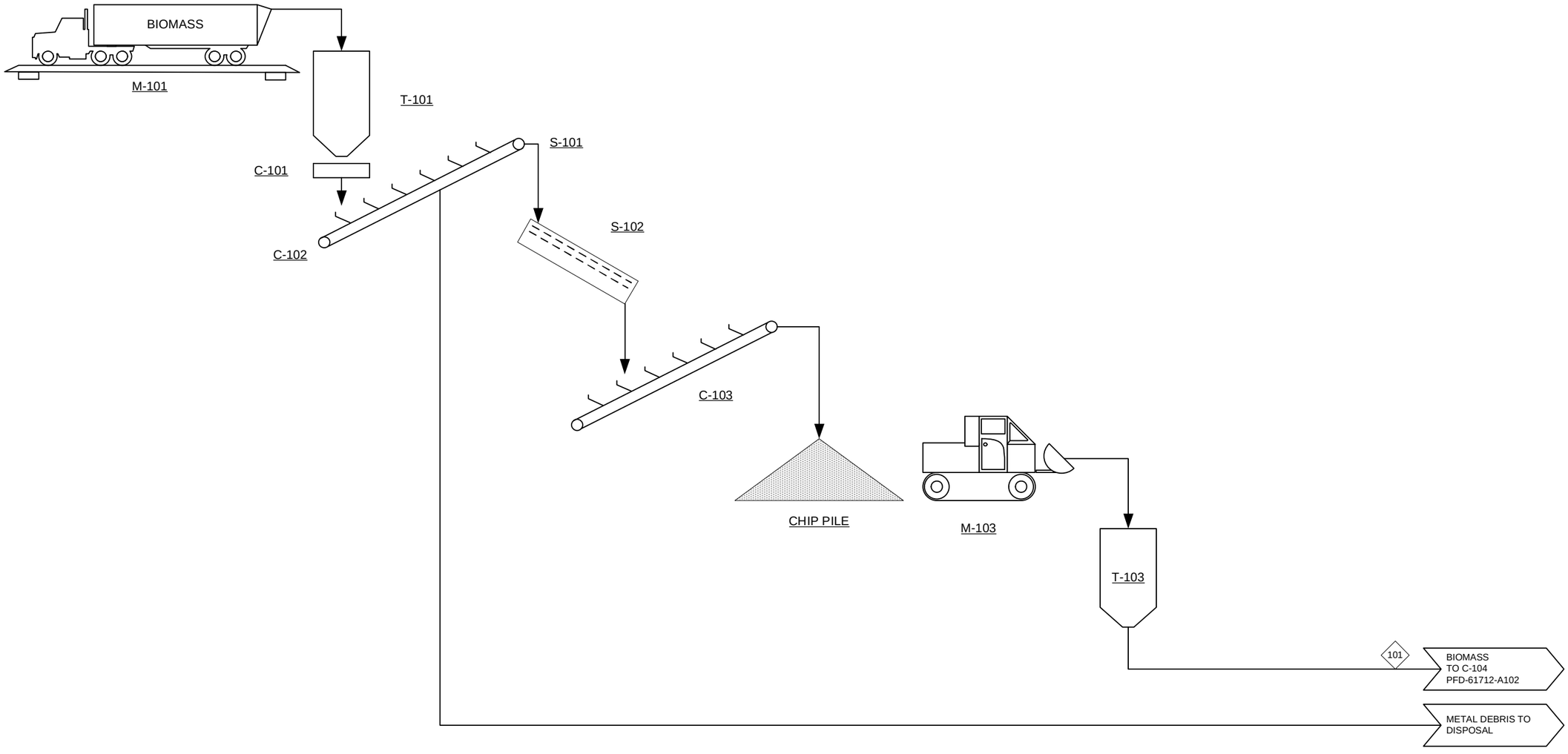
S-101
MAGNETIC
HEAD PULLEY

S-102
VIBRATORY
CONVEYOR

C-103
RADIAL STACKER
CONVEYOR

M-103
FRONT END
LOADERS

T-103
DRYER FEED
BIN



NOTE: FEEDSTOCK HANDLING COSTS ARE INCLUDED IN THE TARGET FEEDSTOCK COST PROVIDED BY THE IDAHO NATIONAL LABORATORY. ONLY A CROSS FLOW DRYER USING PROCESS FLUE GASES FOR FEED PREHEAT IS INCLUDED IN THE CONVERSION COST.

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 100: FEED HANDLING

Rev.	Date	By	Description
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Project No: 30482.00
Drawing: PFD-61712-A101
Rev: 1

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

PFD-61712-A101		101																							
Total Flow	lb/h	204,131	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-569	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	20,413	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	183,718	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

C-104
DRYER FEED SCREW
CONVEYOR

M-104
CROSS FLOW
PELLET DRYER

T-104
DRIED BIOMASS
HOPPER

T-105
LOCK
HOPPER

T-106
FEED
HOPPER

M-102
HAMMERMILL

T-102
HAMMERMILL
SURGE BIN

C-105
BIOMASS FEED
SCREW CONVEYOR

K-101
FLUE GAS
BLOWER

BIOMASS
FROM T-103
PFD-61712-A101

101

C-104

102

M-104

108

K-101

W-K101

110

FLUE GAS
TO M-703
PFD-61712-A701

FLUE GAS
FROM R-530
PFD-61712-A501

549

FLUE GAS
FROM H-208
PFD-61712-A201

239

107

FLUE GAS
FROM H-838
PFD-61712-A802

841

103

T-104

M-102

T-102

104

T-105

PRESSURIZED INERT
GASES

T-106

105

C-105

MILLED BIOMASS
TO R-201
PFD-61712-A201

NOTE: FEEDSTOCK HANDLING COSTS ARE INCLUDED IN THE TARGET FEEDSTOCK COST PROVIDED BY THE IDAHO NATIONAL LABORATORY. ONLY A CROSS FLOW DRYER USING PROCESS FLUE GASES FOR FEED PREHEAT IS INCLUDED IN THE CONVERSION COST.

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 100: FEED HANDLING AND DRYING

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Project No: 30482.00
Drawing: PFD-61712-A102
Rev: 2

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

PFD-61712-A102		101	102	103	104	105	107	108	110	239	297	549	841											
Total Flow	lb/h	204,131	204,131	204,131	204,131	204,131	883,124	883,124	883,124	470,563	210,273	239,418	173,143	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	60	60	218	218	218	228	155	155	229	229	229	229	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	15	16	16	16	125	15	14	14	109	105	15	17	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-569	-569	-553	-553	-553	-1039	-1056	-1056	-501	-213	-476	-63	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	9,581	9,581	9,581	5,499	2,470	1,975	2,108	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	562,024	562,024	562,024	322,673	144,835	115,770	123,581	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	57,307	57,307	57,307	16,464	7,396	7,234	33,609	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	106	106	106	85	0	21	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	13	13	13	0	0	13	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	20,413	20,413	20,413	20,413	20,413	49,518	49,518	49,518	17,679	3,817	23,478	8,361	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	0	0	0	0	204,575	204,575	204,575	108,164	51,754	90,926	5,485	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	183,718	183,718	183,718	183,718	183,718	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
W-K101	502	1
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

K-202 COMBUSTOR AIR COMPRESSOR | H-209 AIR PREHEATER | K-201 FLUIDIZING GAS RECYCLE COMPRESSOR | H-201 FLUIDIZING GAS HEATER | R-201 CATALYTIC FLUIDIZED BED REACTOR | S-201 PRIMARY CYCLONE | S-202 SECONDARY CYCLONE | T-201 CATALYST STEAM STRIPPER | R-202C CATALYST COOLER | R-202 CHAR COMBUSTOR | S-203 CHAR COMBUSTOR PRIMARY CYCLONE | S-204 CHAR COMBUSTOR SECONDARY CYCLONE | C-202 FINES PURGE COOLER | H-210C STEAM STRIPPER SUPERHEATER | H-210B STEAM STRIPPER BOILER | T-202 DEPLETED CATALYST AND ASH STORAGE BIN | T-207 CATALYST FEED BIN | H-208 FLUE GAS HEAT RECOVERY

COMBUSTION AIR
223
224
225A
H-209
Q-H209
232
H-208
Q-H208
239
FLUE GAS TO M-104 PFD-61712-A102
300
PYROLYSIS VAPOR TO H-310 PFD-61712-A301
213
S-202
K-202
W-K202
QA-K202
228
S-204
212
S-201
233
S-203
C-202
QC-M202
T-202
214
208
R-202
235
DEPLETED CATALYST/ ASH TO DISPOSAL
T-201
R-201
217
1
MAKEUP CATALYST FROM M-702 PFD-61712-A702
T-207
MILLED BIOMASS FROM C-105 PFD-61712-A102
105
205
R-202C
Q-ST202A
FLUIDIZATION AIR
LIFT AIR
346
FLUIDIZING GAS FROM M-385/M-575/H-315 PFD-61712-A302
STEAM TO T-605 PFD-61712-A-603
CLEAN WATER FROM P-802 PFD-61712-A804
204
210
210B
K-201
W-K201
203
H-210
Q-H210
H-201
Q-H201

1 NOTE: STREAM 217 FOR ATTRITION MAKEUP. ADDITIONAL MAKEUP TO MAINTAIN ACTIVITY AS IN TABLE 4.

Harris Group

NREL NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM AREA 200: IN-SITU PYROLYSIS

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Project No: 30482.00 | Drawing: PFD-61712-A201 | Rev: 2

Plot date: 3/16/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150316.vsd

ENGINEERING-PDH.COM | CHE-136 |

PFD-61712-A201		105	203	204	205	208	210	210B	212	213	214	216	217	223	224	225A	228	232	233	235	239	300	346		
Total Flow	lb/h	204,131	157,697	157,697	1,383,822	1,745,651	4,151	4,151	1,749,802	330,867	1,418,935	1,736	152	435,390	435,390	435,390	472,391	470,563	1,828	2,032	470,563	329,131	157,697	0	0
Temperature	F	218	149	800	0	932	555	61	931	931	0	0	0	90	288	600	1202	1202	0	209	229	931	96	0	0
Pressure	Psia	125	127	123	125	121	135	150	121	120	120	119	129	15	125	121	115	115	115	15	109	119	99	0	0
Vapor Fraction		0	1	1	0	1	1	0	1	1	0	0	0	1	1	1	1	1	0	0	1	1	1	0	0
Enthalpy Flow	MMBtu/h	-553	-279	-203	-8619	-9389	-23	-29	-9412	-691	-8722	-9	-1	-49	-28	7	-379	-378	-1	-3	-501	-682	-285	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	5,499	5,499	5,499	5,499	5,499	0	0	5,499	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	322,398	322,398	322,398	322,673	322,673	0	0	322,673	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	98,783	98,783	98,783	16,464	16,464	0	0	16,464	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	85	85	0	0	85	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	20,716	20,716	0	18,312	0	0	18,312	18,312	0	0	0	0	0	0	0	0	0	0	0	18,312	20,716	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	20,413	457	457	0	71,025	4,151	4,151	75,176	75,176	0	0	0	8,495	8,495	8,495	17,679	17,679	0	203	17,679	75,176	457	0	0
Carbon Monoxide	lb/h	0	57,939	57,939	0	76,820	0	0	76,820	76,820	0	0	0	0	0	0	0	0	0	0	0	76,820	57,939	0	0
Carbon Dioxide	lb/h	0	48,481	48,481	0	63,964	0	0	63,964	63,964	0	0	0	214	214	214	108,164	108,164	0	0	108,164	63,964	48,481	0	0
Methane	lb/h	0	5,265	5,265	0	7,043	0	0	7,043	7,043	0	0	0	0	0	0	0	0	0	0	0	7,043	5,265	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	14,862	14,862	0	19,913	0	0	19,913	19,913	0	0	0	0	0	0	0	0	0	0	0	19,913	14,862	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	4,839	4,839	0	6,539	0	0	6,539	6,539	0	0	0	0	0	0	0	0	0	0	0	6,539	4,839	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	528	528	0	873	0	0	873	873	0	0	0	0	0	0	0	0	0	0	0	873	528	0	0
1-Butene	lb/h	0	2,338	2,338	0	3,282	0	0	3,282	3,282	0	0	0	0	0	0	0	0	0	0	0	3,282	2,338	0	0
Tetrahydrofuran	lb/h	0	398	398	0	1,022	0	0	1,022	1,022	0	0	0	0	0	0	0	0	0	0	0	1,022	398	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	452	452	0	1,131	0	0	1,131	1,131	0	0	0	0	0	0	0	0	0	0	0	1,131	452	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	15	15	0	3,570	0	0	3,570	3,570	0	0	0	0	0	0	0	0	0	0	0	3,570	15	0	0
1,2-Benzenediol	lb/h	0	0	0	0	3,193	0	0	3,193	3,193	0	0	0	0	0	0	0	0	0	0	0	3,193	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	2	2	0	13	0	0	13	13	0	0	0	0	0	0	0	0	0	0	0	13	2	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	1	1	0	38	0	0	38	38	0	0	0	0	0	0	0	0	0	0	0	38	1	0	0
Cyclohexane	lb/h	0	14	14	0	46	0	0	46	46	0	0	0	0	0	0	0	0	0	0	0	46	14	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	5	5	0	2,385	0	0	2,385	2,385	0	0	0	0	0	0	0	0	0	0	0	2,385	5	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Methyl-Cyclohexane	lb/h	0	194	194	0	991	0	0	991	991	0	0	0	0	0	0	0	0	0	0	0	991	194	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	1	1	0	2,065	0	0	2,065	2,065	0	0	0	0	0	0	0	0	0	0	0	2,065	1	0	0
2,6-dimethoxyphenol	lb/h	0	1	1	0	6,794	0	0	6,794	6,794	0	0	0	0	0	0	0	0	0	0	0	6,794	1	0	0
Vanillyl alcohol	lb/h	0	0	0	0	870	0	0	870	870	0	0	0	0	0	0	0	0	0	0	0	870	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	3	3	0	333	0	0	333	333	0	0	0	0	0	0	0	0	0	0	0	333	3	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	529	529	0	5,174	0	0	5,174	5,174	0	0	0	0	0	0	0	0	0	0	0	5,174	529	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	635	635	0	5,138	0	0	5,138	5,138	0	0	0	0	0	0	0	0	0	0	0	5,138	635	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	1	1	0	463	0	0	463	463	0	0	0	0	0	0	0	0	0	0	0	463	1	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	13	0	0	13	13	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	2,705	0	0	2,705	2,705	0	0	0	0	0	0	0	0	0	0	0	2,705	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	381	0	0	381	381	0	0	0	0	0	0	0	0	0	0	0	381	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	13	0	0	13	13	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0
Decalin	lb/h	0	16	16	0	2,102	0	0	2,102	2,102	0	0	0	0	0	0	0	0	0	0	0	2,102	16	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	1,183	0	0	1,183	1,183	0	0	0	0	0	0	0	0	0	0	0	1,183	0	0	0
1-methyl decahydronaphthene	lb/h	0	5	5	0	1,499	0	0	1,499	1,499	0	0	0	0	0	0	0	0	0	0	0	1,499	5	0	0
Dibenzothiophene	lb/h	0	0	0	0	73	0	0	73	73	0	0	0	0	0	0	0	0	0	0	0	73	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	917	0	0	917	917	0	0	0	0	0	0	0	0	0	0	0	917	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	984	0	0	984	984	0	0	0	0	0	0	0	0	0	0	0	984	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	427	0	0	427	427	0	0	0	0	0	0	0	0	0	0	0	427	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	299	0	0	299	299	0	0	0	0	0	0	0	0	0	0	0	299	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	3,424	0	0	3,424	3,424	0	0	0	0	0	0	0	0	0	0	0	3,424	0	0	0
C21H34	lb/h	0	0	0	0	7,087	0	0	7,087	7,087	0	0	0	0	0	0	0	0	0	0	0	7,087	0	0	0
C22H28O2	lb/h	0	0	0	0	2,855	0	0	2,855	2,855	0	0	0	0	0	0	0	0	0	0	0	2,855	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	1,383,733	1,383,733	0	0	1,383,733	1,384	1,382,349	1,370	152	0	0	0	138	0	138	138	0	14	0	0	0
Ash	lb/h	0	0	0	89	89	0	0	89	1	88	1	0	0	0	0	1,690	0	1,690	1,690	0	0	0	0	0
Wood	lb/h	183,718	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	22,046	0	0	22,046	220	21,826	218	0	0	0	0	0	0	0	0	0	2	0	0	0
Coke	lb/h	0	0	0	0	14,820	0	0	14,820	148	14,672	147	0	0	0	0	0	0	0	0	0	1	0	0	0

Heat	MMBtu/h
QA-K202	43
QC-M202	0
Q-H201	-76
Q-H208	123
Q-H209	-34
Q-H210	-5
Q-ST202A	-259
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
W-K201	2,259	6
W-K202	25,042	64
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

H-310
PYROLYSIS VAPOR
HEAT RECOVERY

D-301
HEAVY FRACTION
CONDENSER ABSORBER

P-318
D-301 BOTTOMS
PUMP

H-318
D-301 BOTTOMS
HEAT RECOVERY

H-312
D-301 VAPOR HEAT
RECOVERY

H-313
D-301 VAPOR ACHE

S-319
D-301 BOTTOMS
FILTER

P-332
QUENCH RECYCLE
PUMP

H-314
D-302 FEED
COOLER

T-332
D-301 CIRCULATION
SURGE TANK

H-315
D-302 FEED/OVERHEAD
HEAT EXCHANGER

H-320
HEAVY FRACTION
ACHE

H-316
D-302 LIQUID FEED
CHILLER

OFFGAS
FROM D-302
PFD-61712-A302

321

312

313

314

315

316

317

CWR

CHWR

VAPOR PHASE
TO D-302
PFD-61712-A302

H-312

Q-H312

H-313

QA-H313

CWS

H-314

QC-H314

H-315

QX-H315

CHWS

H-316

QCH-H316

340

OFFGAS
TO
PFD-61712-A302

332

RECYCLED ORGANICS
FROM S-324
PFD-61712-A302

PYROLYSIS VAPOR
FROM S-202/T-201
PFD-61712-A201

300

311

D-301

T-332

H-310

Q-H310

333

P-332

W-P332

318

319

320

320A

ORGANIC PHASE
TO T-328
PFD-61712-A302

P-318

W-P318

H-318

Q-H318

S-319

H-320

QA-H320

335A

SOLIDS
TO M-805
PFD-61712-A302

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

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NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 300: CONDENSATION STAGE 1

Project No: 30482.00

Drawing: PFD-61712-A301

Rev: 1

PFD-61712-A301		300	311	312	313	314	315	316	317	318	319	320	320A	321	332	333	335A	340
Total Flow	lb/h	329,131	329,131	396,315	396,315	396,315	396,315	396,315	396,315	19,547	19,547	19,529	19,529	199,763	86,730	86,730	18	199,763
Temperature	F	931	466	348	220	140	110	96	60	428	175	175	140	54	85	85	0	95
Pressure	Psia	119	117	114	112	110	108	106	104	117	127	112	107	101	114	117	127	99
Vapor Fraction		1	1	1	1	1	1	1	1	0	0	0	0	1	0	0	0	1
Enthalpy Flow	MMBtu/h	-682	-773	-839	-881	-955	-966	-971	-981	-8	-10	-10	-10	-381	-73	-73	0	-376
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	18,312	18,312	18,315	18,315	18,315	18,315	18,315	18,315	1	1	1	1	18,310	3	3	0	18,310
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	75,176	75,176	75,716	75,716	75,716	75,716	75,716	75,716	63	63	63	63	611	603	603	0	611
Carbon Monoxide	lb/h	76,820	76,820	76,842	76,842	76,842	76,842	76,842	76,842	3	3	3	3	76,807	25	25	0	76,807
Carbon Dioxide	lb/h	63,964	63,964	64,401	64,401	64,401	64,401	64,401	64,401	9	9	9	9	63,785	447	447	0	63,785
Methane	lb/h	7,043	7,043	7,050	7,050	7,050	7,050	7,050	7,050	1	1	1	1	7,039	8	8	0	7,039
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	19,913	19,913	20,015	20,015	20,015	20,015	20,015	20,015	3	3	3	3	19,871	105	105	0	19,871
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	6,539	6,539	6,715	6,715	6,715	6,715	6,715	6,715	2	2	2	2	6,470	178	178	0	6,470
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	873	873	1,317	1,317	1,317	1,317	1,317	1,317	1	1	1	1	705	445	445	0	705
1-Butene	lb/h	3,282	3,282	3,692	3,692	3,692	3,692	3,692	3,692	2	2	2	2	3,126	412	412	0	3,126
Tetrahydrofuran	lb/h	1,022	1,022	2,319	2,319	2,319	2,319	2,319	2,319	2	2	2	2	533	1,299	1,299	0	533
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	1,131	1,131	2,530	2,530	2,530	2,530	2,530	2,530	2	2	2	2	604	1,400	1,400	0	604
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	3,570	3,570	12,661	12,661	12,661	12,661	12,661	12,661	36	36	36	36	20	9,127	9,127	0	20
1,2-Benzenediol	lb/h	3,193	3,193	3,617	3,617	3,617	3,617	3,617	3,617	91	91	91	91	0	515	515	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	13	13	42	42	42	42	42	42	0	0	0	0	2	29	29	0	2
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	38	38	136	136	136	136	136	136	0	0	0	0	1	98	98	0	1
Cyclohexane	lb/h	46	46	117	117	117	117	117	117	0	0	0	0	19	71	71	0	19
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	2,385	2,385	8,592	8,592	8,592	8,592	8,592	8,592	35	35	35	35	7	6,242	6,242	0	7
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	1	1	4	4	4	4	4	4	0	0	0	0	0	3	3	0	0
Methyl-Cyclohexane	lb/h	991	991	2,929	2,929	2,929	2,929	2,929	2,929	3	3	3	3	260	1,941	1,941	0	260
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	1	1	5	5	5	5	5	5	0	0	0	0	0	3	3	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	2,065	2,065	7,362	7,362	7,362	7,362	7,362	7,362	54	54	54	54	1	5,352	5,352	0	1
2,6-dimethoxyphenol	lb/h	6,794	6,794	21,053	21,053	21,053	21,053	21,053	21,053	1,049	1,049	1,049	1,049	1	15,308	15,308	0	1
Vanillyl alcohol	lb/h	870	870	484	484	484	484	484	484	738	738	738	738	0	352	352	0	0
2,4,6-Trimethylpyridine	lb/h	333	333	1,197	1,197	1,197	1,197	1,197	1,197	4	4	4	4	4	868	868	0	4
Cis-1,2-dimethyl cyclohexane	lb/h	5,174	5,174	16,966	16,966	16,966	16,966	16,966	16,966	30	30	30	30	708	11,822	11,822	0	708
Trans-1,2-dimethylcyclohexane	lb/h	5,138	5,138	16,471	16,471	16,471	16,471	16,471	16,471	26	26	26	26	850	11,359	11,359	0	850
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	463	463	1,656	1,656	1,656	1,656	1,656	1,656	10	10	10	10	1	1,203	1,203	0	1
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	13	13	48	48	48	48	48	48	0	0	0	0	0	35	35	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	2,705	2,705	626	626	626	626	626	626	2,534	2,534	2,534	2,534	0	455	455	0	0
Coniferyl Aldehyde	lb/h	381	381	0	0	0	0	0	0	381	381	381	381	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	13	13	38	38	38	38	38	38	3	3	3	3	0	28	28	0	0
Decalin	lb/h	2,102	2,102	7,530	7,530	7,530	7,530	7,530	7,530	32	32	32	32	21	5,460	5,460	0	21
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	1,183	1,183	4,041	4,041	4,041	4,041	4,041	4,041	80	80	80	80	0	2,938	2,938	0	0
1-methyl decahydronaphthene	lb/h	1,499	1,499	5,334	5,334	5,334	5,334	5,334	5,334	38	38	38	38	7	3,874	3,874	0	7
Dibenzothiophene	lb/h	73	73	0	0	0	0	0	0	73	73	73	73	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	917	917	2,958	2,958	2,958	2,958	2,958	2,958	110	110	110	110	0	2,151	2,151	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	984	984	3,317	3,317	3,317	3,317	3,317	3,317	79	79	79	79	0	2,412	2,412	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	427	427	0	0	0	0	0	0	427	427	427	427	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	299	299	0	0	0	0	0	0	299	299	299	299	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	3,424	3,424	0	0	0	0	0	0	3,424	3,424	3,424	3,424	0	0	0	0	0
C21H34	lb/h	7,087	7,087	218	218	218	218	218	218	7,028	7,028	7,028	7,028	0	158	158	0	0
C22H28O2	lb/h	2,855	2,855	0	0	0	0	0	0	2,855	2,855	2,855	2,855	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	14	14	0	0	0	0	0	0	14	14	0	0	0	0	0	14	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	2	2	0	0	0	0	0	0	2	2	0	0	0	0	0	2	0
Coke	lb/h	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0

Heat	MMBtu/h
QA-H313	74
QA-H320	0
QC-H314	12
QCH-H316	10
Q-H310	91
Q-H312	42
Q-H318	2
QX-H315	5

Work	hp	MMBtu/h
W-P318	1	0
W-P332	1	0

D-302
LIGHT FRACTION
CONDENSER ABSORBER

H-326
D-302 QUENCH
CIRCULATION CHILLER

S-322
D-302 BOTTOMS
DECANTER

P-329
AQUEOUS FILTER
CHARGE PUMP

P-323
CIRCULATION FILTER
CHARGE PUMP

S-329
AQUEOUS PHASE
FILTER

S-324
QUENCH
CIRCULATION FILTER

T-328
ORGANIC PRODUCT
SURGE TANK

P-331
ORGANIC
PRODUCT PUMP

MAKEUP HYDROGEN
FROM M-385/M-575
PFD-61712-A504

350

346

FLUIDIZING GAS
TO K-201
PFD-61712-A201

341

321

OFFGAS
TO H-315
PFD-61712-A301

OFFGAS
FROM H-315
PFD-61712-A301

340

343

OFFGAS
TO H-366
PFD-61712-A303

345

PURGE GAS
TO H-513/K-511
PFD-61712-A501

VAPOR PHASE
FROM H-316
PFD-61712-A301

317

D-302

CHWR

327

326

CHWS

H-326

QCH-H326

322

324

325

328

S-322

P-323

W-P323

S-324

335C

RECYCLED ORGANICS
TO T-332
PFD-61712-A301

332

ORGANIC PHASE
FROM H-320
PFD-61712-A301

320A

329

T-328

P-329

W-P329

S-329

335B

337

ORGANIC PHASE
TO S-410
PFD-61712-A401

P-331

W-P331

SOLIDS
FROM S-319
PFD-61712-A301

335A

334

AQUEOUS PHASE
TO T-810
PFD-61712-A801

335

SOLIDS
TO M-805
PFD-61712-A803

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 300: CONDENSATION STAGE 2

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Project No: 30482.00

Drawing: PFD-61712-A302

Rev: 2

ENGINEERING-PDH.COM
| CHE-136 |

PFD-61712-A302		317	320A	321	322	323	324	325	326	327	328	329	332	334	335A	335B	335C	335	337	340	341	343	345	346	350
Total Flow	lb/h	396,315	19,529	199,763	1,161,420	1,084,143	1,084,143	1,084,123	964,869	964,869	32,524	77,278	86,730	77,273	18	5	20	43	52,053	199,763	149,409	48,356	1,998	157,697	8,288
Temperature	F	60	140	54	85	85	85	85	85	50	85	85	85	85		85	85	90	103	95	95	95	95	96	100
Pressure	Psia	104	107	101	104	104	129	114	114	104	114	104	114	104	127	104	114	104	117	99	99	99	99	99	110
Vapor Fraction		1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
Enthalpy Flow	MMBtu/h	-981	-10	-381	-1430	-917	-917	-917	-816	-830	-28	-513	-73	-513	0	0	0	0	-38	-376	-281	-91	-4	-285	-3
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	18,315	1	18,310	40	40	40	40	36	36	1	0	3	0	0	0	0	0	2	18,310	13,695	4,432	183	20,716	7,021
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	75,716	63	611	81,816	7,540	7,540	7,540	6,711	6,711	226	74,276	603	74,271	0	5	0	5	290	611	457	148	6	457	0
Carbon Monoxide	lb/h	76,842	3	76,807	317	317	317	317	282	282	10	0	25	0	0	0	0	0	13	76,807	57,446	18,593	768	57,939	493
Carbon Dioxide	lb/h	64,401	9	63,785	5,585	5,583	5,583	5,583	4,969	4,969	167	2	447	2	0	0	0	0	177	63,785	47,707	15,440	638	48,481	774
Methane	lb/h	7,050	1	7,039	99	99	99	99	88	88	3	0	8	0	0	0	0	0	4	7,039	5,265	1,704	70	5,265	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	20,015	3	19,871	1,316	1,316	1,316	1,316	1,171	1,171	39	0	105	0	0	0	0	0	43	19,871	14,862	4,810	199	14,862	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	6,715	2	6,470	2,229	2,229	2,229	2,229	1,984	1,984	67	0	178	0	0	0	0	0	69	6,470	4,839	1,566	65	4,839	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	1,317	1	705	5,558	5,557	5,557	5,557	4,946	4,946	167	0	445	0	0	0	0	0	168	705	528	171	7	528	0
1-Butene	lb/h	3,692	2	3,126	5,146	5,146	5,146	5,146	4,580	4,580	154	0	412	0	0	0	0	0	156	3,126	2,338	757	31	2,338	0
Tetrahydrofuran	lb/h	2,319	2	533	16,233	16,233	16,233	16,233	14,447	14,447	487	0	1,299	0	0	0	0	0	489	533	398	129	5	398	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	2,530	2	604	17,505	17,505	17,505	17,505	15,579	15,579	525	0	1,400	0	0	0	0	0	527	604	452	146	6	452	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	12,661	36	20	114,179	114,090	114,090	114,088	101,538	101,538	3,423	89	9,127	89	0	2	2	3,459	20	15	5	0	15	0
1,2-Benzenediol	lb/h	3,617	91	0	9,342	6,433	6,433	6,433	5,725	5,725	193	2,909	515	2,909	0	0	0	284	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	42	0	2	362	362	362	362	322	322	11	0	29	0	0	0	0	11	2	2	1	0	2	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	136	0	1	1,228	1,228	1,228	1,228	1,093	1,093	37	0	98	0	0	0	0	0	37	1	1	0	0	1	0
Cyclohexane	lb/h	117	0	19	891	891	891	891	793	793	27	0	71	0	0	0	0	0	27	19	14	5	0	14	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	8,592	35	7	78,022	78,021	78,021	78,019	69,437	69,437	2,341	1	6,242	1	0	1	1	2,376	7	5	2	0	5	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	4	0	0	35	35	35	35	31	31	1	0	3	0	0	0	0	1	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	2,929	3	260	24,266	24,266	24,266	24,266	21,596	21,596	728	0	1,941	0	0	0	0	0	731	260	194	63	3	194	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	5	0	0	41	41	41	41	37	37	1	0	3	0	0	0	0	0	1	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	7,362	54	1	66,897	66,896	66,896	66,895	59,536	59,536	2,007	1	5,352	1	0	1	1	2,061	1	1	0	0	1	0
2,6-dimethoxyphenol	lb/h	21,053	1,049	1	191,357	191,357	191,357	191,353	170,305	170,305	5,741	0	15,308	0	0	4	4	6,790	1	1	0	0	1	0
Vanillyl alcohol	lb/h	484	738	0	4,400	4,399	4,399	4,399	3,915	3,915	132	0	352	0	0	0	0	870	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	1,197	4	4	10,852	10,852	10,852	10,852	9,658	9,658	326	0	868	0	0	0	0	330	4	3	1	0	3	0
Cis-1,2-dimethyl cyclohexane	lb/h	16,966	30	708	147,784	147,784	147,784	147,781	131,525	131,525	4,433	0	11,822	0	0	3	3	4,463	708	529	171	7	529	0
Trans-1,2-dimethylcyclohexane	lb/h	16,471	26	850	141,987	141,987	141,987	141,984	126,366	126,366	4,260	0	11,359	0	0	3	3	4,286	850	635	206	8	635	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	1,656	10	1	15,042	15,042	15,042	15,042	13,387	13,387	451	0	1,203	0	0	0	0	461	1	1	0	0	1	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	48	0	0	433	433	433	433	385	385	13	0	35	0	0	0	0	13	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	626	2,534	0	5,693	5,693	5,693	5,693	5,067	5,067	171	0	455	0	0	0	0	2,705	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	381	0	0	0	0	0	0	0	0	0	0	0	0	0	0	381	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	38	3	0	348	348	348	348	310	310	10	0	28	0	0	0	0	13	0	0	0	0	0	0	0
Decalin	lb/h	7,530	32	21	68,254	68,254	68,254	68,253	60,745	60,745	2,048	0	5,460	0	0	1	1	2,079	21	16	5	0	16	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	4,041	80	0	36,727	36,727	36,727	36,726	32,686	32,686	1,102	0	2,938	0	0	1	1	1,181	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	5,334	38	7	48,421	48,421	48,421	48,421	43,094	43,094	1,453	0	3,874	0	0	1	1	1,490	7	5	2	0	5	0	0
Dibenzothiophene	lb/h	0	73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	73	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	2,958	110	0	26,887	26,887	26,887	26,887	23,929	23,929	807	0	2,151	0	0	0	0	916	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	3,317	79	0	30,149	30,149	30,149	30,148	26,832	26,832	904	0	2,412	0	0	0	1	1	983	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	427	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	427	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	299	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	299	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	3,424	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,424	0	0	0	0	0	0
C21H34	lb/h	218	7,028	0	1,978	1,978	1,978	1,978	1,760	1,760	59	0	158	0	0	0	0	0	7,087	0	0	0	0	0	0
C22H28O2	lb/h	0	2,855	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,855	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	14	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0

Heat	MMBtu/h
QCH-H326	13
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
W-P323	43	0
W-P329	3	0
W-P331	1	0
	0	0
	0	0
	0

H-366
WGS FEED
SUPERHEATER

H-367
WGS STEAM
SUPERHEATER

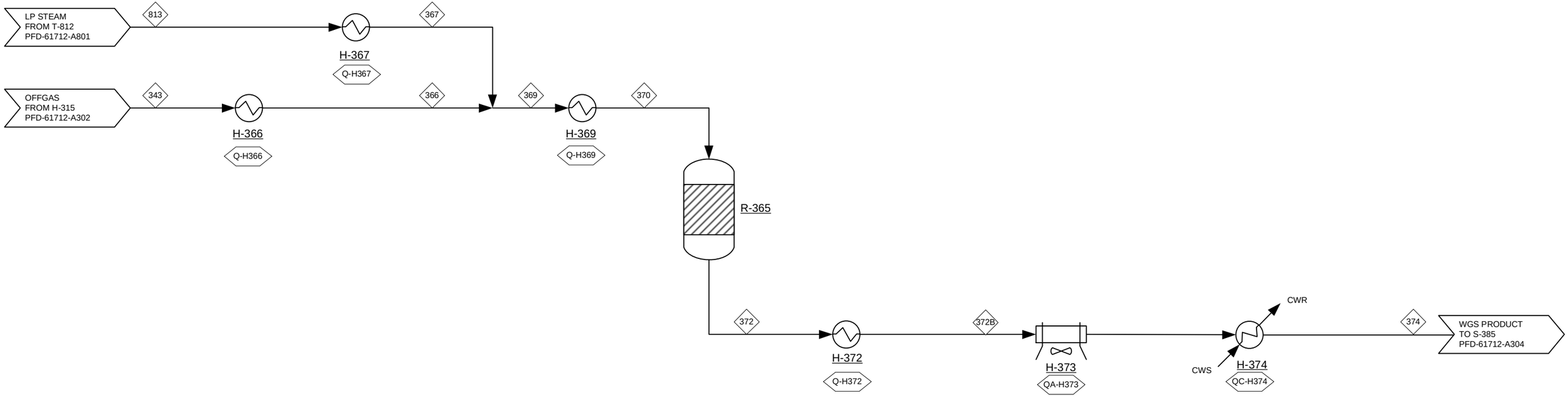
H-369
PRE-WGS HEAT
RECOVERY

R-365
HIGH-TEMPERATURE
WGS

H-372
POST-WGS HEAT
RECOVERY

H-373
POST-WGS ACHE

H-374
POST-WGS
COOLER



Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

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NREL
NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 300: WATER GAS SHIFT

Rev.	Date	By	Description
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Project No: 30482.00
Drawing: PFD-61712-A303
Rev. 1

PFD-61712-A303		343	366	367	369	370	372	372B	374	813														
Total Flow	lb/h	48,356	48,356	29,556	77,912	77,912	77,912	77,912	77,912	29,556	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	95	400	404	397	464	663	200	110	354	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	99	95	135	95	93	88	86	82	140	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-91	-82	-166	-248	-245	-245	-275	-290	-167	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	4,432	4,432	0	4,432	4,432	5,509	5,509	5,509	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	148	148	29,430	29,578	29,578	19,959	19,959	19,959	29,430	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	18,593	18,593	0	18,593	18,593	3,637	3,637	3,637	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	15,440	15,440	2	15,442	15,442	38,940	38,940	38,940	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	1,704	1,704	0	1,704	1,704	1,704	1,704	1,704	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	4,810	4,810	0	4,810	4,810	4,810	4,810	4,810	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	1,566	1,566	0	1,566	1,566	1,566	1,566	1,566	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	171	171	0	171	171	171	171	171	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	757	757	0	757	757	757	757	757	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	129	129	0	129	129	129	129	129	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	146	146	0	146	146	146	146	146	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	5	5	47	52	52	52	52	52	47	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	75	75	75	75	75	75	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	5	5	0	5	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	2	2	1	2	2	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	63	63	0	63	63	63	63	63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	171	171	0	171	171	171	171	171	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	206	206	0	206	206	206	206	206	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	5	5	0	5	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	2	2	0	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QA-H373	12
QC-H374	3
Q-H366	-9
Q-H367	-1
Q-H369	-3
Q-H372	30
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

S-385
PSA COMPRESSOR
SUCTION KO

K-390
PSA COMPRESSOR:
MULTISTAGE

T-377
COMPRESSOR
CONDENSATE TANK

S-386
PSA COMPR DISCH
KO

P-377
COMPRESSOR
CONDENSATE PUMP

M-385
PSA

WGS PRODUCT
FROM H-374
PFD-61712-A303

374

S-385

376

CWR

CWS

K-390

W-K390

QC-K390

QA-K390

377A

385

382

S-386

386

388

M-385

389

PSA OFFGAS
TO H-513/K-511
PFD-61712-A501

390

HYDROGEN
TO K-211/K-412/K-462
PFD-61712-A504

T-377

P-377

W-P377

377

CONDENSATE
TO T-860
PFD-61712-A804

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

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NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 300: PSA

Project No: 30482.00

Drawing: PFD-61712-A304

Rev: 2

PFD-61712-A304		374	376	377	377A	382	385	386	388	389	390															
Total Flow	lb/h	77,912	58,915	19,648	18,997	500	58,415	151	58,265	52,802	5,462	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	110	110	110	110	110	110	110	110	110	110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	82	82	87	82	82	227	225	225	22	215	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-290	-161	-134	-129	-3	-158	-1	-157	-155	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	5,509	5,509	0	0	0	5,509	0	5,509	881	4,627	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	19,959	1,057	19,552	18,902	500	557	150	407	407	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	3,637	3,637	0	0	0	3,637	0	3,637	3,312	325	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	38,940	38,939	1	1	0	38,939	0	38,939	38,429	510	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	1,704	1,704	0	0	0	1,704	0	1,704	1,704	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	4,810	4,810	0	0	0	4,810	0	4,810	4,810	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	1,566	1,566	0	0	0	1,566	0	1,566	1,566	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	171	171	0	0	0	171	0	171	171	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	757	757	0	0	0	757	0	757	757	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	129	129	0	0	0	129	0	129	129	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	146	146	0	0	0	146	0	146	146	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	52	33	19	18	0	33	0	33	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	75	0	75	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	1	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	5	5	0	0	0	5	0	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	2	2	0	0	0	2	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	63	63	0	0	0	63	0	63	63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	1	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	1	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	171	171	0	0	0	171	0	171	171	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	206	206	0	0	0	206	0	206	206	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	5	5	0	0	0	5	0	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	2	2	0	0	0	2	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QA-K390	3
QC-K390	4
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
W-K390	2,506	6
W-P377	0	0
	0	0
	0	0

S-410 VAPOR KO DRUM | P-410 HT FEED PUMP | H-444 QUENCH HYDROGEN STAGE 2 COOLER | H-445 QUENCH HYDROGEN STAGE 3 COOLER | K-412 HYDROGEN MAKEUP COMPRESSOR | H-410 FEED-EFFLUENT EXCH | H-411 FEED FURNACE | R-410 HYDROTREATER | K-442 HYDROGEN RECYCLE COMPRESSOR | H-412 HT PRODUCT HEAT RECOVERY | H-413A HT PRODUCT ACHE | H-413C HT PRODUCT COOLER | S-411 HP HT EFFLUENT FLASH: 3 PHASE | S-412 LP HT EFFLUENT FLASH: 3 PHASE

ORGANIC PHASE FROM P-331 PFD-61712-A302

337

S-410

411

OFFGAS TO K-511/H-513 PFD-61712-A501

419

H-412

Q-H412

414

415

417

420

P-410

W-P410

H-410

QX-H410

H-411

QF-H411

H-413A

QA-H413

CWR

H-413C

QC-H413

CWS

443A

431

RECYCLE GAS PURGE TO M-575 PFD-61712-A503

CWR

444B

CWS

H-444

QC-H444

428

OFFGAS TO K-511/H-513 PFD-61712-A501

422

CWR

444C

CWS

H-445

QC-H445

R-410

421

S-411

426

S-412

429

ORGANIC PHASE TO H-450 PFD-61712-A402

430

AQUEOUS PHASE TO T-860 PFD-61712-A804

418

424

AQUEOUS PHASE TO M-805 PFD-61712-A804

MAKEUP HYDROGEN FROM PFD-61712-A504

435

432

K-412

W-K412

QA-K412

K-442

W-K442

443

1 NOTE: FUEL GAS AND COMBUSTION DUTY ASSOCIATED WITH H-411 ACCOUNTED FOR BY QF-H548 ON PFD-61712-A501

Harris Group

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM AREA 400: HYDROTREATING

Project No: 30482.00 | Drawing: PFD-61712-A401 | Rev: 1

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

PFD-61712-A401		337	411	414	415	417	418	419	420	421	422	424	426	428	429	430	431	432	435	443	443A	444B	444C		
Total Flow	lb/h	52,053	0	52,053	61,262	61,262	79,137	79,137	79,137	79,137	28,548	4,696	45,894	870	45,023	0	5,327	23,220	3,865	27,085	9,209	8,938	8,938	0	0
Temperature	F	103	0	118	123	707	757	415	175	110	110	110	110	110	110	0	110	110	110	131	131	110	110	0	0
Pressure	Psia	117	117	1900	1900	1845	1815	1810	1805	1795	1793	1793	1793	53	53	53	1793	1793	245	1900	1900	1895	1895	0	0
Vapor Fraction		0	0	0	1	1	1	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0
Enthalpy Flow	MMBtu/h	-38	0	-37	-47	-17	-37	-64	-84	-89	-34	-32	-26	-1	-24	0	-6	-28	-1	-28	-10	-10	-10	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	2	0	2	3,820	3,820	9,855	9,855	9,855	9,855	9,779	0	75	74	1	0	1,825	7,955	3,274	11,229	3,818	3,705	3,705	0	0
Ammonia	lb/h	0	0	0	6	6	63	63	63	63	20	36	7	3	4	0	4	16	0	16	6	5	5	0	0
H2S	lb/h	0	0	0	9	9	39	39	39	39	32	0	8	4	4	0	6	26	0	26	9	8	8	0	0
Water	lb/h	290	0	290	319	319	5,008	5,008	5,008	5,008	106	4,660	243	22	221	0	20	86	0	86	29	28	28	0	0
Carbon Monoxide	lb/h	13	0	13	2,377	2,377	8,366	8,366	8,366	8,366	8,266	0	100	97	3	0	1,542	6,723	230	6,953	2,364	2,294	2,294	0	0
Carbon Dioxide	lb/h	177	0	177	869	869	2,267	2,267	2,267	2,267	2,061	0	205	152	53	0	385	1,677	361	2,038	693	672	672	0	0
Methane	lb/h	4	0	4	1,498	1,498	5,565	5,565	5,565	5,565	5,405	0	160	147	13	0	1,009	4,396	0	4,396	1,495	1,451	1,451	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	43	0	43	59	59	65	65	65	65	59	0	6	4	1	0	11	48	0	48	16	16	16	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	179	179	736	736	736	736	649	0	87	58	29	0	121	528	0	528	179	174	174	0	0
Propylene	lb/h	69	0	69	70	70	6	6	6	6	5	0	2	1	1	0	1	4	0	4	1	1	1	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	34	34	170	170	170	170	124	0	47	18	29	0	23	101	0	101	34	33	33	0	0
Furan	lb/h	168	0	168	168	168	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	156	0	156	158	158	14	14	14	14	7	0	7	1	5	0	1	6	0	6	2	2	2	0	0
Tetrahydrofuran	lb/h	489	0	489	489	489	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	174	174	1,202	1,202	1,202	1,202	628	0	573	89	484	0	117	511	0	511	174	169	169	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	527	0	527	527	527	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	43	43	588	588	588	588	154	0	434	25	409	0	29	125	0	125	43	41	41	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	114	114	4,694	4,694	4,694	4,694	414	0	4,280	67	4,213	0	77	336	0	336	114	111	111	0	0
Phenol	lb/h	3,459	0	3,459	3,459	3,459	54	54	54	54	0	0	54	0	54	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	284	0	284	284	284	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	11	0	11	11	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	37	0	37	37	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	27	0	27	84	84	2,470	2,470	2,470	2,470	206	0	2,263	32	2,232	0	38	168	0	168	57	55	55	0	0
N-Hexane	lb/h	0	0	0	29	29	856	856	856	856	105	0	750	15	735	0	20	86	0	86	29	28	28	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	24	24	1,818	1,818	1,818	1,818	88	0	1,730	9	1,721	0	16	72	0	72	24	24	24	0	0
2-Methylphenol	lb/h	2,376	0	2,376	2,376	2,376	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	731	0	731	755	755	1,743	1,743	1,743	1,743	84	0	1,659	11	1,647	0	16	68	0	68	23	22	22	0	0
2-Methylhexane	lb/h	0	0	0	16	16	842	842	842	842	59	0	783	8	775	0	11	48	0	48	16	16	16	0	0
VinylPhenol	lb/h	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	4	4	1,185	1,185	1,185	1,185	14	0	1,171	2	1,169	0	3	11	0	11	4	4	4	0	0
Ethylbenzne	lb/h	0	0	0	1	1	138	138	138	138	2	0	136	0	135	0	0	2	0	2	1	1	1	0	0
2,3-Dimethyl-phenol	lb/h	2,061	0	2,061	2,061	2,061	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	6,790	0	6,790	6,790	6,790	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	870	0	870	870	870	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	330	0	330	330	330	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	4,463	0	4,463	4,492	4,492	4,446	4,446	4,446	4,446	105	0	4,341	12	4,329	0	20	85	0	85	29	28	28	0	0
Trans-1,2-dimethylcyclohexane	lb/h	4,286	0	4,286	4,325	4,325	5,054	5,054	5,054	5,054	141	0	4,913	17	4,896	0	26	115	0	115	39	38	38	0	0
Ethylcyclohexane	lb/h	0	0	0	2	2	399	399	399	399	8	0	391	1	390	0	2	7	0	7	2	2	2	0	0
4-Methylheptane	lb/h	0	0	0	3	3	319	319	319	319	10	0	309	1	308	0	2	8	0	8	3	3	3	0	0
2-Methyl-Benzofuran	lb/h	461	0	461	461	461	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	13	0	13	13	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	10	10	10	10	0	0	10	0	10	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	1,108	1,108	1,108	1,108	1	0	1,107	0	1,106	0	0	1	0	1	0	0	0	0	0
1-Naphthalenol	lb/h	2,705	0	2,705	2,705	2,705	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	381	0	381	381	381	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	461	461	461	461	1	0	460	0	460	0	0	1	0	1	0	0	0	0	0
Isoeugenol	lb/h	13	0	13	13	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	2,079	0	2,079	2,082	2,082	3,005	3,005	3,005	3,005	8	0	2,996	1	2,996	0	2	7	0	7	2	2	2	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	1,181	0	1,181	1,182	1,182	544	544	544	544	0	0	544	0	544	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	1,490	0	1,490	1,491	1,491	2,176	2,176	2,176	2,176	4	0	2,172	0	2,172	0	1	3	0	3	1	1	1	0	0
Dibenzothiophene	lb/h	73	0	73	73	73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	62	62	62	62	0	0	62	0	61	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	1,390	1,390	1,390	1,390	0	0	1,390	0	1,390	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	916	0	916	916	916	916	916	916	916	0	0	916	0	916	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	1,859	1,859	1,859	1,859	1	0	1,857	0	1,857	0	0	1	0	1	0	0	0	0	0
C15H26-N4	lb/h	983	0	983	983	983	880	880	880	880	0	0	880	0	880	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	427	0	427	427	427	427	427	427	427	0	0	427	0	427	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	299	0	299	299	299	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	283	283	283	283	0	0	283	0	283	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	3,424	0	3,424	3,424	3,424	685	685	685	685	0	0	685	0	685	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	7,087	0	7,087	7,087	7,087	7,087	7,087	7,087	7,087	0	0	7,087	0	7,087	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	2,855	0	2,855	2,855	2,855	286	286	286	286	0	0	286	0	286	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QA-H413	3
QA-K412	6
QC-H413	2
QC-H444	0
QC-H445	0
QF-H411	-3
Q-H412	20
QX-H410	-27

Work	hp	MMBtu/h
W-K412	2,367	6
W-K442	236	1
W-P410	224	1

H-450 GASOLINE COLUMN HEAT RECOVERY

H-452 GASOLINE COLUMN HEAT RECOVERY

D-450 GASOLINE COLUMN

H-450C D-450 CONDENSER

P-450 D-450 REFLUX PUMP

H-450R D-450 REBOILER

S-450 D-450 OVERHEAD ACCUMULATOR

D-451 DIESEL COLUMN

H-451C D-451 CONDENSER

P-451 D-451 REFLUX PUMP

H-451R D-451 REBOILER

S-451 D-451 OVERHEAD ACCUMULATOR

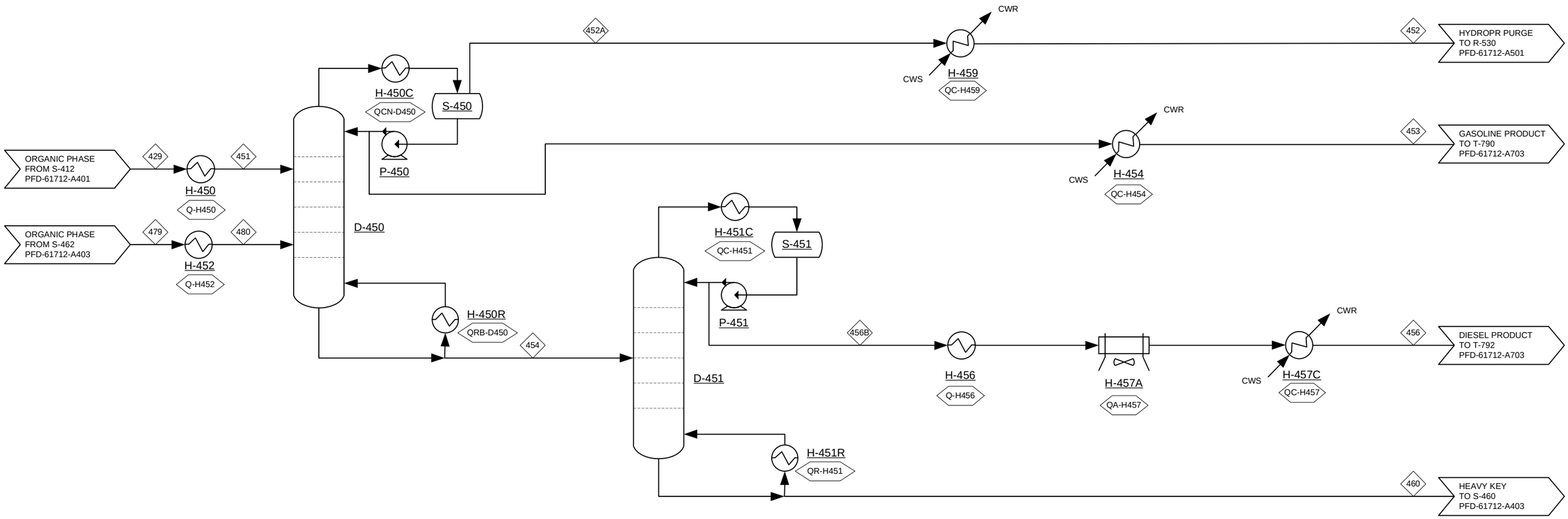
H-459 D-450 OVERHEAD VAPOR COOLER

H-456 DIESEL PRODUCT HEAT RECOVERY

H-454 GASOLINE PRODUCT COOLER

H-457A DIESEL PRODUCT ACHE

H-457C DIESEL PRODUCT COOLER



Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

Harris Group

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 400: PRODUCT SEPARATION

Project No: 30482.00

Drawing: PFD-61712-A402

Rev: 1

PFD-61712-A402		429	451	452	452A	453	454	456	456B	460	480
Total Flow	lb/h	45,023	45,023	547	547	31,866	20,678	11,845	11,845	8,833	8,068
Temperature	F	110	450	110	200	60	599	60	463	733	550
Pressure	Psia	53	43	33	35	15	40	15	35	20	43
Vapor Fraction		0	1	1	1	0	0	0	0	0	1
Enthalpy Flow	MMBtu/h	-24	-13	-1	-1	-20	-6	-8	-5	-1	-4
Argon	lb/h	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	1	1	2	2	0	0	0	0	0	0
Ammonia	lb/h	4	4	1	1	2	0	0	0	0	0
H2S	lb/h	4	4	1	1	2	0	0	0	0	0
Water	lb/h	221	221	22	22	217	0	0	0	0	19
Carbon Monoxide	lb/h	3	3	3	3	0	0	0	0	0	0
Carbon Dioxide	lb/h	53	53	35	35	22	0	0	0	0	4
Methane	lb/h	13	13	12	12	3	0	0	0	0	2
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	1	1	3	3	2	0	0	0	0	3
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	29	29	41	41	39	0	0	0	0	50
Propylene	lb/h	1	1	0	0	1	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	29	29	9	9	21	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	5	5	1	1	5	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	484	484	67	67	417	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	409	409	27	27	383	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	4,213	4,213	93	93	4,120	0	0	0	0	0
Phenol	lb/h	54	54	0	0	54	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	2,232	2,232	45	45	2,214	0	0	0	0	28
N-Hexane	lb/h	735	735	50	50	1,685	0	0	0	0	1,000
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	1,721	1,721	16	16	1,706	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	1,647	1,647	19	19	1,628	0	0	0	0	0
2-Methylhexane	lb/h	775	775	32	32	1,874	0	0	0	0	1,131
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	1,169	1,169	4	4	1,165	0	0	0	0	0
Ethylbenzne	lb/h	135	135	1	1	135	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	4,329	4,329	24	24	4,306	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	4,896	4,896	31	31	4,864	0	0	0	0	0
Ethylcyclohexane	lb/h	390	390	2	2	388	0	0	0	0	0
4-Methylheptane	lb/h	308	308	2	2	305	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	10	10	0	0	10	0	0	0	0	0
Naphthalene	lb/h	1,106	1,106	0	0	858	248	248	248	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	460	460	0	0	437	23	23	23	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	2,996	2,996	2	2	3,035	7	7	7	0	49
2,5-Dimethyloctane	lb/h	0	0	0	0	116	1	1	1	0	116
1-Methyl naphthalene	lb/h	544	544	0	0	11	533	533	533	0	0
1-methyl decahydronaphthene	lb/h	2,172	2,172	1	1	1,696	476	476	476	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	61	61	0	0	0	61	61	61	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	1,390	1,390	0	0	1	1,389	1,388	1,388	1	0
C14H24-N5	lb/h	916	916	0	0	0	918	916	916	2	2
3,5-Dimethyldodecane	lb/h	1,857	1,857	0	0	144	4,498	4,498	4,498	0	2,785
C15H26-N4	lb/h	880	880	0	0	1	880	879	879	1	1
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	2,263	2,263	2,263	0	2,263
1,4-Dimethyl-Phenanthrene	lb/h	427	427	0	0	0	545	37	37	508	118
N-Cetane	lb/h	0	0	0	0	0	162	162	162	0	162
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	283	283	0	0	0	617	283	283	333	333
C21H26O2	lb/h	685	685	0	0	0	685	0	0	685	0
C21H34	lb/h	7,087	7,087	0	0	0	7,087	71	71	7,016	0
C22H28O2	lb/h	286	286	0	0	0	286	0	0	286	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QA-H457	0
QC-H451	3
QC-H454	1
QC-H457	0
QC-H459	0
QCN-D450	14
Q-H450	-12
Q-H452	-3
Q-H456	2
QRB-D450	-7
QR-H451	-3
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

S-460 VAPOR KO DRUM | P-460 HC FEED PUMP | H-494 QUENCH HYDROGEN STAGE 2 COOLER | H-495 QUENCH HYDROGEN STAGE 3 COOLER | K-462 HYDROGEN MAKEUP COMPRESSOR | H-460 FEED-EFFLUENT EXCH | H-461 FEED FURNACE | R-460 HYDROCRACKER | K-492 HYDROGEN RECYCLE COMPRESSOR | H-462 HC PRODUCT HEAT RECOVERY | H-463A HC PRODUCT ACHE | H-463C HC PRODUCT COOLER | S-461 HP EFFLUENT FLASH: 3 PHASE | S-462 LP EFFLUENT FLASH

HEAVY KEY FROM D-451 PFD-61712-A402

460 S-460

461 OFFGAS TO K-511/H-513 PFD-61712-A501

464 P-460 W-P460

465 H-460 QX-H460

466 H-461 QF-H461

467 469 H-462 Q-H462

470 H-463A QA-H463

493A H-494 QC-H494 CWR CWS

494B

494C H-495 QC-H495 CWR CWS

R-460

468

H-463C QC-H463 CWR CWS

472

471 S-461

475 S-462

481 RECYCLE GAS PURGE TO M-575 PFD-61712-A503

478 OFFGAS TO K-511/H-513 PFD-61712-A501

479 ORGANIC PHASE TO H-452 PFD-61712-A402

474 AQUEOUS PHASE TO M-805 PFD-61712-A804

MAKEUP HYDROGEN FROM M-385/M-575 PFD-61712-A504

485 K-462 W-K462 QA-K462

482 K-492 W-K492

493

1 NOTE: FUEL GAS AND COMBUSTION DUTY ASSOCIATED WITH H-461 ACCOUNTED FOR BY QF-H548 ON PFD-61712-A501

Harris Group

NREL NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM AREA 400: HYDROCRACKING

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Project No: 30482.00 | Drawing: PFD-61712-A403 | Rev: 2

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

ENGINEERING-PDH.COM | CHE-136 |

PFD-61712-A403		460	461	464	465	467	468	469	470	471	472	474	475	478	479	481	482	485	493	493A	494B	494C			
Total Flow	lb/h	8,833	0	8,833	10,606	10,606	14,047	14,047	14,047	14,047	5,487	80	8,480	412	8,068	1,342	4,146	1,068	5,214	1,773	1,721	1,721	0	0	0
Temperature	F	733	733	767	543	738	787	688	175	110	110	110	110	110	110	110	110	110	132	132	110	110	0	0	0
Pressure	Psia	20	20	2000	2000	1945	1915	1910	1905	1895	1893	1893	1893	53	53	1893	1893	245	2000	2000	1995	1995	0	0	0
Vapor Fraction		0	1	0	1	1	1	1	1	1	1	0	0	1	0	1	1	1	1	1	1	1	0	0	0
Enthalpy Flow	MMBtu/h	-1	0	-1	-3	-1	-4	-5	-13	-14	-6	-1	-7	-1	-7	-1	-4	0	-5	-2	-2	-2	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	732	732	1,673	1,673	1,673	1,673	1,653	0	20	20	0	404	1,249	905	2,154	732	711	711	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	0	0	0	5	5	126	126	126	126	20	80	26	7	19	5	15	0	15	5	5	5	0	0	0
Carbon Monoxide	lb/h	0	0	0	84	84	246	246	246	246	241	0	5	4	0	59	182	64	246	84	81	81	0	0	0
Carbon Dioxide	lb/h	0	0	0	106	106	313	313	313	313	282	0	31	27	4	69	213	100	313	106	103	103	0	0	0
Methane	lb/h	0	0	0	281	281	1,140	1,140	1,140	1,140	1,096	0	44	42	2	268	828	0	828	281	273	273	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	44	44	191	191	191	191	171	0	20	17	3	42	129	0	129	44	43	43	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	444	444	1,992	1,992	1,992	1,992	1,729	0	264	213	50	423	1,306	0	1,306	444	431	431	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	1	1	33	33	33	33	4	0	29	1	28	1	3	0	3	1	1	1	0	0	0
N-Hexane	lb/h	0	0	0	46	46	1,230	1,230	1,230	1,230	178	0	1,052	51	1,000	44	135	0	135	46	44	44	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	28	28	1,267	1,267	1,267	1,267	108	0	1,159	28	1,131	26	82	0	82	28	27	27	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	49	49	49	49	0	0	49	0	49	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	118	118	118	118	1	0	117	0	116	0	1	0	1	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N3S	lb/h	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	2	0	2	2	2	2	2	2	2	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	1	1	2,787	2,787	2,787	2,787	2	0	2,785	0	2,785	1	2	0	2	1	1	1	0	0	0
C15H26-N4	lb/h	1	0	1	1	1	1	1	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	1	1	2,265	2,265	2,265	2,265	2	0	2,264	0	2,263	0	1	0	1	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	508	0	508	508	508	118	118	118	118	0	0	118	0	118	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	162	162	162	162	0	0	162	0	162	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	333	0	333	333	333	333	333	333	333	0	0	333	0	333	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	685	0	685	685	685	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	7,016	0	7,016	7,016	7,016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	286	0	286	286	286	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QA-H463	0
QA-K462	2
QC-H463	0
QC-H494	0
QC-H495	0
QF-H461	0
Q-H462	8
QX-H460	-1

Work	hp	MMBtu/h
W-P460	95	0
W-K492	43	0
W-K462	692	2

K-545 REFORMER COMBUSTOR AIR BLOWER | H-511 HEAT RECOVERY | K-511 PYROLYSIS OFFGAS COMPRESSOR TO REFORMER | H-513 HEAT RECOVERY | H-525 HEAT RECOVERY | H-514 HEAT RECOVERY | R-530 STEAM REFORMER PACKAGE | H-548 HYDROPROCESSING FURNACE HEAT EXCHANGER | H-530 HEAT RECOVERY | H-546 REF COMBUSTOR FLUE GAS HEAT RECOVERY | H-545 REFORMER COMBUSTOR AIR HEAT RECOVERY | H-547 REF COMBUSTOR FLUE GAS HEAT RECOVERY

LP STEAM FROM T-822 PFD-61712-A801
823
H-525
Q-H525
519
NATURAL GAS FROM UTILITY
502
H-511
Q-H511
OFFGAS FROM S-412 PFD-61712-A401
428
515
512
H-514
Q-H514
OFFGAS FROM S-462 PFD-61712-A403
478
K-511
W-K511
PURGE GAS FROM H-315 PFD-61712-A302
345
537
OFFGAS FROM S-460 PFD-61712-A403
461
522
OFFGAS FROM S-410 PFD-61712-A401
411
PSA OFFGAS FROM M-385 PFD-61712-A304
389
516
H-513
Q-H513
541
HYDROPR PURGE FROM H-459 PFD-61712-A402
452
593
R-530
PSA OFFGAS FROM M-575 PFD-61712-A503
589
546
H-548 QF-H548
H-530 Q-H530
H-546 Q-H546
H-545 Q-H545
H-547 Q-H547
1
549
FLUE GAS TO M-104 PFD-61712-A102
540
REFORMER PRODUCT TO H-565 PFD-61712-A502
591
COMBUSTION AIR
542
K-545
W-K545

1 NOTE: H-548 NOT PHYSICALLY PRESENT IN R-530 FLUE, BUT IS SHOWN TO ACCOUNT FOR FLUE GASES AND COMBUSTION DUTIES OF H-411 AND H-461

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712150128.vsd

Harris Group

NREL NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 500: REFORMER

Rev.	Date	By	Description
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Project No: 30482.00 | Drawing: PFD-61712-A501 | Rev: 1

PFD-61712-A501		345	389	411	428	452	461	478	502	512	515	516	519	522	537	540	541	542	546	549	589	591	593	823	
Total Flow	lb/h	1,998	52,802	0	870	547	0	412	54	61,804	61,804	3,103	54	0	103,323	103,323	83,078	156,340	156,340	239,418	88,253	79,428	8,825	41,466	0
Temperature	F	95	110	0	110	110	733	110	60	109	500	500	60	500	1400	1616	447	90	600	229	111	111	111	356	0
Pressure	Psia	99	22	117	53	33	20	53	200	20	118	18	200	198	118	115	18	15	20	15	22	22	22	135	0
Vapor Fraction		1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
Enthalpy Flow	MMBtu/h	-4	-155	0	-1	-1	0	-1	0	-183	-175	-9	0	0	-360	-300	-284	-17	2	-476	-314	-283	-31	-232	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,975	1,975	1,975	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	1	0	0	0	1	0	1	4	3	115,767	115,767	115,770	4	3	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35,471	35,471	7,234	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	0
Hydrogen	lb/h	183	881	0	74	2	0	20	0	1,259	1,259	63	0	0	1,259	4,128	1,544	0	0	0	1,643	1,479	164	0	0
Ammonia	lb/h	0	0	0	3	1	0	0	0	3	3	0	0	0	3	0	5	0	0	0	4	4	0	0	0
H2S	lb/h	0	0	0	4	1	0	0	0	5	5	0	0	0	5	5	11	0	0	0	11	10	1	0	0
Water	lb/h	6	407	0	22	22	0	7	0	467	467	23	0	0	41,308	31,037	472	3,050	3,050	23,478	474	427	47	40,842	0
Carbon Monoxide	lb/h	768	3,312	0	97	3	0	4	0	4,552	4,552	229	0	0	4,552	30,667	5,617	0	0	0	5,984	5,385	598	0	0
Carbon Dioxide	lb/h	638	38,429	0	152	35	0	27	0	44,745	44,745	2,247	0	0	44,745	37,159	71,996	77	77	90,926	77,460	69,714	7,746	0	0
Methane	lb/h	70	1,704	0	147	12	0	42	47	2,022	2,022	102	47	0	2,069	323	1,554	0	0	0	1,600	1,440	160	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	199	4,810	0	4	3	0	17	0	4,795	4,795	241	0	0	4,795	0	291	0	0	0	53	48	5	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	58	41	0	213	3	310	310	16	3	0	313	0	546	0	0	0	544	489	54	0	0
Propylene	lb/h	65	1,566	0	1	0	0	0	0	1,554	1,554	78	0	0	1,554	0	79	0	0	0	1	1	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	18	9	0	0	1	19	19	1	1	0	20	0	30	0	0	0	23	21	2	0	0
Furan	lb/h	7	171	0	0	0	0	0	0	169	169	9	0	0	169	0	9	0	0	0	0	0	0	0	0
1-Butene	lb/h	31	757	0	1	1	0	0	0	752	752	38	0	0	752	0	40	0	0	0	1	1	0	0	0
Tetrahydrofuran	lb/h	5	129	0	0	0	0	0	0	128	128	6	0	0	128	0	6	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	89	67	0	0	1	96	96	5	1	0	97	0	178	0	0	0	117	106	12	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	6	146	0	0	0	0	0	0	145	145	7	0	0	145	0	7	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	25	27	0	0	0	27	27	1	0	0	27	0	54	0	0	0	29	26	3	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	67	93	0	0	0	71	71	4	0	0	71	0	166	0	0	0	77	69	8	0	0
Phenol	lb/h	0	33	0	0	0	0	0	0	31	31	2	0	0	69	0	2	0	0	0	0	0	0	37	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	587	0	0	0	0	0	0	0	0	587	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	1	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	5	0	32	45	0	1	0	40	40	2	0	0	40	0	83	0	0	0	39	35	4	0	0
N-Hexane	lb/h	0	0	0	15	50	0	51	0	69	69	3	0	0	69	0	110	0	0	0	63	57	6	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	9	16	0	0	0	10	10	0	0	0	10	0	31	0	0	0	16	15	2	0	0
2-Methylphenol	lb/h	0	2	0	0	0	0	0	0	2	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	3	63	0	11	19	0	0	0	75	75	4	0	0	75	0	37	0	0	0	16	14	2	0	0
2-Methylhexane	lb/h	0	0	0	8	32	0	28	0	38	38	2	0	0	38	0	67	0	0	0	37	34	4	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	2	4	0	0	0	2	2	0	0	0	2	0	6	0	0	0	3	2	0	0	0
Ethylbenzne	lb/h	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	1	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	1	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	7	171	0	12	24	0	0	0	183	183	9	0	0	183	0	50	0	0	0	20	18	2	0	0
Trans-1,2-dimethylcyclohexane	lb/h	8	206	0	17	31	0	0	0	222	222	11	0	0	222	0	66	0	0	0	26	24	3	0	0
Ethylcyclohexane	lb/h	0	0	0	1	2	0	0	0	1	1	0	0	0	1	0	3	0	0	0	2	1	0	0	0
4-Methylheptane	lb/h	0	0	0	1	2	0	0	0	1	1	0	0	0	1	0	4	0	0	0	2	2	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	5	0	1	2	0	0	0	6	6	0	0	0	6	0	4	0	0	0	2	1	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	2	0	0	1	0	0	0	2	2	0	0	0	2	0	2	0	0	0	1	1	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QF-H548	3
Q-H456	131
Q-H511	0
Q-H513	0
Q-H514	0
Q-H525	-4
Q-H530	-42
Q-H545	-17
Q-H547	-8

Work	hp	MMBtu/h
W-K511	3,186	8
W-K545	1,247	3

H-565
HT WGS FEED
HEAT RECOVERY

R-565
WGS
REACTOR

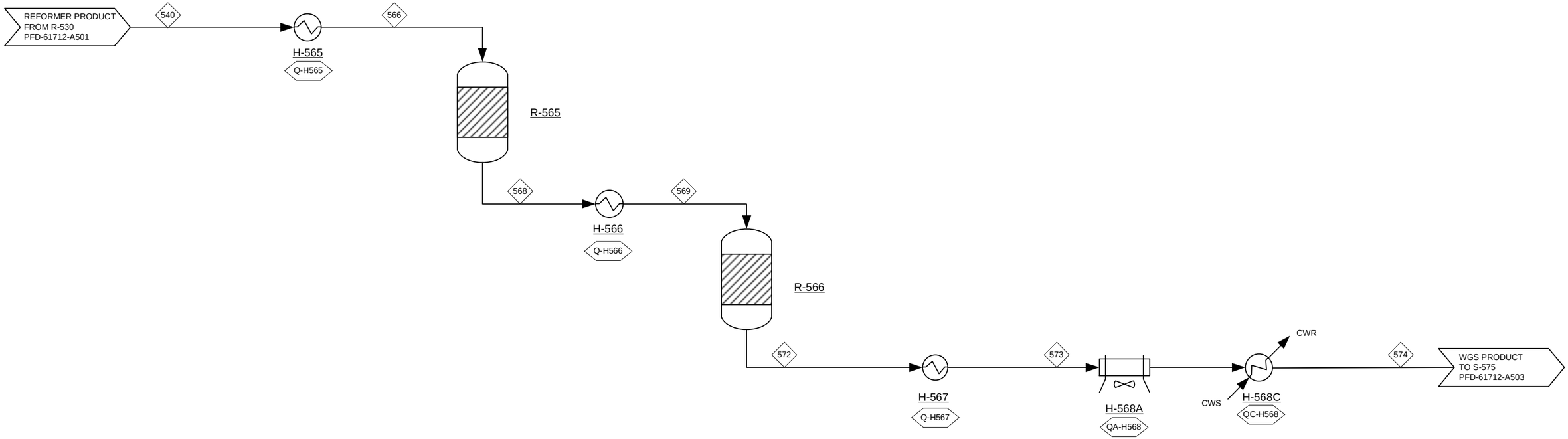
H-566
LTS FEED HEAT
RECOVERY

R-566
LTS REACTOR

H-567
LTS EFFLUENT
HEAT RECOVERY

H-568A
WGS EFFLUENT
ACHE

H-568C
WGS EFFLUENT
COOLER



Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 500: WATER GAS SHIFT

Project No: 30482.00
Drawing: PFD-61712-A502
Rev: 1

PFD-61712-A502		540	566	568	569	572	573	574																	
Total Flow	lb/h	103,323	103,323	103,323	103,323	103,323	103,323	103,323	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	1616	644	841	428	546	200	110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	115	113	108	106	101	99	97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-300	-349	-349	-369	-369	-389	-404	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	4	4	4	4	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	4,128	4,128	5,311	5,311	5,987	5,987	5,987	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	5	5	5	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	31,037	31,037	20,466	20,466	14,428	14,428	14,428	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	30,667	30,667	14,232	14,232	4,844	4,844	4,844	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	37,159	37,159	62,982	62,982	77,732	77,732	77,732	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	323	323	323	323	323	323	323	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QA-H568	12
QC-H568	3
Q-H565	49
Q-H566	20
Q-H567	20
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

S-575
COMPRESSOR
SUCTION KO DRUM

K-580
PSA COMPRESSOR
MULTISTAGE

T-576
COMRPESSOR
CONDENSATE TANK

S-586
PSA COMPRESSOR
DISCHARGE KO DRUM

P-576
COMPRESSOR
CONDENSATE PUMP

M-575
PSA

RECYCLE GAS PURGE
FROM S-461
PFD-61712-A403

481

RECYCLE GAS PURGE
FROM S-411
PFD-61712-A401

431

449

588

M-575

589

PSA OFFGAS
TO H-547/K-511/H-513
PFD-61712-A501

590

HYDROGEN
TO K-211/K-412/K-462
PFD-61712-A504

577

CWR

CWS

586

WGS PRODUCT
FROM H-568C
PFD-61712-A502

574

S-575

585

S-586

582

587

K-580

W-K580

QC-K580

QA-K580

576A

T-576

576

CONDENSATE
TO T-860
PFD-61712-A804

P-576

W-P576

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 500: PSA

Project No: 30482.00

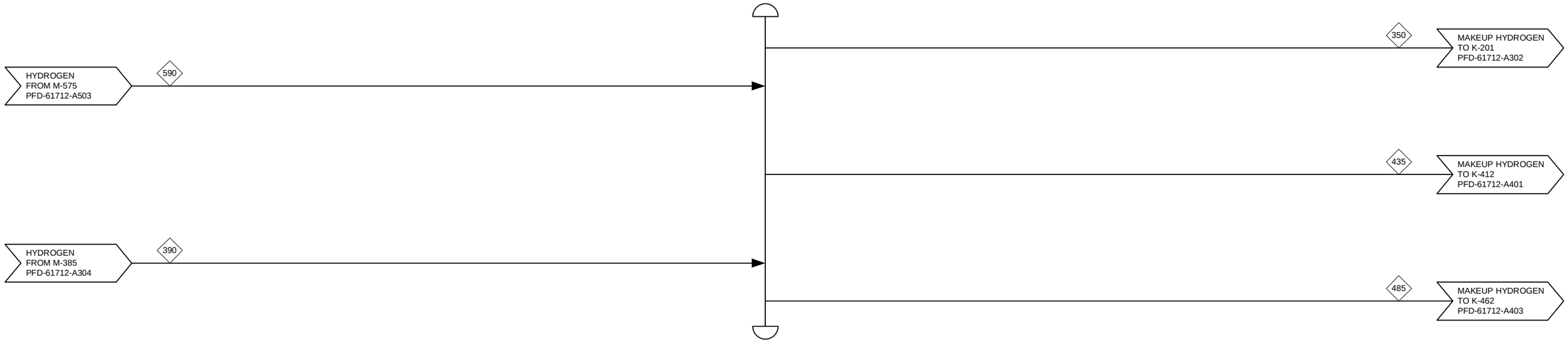
Drawing: PFD-61712-A503

Rev: 2

PFD-61712-A503		431	449	481	574	576	576A	577	582	585	586	587	588	589	590											
Total Flow	lb/h	5,327	6,669	1,342	103,323	13,980	13,346	89,977	520	89,457	89,343	114	96,012	88,253	7,759	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	110	110	110	110	110	110	110	110	110	113	113	111	111	111	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	1793	1793	1893	97	102	97	97	97	278	276	276	276	22	266	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	1	0	0	1	0	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-6	-8	-1	-404	-95	-91	-313	-4	-310	-309	-1	-317	-314	-3	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	4	0	0	4	0	4	4	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	1,825	2,229	404	5,987	0	0	5,987	0	5,987	5,987	0	8,216	1,643	6,573	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	4	4	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	6	6	0	5	0	0	5	0	5	5	0	11	11	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	20	24	5	14,428	13,979	13,345	1,084	520	563	449	114	474	474	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	1,542	1,601	59	4,844	0	0	4,844	0	4,844	4,844	0	6,445	5,984	461	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	385	454	69	77,732	1	1	77,731	0	77,731	77,731	0	78,185	77,460	725	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	1,009	1,277	268	323	0	0	323	0	323	323	0	1,600	1,600	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	11	53	42	0	0	0	0	0	0	0	0	53	53	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	121	544	423	0	0	0	0	0	0	0	0	544	544	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	23	23	0	0	0	0	0	0	0	0	0	23	23	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	117	117	0	0	0	0	0	0	0	0	0	117	117	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	29	29	0	0	0	0	0	0	0	0	0	29	29	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	77	77	0	0	0	0	0	0	0	0	0	77	77	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	38	39	1	0	0	0	0	0	0	0	0	39	39	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	20	63	44	0	0	0	0	0	0	0	0	63	63	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	16	16	0	0	0	0	0	0	0	0	0	16	16	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	16	16	0	0	0	0	0	0	0	0	0	16	16	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	11	37	26	0	0	0	0	0	0	0	0	37	37	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	3	3	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	20	20	0	0	0	0	0	0	0	0	0	20	20	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	26	26	0	0	0	0	0	0	0	0	0	26	26	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	2	2	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	2	2	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	2	2	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QC-K580	4
QA-K580	4
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
WK-580	3,071	8
W-P576	0	0
	0	0
	0	0



Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 500: HYDROGEN DISTRIBUTION

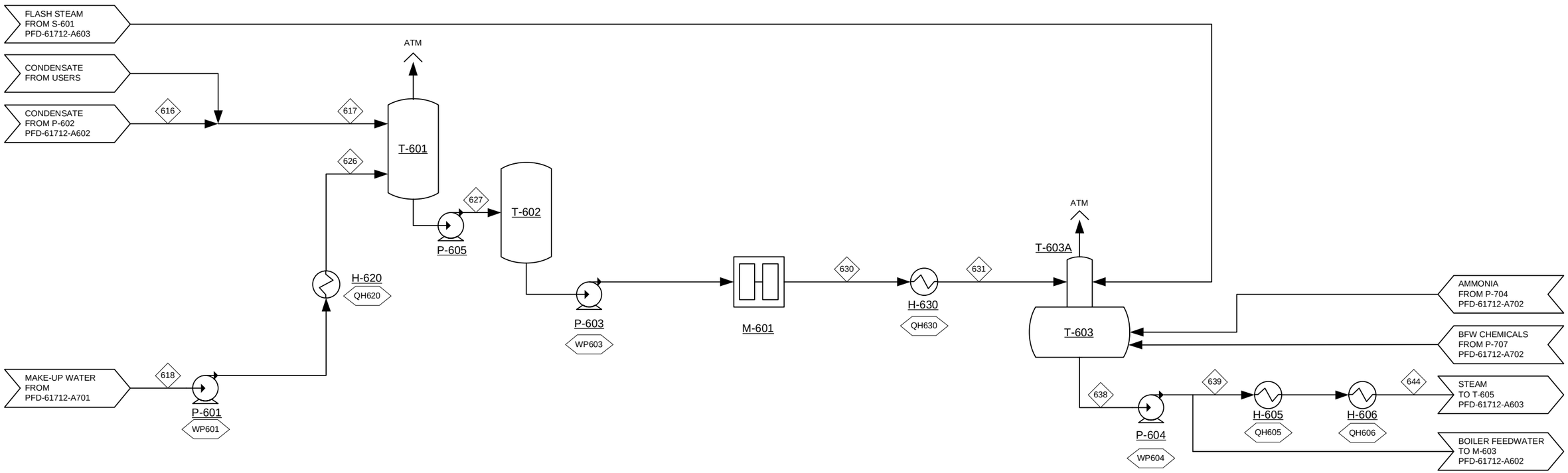
Project No: 30482.00
Drawing: PFD-61712-A504
Rev: 1

PFD-61712-A504		350	390	435	485	590																			
Total Flow	lb/h	8,288	5,462	3,865	1,068	7,759	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	100	110	110	110	111	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	110	215	245	245	266	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-3	-2	-1	0	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	7,021	4,627	3,274	905	6,573	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	493	325	230	64	461	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	774	510	361	100	725	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

P-601 MAKE-UP PUMP | H-620 CONDENSATE HEATER | T-601 CONDENSATE COLLECTION TANK | P-605 CONDENSATE COLLECTION PUMP | T-602 CONDENSATE SURGE TANK | P-603 EDI PUMP | M-601 BFW ELECTRODEIONIZATION (EDI) + POLISHING | H-630 DEAERATOR FEED HEATER | T-603A DEAERATOR PACKED COLUMN | T-603 DEAERATOR | P-604 BOILER FEEDWATER PUMP | H-605 BOILER FEEDWATER PREHEATER | H-606 STEAM GENERATOR



Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

Rev.	Date	By	Description
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Harris Group

NREL NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 600: STEAM SYSTEM & POWER GENERATION

Project No: 30482.00 | Drawing: PFD-61712-A601 | Rev: 1

PFD-61712-A601		616	617	618	626	627	630	631	638	639	644														
Total Flow	lb/h	346,272	346,272	7,064	7,064	353,336	353,336	353,336	353,338	353,338	353,338	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	136	136	60	212	138	138	232	232	235	581	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	25	15	15	15	15	25	22	22	1401	1336	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-2342	-2342	-48	-47	-2389	-2389	-2355	-2355	-2353	-2014	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	346,272	346,272	7,064	7,064	353,336	353,336	353,336	353,338	353,338	353,338	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QH605	-136
QH606	-203
QH620	-1
QH630	-33
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
WP601	0	0
WP603	14	0
WP604	800	2
	0	0
	0	0
	0	0

M-603
STARTUP BOILER

M-602
TURBINE GENERATOR

H-601
STEAM TURBINE
CONDENSER

T-606
STEAM TURBINE
CONDENSATE TANK

P-602
CONDENSATE
PUMP

BOILER FEEDWATER
FROM P-604
PFD-61712-A601

M-603

LP STEAM
TO USERS

SUPERHEATED STEAM
FROM H-607
PFD-61712-A603

607

M-602

W-602A

QH602B

614A

H-601

QAH601

T-606

615

616

CONDENSATE
TO T-601
PFD-61712-A601

P-602

WP602

Plot date: 1/29/2015 J11A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 600: STEAM SYSTEM & POWER GENERATION

Project No: 30482.00

Drawing: PFD-61712-A602

Rev: 1

PFD-61712-A602		607	614A	615	616																				
Total Flow	lb/h	346,272	346,272	346,272	346,272	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	1000	234	136	136	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	1321	4	3	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-1860	-1974	-2342	-2342	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	346,272	346,272	346,272	346,272	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QH602B	-55
QAH601	357
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
W-602A	-64,759	-165
WP602	12	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

T-605
STEAM
DRUM

S-601
BLOWDOWN
FLASH DRUM

H-602
STEAM TURBINE EXHAUST
HEAT RECOVERY

H-607
STEAM
SUPERHEATER

H-603
BLOWDOWN
COOLER

STEAM
FROM H-606
PFD-61712-A601

644

STEAM
FROM R-202C
PFD-61712-A201

T-605

606

H-607

QH607

607

SUPERHEATED STEAM
TO M-602
PFD-61712-A602

FLASH STEAM
TO T-603
PFD-61712-A601

S-601

604

H-602

QH602

603

H-603

QCH603

600

BLOWDOWN
TO M-701
PFD-61712-A701

Plot date: 1/29/2015 J11A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 600: STEAM SYSTEM & POWER GENERATION

Project No: 30482.00

Drawing: PFD-61712-A603

Rev: 1

PFD-61712-A603		600	603	604	606	607	644																			
Total Flow	lb/h	7,067	7,067	7,067	346,272	346,272	353,338																			
Temperature	F	113	170	581	580	1000	581																			
Pressure	Psia	15	1326	1336	1326	1321	1336																			
Vapor Fraction		0	0	0	1	1	1																			
Enthalpy Flow	MMBtu/h	-48	-48	-44	-1970	-1860	-2014																			
Argon	lb/h	0	0	0	0	0	0																			
Nitrogen	lb/h	0	0	0	0	0	0																			
Oxygen	lb/h	0	0	0	0	0	0																			
SO2	lb/h	0	0	0	0	0	0																			
NO2	lb/h	0	0	0	0	0	0																			
Hydrogen	lb/h	0	0	0	0	0	0																			
Ammonia	lb/h	0	0	0	0	0	0																			
H2S	lb/h	0	0	0	0	0	0																			
Water	lb/h	7,067	7,067	7,067	346,272	346,272	353,338																			
Carbon Monoxide	lb/h	0	0	0	0	0	0																			
Carbon Dioxide	lb/h	0	0	0	0	0	0																			
Methane	lb/h	0	0	0	0	0	0																			
Methanol	lb/h	0	0	0	0	0	0																			
Formic Acid	lb/h	0	0	0	0	0	0																			
Glyoxal	lb/h	0	0	0	0	0	0																			
Ethylene	lb/h	0	0	0	0	0	0																			
Acetaldehyde	lb/h	0	0	0	0	0	0																			
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0																			
Acetic Acid	lb/h	0	0	0	0	0	0																			
Ethane	lb/h	0	0	0	0	0	0																			
Propylene	lb/h	0	0	0	0	0	0																			
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0																			
Propionic Acid	lb/h	0	0	0	0	0	0																			
Propane	lb/h	0	0	0	0	0	0																			
Furan	lb/h	0	0	0	0	0	0																			
1-Butene	lb/h	0	0	0	0	0	0																			
Tetrahydrofuran	lb/h	0	0	0	0	0	0																			
N-Butane	lb/h	0	0	0	0	0	0																			
Furfural	lb/h	0	0	0	0	0	0																			
2-methylfuran	lb/h	0	0	0	0	0	0																			
Furfuryl Alcohol	lb/h	0	0	0	0	0	0																			
n-Pentane	lb/h	0	0	0	0	0	0																			
Pentenone	lb/h	0	0	0	0	0	0																			
Benzene	lb/h	0	0	0	0	0	0																			
Phenol	lb/h	0	0	0	0	0	0																			
1,2-Benzenediol	lb/h	0	0	0	0	0	0																			
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0																			
2,5-dimethylfuran	lb/h	0	0	0	0	0	0																			
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0																			
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0																			
Cyclohexanone	lb/h	0	0	0	0	0	0																			
Levoglucosan	lb/h	0	0	0	0	0	0																			
1-Hexanal	lb/h	0	0	0	0	0	0																			
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0																			
Cyclohexane	lb/h	0	0	0	0	0	0																			
N-Hexane	lb/h	0	0	0	0	0	0																			
Hexanol	lb/h	0	0	0	0	0	0																			
Toluene	lb/h	0	0	0	0	0	0																			
2-Methylphenol	lb/h	0	0	0	0	0	0																			
3-Methyl-phenol	lb/h	0	0	0	0	0	0																			
Guaiacol	lb/h	0	0	0	0	0	0																			
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0																			
2-Methylhexane	lb/h	0	0	0	0	0	0																			
VinylPhenol	lb/h	0	0	0	0	0	0																			
O-Xylene	lb/h	0	0	0	0	0	0																			
Ethylbenzne	lb/h	0	0	0	0	0	0																			
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0																			
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0																			
Vanillyl alcohol	lb/h	0	0	0	0	0	0																			
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0																			
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0																			
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0																			
Ethylcyclohexane	lb/h	0	0	0	0	0	0																			
4-Methylheptane	lb/h	0	0	0	0	0	0																			
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0																			
Indane	lb/h	0	0	0	0	0	0																			
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0																			
Syringaldehyde	lb/h	0	0	0	0	0	0																			
n-Propylbenzene	lb/h	0	0	0	0	0	0																			
Naphthalene	lb/h	0	0	0	0	0	0																			
1-Naphthalenol	lb/h	0	0	0	0	0	0																			
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0																			
Tetralin	lb/h	0	0	0	0	0	0																			
Isoeugenol	lb/h	0	0	0	0	0	0																			
Decalin	lb/h	0	0	0	0	0	0																			
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0																			
1-Methyl naphthalene	lb/h	0	0	0	0	0	0																			
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0																			
Dibenzothiophene	lb/h	0	0	0	0	0	0																			
Biphenyl	lb/h	0	0	0	0	0	0																			
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0																			
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0																			
C14H20-N35	lb/h	0	0	0	0	0	0																			
C14H24-N5	lb/h	0	0	0	0	0	0																			
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0																			
C15H26-N4	lb/h	0	0	0	0	0	0																			
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0																			
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0																			
N-Cetane	lb/h	0	0	0	0	0	0																			
C18H26O	lb/h	0	0	0	0	0	0																			
C18H28	lb/h	0	0	0	0	0	0																			
C21H26O2	lb/h	0	0	0	0	0	0																			
C21H34	lb/h	0	0	0	0	0	0																			
C22H28O2	lb/h	0	0	0	0	0	0																			
Carbon	lb/h	0	0	0	0	0	0																			
Sulfur	lb/h	0	0	0	0	0	0																			
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0																			
Ash	lb/h	0	0	0	0	0	0																			
Wood	lb/h	0	0	0	0	0	0																			
Char	lb/h	0	0	0	0	0	0																			
Coke	lb/h	0	0	0	0	0	0																			

Heat	MMBtu/h
QH602	3
QCH603	0
QH607	-110
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

P-708
FLUE GAS SCRUBBER
CIRCULATION PUMP

M-703
FLUE GAS
SCRUBBER

M-704
FLUE GAS
STACK

M-701
COOLING
TOWER SYSTEM

P-701
COOLING
WATER PUMP

124
BLOWDOWN
TO T-860
PFD-61712-A804

ATM

M-704

FLUE GAS
FROM K-101
PFD-61712-A102

110

M-703

P-708

ATM
ATM

DRIFT
EVAP

718

M-701
WM701

BLOWDOWN
FROM H-603
PFD-61712-A603

600

COOLING TOWER
CHEMICALS

715

CWS
TO HEADER

CWR
FROM HEADER

P-701
WP701

CW USERS
H-314
H-374
K-390
K-580
M-708

QM701

NAOH
FROM P-705
PFD-61712-A702

SAND FILTER FILTRATE
FROM M-807
PFD-61712-A803

713
CT BLOWDOWN
TO T-860
PFD-61712-A804

MAKE-UP WATER

618
MAKE-UP WATER
TO P-601
PFD-61712-A601

815
MAKE-UP WATER
TO P-815
PFD-61712-A801

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 700: COOLING WATER & FLUE GAS SCRUBBER

Project No: 30482.00
Drawing: PFD-61712-A701
Rev: 2

PFD-61712-A701		110	124	600	618	713	715	718	815																
Total Flow	lb/h	883,124	22,360	7,067	7,064	10,788	2,581,093	2,581,093	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	155	119	113	60	90	90	110	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	14	14	15	15	15	75	60	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-1056	-152	-48	-48	-74	-17676	-17621	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	9,581	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	562,024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	57,307	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	106	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	49,518	22,360	7,067	7,064	10,788	2,581,093	2,581,093	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	204,575	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QM701	56
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
WM701	145	0
WP701	249	1
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

T-702
FIREWATER
STORAGE TANK

T-703
PURCHASED DIESEL
STORAGE TANK

T-704
AMMONIA
STORAGE TANK

T-705
CAUSTIC
STORAGE TANK

T-708
BFW CHEMICAL
STORAGE TANK

M-702
HYDRAULIC TRUCK DUMP
WITH SCALE

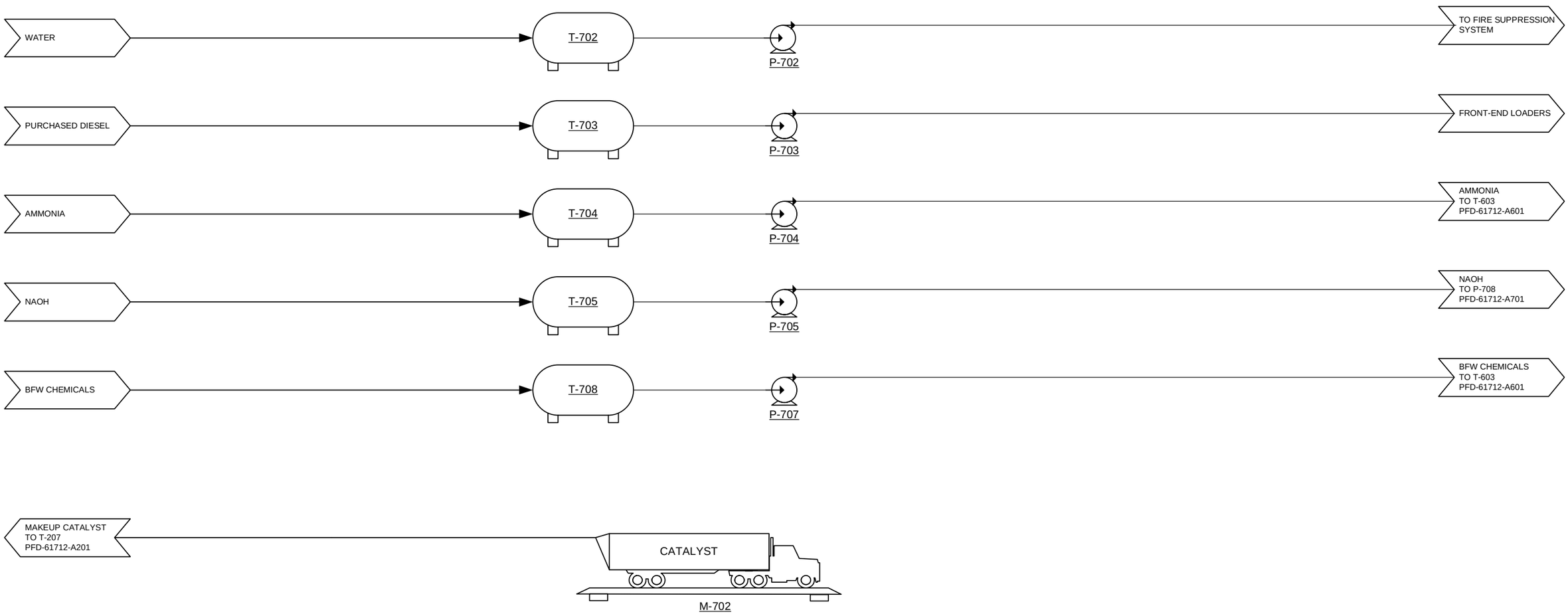
P-702
FIREWATER
PUMP

P-703
DIESEL
PUMP

P-704
AMMONIA
PUMP

P-705
CAUSTIC
PUMP

P-707
BFW CHEMICAL
PUMP



Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

ENGINEERING-PDH.COM
| CHE-136 |

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 700: MATERIALS STORAGE

Project No: 30482.00
Drawing: PFD-61712-A702
Rev. 1

PFD-61712-A702																										
Total Flow	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

K-701
PLANT AIR
COMPRESSOR

S-701
INSTRUMENT
AIR DRYER

T-701
PLANT AIR
RECEIVER

T-792
DIESEL PRODUCT
STORAGE TANK

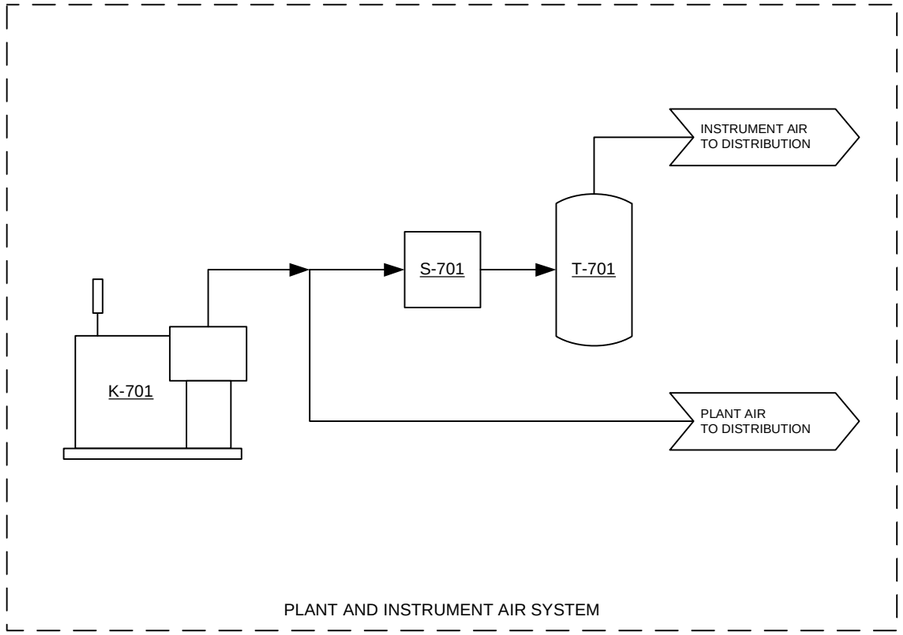
P-792
DIESEL PRODUCT
PUMP

T-790
GASOLINE PRODUCT
STORAGE TANK

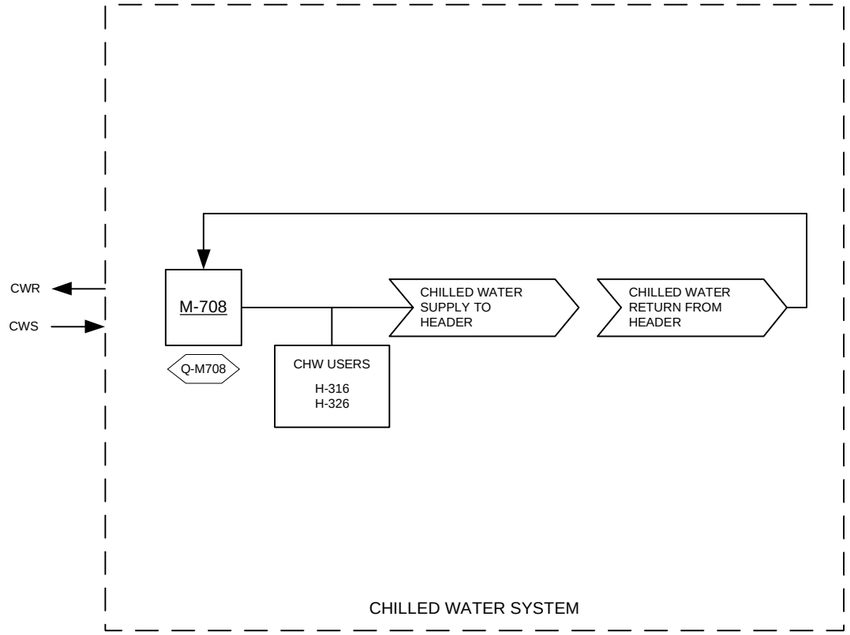
P-790
GASOLINE PRODUCT
PUMP

M-710
PRODUCT
LOADING RACK

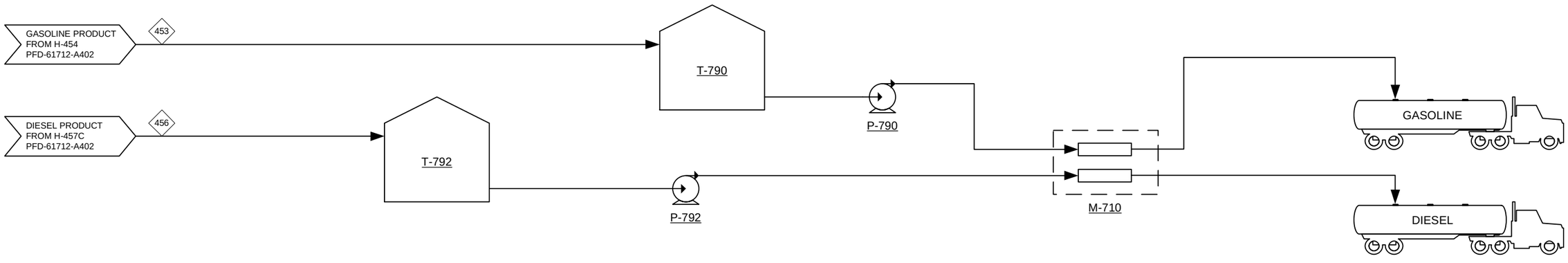
M-708
CHILLED WATER
SYSTEM



PLANT AND INSTRUMENT AIR SYSTEM



CHILLED WATER SYSTEM



Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

ENGINEERING-PDH.COM
| CHE-136 |

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 700: UTILITIES AND PRODUCT LOADOUT

Project No: 30482.00
Drawing: PFD-61712-A703
Rev: 2

PFD-61712-A703		453	456																						
Total Flow	lb/h	31,866	11,845	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	60	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	15	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-20	-8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	217	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	417	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	383	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	4,120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	2,214	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	1,685	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	1,706	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	1,628	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	1,874	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	1,165	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	4,306	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	4,864	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	388	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	305	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	858	248	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	437	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	3,035	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	116	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	11	533	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	1,696	476	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	1	1,388	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	916	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	144	4,498	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	1	879	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	2,263	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	162	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	283	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
Q-M708	24
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

P-815
BOILER MAKEUP
PUMP

T-810
BOILER FEED TANK

P-810
BOILER
CHARGE PUMP

H-811
BOILER
PREHEATER

H-812
WGS STEAM
BOILER

T-812
STEAM
DRUM

P-812
CONDENSATE
PUMP

T-814
BOILER FEED TANK

P-814
BOILER
CHARGE PUMP

T-822
STEAM
DRUM

H-822
REFORMER
STEAM BOILER

P-822
CONCENTRATED
WASTEWATER PUMP

AQUEOUS PHASE
FROM S-329
PFD-61712-A302

334

T-810

P-810

W-P810

H-811

Q-H811

812

H-812

Q-H812

T-812

813

LP STEAM
TO H-367
PFD-61712-A303

814

P-812

W-P812

MAKEUP WATER
FROM
PFD-61712-A701

815

P-815

W-P815

T-814

822

P-814

W-P814

H-822

Q-H822

T-822

823

LP STEAM
TO H-525
PFD-61712-A501

825

CONC WASTE WATER
TO K-831
PFD-61712-A802

P-822

W-P822

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 800: WASTEWATER MANAGEMENT

Project No: 30482.00

Drawing: PFD-61712-A801

Rev: 1

PFD-61712-A801		334	812	813	814	815	822	823	825																
Total Flow	lb/h	77,273	77,273	29,556	47,717	0	47,717	41,466	6,251	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	85	359	354	354	60	354	356	356	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	104	150	140	145	15	145	135	140	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-513	-490	-167	-297	0	-297	-232	-29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	74,271	74,271	29,430	44,840	0	44,840	40,842	3,999	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	89	89	47	42	0	42	37	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	2,909	2,909	75	2,833	0	2,833	587	2,247	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QH811	-23
QH812	-26
QH822	-37
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

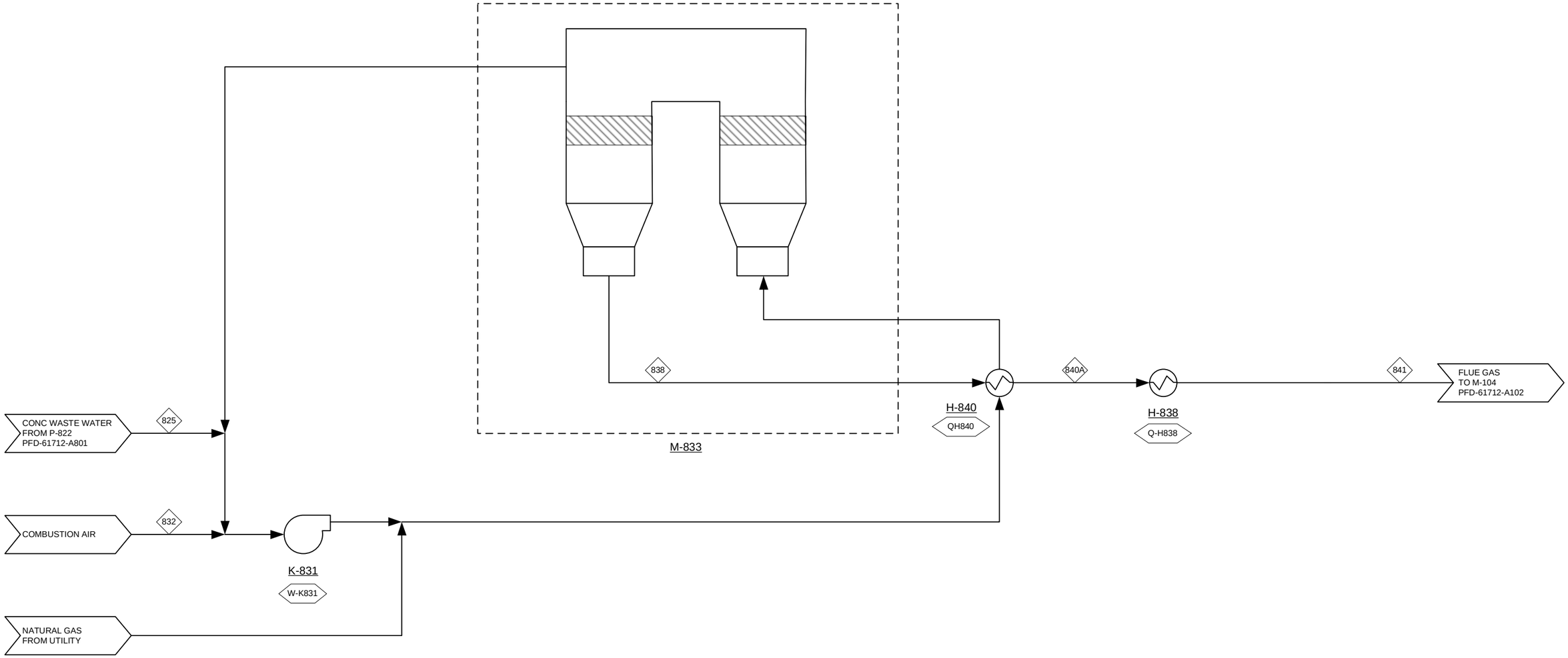
Work	hp	MMBtu/h
WP810	10	0
WP812	1	0
WP814	1	0
WP815	0	0
WP822	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

K-831
RTO
BLOWER

M-833
AQUEOUS REGENERATIVE
THERMAL OXIDIZER

H-840
RTO FEED/EFFLUENT
EXCHANGER

H-838
HEAT
RECOVERY



Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

Rev.	Date	By	Description
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Harris Group

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 800: AQUEOUS RTO

Project No: 30482.00
Drawing: PFD-61712-A802
Rev: 1

PFD-61712-A802		825	832	838	840A	841																			
Total Flow	lb/h	6,251	166,893	173,143	173,143	173,143	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	356	90	862	270	229	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	140	15	22	19	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-29	-19	-34	-61	-63	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	2,108	2,108	2,108	2,108	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	123,581	123,581	123,581	123,581	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	37,865	33,609	33,609	33,609	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	3,999	3,256	8,361	8,361	8,361	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	82	5,485	5,485	5,485	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	2,247	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
Q-H838	19
QH840	2
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
W-K831	2,222	6
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

T-801
CLARIFIER
OVERFLOW TANK

P-801
CLARIFIER
OVERFLOW PUMP

M-807
SAND
FILTER

M-805
CLARIFIER

T-809
SLURRY
TANK

P-809
SLURRY
PUMP

M-806
BELT
PRESS

SOLIDS
FROM S-319/S-324/S-329
PFD-61712-A302

335

WASTE WATER
FROM S-411/S-461/M-861
PFD-61712-A804

880

FLOCCULANT/
COAGULANT

SOLIDS TO DISPOSAL

M-806

M-805

T-809

P-809

T-801

P-801

M-807

BACKWASH

SAND FILTER FILTRATE
TO M-701/P-708
PFD-61712-A701

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 800: CLARIFIER AND SAND FILTER

Project No: 30482.00

Drawing: PFD-61712-A803

Rev: 2

PFD-61712-A803		335	880																							
Total Flow	lb/h	43	21,470	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	90	111	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	104	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	0	-146	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	5	21,410	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

T-860
RO FEED TANK

P-860
RO FEED PUMP

M-861
REVERSE OSMOSIS
UNIT

T-866
CLEAN WATER
TANK

P-866
CLEAN WATER
PUMP

AQUEOUS PHASE
FROM S-411
PFD-61712-A401

424

AQUEOUS PHASE
FROM S-461
PFD-61712-A403

474

880

WASTE WATER
TO M-805
PFD-61712-A803

BLOWDOWN
FROM P-708
PFD-61712-A701

124

CONDENSATE
FROM P-377
PFD-61712-A304

377

AQUEOUS PHASE
FROM S-412
PFD-61712-A401

430

CONDENSATE
FROM P-576
PFD-61712-A503

576

CT BLOWDOWN
FROM P-701
PFD-61712-A701

713

T-860

860

P-860

W-P860

864

RO BRINE

RO

M-861

865

T-866

P-866

W-P866

CLEAN WATER
HEADER

CLEAN WATER
TO R-202C/H-210B
PFD-61712-A201

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis In-Situ PFDs 61712 150128.vsd

Rev.	Date	By	Description
1	12/12/14	DMS	UPDATED EQ NUMBERS
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Harris Group

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
CATALYTIC FAST PYROLYSIS

PROCESS FLOW DIAGRAM
AREA 800: WASTEWATER REVERSE OSMOSIS

Project No: 30482.00

Drawing: PFD-61712-A804

Rev: 1

PFD-61712-A804		124	377	424	430	474	576	713	860	864	865	880													
Total Flow	lb/h	22,360	19,648	4,696	0	80	13,980	10,788	66,776	16,694	50,082	21,470	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	119	110	110	0	110	110	90	110	110	110	111	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	14	87	1793	0	1893	102	15	14	15	15	15	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-152	-134	-32	0	-1	-95	-74	-455	-114	-341	-146	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	36	0	0	0	0	0	0	0	36	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	22,360	19,552	4,660	0	80	13,979	10,788	66,679	16,670	50,009	21,410	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	1	0	0	0	1	0	3	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	19	0	0	0	0	0	19	5	14	5	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	75	0	0	0	0	0	75	19	56	19	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
W-P860	10	0
W-P866	2	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

Appendix G-2. Process Flow Diagrams and Stream Summary for the *Ex Situ* Case, Including Detailed Heat Exchange Network

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| CHE-136 |
This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

M-101
HYDRAULIC TRUCK
DUMP WITH SCALE

T-101
DUMP HOPPER

C-101
HOPPER FEEDER

C-102
SCREENER FEEDER
CONVEYOR

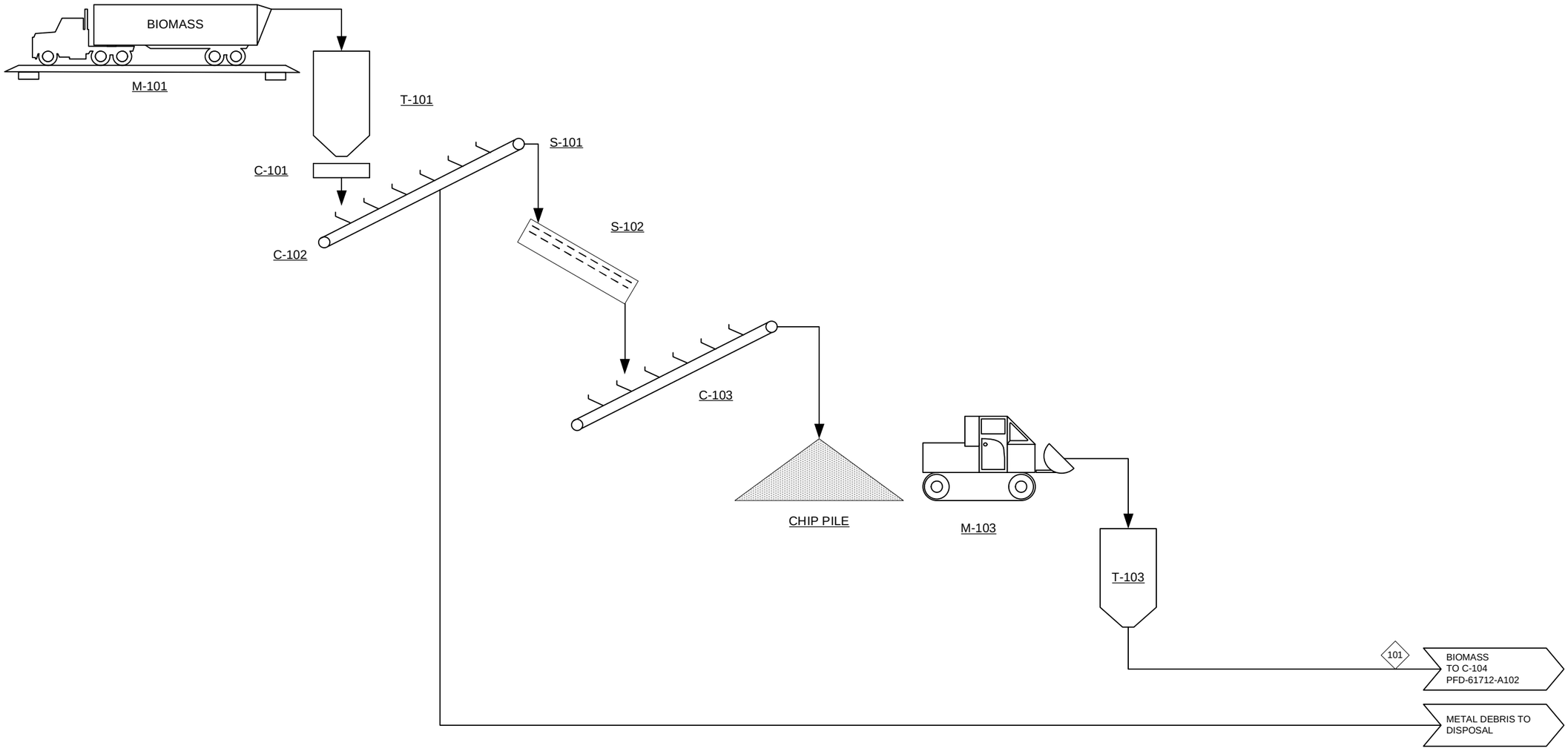
S-101
MAGNETIC
HEAD PULLEY

S-102
VIBRATORY
CONVEYOR

C-103
RADIAL STACKER
CONVEYOR

M-103
FRONT END
LOADERS

T-103
DRYER FEED
BIN



NOTE: FEEDSTOCK HANDLING COSTS ARE INCLUDED IN THE TARGET FEEDSTOCK COST PROVIDED BY THE IDAHO NATIONAL LABORATORY. ONLY A CROSS FLOW DRYER USING PROCESS FLUE GASES FOR FEED PREHEAT IS INCLUDED IN THE CONVERSION COST.

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 100: FEED HANDLING

Rev.	Date	By	Description
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Project No: 30482.00
Drawing: PFD-61712-A101
Rev: 1

ENGINEERING-PDH.COM
| CHE-136 |

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

PFD-61712-A101		101																							
Total Flow	lb/h	204,131	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-569	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	20,413	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	183,718	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

C-104
DRYER FEED SCREW
CONVEYOR

M-104
CROSS FLOW
PELLET DRYER

T-104
DRIED BIOMASS
HOPPER

T-105
LOCK
HOPPER

T-106
FEED
HOPPER

M-102
HAMMERMILL

T-102
HAMMERMILL
SURGE BIN

C-105
BIOMASS FEED
SCREW CONVEYOR

K-101
FLUE GAS
BLOWER

BIOMASS
FROM T-103
PFD-61712-A101

101

C-104

102

M-104

108

K-101

W-K101

110

FLUE GAS
TO M-703
PFD-61712-A701

103

T-104

FLUE GAS
FROM R-530
PFD-61712-A501-A

549

FLUE GAS
FROM H-BP-16
PFD-61712-A201

239P

107

FLUE GAS
FROM H-BP-13
PFD-61712-A802

841

VPU FLUE GAS
FROM H-BP-17
PFD-61712-A202

297

M-102

T-102

104

T-105

PRESSURIZED INERT
GASES

T-106

105

MILLED BIOMASS
TO R-211
PFD-61712-A201

C-105

NOTE: FEEDSTOCK HANDLING COSTS ARE INCLUDED IN THE TARGET FEEDSTOCK COST PROVIDED BY THE IDAHO NATIONAL LABORATORY. ONLY A CROSS FLOW DRYER USING PROCESS FLUE GASES FOR FEED PREHEAT IS INCLUDED IN THE CONVERSION COST.

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 100: FEED HANDLING AND DRYING

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Project No: 30482.00
Drawing: PFD-61712-A102
Rev: 2

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.rsd

PFD-61712-A102		101	102	103	104	105	107	108	110	239P	297	549	841												
Total Flow	lb/h	204,131	204,131	204,131	204,131	204,131	770,436	770,436	770,436	258,265	210,963	220,944	80,265	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	60	60	218	218	218	243	160	160	245	245	245	245	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	15	16	16	16	125	17	16	16	109	105	17	17	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-569	-569	-553	-553	-553	-989	-1005	-1005	-284	-213	-463	-28	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	8,183	8,183	8,183	3,005	2,478	1,721	979	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	480,047	480,047	480,047	176,443	145,311	100,912	57,382	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	38,240	38,240	38,240	8,996	7,421	6,218	15,606	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	107	107	107	85	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	17	17	17	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	20,413	20,413	20,413	20,413	20,413	42,895	42,895	42,895	13,826	3,830	21,487	3,752	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	0	0	0	0	200,947	200,947	200,947	55,910	51,924	90,566	2,547	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	183,718	183,718	183,718	183,718	183,718	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
W-K101	383	1
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

K-211 FLUIDIZING GAS RECYCLE COMPRESSOR
K-212 COMBUSTOR AIR COMPRESSOR
R-211 FLUIDIZED BED REACTOR
S-211 PRIMARY CYCLONE
S-212 SECONDARY CYCLONE
T-211 BED MEDIA BIN
T-212 DEPLETED BED MEDIA AND ASH STORAGE BIN
R-212 CHAR COMBUSTOR
R-212C SAND COOLER
H-AP-1 CHAR COMBUSTOR SAND COOLER/ STEAM PRODUCTION
H-AP-2 CHAR COMBUSTOR SAND COOLER/STEAM SUPERHEAT
S-213 CHAR COMBUSTOR PRIMARY CYCLONE
S-214 CHAR COMBUSTOR SECONDARY CYCLONE
C-212 FINES PURGE COOLER
T-217 CHAR COMBUSTOR BED MEDIA FEED BIN

COMBUSTION AIR
223P
K-212
W-K212
QA-K212
224P
COMBUSTION AIR TO H-AP-17 PFD-61712-A203
225P
COMBUSTION AIR FROM H-AP-38 PFD-61712-A203
232P
FLUE GAS TO H-AP-9 PFD-61712-A203
FLUE GAS FROM H-BP-16 PFD-61712-A203
239P
FLUE GAS TO M-104 PFD-61712-A102
261
PYROLYSIS VAPOR TO R-261 PFD-61712-A202
213P
S-212
228P
S-214
S-211
S-213
233P
C-212
QC-M212
212P
216P
214P
T-212
235-P
DEPLETED MEDIA/ASH TO DISPOSAL
217P
OLIVINE FROM M-702 PFD-61712-A702
R-212
T-217
R-211
T-211
MILLED BIOMASS FROM C-105 PFD-61712-A102
105
205P
H-AP-2
QHAP2
SUPERHEATED STEAM TO M-602 PFD-61712-A603
SATURATED STEAM FROM T-605 PFD-61712-A603
H-AP-1
QHAP1
FLUIDIZATION AIR
R-212C
LIFT AIR
SATURATED STEAM TO T-605 PFD-61712-A603
SATURATED WATER FROM H-AP-51 PFD-61712-A603
FLUIDIZING GAS FROM M-385/M-575/H-315 PFD-61712-A302
346
K-211
W-K211
203P
FLUIDIZING GAS TO H-BP-36 PFD-61712-A203
FLUIDIZING GAS FROM H-AP-8 PFD-61712-A203
204P

Plot date: 3/16/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150316.vsd

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Harris Group
NREL NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 200: FAST PYROLYSIS

Project No: 30482.00
Drawing: PFD-61712-A201
Rev: 2

PFD-61712-A201		105	203P	204P	205P	212P	213P	214P	216P	217P	223P	224P	225P	228P	232P	233P	235P	239P	261	346						
Total Flow	lb/h	204,131	140,215	140,215	1,438,038	1,782,384	323,959	1,458,425	1,643	158	237,911	237,911	237,911	260,099	258,265	1,834	2,038	258,265	322,317	140,215	0	0	0	0	0	0
Temperature	F	218	160	800	0	932	932	0	0	0	90	287	600	1328	1328	0	210	245	932	96	0	0	0	0	0	0
Pressure	Psia	125	127	123	125	121	120	120	119	130	15	123	119	115	115	115	15	109	119	95	0	0	0	0	0	0
Vapor Fraction		0	1	1	0	1	1	0	0	0	1	1	1	1	1	0	0	1	1	1	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-553	-231	-152	-8896	-9616	-540	-9076	-9	-1	-27	-15	4	-209	-208	-1	-3	-284	-531	-239	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	3,005	3,005	3,005	3,005	3,005	0	0	3,005	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	176,169	176,169	176,169	176,443	176,443	0	0	176,443	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	53,978	53,978	53,978	8,996	8,996	0	0	8,996	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	85	85	0	0	85	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	24,531	24,531	0	24,531	24,531	0	0	0	0	0	0	0	0	0	0	0	24,531	24,531	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	20,413	353	353	0	40,227	40,227	0	0	0	4,642	4,642	4,642	13,826	13,826	0	204	13,826	40,227	353	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	47,501	47,501	0	56,944	56,944	0	0	0	0	0	0	0	0	0	0	0	56,944	47,501	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	40,152	40,152	0	53,301	53,301	0	0	0	117	117	117	55,910	55,910	0	0	55,910	53,301	40,152	0	0	0	0	0	0
Methane	lb/h	0	5,884	5,884	0	6,696	6,696	0	0	0	0	0	0	0	0	0	0	0	6,696	5,884	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	1,250	1,250	0	0	0	0	0	0	0	0	0	0	0	1,250	0	0	0	0	0	0	0
Ethylene	lb/h	0	11,780	11,780	0	12,187	12,187	0	0	0	0	0	0	0	0	0	0	0	12,187	11,780	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	5,688	5,688	0	0	0	0	0	0	0	0	0	0	0	5,688	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	9,247	9,247	0	0	0	0	0	0	0	0	0	0	0	9,247	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	3,982	3,982	0	4,006	4,006	0	0	0	0	0	0	0	0	0	0	0	4,006	3,982	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	2,082	2,082	0	0	0	0	0	0	0	0	0	0	0	2,082	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	924	924	0	0	0	0	0	0	0	0	0	0	0	924	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	500	500	0	500	500	0	0	0	0	0	0	0	0	0	0	0	500	500	0	0	0	0	0	0
1-Butene	lb/h	0	1,975	1,975	0	2,004	2,004	0	0	0	0	0	0	0	0	0	0	0	2,004	1,975	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	422	422	0	422	422	0	0	0	0	0	0	0	0	0	0	0	422	422	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	3,195	3,195	0	0	0	0	0	0	0	0	0	0	0	3,195	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	466	466	0	466	466	0	0	0	0	0	0	0	0	0	0	0	466	466	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	5,829	5,829	0	0	0	0	0	0	0	0	0	0	0	5,829	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	14	14	0	446	446	0	0	0	0	0	0	0	0	0	0	0	446	14	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	6,366	6,366	0	0	0	0	0	0	0	0	0	0	0	6,366	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	2	2	0	2	2	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	3,212	3,212	0	0	0	0	0	0	0	0	0	0	0	3,212	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	3,118	3,118	0	0	0	0	0	0	0	0	0	0	0	3,118	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	584	584	0	0	0	0	0	0	0	0	0	0	0	584	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	19,211	19,211	0	0	0	0	0	0	0	0	0	0	0	19,211	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	1,250	1,250	0	0	0	0	0	0	0	0	0	0	0	1,250	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	1	1	0	8,521	8,521	0	0	0	0	0	0	0	0	0	0	0	8,521	1	0	0	0	0	0	0
Cyclohexane	lb/h	0	1,673	1,673	0	1,673	1,673	0	0	0	0	0	0	0	0	0	0	0	1,673	1,673	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	324	324	0	0	0	0	0	0	0	0	0	0	0	324	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	191	191	0	191	191	0	0	0	0	0	0	0	0	0	0	0	191	191	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	13,119	13,119	0	0	0	0	0	0	0	0	0	0	0	13,119	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	2	2	0	2	2	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	3	3	0	333	333	0	0	0	0	0	0	0	0	0	0	0	333	3	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	295	295	0	295	295	0	0	0	0	0	0	0	0	0	0	0	295	295	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	484	484	0	484	484	0	0	0	0	0	0	0	0	0	0	0	484	484	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	9,901	9,901	0	0	0	0	0	0	0	0	0	0	0	9,901	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	2,503	2,503	0	0	0	0	0	0	0	0	0	0	0	2,503	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	21,188	21,188	0	0	0	0	0	0	0	0	0	0	0	21,188	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	73	73	0	0	0	0	0	0	0	0	0	0	0	73	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	1,437,949	1,437,949	1,438	1,436,511	1,424	158	0	0	0	144	0	144	144	0	14	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	89	89	1	88	1	0	0	0	0	1,690	0	1,690	1,690	0	0	0	0	0	0	0	0	0
Wood	lb/h	183,718	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	22,046	220	21,826	218	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QA-K212	23
QC-M212	0
QHAP1	5
QHAP2	3
Q-ST212A	-7
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
W-K211	2,887	7
W-K212	13,584	35
	0	0
	0	0
	0	0

K-262 REGENERATOR AIR COMPRESSOR | R-261 CATALYTIC FLUIDIZED BED REACTOR | H-AP-5 EX-SITU CATALYST RETURN COOLER/ STEAM PRODUCTION | H-AP-6 EX-SITU CATALYST RETURN COOLER STEAM SUPERHEAT | S-261 PRIMARY CYCLONE | S-262 SECONDARY CYCLONE | T-261 CATALYST STEAM STRIPPER | R-262C1 CATALYST COOLER | R-262 CATALYST REGENERATOR | H-AP-3 EX-SITU CATALYST REGEN COOLER/ STEAM PRODUCTION | H-AP-4 EX-SITU CATALYST REGEN COOLER/ STEAM SUPERHEAT | R-262C CATALYST COOLER | S-263 CHAR COMBUSTOR PRIMARY CYCLONE | S-264 CHAR COMBUSTOR SECONDARY CYCLONE | C-262 FINES PURGE COOLER | T-262 DEPLETED CATALYST AND ASH STORAGE BIN | T-267 CATALYST FEED BIN

COMBUSTION AIR

283

K-262

W-K262

QA-K262

284

COMBUSTION AIR TO H-AP-18 PFD-61712-A203

COMBUSTION AIR FROM H-AP-39 PFD-61712-A203

285

292

VPU FLUE GAS TO H-AP-49 PFD-61712-A203

VPU FLUE GAS FROM H-BP-17 PFD-61712-A203

297

VPU FLUE GAS TO M-104 PFD-61712-A102

300

PYROLYSIS VAPOR TO H-AP-48 PFD-61712-A301

275

273

S-262

288

S-264

272

S-261

276

S-263

293

C-262

QC-M262

T-262

268

274

295

DEPLETED CATALYST/ ASH TO DISPOSAL

277

MAKEUP CATALYST FROM M-702 PFD-61712-A702

1

R-262

T-267

285A

T-261

287

H-AP-4

QHAP4

H-AP-3

QHAP3

H-AP-6

QHAP6

H-AP-5

QHAP5

FLUIDIZATION AIR

R-262C

LIFT AIR

SUPERHEATED STEAM TO M-602 PFD-61712-A603

SATURATED STEAM FROM T-605 PFD-61712-A603

SATURATED STEAM TO T-605 PFD-61712-A603

R-261

265

R-262C-1

PYROLYSIS VAPOR FROM S-212 PFD-61712-A201

261

SATURATED WATER FROM H-AP-51 PFD-61712-A603

270

STEAM FROM H-AP-46 PFD-61712-A804

(1) NOTE: STREAM 277 FOR ATTRITION MAKEUP. ADDITIONAL MAKEUP TO MAINTAIN ACTIVITY AS IN TABLE 4.

Plot date: 3/16/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150316.vsd

Harris Group

NREL NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 200: VAPOR PHASE UPGRADING

Rev.	Date	By	Description
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Project No: 30482.00 | Drawing: PFD-61712-A202 | Rev: 1

ENGINEERING-PDH.COM
| CHE-136 |

PFD-61712-A202		261	265	268	270	272	273	274	275	276	277	283	284	285	285A	287	288	289	292	293	295	297	300		
Total Flow	lb/h	322,317	918,615	1,240,932	2,756	1,243,687	311,397	932,291	310,342	1,055	101	196,238	196,238	196,238	196,238	918,615	211,055	210,963	210,963	92	102	210,963	310,342	0	0
Temperature	F	932	0	932	555	931	931	0	931	0	0	90	285	600	600	0	1202	1202	1202	0	213	245	931	0	0
Pressure	Psia	119	120	117	135	117	116	116	115	115	129	15	119	115	115	120	111	111	111	111	15	105	115	0	0
Vapor Fraction		1	0	1	1	1	1	0	1	0	0	1	1	1	1	0	1	1	1	0	0	1	1	0	0
Enthalpy Flow	MMBtu/h	-531	-5869	-6407	-15	-6422	-643	-5779	-638	-6	-1	-22	-13	3	3	-5722	-161	-160	-160	-1	-1	-213	-638	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	2,478	2,478	2,478	2,478	0	2,478	2,478	2,478	0	0	2,478	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	145,311	145,311	145,311	145,311	0	145,311	145,311	145,311	0	0	145,311	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	44,523	44,523	44,523	44,523	0	7,421	7,421	7,421	0	0	7,421	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	24,531	0	21,258	0	21,258	21,258	0	21,258	0	0	0	0	0	0	0	0	0	0	0	0	0	21,258	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	40,227	0	73,915	2,756	76,670	76,670	0	76,670	0	0	3,829	3,829	3,829	3,829	0	3,830	3,830	3,830	0	10	3,830	76,670	0	0
Carbon Monoxide	lb/h	56,944	0	66,248	0	66,248	66,248	0	66,248	0	0	0	0	0	0	0	0	0	0	0	0	0	66,248	0	0
Carbon Dioxide	lb/h	53,301	0	55,426	0	55,426	55,426	0	55,426	0	0	97	97	97	97	0	51,924	51,924	51,924	0	0	51,924	55,426	0	0
Methane	lb/h	6,696	0	8,325	0	8,325	8,325	0	8,325	0	0	0	0	0	0	0	0	0	0	0	0	0	8,325	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	1,250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	12,187	0	16,692	0	16,692	16,692	0	16,692	0	0	0	0	0	0	0	0	0	0	0	0	0	16,692	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	5,688	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	9,247	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	4,006	0	5,682	0	5,682	5,682	0	5,682	0	0	0	0	0	0	0	0	0	0	0	0	0	5,682	0	0
1-Hydroxy-2-propanone	lb/h	2,082	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	924	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	500	0	845	0	845	845	0	845	0	0	0	0	0	0	0	0	0	0	0	0	0	845	0	0
1-Butene	lb/h	2,004	0	2,919	0	2,919	2,919	0	2,919	0	0	0	0	0	0	0	0	0	0	0	0	0	2,919	0	0
Tetrahydrofuran	lb/h	422	0	1,046	0	1,046	1,046	0	1,046	0	0	0	0	0	0	0	0	0	0	0	0	0	1,046	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	3,195	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	466	0	1,144	0	1,144	1,144	0	1,144	0	0	0	0	0	0	0	0	0	0	0	0	0	1,144	0	0
Furfuryl Alcohol	lb/h	5,829	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	446	0	2,161	0	2,161	2,161	0	2,161	0	0	0	0	0	0	0	0	0	0	0	0	0	2,161	0	0
1,2-Benzenediol	lb/h	0	0	1,872	0	1,872	1,872	0	1,872	0	0	0	0	0	0	0	0	0	0	0	0	0	1,872	0	0
Hydroxymethylfurfural	lb/h	6,366	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	2	0	13	0	13	13	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0
Methyl Cyclopentenone	lb/h	3,212	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	3,118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	584	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	19,211	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	1,250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	8,521	0	38	0	38	38	0	38	0	0	0	0	0	0	0	0	0	0	0	0	0	38	0	0
Cyclohexane	lb/h	1,673	0	5,348	0	5,348	5,348	0	5,348	0	0	0	0	0	0	0	0	0	0	0	0	0	5,348	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	324	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Methyl-Cyclohexane	lb/h	191	0	990	0	990	990	0	990	0	0	0	0	0	0	0	0	0	0	0	0	0	990	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	13,119	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	2	0	2,627	0	2,627	2,627	0	2,627	0	0	0	0	0	0	0	0	0	0	0	0	0	2,627	0	0
2,6-dimethoxyphenol	lb/h	0	0	898	0	898	898	0	898	0	0	0	0	0	0	0	0	0	0	0	0	0	898	0	0
Vanillyl alcohol	lb/h	0	0	870	0	870	870	0	870	0	0	0	0	0	0	0	0	0	0	0	0	0	870	0	0
2,4,6-Trimethylpyridine	lb/h	333	0	333	0	333	333	0	333	0	0	0	0	0	0	0	0	0	0	0	0	0	333	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	295	0	3,060	0	3,060	3,060	0	3,060	0	0	0	0	0	0	0	0	0	0	0	0	0	3,060	0	0
Trans-1,2-dimethylcyclohexane	lb/h	484	0	4,153	0	4,153	4,153	0	4,153	0	0	0	0	0	0	0	0	0	0	0	0	0	4,153	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	1	0	463	0	463	463	0	463	0	0	0	0	0	0	0	0	0	0	0	0	0	463	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	13	0	13	13	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0
Syringaldehyde	lb/h	9,901	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	2,503	0	353	0	353	353	0	353	0	0	0	0	0	0	0	0	0	0	0	0	0	353	0	0
Coniferyl Aldehyde	lb/h	21,188	0	381	0	381	381	0	381	0	0	0	0	0	0	0	0	0	0	0	0	0	381	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	13	0	13	13	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0
Decalin	lb/h	0	0	44	0	44	44	0	44	0	0	0	0	0	0	0	0	0	0	0	0	0	44	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	417	0	417	417	0	417	0	0	0	0	0	0	0	0	0	0	0	0	0	417	0	0
1-methyl decahydronaphthene	lb/h	0	0	62	0	62	62	0	62	0	0	0	0	0	0	0	0	0	0	0	0	0	62	0	0
Dibenzothiophene	lb/h	73	0	73	0	73	73	0	73	0	0	0	0	0	0	0	0	0	0	0	0	0	73	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	4,709	0	4,709	4,709	0	4,709	0	0	0	0	0	0	0	0	0	0	0	0	0	4,709	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	3,313	0	3,313	3,313	0	3,313	0	0	0	0	0	0	0	0	0	0	0	0	0	3,313	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	1	0	3,555	0	3,555	3,555	0	3,555	0	0	0	0	0	0	0	0	0	0	0	0	0	3,555	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	427	0	427	427	0	427	0	0	0	0	0	0	0	0	0	0	0	0	0	427	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	4,923	0	4,923	4,923	0	4,923	0	0	0	0	0	0	0	0	0	0	0	0	0	4,923	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	3,421	0	3,421	3,421	0	3,421	0	0	0	0	0	0	0	0	0	0	0	0	0	3,421	0	0
C21H34	lb/h	0	0	7,754	0	7,754	7,754	0	7,754	0	0	0	0	0	0	0	0	0	0	0	0	0	7,754	0	0
C22H28O2	lb/h	0	0	1,788	0	1,788	1,788	0	1,788	0	0	0	0	0	0	0	0	0	0	0	0	0	1,788	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	14	918,615	918,629	0	918,629	919	917,711	9	909	101	0	0	0	0	918,615	92	0	0	92	92	0	9	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	2	0	2	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	14,725	0	14,725	147	14,578	1	146	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Heat	MMBtu/h
QA-K262	19
QC-M262	0
QHAP3	60
QHAP4	33
QHAP5	121
QHAP6	26

Work	hp	MMBtu/h
W-K262	11,036	28

H-AP-17
POST-ABSORBER 1 VAPOR COOLER/CHAR COMBUSTOR AIR PREHEAT

H-AP-18
POST-ABSORBER 1 VAPOR COOLER/EX-SITU CATALYST REGEN AIR PREHEAT

H-AP-38
EX-SITU CATALYST REGEN FLUE GAS COOLER/CHAR COMBUSTOR AIR PREHEAT

H-AP-39
EX-SITU CATALYST REGEN FLUE GAS COOLER/EX-SITU CATALYST REGEN AIR PREHEAT

H-AP-8
CHAR COMBUSTOR FLUE GAS COOLER/FAST PYROLYSIS FLUIDIZING GAS PREHEAT

FLUE GAS FROM S-214 PFD-61712-A201
232P
FLUE GAS TO H-AP-9 PFD-61712-A602
FLUE GAS FROM H-AP-9 PFD-61712-A602
H-AP-8
QHAP8
204P
FLUIDIZING GAS TO R-211/T-211 PFD-61712-A201
FLUE GAS TO H-BP-21 PFD-61712-A605
FLUE GAS FROM H-BP-21 PFD-61712-A605
FLUE GAS TO H-BP-16 PFD-61712-A604
FLUE GAS FROM H-BP-16 PFD-61712-A604
239P
FLUE GAS TO M-104 PFD-61712-A201

FLUIDIZING GAS FROM K-211 PFD-61712-A201
203P
FLUIDIZING GAS TO H-BP-36 PFD-61712-A303
FLUIDIZING GAS FROM H-BP-36 PFD-61712-A303
FLUIDIZING GAS TO H-BP-3 PFD-61712-A305
FLUIDIZING GAS FROM H-BP-3 PFD-61712-A305

VPU FLUE GAS FROM S-264 PFD-61712-A202
289
VPU FLUE GAS TO H-AP-49 PFD-61712-A603
VPU FLUE GAS FROM H-AP-49 PFD-61712-A603
H-AP-38
QHAP38
225P
COMBUSTION AIR TO R-212 PFD-61712-A201
VPU FLUE GAS TO H-AP-37 PFD-61712-A605
VPU FLUE GAS FROM H-AP-37 PFD-61712-A605
VPU FLUE GAS TO H-BP-40 PFD-61712-A601
VPU FLUE GAS FROM H-BP-40 PFD-61712-A601
VPU FLUE GAS TO H-BP-17 PFD-61712-A604
VPU FLUE GAS FROM H-BP-17 PFD-61712-A604
297
VPU FLUE GAS TO M-104 PFD-61712-A202

ABSORBER VAPOR TO H-BP-3/H-BP-20 PFD-61712-A305
COMBUSTION AIR FROM K-212 PFD-61712-A201
224P
H-AP-17
QHAP17
285
COMBUSTION AIR TO R-262 PFD-61712-A202
ABSORBER VAPOR FROM D-301 PFD-61712-A305
VPU FLUE GAS TO H-BP-22 PFD-61712-A605
VPU FLUE GAS FROM H-BP-22 PFD-61712-A605
VPU FLUE GAS TO H-BP-41 PFD-61712-A804
VPU FLUE GAS FROM H-BP-41 PFD-61712-A804
VPU FLUE GAS TO H-BP-42 PFD-61712-A801
VPU FLUE GAS FROM H-BP-42 PFD-61712-A801

ABSORBER VAPOR TO H-BP-3/H-BP-20 PFD-61712-A305
H-AP-39
QHAP39
COMBUSTION AIR FROM K-262 PFD-61712-A202
284
H-AP-18
QHAP18
ABSORBER VAPOR FROM D-301 PFD-61712-A305

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Rev.	Date	By	Description
0	12/12/14	DMS	ADDED HX NETWORK

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Harris Group

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 200: A200 HEAT RECOVERY

Project No: 30482.00
Drawing: PFD-61712-A203
Rev: 0

PFD-61712-A203		203P	204P	224P	225P	232P	239P	284	285	289	297														
Total Flow	lb/h	140,215	140,215	237,911	237,911	258,265	258,265	196,238	196,238	210,963	210,963	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	160	800	287	600	1328	245	285	600	1202	245	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	127	123	123	119	115	109	119	115	111	105	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-231	-152	-15	4	-208	-284	-13	3	-160	-213	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	3,005	3,005	3,005	3,005	2,478	2,478	2,478	2,478	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	176,169	176,169	176,443	176,443	145,311	145,311	145,311	145,311	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	53,978	53,978	8,996	8,996	44,523	44,523	7,421	7,421	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	85	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	24,531	24,531	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	353	353	4,642	4,642	13,826	13,826	3,829	3,829	3,830	3,830	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	47,501	47,501	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	40,152	40,152	117	117	55,910	55,910	97	97	51,924	51,924	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	5,884	5,884	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	11,780	11,780	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	3,982	3,982	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	500	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	1,975	1,975	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	422	422	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	466	466	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	14	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	1,673	1,673	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	191	191	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	295	295	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	484	484	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N3S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QHAP8	64
QHAP17	3
QHAP18	3
QHAP38	16
QHAP39	13
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0

D-301
HEAVY FRACTION
CONDENSER ABSORBER

P-318
D-301 BOTTOMS
PUMP

H-313
D-301 VAPOR ACHE

S-319
D-301 BOTTOMS
FILTER

P-332
QUENCH RECYCLE
PUMP

H-314
D-302 FEED
COOLER

T-332
D-301 CIRCULATION
SURGE TANK

H-315
D-302 FEED/OVERHEAD
HEAT EXCHANGER

H-320
HEAVY FRACTION
ACHE

H-316
D-302 LIQUID FEED
CHILLER

PYROLYSIS VAPOR
FROM S-262/T-261
PFD-61712-A202

300

PYROLYSIS VAPOR
TO H-AP-48
PFD-61712-A305

PYROLYSIS VAPOR
FROM H-AP-53/56/60
PFD-61712-A305

311

D-301

312

ABSORBER VAPOR
TO H-AP-17/18/31
PFD-61712-A305

ABSORBER VAPOR
FROM H-BP-3/H-BP-11
PFD-61712-A305

313

H-313

QA-H313

314

CWR

CWS

H-314

QC-H314

315

OFFGAS
FROM D-302
PFD-61712-A302

321

H-315

QX-H315

316

CHWR

CHWS

H-316

QCH-H316

317

VAPOR PHASE
TO D-302
PFD-61712-A302

340

OFFGAS
TO
PFD-61712-A302

332

RECYCLED ORGANICS
FROM S-324
PFD-61712-A302

T-332

333

P-332

W-P332

318

ABSORBER BOTTOMS
TO H-AP-23
PFD-61712-A305

ABSORBER BOTTOMS
FROM H-BP-44
PFD-61712-A305

319

S-319

320

H-320

QA-H320

320A

ORGANIC PHASE
TO T-328
PFD-61712-A302

P-318

W-P318

335A

SOLIDS
TO M-805
PFD-61712-A302

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Rev.	Date	By	Description
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Harris Group

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 300: CONDENSATION STAGE 1

Project No: 30482.00

Drawing: PFD-61712-A301

Rev: 1

PFD-61712-A301		300	311	312	313	314	315	316	317	318	319	320	320A	321	332	333	335A	340
Total Flow	lb/h	310,342	310,342	371,714	371,714	371,714	371,714	371,714	371,714	19,671	19,671	19,660	19,660	182,444	81,043	81,043	11	182,444
Temperature	F	931	466	358	220	140	110	95	60	461	175	175	140	53	86	86	0	95
Pressure	Psia	115	113	110	108	106	104	102	100	113	123	108	103	97	110	113	123	95
Vapor Fraction		1	1	1	1	1	1	1	1	0	0	0	0	1	0	0	0	1
Enthalpy Flow	MMBtu/h	-638	-731	-786	-827	-904	-916	-921	-931	-7	-10	-10	-10	-336	-62	-62	0	-332
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	21,258	21,258	21,261	21,261	21,261	21,261	21,261	21,261	1	1	1	1	21,256	4	4	0	21,256
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	76,670	76,670	77,078	77,078	77,078	77,078	77,078	77,078	43	43	43	43	499	451	451	0	499
Carbon Monoxide	lb/h	66,248	66,248	66,266	66,266	66,266	66,266	66,266	66,266	3	3	3	3	66,238	21	21	0	66,238
Carbon Dioxide	lb/h	55,426	55,426	55,716	55,716	55,716	55,716	55,716	55,716	7	7	7	7	55,306	297	297	0	55,306
Methane	lb/h	8,325	8,325	8,333	8,333	8,333	8,333	8,333	8,333	1	1	1	1	8,321	8	8	0	8,321
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	16,692	16,692	16,766	16,766	16,766	16,766	16,766	16,766	2	2	2	2	16,661	76	76	0	16,661
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	5,682	5,682	5,810	5,810	5,810	5,810	5,810	5,810	1	1	1	1	5,632	129	129	0	5,632
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	845	845	1,212	1,212	1,212	1,212	1,212	1,212	1	1	1	1	707	367	367	0	707
1-Butene	lb/h	2,919	2,919	3,251	3,251	3,251	3,251	3,251	3,251	1	1	1	1	2,793	333	333	0	2,793
Tetrahydrofuran	lb/h	1,046	1,046	2,236	2,236	2,236	2,236	2,236	2,236	1	1	1	1	597	1,192	1,192	0	597
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	1,144	1,144	2,432	2,432	2,432	2,432	2,432	2,432	1	1	1	1	659	1,289	1,289	0	659
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	2,161	2,161	7,632	7,632	7,632	7,632	7,632	7,632	11	11	11	11	20	5,482	5,482	0	20
1,2-Benzenediol	lb/h	1,872	1,872	2,049	2,049	2,049	2,049	2,049	2,049	20	20	20	20	0	197	197	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	13	13	42	42	42	42	42	42	0	0	0	0	3	28	28	0	3
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	38	38	136	136	136	136	136	136	0	0	0	0	1	98	98	0	1
Cyclohexane	lb/h	5,348	5,348	13,262	13,262	13,262	13,262	13,262	13,262	9	9	9	9	2,367	7,922	7,922	0	2,367
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	1	1	4	4	4	4	4	4	0	0	0	0	0	3	3	0	0
Methyl-Cyclohexane	lb/h	990	990	2,898	2,898	2,898	2,898	2,898	2,898	2	2	2	2	270	1,911	1,911	0	270
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	1	1	5	5	5	5	5	5	0	0	0	0	0	3	3	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	2,627	2,627	9,506	9,506	9,506	9,506	9,506	9,506	30	30	30	30	3	6,910	6,910	0	3
2,6-dimethoxyphenol	lb/h	898	898	3,184	3,184	3,184	3,184	3,184	3,184	29	29	29	29	0	2,316	2,316	0	0
Vanillyl alcohol	lb/h	870	870	3,063	3,063	3,063	3,063	3,063	3,063	32	32	32	32	0	2,225	2,225	0	0
2,4,6-Trimethylpyridine	lb/h	333	333	1,203	1,203	1,203	1,203	1,203	1,203	2	2	2	2	4	872	872	0	4
Cis-1,2-dimethyl cyclohexane	lb/h	3,060	3,060	10,060	10,060	10,060	10,060	10,060	10,060	12	12	12	12	417	7,012	7,012	0	417
Trans-1,2-dimethylcyclohexane	lb/h	4,153	4,153	13,344	13,344	13,344	13,344	13,344	13,344	14	14	14	14	685	9,205	9,205	0	685
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	463	463	1,673	1,673	1,673	1,673	1,673	1,673	5	5	5	5	2	1,216	1,216	0	2
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	13	13	49	49	49	49	49	49	0	0	0	0	0	35	35	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	353	353	1,236	1,236	1,236	1,236	1,236	1,236	16	16	16	16	0	898	898	0	0
Coniferyl Aldehyde	lb/h	381	381	30	30	30	30	30	30	373	373	373	373	0	22	22	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	13	13	48	48	48	48	48	48	0	0	0	0	0	35	35	0	0
Decalin	lb/h	44	44	158	158	158	158	158	158	0	0	0	0	0	114	114	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	417	417	1,489	1,489	1,489	1,489	1,489	1,489	11	11	11	11	0	1,082	1,082	0	0
1-methyl decahydronaphthene	lb/h	62	62	222	222	222	222	222	222	1	1	1	1	0	161	161	0	0
Dibenzothiophene	lb/h	73	73	120	120	120	120	120	120	41	41	41	41	0	88	88	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	4,709	4,709	16,038	16,038	16,038	16,038	16,038	16,038	333	333	333	333	0	11,662	11,662	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N3S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	3,313	3,313	11,462	11,462	11,462	11,462	11,462	11,462	185	185	185	185	1	8,334	8,334	0	1
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	3,555	3,555	12,429	12,429	12,429	12,429	12,429	12,429	163	163	163	163	1	9,037	9,037	0	1
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	427	427	0	0	0	0	0	0	427	427	427	427	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	4,923	4,923	0	0	0	0	0	0	4,923	4,923	4,923	4,923	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	3,421	3,421	0	0	0	0	0	0	3,421	3,421	3,421	3,421	0	0	0	0	0
C21H34	lb/h	7,754	7,754	10	10	10	10	10	10	7,751	7,751	7,751	7,751	0	8	8	0	0
C22H28O2	lb/h	1,788	1,788	0	0	0	0	0	0	1,788	1,788	1,788	1,788	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	9	9	0	0	0	0	0	0	9	9	0	0	0	0	0	9	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0

Heat	MMBtu/h
QA-H313	77
QA-H320	0
QC-H314	12
QCH-H316	10
QX-H315	5
	0
	0
	0

D-302
LIGHT FRACTION
CONDENSER ABSORBER

H-326
D-302 QUENCH
CIRCULATION CHILLER

S-322
D-302 BOTTOMS
DECANTER

P-329
AQUEOUS FILTER
CHARGE PUMP

P-323
CIRCULATION FILTER
CHARGE PUMP

S-329
AQUEOUS PHASE
FILTER

S-324
QUENCH
CIRCULATION FILTER

T-328
ORGANIC PRODUCT
SURGE TANK

P-331
ORGANIC
PRODUCT PUMP

MAKEUP HYDROGEN
FROM M-385/M-575
PFD-61712-A504

350

346

FLUIDIZING GAS
TO K-211
PFD-61712-A201

341

321

OFFGAS
TO H-315
PFD-61712-A301

OFFGAS
FROM H-315
PFD-61712-A301

340

343

OFFGAS
TO H-BP-4
PFD-61712-A303

345

PURGE GAS
TO H-BP-9/K-511
PFD-61712-A501

VAPOR PHASE
FROM H-316
PFD-61712-A301

317

D-302

CHWR

327

326

CHWS

H-326

QCH-H326

322

323

324

325

328

S-322

P-323

W-P323

S-324

335C

RECYCLED ORGANICS
TO T-332
PFD-61712-A301

332

ORGANIC PHASE
FROM H-320
PFD-61712-A301

320A

329

T-328

P-329

W-P329

S-329

335B

337

ORGANIC PHASE
TO S-410
PFD-61712-A401

P-331

W-P331

334

AQUEOUS PHASE
TO T-810
PFD-61712-A801

SOLIDS
FROM S-319
PFD-61712-A301

335A

335

SOLIDS
TO M-805
PFD-61712-A803

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 300: CONDENSATION STAGE 2

Project No: 30482.00

Drawing: PFD-61712-A302

Rev: 2

PFD-61712-A302		317	320A	321	322	323	324	325	326	327	328	329	332	334	335A	335B	335C	335	337	340	341	343	345	346	350
Total Flow	lb/h	371,714	19,660	182,444	1,090,871	1,013,055	1,013,055	1,013,035	901,601	901,601	30,391	77,816	81,043	77,811	11	5	20	36	50,051	182,444	128,998	51,621	1,824	140,215	11,217
Temperature	F	60	140	53	86	86	86	86	86	50	86	86	86	86	0	86	86	90	105	95	95	95	95	96	100
Pressure	Psia	100	103	97	100	100	125	110	110	100	110	100	110	100	123	100	110	100	113	95	95	95	95	95	110
Vapor Fraction		1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
Enthalpy Flow	MMBtu/h	-931	-10	-336	-1296	-773	-773	-773	-688	-701	-23	-523	-62	-523	0	0	0	0	-33	-332	-234	-94	-3	-239	-4
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	21,261	1	21,256	44	44	44	44	39	39	1	0	4	0	0	0	0	0	2	21,256	15,029	6,014	213	24,531	9,502
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	77,078	43	499	81,591	5,632	5,632	5,632	5,012	5,012	169	75,959	451	75,955	0	5	0	5	212	499	353	141	5	353	0
Carbon Monoxide	lb/h	66,266	3	66,238	256	256	256	256	228	228	8	0	21	0	0	0	0	0	10	66,238	46,834	18,741	662	47,501	667
Carbon Dioxide	lb/h	55,716	7	55,306	3,714	3,713	3,713	3,713	3,304	3,304	111	2	297	2	0	0	0	0	118	55,306	39,105	15,648	553	40,152	1,048
Methane	lb/h	8,333	1	8,321	104	104	104	104	92	92	3	0	8	0	0	0	0	0	4	8,321	5,884	2,354	83	5,884	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	16,766	2	16,661	950	949	949	949	845	845	28	0	76	0	0	0	0	0	31	16,661	11,780	4,714	167	11,780	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	5,810	1	5,632	1,616	1,616	1,616	1,616	1,438	1,438	48	0	129	0	0	0	0	0	50	5,632	3,982	1,594	56	3,982	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	1,212	1	707	4,592	4,592	4,592	4,592	4,087	4,087	138	0	367	0	0	0	0	0	138	707	500	200	7	500	0
1-Butene	lb/h	3,251	1	2,793	4,164	4,164	4,164	4,164	3,706	3,706	125	0	333	0	0	0	0	0	126	2,793	1,975	790	28	1,975	0
Tetrahydrofuran	lb/h	2,236	1	597	14,896	14,896	14,896	14,896	13,257	13,257	447	0	1,192	0	0	0	0	0	448	597	422	169	6	422	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	2,432	1	659	16,115	16,115	16,115	16,115	14,342	14,342	483	0	1,289	0	0	0	0	0	485	659	466	187	7	466	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	7,632	11	20	68,598	68,525	68,525	68,524	60,986	60,986	2,056	73	5,482	73	0	0	1	1	2,067	20	14	6	0	14	0
1,2-Benzenediol	lb/h	2,049	20	0	4,241	2,463	2,463	2,463	2,192	2,192	74	1,778	197	1,778	0	0	0	0	94	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	42	0	3	355	355	355	355	316	316	11	0	28	0	0	0	0	0	11	3	2	1	0	2	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	136	0	1	1,229	1,229	1,229	1,229	1,094	1,094	37	0	98	0	0	0	0	0	37	1	1	0	0	1	0
Cyclohexane	lb/h	13,262	9	2,367	99,032	99,032	99,032	99,030	88,137	88,137	2,971	0	7,922	0	0	0	2	2	2,980	2,367	1,673	670	24	1,673	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	4	0	0	35	35	35	35	31	31	1	0	3	0	0	0	0	0	1	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	2,898	2	270	23,888	23,888	23,888	23,887	21,260	21,260	717	0	1,911	0	0	0	0	0	719	270	191	76	3	191	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	5	0	0	42	42	42	42	37	37	1	0	3	0	0	0	0	0	1	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	9,506	30	3	86,372	86,371	86,371	86,369	76,869	76,869	2,591	1	6,910	1	0	0	2	2	2,621	3	2	1	0	2	0
2,6-dimethoxyphenol	lb/h	3,184	29	0	28,944	28,944	28,944	28,944	25,760	25,760	868	0	2,316	0	0	0	1	1	897	0	0	0	0	0	0
Vanillyl alcohol	lb/h	3,063	32	0	27,819	27,816	27,816	27,816	24,756	24,756	834	3	2,225	3	0	0	1	1	867	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	1,203	2	4	10,902	10,902	10,902	10,902	9,702	9,702	327	0	872	0	0	0	0	0	329	4	3	1	0	3	0
Cis-1,2-dimethyl cyclohexane	lb/h	10,060	12	417	87,651	87,651	87,651	87,649	78,008	78,008	2,629	0	7,012	0	0	0	2	2	2,641	417	295	118	4	295	0
Trans-1,2-dimethylcyclohexane	lb/h	13,344	14	685	115,062	115,062	115,062	115,059	102,403	102,403	3,452	0	9,205	0	0	0	2	2	3,466	685	484	194	7	484	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	1,673	5	2	15,195	15,195	15,195	15,195	13,523	13,523	456	0	1,216	0	0	0	0	0	461	2	1	0	0	1	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	49	0	0	443	443	443	443	394	394	13	0	35	0	0	0	0	0	13	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	1,236	16	0	11,230	11,230	11,230	11,230	9,994	9,994	337	0	898	0	0	0	0	0	353	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	30	373	0	270	270	270	270	240	240	8	0	22	0	0	0	0	0	381	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	48	0	0	434	434	434	434	387	387	13	0	35	0	0	0	0	0	13	0	0	0	0	0	0
Decalin	lb/h	158	0	0	1,429	1,429	1,429	1,429	1,272	1,272	43	0	114	0	0	0	0	0	43	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	1,489	11	0	13,530	13,530	13,530	13,530	12,042	12,042	406	0	1,082	0	0	0	0	0	417	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	222	1	0	2,013	2,013	2,013	2,013	1,791	1,791	60	0	161	0	0	0	0	0	61	0	0	0	0	0	0
Dibenzothiophene	lb/h	120	41	0	1,094	1,094	1,094	1,094	974	974	33	0	88	0	0	0	0	0	73	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	16,038	333	0	145,776	145,776	145,776	145,773	129,738	129,738	4,373	0	11,662	0	0	0	3	3	4,706	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	11,462	185	1	104,182	104,182	104,182	104,180	92,720	92,720	3,125	0	8,334	0	0	0	2	2	3,310	1	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	12,429	163	1	112,967	112,967	112,967	112,965	100,539	100,539	3,389	0	9,037	0	0	0	2	2	3,552	1	1	0	0	1	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	427	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	427	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	4,923	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4,923	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	3,421	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3,421	0	0	0	0	0	0
C21H34	lb/h	10	7,751	0	94	94	94	94	84	84	3	0	8	0	0	0	0	0	7,754	0	0	0	0	0	0
C22H28O2	lb/h	0	1,788	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,788	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	9	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0

Heat	MMBtu/h
QCH-H326	13
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
W-P323	41	0
W-P331	1	0
W-P329	3	0
	0	0
	0	0
	0

H-AP-53
PRE-ABSORBER UPGRADED VAPOR COOLER/A300 WGS STEAM SUPERHEAT

H-AP-14
A300 WGS OUTLET COOLER/A300 PYROLYSIS OFFGAS TO WGS PREHEAT

H-AP-32
A300 WGS OUTLET COOLER/WW PREHEAT FOR STEAM PRODUCTION

H-AP-15
A300 WGS OUTLET COOLER/A300 WGS FEED PREHEAT

R-365
HIGH-TEMPERATURE WGS

H-BP-14
A300 WGS OUTLET COOLER/ PYROLYSIS OFFGAS FEED TO WGS PREHEAT

H-BP-36
A300 WGS OUTLET COOLER/ FAST PYROLYSIS FLUIDIZING GAS PREHEAT

H-BP-4
A300 WGS OUTLET COOLER/ PYROLYSIS OFFGAS FEED TO WGS PREHEAT

H-373
POST-WGS ACHE

H-374
POST-WGS COOLER

PYROLYSIS VAPOR FROM H-AP-51 PFD-61712-A305

LP STEAM FROM T-812 PFD-61712-A801

813

H-AP-53

QHAP53

367

PYROLYSIS VAPOR TO D-301 PFD-61712-A305

H-AP-15

QHAP15

366

369

370

R-365

372

WGS OUTLET TO H-AP-52 PFD-61712-A605

WGS OUTLET FROM H-AP-52 PFD-61712-A605

OFFGAS FROM H-315 PFD-61712-A302

343

372B

CWR

374

WGS PRODUCT TO S-385 PFD-61712-A304

H-373

QA-H373

CWS

H-374

QC-H374

H-AP-14

QHAP14

H-BP-14

QHBP14

H-BP-4

QHBP4

WASTEWATER FROM H-BP-33/H-BP-26 PFD-61712-A805

WGS OUTLET TO H-BP-35 PFD-61712-A604

WGS OUTLET FROM H-BP-27 PFD-61712-A604

FLUIDIZING GAS FROM K-211 PFD-61712-A203

203P

H-BP-36

QHBP36

FLUIDIZING GAS TO H-BP-3 PFD-61712-A203

H-AP-32

QHAP32

WASTEWATER TO H-AP-59/61/62 PFD-61712-A805

WGS OUTLET TO H-BP-1 PFD-61712-A604

WGS OUTLET FROM H-BP-1 PFD-61712-A604

WGS OUTLET TO H-AP-33 PFD-61712-A605

WGS OUTLET FROM H-AP-33 PFD-61712-A605

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 300: WATER GAS SHIFT

Project No: 30482.00

Drawing: PFD-61712-A303

Rev: 1

Plot date: 12/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

PFD-61712-A303		203P	343	366	367	369	370	372	372B	374	813														
Total Flow	lb/h	140,215	51,621	51,621	30,755	82,376	82,376	82,376	82,376	82,376	30,755	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	160	95	400	404	397	464	637	185	110	354	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	127	95	91	135	91	89	84	82	78	140	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-231	-94	-83	-173	-256	-253	-253	-288	-301	-174	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	24,531	6,014	6,014	0	6,014	6,014	7,092	7,092	7,092	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	353	141	141	30,663	30,804	30,804	21,172	21,172	21,172	30,663	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	47,501	18,741	18,741	0	18,741	18,741	3,766	3,766	3,766	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	40,152	15,648	15,648	2	15,650	15,650	39,180	39,180	39,180	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	5,884	2,354	2,354	0	2,354	2,354	2,354	2,354	2,354	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	11,780	4,714	4,714	0	4,714	4,714	4,714	4,714	4,714	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	3,982	1,594	1,594	0	1,594	1,594	1,594	1,594	1,594	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	500	200	200	0	200	200	200	200	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	1,975	790	790	0	790	790	790	790	790	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	422	169	169	0	169	169	169	169	169	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	466	187	187	0	187	187	187	187	187	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	14	6	6	40	45	45	45	45	45	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	49	49	49	49	49	49	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	2	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	1,673	670	670	0	670	670	670	670	670	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	191	76	76	0	76	76	76	76	76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	2	1	1	1	2	2	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	3	1	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	295	118	118	0	118	118	118	118	118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	484	194	194	0	194	194	194	194	194	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QA-H373	9
QC-H374	4
QHAP14	4
QHAP15	3
QHAP32	1
QHAP53	13
QHBP14	3
QHBP36	5
QHBP4	4
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0

S-385
PSA COMPRESSOR
SUCTION KO

K-390
PSA COMPRESSOR:
MULTISTAGE

T-377
COMPRESSOR
CONDENSATE TANK

S-386
PSA COMPR DISCH
KO

P-377
COMPRESSOR
CONDENSATE PUMP

M-385
PSA

WGS PRODUCT
FROM H-374
PFD-61712-A303

374

S-385

376

377A

K-390

W-K390

QC-K390

QA-K390

CWR

CWS

385

S-386

382

386

388

M-385

389

PSA OFFGAS
TO H-BP-9/K-511
PFD-61712-A501

390

HYDROGEN
TO K-211/K-412/K-462
PFD-61712-A504

T-377

P-377

W-P377

377

CONDENSATE
TO T-860
PFD-61712-A804

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 300: PSA

Project No: 30482.00

Drawing: PFD-61712-A304

Rev: 2

PFD-61712-A304		374	376	377	377A	382	385	386	388	389	390														
Total Flow	lb/h	82,376	62,478	20,723	19,898	634	61,844	191	61,652	54,620	7,032	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	110	110	110	110	110	110	110	110	110	110	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	78	78	83	78	78	214	212	212	22	202	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-301	-165	-141	-135	-4	-162	-1	-160	-158	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	7,092	7,092	0	0	0	7,092	0	7,092	1,135	5,957	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	21,172	1,338	20,658	19,834	634	705	191	514	514	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	3,766	3,766	0	0	0	3,766	0	3,766	3,348	418	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	39,180	39,179	1	1	0	39,179	0	39,179	38,522	657	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	2,354	2,354	0	0	0	2,354	0	2,354	2,354	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	4,714	4,714	0	0	0	4,714	0	4,714	4,714	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	1,594	1,594	0	0	0	1,594	0	1,594	1,594	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	200	200	0	0	0	200	0	200	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	790	790	0	0	0	790	0	790	790	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	169	169	0	0	0	169	0	169	169	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	187	187	0	0	0	187	0	187	187	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	45	31	15	14	0	31	0	31	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	49	0	49	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	1	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	670	670	0	0	0	670	0	670	670	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	76	76	0	0	0	76	0	76	76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	2	2	0	0	0	2	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	1	1	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	118	118	0	0	0	118	0	118	118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	194	194	0	0	0	194	0	194	194	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QA-K390	4
QC-K390	4
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
W-K390	3,031	8
W-P377	0	0
	0	0
	0	0

H-AP-23
ABSORBER 1 BOTTOMS
COOLER/WW PREHEAT FOR
STEAM PRODUCTION

H-BP-3
POST-ABSORBER 1 VAPOR
COOLER/FAST PYROLYSIS
FLUIDIZING GAS PREHEAT

PYROLYSIS VAPOR
FROM S-262/T-261
PFD-61712-A301

300

PYROLYSIS VAPOR
TO H-AP-48
PFD-61712-A603

PYROLYSIS VAPOR
FROM H-AP-51
PFD-61712-A605

PYROLYSIS VAPOR
TO H-AP-53
PFD-61712-A303

PYROLYSIS VAPOR
FROM H-AP-53
PFD-61712-A303

PYROLYSIS VAPOR
TO H-AP-56
PFD-61712-A605

PYROLYSIS VAPOR
FROM H-AP-56
PFD-61712-A605

PYROLYSIS VAPOR
TO H-AP-60
PFD-61712-A805

PYROLYSIS VAPOR
FROM H-AP-60
PFD-61712-A805

311

PYROLYSIS VAPOR
TO D-301
PFD-61712-A301

ABSORBER VAPOR
FROM D-301
PFD-61712-A301

312

ABSORBER VAPOR
TO H-AP-17
PFD-61712-A203

ABSORBER VAPOR
FROM H-AP-17
PFD-61712-A203

ABSORBER VAPOR
TO H-AP-18
PFD-61712-A203

ABSORBER VAPOR
FROM H-AP-18
PFD-61712-A203

ABSORBER VAPOR
TO H-AP-31
PFD-61712-A605

ABSORBER VAPOR
FROM H-AP-31
PFD-61712-A605

ABSORBER VAPOR
TO H-BP-20
PFD-61712-A605

ABSORBER VAPOR
FROM H-BP-11
PFD-61712-A604

FLUIDIZING GAS
FROM H-BP-36
PFD-61712-A203

H-BP-3
QHBP3

FLUIDIZING GAS
TO H-AP-8
PFD-61712-A203

313

ABSORBER VAPOR
TO H-313
PFD-61712-A301

WASTEWATER
FROM H-BP-26/H-BP-33
PFD-61712-A805

H-AP-23
QHAP23

ABSORBER BOTTOMS
FROM D-301
PFD-61712-A301

318

WASTEWATER
TO H-AP-59/61/62
PFD-61712-A805

ABSORBER BOTTOMS
TO H-BP-43
PFD-61712-A805

ABSORBER BOTTOMS
FROM H-BP-43
PFD-61712-A805

ABSORBER BOTTOMS
TO H-BP-34
PFD-61712-A604

ABSORBER BOTTOMS
FROM H-BP-34
PFD-61712-A604

ABSORBER BOTTOMS
TO H-BP-31
PFD-61712-A604

ABSORBER BOTTOMS
FROM H-BP-31
PFD-61712-A604

ABSORBER BOTTOMS
TO H-BP-44
PFD-61712-A601

ABSORBER BOTTOMS
FROM H-BP-44
PFD-61712-A601

319

ABSORBER BOTTOMS
TO S-319
PFD-61712-A301

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Rev.	Date	By	Description
0	12/12/14	DMS	ADDED HX NETWORK

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 300: A300 HEAT RECOVERY

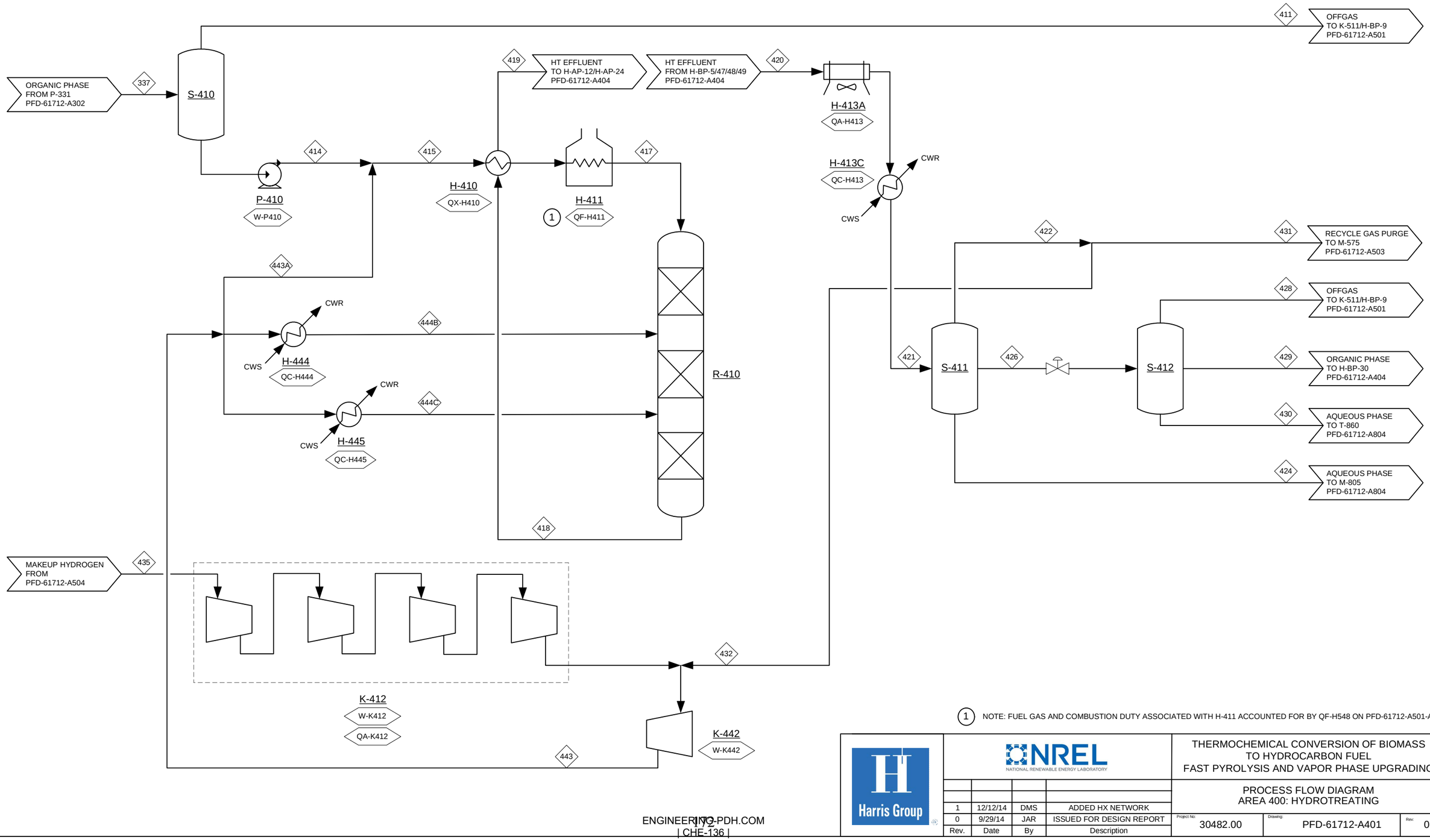
Project No: 30482.00
Drawing: PFD-61712-A305
Rev: 0

PFD-61712-A305		300	311	312	313	318	319																			
Total Flow	lb/h	310,342	310,342	371,714	371,714	19,671	19,671	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	931	466	358	220	461	175	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	115	113	110	108	113	123	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-638	-731	-786	-827	-7	-10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	21,258	21,258	21,261	21,261	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	76,670	76,670	77,078	77,078	43	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	66,248	66,248	66,266	66,266	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	55,426	55,426	55,716	55,716	7	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	8,325	8,325	8,333	8,333	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h		0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	16,692	16,692	16,766	16,766	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	5,682	5,682	5,810	5,810	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	845	845	1,212	1,212	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	2,919	2,919	3,251	3,251	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	1,046	1,046	2,236	2,236	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	1,144	1,144	2,432	2,432	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	2,161	2,161	7,632	7,632	11	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	1,872	1,872	2,049	2,049	20	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	13	13	42	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	38	38	136	136	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	5,348	5,348	13,262	13,262	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	1	1	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	990	990	2,898	2,898	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	1	1	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	2,627	2,627	9,506	9,506	30	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	898	898	3,184	3,184	29	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	870	870	3,063	3,063	32	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	333	333	1,203	1,203	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	3,060	3,060	10,060	10,060	12	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	4,153	4,153	13,344	13,344	14	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	463	463	1,673	1,673	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	13	13	49	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	353	353	1,236	1,236	16	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	381	381	30	30	373	373	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	13	13	48	48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	44	44	158	158	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	417	417	1,489	1,489	11	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	62	62	222	222	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	73	73	120	120	41	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	4,709	4,709	16,038	16,038	333	333	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N3S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	3,313	3,313	11,462	11,462	185	185	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	3,555	3,555	12,429	12,429	163	163	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	427	427	0	0	427	427	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	4,923	4,923	0	0	4,923	4,923	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	3,421	3,421	0	0	3,421	3,421	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	7,754	7,754	10	10	7,751	7,751	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	1,788	1,788	0	0	1,788	1,788	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	9	9	0	0	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QHAP23	2
QHBP3	10
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0

S-410 VAPOR KO DRUM | P-410 HT FEED PUMP | H-444 QUENCH HYDROGEN STAGE 2 COOLER | H-445 QUENCH HYDROGEN STAGE 3 COOLER | K-412 HYDROGEN MAKEUP COMPRESSOR | H-410 FEED-EFFLUENT EXCH | H-411 FEED FURNACE | R-410 HYDROTREATER | K-442 HYDROGEN RECYCLE COMPRESSOR | H-413A HT PRODUCT ACHE | H-413C HT PRODUCT COOLER | S-411 HP HT EFFLUENT FLASH: 3 PHASE | S-412 LP HT EFFLUENT FLASH: 3 PHASE



1 NOTE: FUEL GAS AND COMBUSTION DUTY ASSOCIATED WITH H-411 ACCOUNTED FOR BY QF-H548 ON PFD-61712-A501-A

Rev.	Date	By	Description
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Harris Group

NREL NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 400: HYDROTREATING

Project No: 30482.00 | Drawing: PFD-61712-A401 | Rev: 0

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

PFD-61712-A401		337	411	414	415	417	418	419	420	421	422	424	426	428	429	430	431	432	435	443	443A	444B	444C		
Total Flow	lb/h	50,051	0	50,051	56,010	56,010	67,579	67,579	67,579	67,579	17,435	2,912	47,232	787	46,446	0	2,061	15,374	2,154	17,528	5,959	5,784	5,784	0	0
Temperature	F	105	0	117	122	707	757	415	175	110	110	110	110	110	110	0	110	110	110	132	132	110	110	0	0
Pressure	Psia	113	113	1600	1600	1545	1515	1510	1505	1495	1493	1493	1493	53	53	53	1493	1493	245	1600	1600	1595	1595	0	0
Vapor Fraction		0	0	0	1	1	1	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	0	0
Enthalpy Flow	MMBtu/h	-33	0	-33	-39	-14	-27	-49	-65	-68	-21	-20	-30	-1	-28	0	-2	-18	-1	-18	-6	-6	-6	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	2	0	2	2,467	2,467	6,209	6,209	6,209	6,209	6,152	0	57	56	1	0	727	5,424	1,825	7,249	2,465	2,392	2,392	0	0
Ammonia	lb/h	0	0	0	7	7	66	66	66	66	23	34	9	4	5	0	3	20	0	20	7	7	7	0	0
H2S	lb/h	0	0	0	10	10	42	42	42	42	33	0	10	5	5	0	4	29	0	29	10	9	9	0	0
Water	lb/h	212	0	212	234	234	3,151	3,151	3,151	3,151	73	2,877	201	18	183	0	9	65	0	65	22	21	21	0	0
Carbon Monoxide	lb/h	10	0	10	1,104	1,104	3,555	3,555	3,555	3,555	3,502	0	53	51	2	0	414	3,088	128	3,216	1,093	1,061	1,061	0	0
Carbon Dioxide	lb/h	118	0	118	642	642	1,713	1,713	1,713	1,713	1,521	0	192	139	53	0	180	1,341	201	1,543	524	509	509	0	0
Methane	lb/h	4	0	4	1,011	1,011	3,485	3,485	3,485	3,485	3,358	0	126	115	12	0	397	2,961	0	2,961	1,007	977	977	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	31	0	31	67	67	137	137	137	137	122	0	15	11	4	0	14	107	0	107	37	35	35	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	398	398	1,553	1,553	1,553	1,553	1,326	0	227	147	80	0	157	1,169	0	1,169	398	386	386	0	0
Propylene	lb/h	50	0	50	51	51	5	5	5	5	3	0	2	1	1	0	0	3	0	3	1	1	1	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	25	25	123	123	123	123	83	0	41	14	26	0	10	73	0	73	25	24	24	0	0
Furan	lb/h	138	0	138	138	138	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	126	0	126	128	128	12	12	12	12	5	0	7	1	6	0	1	5	0	5	2	2	2	0	0
Tetrahydrofuran	lb/h	448	0	448	448	448	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	135	135	1,000	1,000	1,000	1,000	451	0	549	80	469	0	53	398	0	398	135	131	131	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	485	0	485	485	485	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	33	33	522	522	522	522	109	0	413	22	391	0	13	96	0	96	33	32	32	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	32	32	1,548	1,548	1,548	1,548	108	0	1,440	22	1,418	0	13	96	0	96	32	32	32	0	0
Phenol	lb/h	2,067	0	2,067	2,067	2,067	18	18	18	18	0	0	18	0	18	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	94	0	94	94	94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	11	0	11	11	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	37	0	37	37	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	2,980	0	2,980	3,058	3,058	4,040	4,040	4,040	4,040	263	0	3,777	51	3,726	0	31	232	0	232	79	76	76	0	0
N-Hexane	lb/h	0	0	0	20	20	734	734	734	734	68	0	666	12	653	0	8	60	0	60	20	20	20	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	5	5	477	477	477	477	17	0	460	2	458	0	2	15	0	15	5	5	5	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	719	0	719	729	729	898	898	898	898	33	0	866	6	860	0	4	29	0	29	10	9	9	0	0
2-Methylhexane	lb/h	0	0	0	6	6	405	405	405	405	21	0	384	4	380	0	2	19	0	19	6	6	6	0	0
VinylPhenol	lb/h	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	4	4	1,533	1,533	1,533	1,533	13	0	1,519	2	1,517	0	2	12	0	12	4	4	4	0	0
Ethylbenzne	lb/h	0	0	0	0	0	139	139	139	139	2	0	137	0	137	0	0	1	0	1	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	2,621	0	2,621	2,621	2,621	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	897	0	897	897	897	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	867	0	867	867	867	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	329	0	329	329	329	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	2,641	0	2,641	2,654	2,654	2,620	2,620	2,620	2,620	45	0	2,575	7	2,569	0	5	39	0	39	13	13	13	0	0
Trans-1,2-dimethylcyclohexane	lb/h	3,466	0	3,466	3,492	3,492	4,343	4,343	4,343	4,343	88	0	4,255	14	4,242	0	10	78	0	78	26	26	26	0	0
Ethylcyclohexane	lb/h	0	0	0	2	2	398	398	398	398	6	0	391	1	391	0	1	5	0	5	2	2	2	0	0
4-Methylheptane	lb/h	0	0	0	2	2	317	317	317	317	7	0	310	1	309	0	1	6	0	6	2	2	2	0	0
2-Methyl-Benzofuran	lb/h	461	0	461	461	461	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	13	0	13	13	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	10	10	10	10	0	0	10	0	10	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	147	147	147	147	0	0	147	0	147	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	353	0	353	353	353	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	381	0	381	381	381	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	61	61	61	61	0	0	61	0	61	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	13	0	13	13	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	43	0	43	43	43	160	160	160	160	0	0	159	0	159	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	417	0	417	417	417	196	196	196	196	0	0	195	0	195	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	61	0	61	61	61	299	299	299	299	0	0	298	0	298	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	73	0	73	73	73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	61	61	61	61	0	0	61	0	61	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	4,706	0	4,706	4,706	4,706	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	4,463	4,463	4,463	4,463	1	0	4,463	0	4,462	0	0	1	0	1	0	0	0	0	0
C14H20-N3S	lb/h	0	0	0	0	0	934	934	934	934	0	0	934	0	934	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	3,310	0	3,310	3,311	3,311	3,311	3,311	3,311	3,311	0	0	3,310	0	3,310	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	1,312	1,312	1,312	1,312	1	0	1,312	0	1,312	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	3,552	0	3,552	3,552	3,552	3,179	3,179	3,179	3,179	0	0	3,179	0	3,179	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	427	0	427	427	427	427	427	427	427	0	0	427	0	427	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	4,923	0	4,923	4,923	4,923	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	4,656	4,656	4,656	4,656	0	0	4,656	0	4,656	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	3,421	0	3,421	3,421	3,421	1,026	1,026	1,026	1,026	0	0	1,026	0	1,026	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	7,754	0	7,754	7,754	7,754	7,754	7,754	7,754	7,754	0	0	7,754	0	7,754	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	1,788	0	1,788	1,788	1,788	536	536	536	536	0	0	536	0	536	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QA-H413	2
QA-K412	3
QC-H413	2
QC-H444	0
QC-H445	0
QF-H411	-2
QX-H410	-23

Work	hp	MMBtu/h
W-P410	189	0
W-K442	180	0
W-K412	1,191	3

D-450 GASOLINE COLUMN

H-BP-26 NAPHTHA COLUMN CONDENSER/WW PREHEAT FOR STEAM PRODUCTION

P-450 D-450 REFLUX PUMP

S-450 D-450 OVERHEAD ACCUMULATOR

H-450C D-450 CONDENSER

H-450R D-450 REBOILER

D-451 DIESEL COLUMN

H-AP-58 DISTILLATE COLUMN CONDENSER/STEAM PRODUCTION FROM WW FOR REFORMER

H-451C D-451 CONDENSER

H-451R D-451 REBOILER

P-451 D-451 REFLUX PUMP

S-451 D-451 OVERHEAD ACCUMULATOR

H-AP-13 DISTILLATE COLUMN CONDENSER/HT PRODUCT TO NAPHTHA COLUMN PREHEAT

H-457A DIESEL PRODUCT ACHE

H-459 D-450 OVERHEAD VAPOR COOLER

H-454 GASOLINE PRODUCT COOLER

H-457C DIESEL PRODUCT COOLER

WASTEWATER FROM H-BP-10 PFD-61712-A805

CWR

H-BP-26

QHBP26

CWS

H-450C (1)

Q-H450C

WASTEWATER TO H-AP-23/24/25/32 PFD-61712-A805

S-450

P-450

451

D-450

HC ORGANIC PHASE FROM H-AP-43 PFD-61712-A404

480

CND

H-450R (1)

Q-H450R

LPS

D-450 BOTTOMS FROM H-AP-28 PFD-61712-A501-A

D-450 BOTTOMS TO H-AP-28 PFD-61712-A501-A

454

HT ORGANIC PHASE FROM H-AP-12 PFD-61712-A404

H-AP-13

QHAP13

CONC WASTEWATER FROM P-814 PFD-61712-A805

H-AP-58

QHAP58

CWR

CWS

H-451C (1)

Q-H451C

CONC WASTEWATER TO T-822 PFD-61712-A805

S-451

P-451

D-451

DIESEL PRODUCT TO H-AP-16/H-AP-25 PFD-61712-A404

DIESEL PRODUCT FROM H-BP-30 PFD-61712-A404

H-457A

QA-H457

CWR

CWS

H-457C

QC-H457

456

DIESEL PRODUCT TO T-792 PFD-61712-A703

CND

H-451R (1)

Q-H451R

LPS

D-451 BOTTOMS FROM H-AP-27 PFD-61712-A501-A

D-451 BOTTOMS TO H-AP-27 PFD-61712-A501-A

460

HEAVY KEY TO S-460 PFD-61712-A403

CWR

CWS

H-459

QC-H459

452

HYDROPR PURGE TO R-530 PFD-61712-A501

CWR

CWS

H-454

QC-H454

453

GASOLINE PRODUCT TO T-790 PFD-61712-A703

(1) FOR STARTUP ONLY

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Harris Group

NREL NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 400: PRODUCT SEPARATION

Rev.	Date	By	Description
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Project No.: 30482.00

Drawing: PFD-61712-A402

Rev.: 0

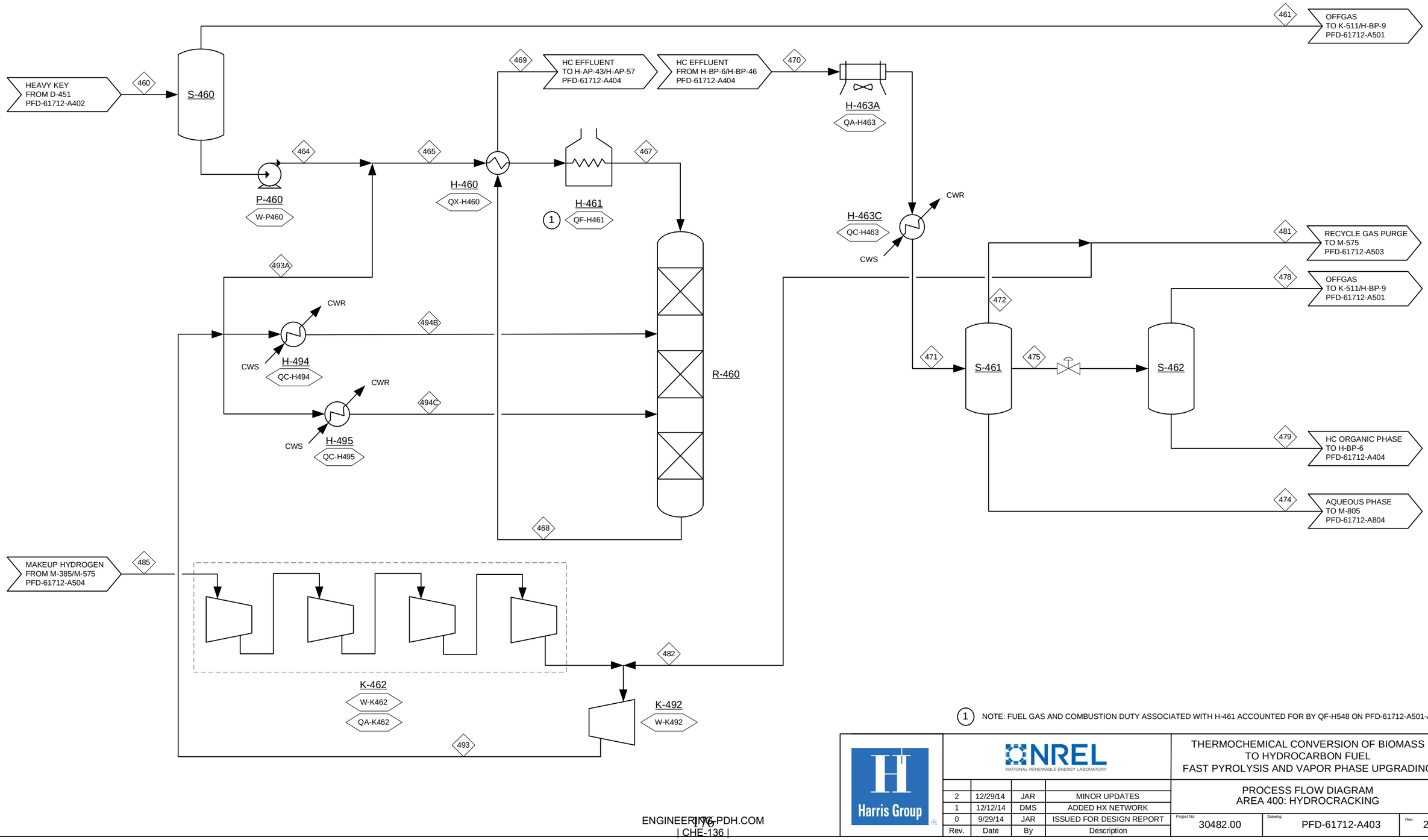
ENGINEERING-PDH.COM
| CHE-136 |

PFD-61712-A402		451	452	453	454	456	460	480																		
Total Flow	lb/h	46,446	1,281	20,408	41,393	24,739	16,654	16,636	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	450	110	60	627	60	713	550	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	43	33	15	40	15	20	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-18	-1	-15	-11	-16	-2	-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	5	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	5	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	183	55	168	0	0	0	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	53	53	11	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	12	15	1	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	4	5	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	80	94	28	0	0	0	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	26	15	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	6	2	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	469	158	311	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	391	70	321	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	1,418	96	1,321	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	18	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	3,726	230	3,526	0	0	0	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	653	180	1,942	0	0	0	1,470	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	458	13	445	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	860	31	829	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	380	88	1,645	1	1	0	1,353	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	1,517	16	1,501	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	137	2	135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	2,569	44	2,524	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	4,242	86	4,156	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	391	6	384	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	309	7	301	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	10	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	147	0	120	26	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	61	0	58	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	159	1	200	9	9	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	1	114	3	3	0	117	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	195	0	5	191	191	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	298	0	222	76	76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	61	0	0	61	61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	4,462	0	22	4,441	4,440	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	934	0	1	933	933	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	3,310	0	1	3,316	3,309	7	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	1,312	0	65	4,632	4,632	0	3,385	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	3,179	0	2	3,180	3,177	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	2,947	2,946	0	2,947	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	427	0	0	547	34	512	120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	163	162	0	163	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	4,656	0	0	11,547	4,656	6,890	6,890	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	1,026	0	0	1,026	0	1,026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	7,754	0	0	7,754	78	7,677	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	536	0	0	536	0	536	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QA-H457	0
QC-H454	1
QC-H457	1
QC-H459	0
Q-H450C	7
Q-H450R	-5
Q-H451C	7
Q-H451R	-6
QHAP13	3
QHAP58	5
QHBP26	7
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

S-460 VAPOR KO DRUM | P-460 HC FEED PUMP | H-494 QUENCH HYDROGEN STAGE 2 COOLER | H-495 QUENCH HYDROGEN STAGE 3 COOLER | K-462 HYDROGEN MAKEUP COMPRESSOR | H-460 FEED-EFFLUENT EXCH | H-461 FEED FURNACE | R-460 HYDROCRACKER | K-492 HYDROGEN RECYCLE COMPRESSOR | H-463A HC PRODUCT ACHE | H-463C HC PRODUCT COOLER | S-461 HP EFFLUENT FLASH: 3 PHASE | S-462 LP EFFLUENT FLASH



1 NOTE: FUEL GAS AND COMBUSTION DUTY ASSOCIATED WITH H-461 ACCOUNTED FOR BY QF-H548 ON PFD-61712-A501-A

Harris Group

NREL NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 400: HYDROCRACKING

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Project No: 30482.00 | Drawing: PFD-61712-A403 | Rev: 2

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

PFD-61712-A403		460	461	464	465	467	468	469	470	471	472	474	475	478	479	481	482	485	493	493A	494B	494C	494C		
Total Flow	lb/h	16,654	0	16,654	18,293	18,293	21,473	21,473	21,473	21,473	4,353	129	16,992	356	16,636	298	4,055	764	4,819	1,639	1,590	1,590	1,590	0	0
Temperature	F	713	0	739	605	738	787	717	175	110	110	110	110	110	110	110	110	110	130	130	110	110	110	0	0
Pressure	Psia	20	20	2000	2000	1945	1915	1910	1905	1895	1893	1893	1893	53	53	1893	1893	245	2000	2000	1995	1995	1995	0	0
Vapor Fraction		0	0	0	1	1	1	1	1	1	1	0	0	1	0	1	1	1	1	1	1	1	1	0	0
Enthalpy Flow	MMBtu/h	-2	0	-1	-3	-1	-4	-6	-17	-18	-5	-1	-12	-1	-11	0	-5	0	-5	-2	-2	-2	-2	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	717	717	1,597	1,597	1,597	1,597	1,569	0	28	27	0	107	1,462	647	2,109	717	696	696	696	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	0	0	0	5	5	195	195	195	195	17	129	49	9	40	1	16	0	16	5	5	5	5	0	0
Carbon Monoxide	lb/h	0	0	0	164	164	483	483	483	483	470	0	13	13	0	32	438	45	483	164	159	159	159	0	0
Carbon Dioxide	lb/h	0	0	0	111	111	327	327	327	327	274	0	53	42	10	19	255	71	327	111	108	108	108	0	0
Methane	lb/h	0	0	0	370	370	1,243	1,243	1,243	1,243	1,167	0	75	70	5	80	1,087	0	1,087	370	359	359	359	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	15	15	56	56	56	56	47	0	9	7	2	3	44	0	44	15	14	14	14	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	194	194	774	774	774	774	613	0	161	118	42	42	571	0	571	194	189	189	189	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	1	1	32	32	32	32	2	0	30	1	29	0	2	0	2	1	1	1	1	0	0
N-Hexane	lb/h	0	0	0	41	41	1,644	1,644	1,644	1,644	128	0	1,516	46	1,470	9	119	0	119	41	39	39	39	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	20	20	1,437	1,437	1,437	1,437	63	0	1,374	21	1,353	4	59	0	59	20	19	19	19	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	50	50	50	50	0	0	50	0	50	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	118	118	118	118	1	0	117	0	117	0	1	0	1	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	1	0	1	1	1	1	1	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
C14H20-N3S	lb/h	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	7	0	7	7	7	7	7	7	7	0	0	7	0	7	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	1	1	3,387	3,387	3,387	3,387	1	0	3,386	0	3,385	0	1	0	1	0	0	0	0	0	0
C15H26-N4	lb/h	3	0	3	3	3	3	3	3	3	0	0	3	0	3	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	1	1	2,948	2,948	2,948	2,948	1	0	2,947	0	2,947	0	1	0	1	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	512	0	512	512	512	120	120	120	120	0	0	120	0	120	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	163	163	163	163	0	0	163	0	163	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	6,890	0	6,890	6,890	6,890	6,890	6,890	6,890	6,890	0	0	6,890	0	6,890	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	1,026	0	1,026	1,026	1,026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	7,677	0	7,677	7,677	7,677	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	536	0	536	536	536	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QA-H463	1
QA-K462	1
QC-H463	0
QC-H494	0
QC-H495	0
QF-H461	-1
QX-H460	-1

Work	hp	MMBtu/h
W-P460	142	0
W-K492	42	0
W-K462	495	1

H-AP-57 HYDROTREATER OUTLET COOLER/STEAM PRODUCTION FROM WW FOR REFORMER

H-AP-43 HYDROTREATER OUTLET COOLER/HC PRODUCT TO NAPHTHA COLUMN PREHEAT

H-AP-12 HYDROTREATER OUTLET COOLER/HT PRODUCT TO NAPHTHA COLUMN PREHEAT

H-AP-24 HYDROTREATER OUTLET COOLER/WW PREHEAT FOR STEAM PRODUCTION

H-AP-25 DISTILLATE PRODUCT COOLER/ WW PREHEAT FOR STEAM PRODUCTION

H-AP-16 DISTILLATE PRODUCT COOLER/HC PRODUCT TO NAPHTHA COLUMN PREHEAT

H-BP-5 HYDROTREATER OUTLET COOLER/HT PRODUCT TO NAPHTHA COLUMN PREHEAT

H-BP-6 HYDROCRACKER OUTLET COOLER/HC PRODUCT TO NAPHTHA COLUMN PREHEAT

H-BP-30 DISTILLATE PRODUCT COOLER/HT PRODUCT TO NAPHTHA COLUMN PREHEAT

H-BP-47 HYDROTREATER OUTLET COOLER/RECYCLED BOILER FEEDWATER PREHEAT

H-BP-48 HYDROTREATER OUTLET COOLER/CATALYST STRIPPER WATER PREHEAT FOR STEAM

H-BP-49 HYDROTREATER OUTLET COOLER/WATER PREHEAT FOR MIX WITH WW FOR STEAM

CONC WASTEWATER FROM P-814 PFD-61712-A805

H-AP-57 QHAP57

HC EFFLUENT FROM H-460 PFD-61712-A403

469

CONC WASTEWATER TO T-822 PFD-61712-A805

HC EFFLUENT TO H-AP-41 PFD-61712-A605

HC EFFLUENT FROM H-AP-34 PFD-61712-A605

H-BP-6 QHBP6

479

HC ORGANIC PHASE FROM S-462 PFD-61712-A403

470

HC EFFLUENT TO H-463A PFD-61712-A403

H-AP-16 QHAP16

HC EFFLUENT TO H-BP-24 PFD-61712-A604

HC EFFLUENT FROM H-BP-46 PFD-61712-A601

H-AP-43 QHAP43

WASTEWATER FROM H-BP-26/H-BP-33 PFD-61712-A805

HC ORGANIC PHASE TO D-450 PFD-61712-A402

480

429

HT ORGANIC PHASE FROM S-412 PFD-61712-A401

DIESEL PRODUCT FROM P-451 PFD-61712-A402

456B

DIESEL PRODUCT TO H-BP-29 PFD-61712-A604

DIESEL PRODUCT FROM H-BP-29 PFD-61712-A604

456C

DIESEL PRODUCT TO H-457A PFD-61712-A402

H-AP-25 QHAP25

H-BP-30 QHBP30

WASTEWATER TO H-AP-59/61/62 PFD-61712-A805

HT ORGANIC PHASE TO H-AP-13 PFD-61712-A402

H-AP-12 QHAP12

H-BP-5 QHBP5

HT EFFLUENT FROM H-410 PFD-61712-A401

419

420

HT EFFLUENT TO H-413A PFD-61712-A401

MAKEUP WATER FROM P-601 PFD-61712-A601

H-BP-47 QHBP47

MAKEUP WATER TO H-BP-32/H-BP-40 PFD-61712-A601

CLEAN WATER FROM P-866 PFD-61712-A804

H-BP-48 QHBP48

CLEAN WATER TO H-BP-39/H-BP-41 PFD-61712-A804

WASTEWATER FROM H-BP-26/H-BP-33 PFD-61712-A805

HT EFFLUENT TO H-BP-23 PFD-61712-A604

HT EFFLUENT FROM H-BP-18 PFD-61712-A604

MAKEUP WATER FROM P-815 PFD-61712-A801

H-BP-49 QHBP49

MAKEUP WATER TO H-BP-42/H-BP-43 PFD-61712-A801

H-AP-24 QHAP24

WASTEWATER TO TO H-AP-59/61/62 PFD-61712-A805

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Harris Group

NREL NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 400: A400 HEAT RECOVERY

Rev.	Date	By	Description
0	12/12/14	DMS	ADDED HX NETWORK

Project No: 30482.00

Drawing: PFD-61712-A404

Rev: 0

ENGINEERING-PDH.COM
| CHE-136 |

PFD-61712-A404		419	420	429	456B	456C	469	470	479	480															
Total Flow	lb/h	67,579	67,579	46,446	24,739	24,739	21,473	21,473	16,636	16,636	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	415	175	110	491	175	717	175	110	550	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	1510	1505	53	35	25	1910	1905	53	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-49	-65	-28	-11	-15	-6	-17	-11	-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	6,209	6,209	1	0	0	1,597	1,597	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	66	66	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	42	42	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	3,151	3,151	183	0	0	195	195	40	40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	3,555	3,555	2	0	0	483	483	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	1,713	1,713	53	0	0	327	327	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	3,485	3,485	12	0	0	1,243	1,243	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	137	137	4	0	0	56	56	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	1,553	1,553	80	0	0	774	774	42	42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	5	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	123	123	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	12	12	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	1,000	1,000	469	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	522	522	391	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	1,548	1,548	1,418	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	18	18	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	4,040	4,040	3,726	0	0	32	32	29	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	734	734	653	0	0	1,644	1,644	1,470	1,470	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	477	477	458	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	898	898	860	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	405	405	380	1	1	1,437	1,437	1,353	1,353	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	1,533	1,533	1,517	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	139	139	137	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	2,620	2,620	2,569	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	4,343	4,343	4,242	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	398	398	391	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	317	317	309	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	10	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	147	147	147	26	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	61	61	61	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	160	160	159	9	9	50	50	50	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	3	3	118	118	117	117	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	196	196	195	191	191	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	299	299	298	76	76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	61	61	61	61	61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	4,463	4,463	4,462	4,440	4,440	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	934	934	934	933	933	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	3,311	3,311	3,310	3,309	3,309	7	7	7	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	1,312	1,312	1,312	4,632	4,632	3,387	3,387	3,385	3,385	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	3,179	3,179	3,179	3,177	3,177	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	2,946	2,946	2,948	2,948	2,947	2,947	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	427	427	427	34	34	120	120	120	120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	162	162	163	163	163	163	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	4,656	4,656	4,656	4,656	4,656	6,890	6,890	6,890	6,890	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	1,026	1,026	1,026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	7,754	7,754	7,754	78	78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	536	536	536	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QHAP12	3
QHAP16	2
QHAP24	3
QHAP25	0
QHAP43	1
QHAP57	3
QHBP30	0
QHBP47	0
QHBP48	0
QHBP49	0
QHBP5	4
QHBP6	2
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0

K-511
PYROLYSIS OFFGAS
COMPRESSOR TO REFORMER

H-BP-37
BOILER FEEDWATER
BLOWDOWN COOLER/NATURAL
GAS TO REFORMER PREHEAT

H-AP-21
A500 LOW TEMP WGS
COOLER/NATURAL GAS
TO REFORMER PREHEAT

BLOWDOWN
FROM H-AP-10/11/35
PFD-61712-A603

LTS EFFLUENT
FROM R-566
PFD-61712-A505

H-BP-37
QHBP37

H-AP-21
QHAP21

519

521

526

LP STEAM
FROM H-AP-44
PFD-61712-A502

NATURAL GAS
FROM UTILITY

502

536

REFORMER FEED GAS
TO H-AP-7
PFD-61712-A501-A

522

BLOWDOWN
TO H-BP-32
PFD-61712-A603

LTS EFFLUENT
TO H-AP-19/H-AP-20
PFD-61712-A505

OFFGAS
FROM S-412
PFD-61712-A401

428

OFFGAS
FROM S-462
PFD-61712-A403

478

PURGE GAS
FROM H-315
PFD-61712-A302

345

OFFGAS
FROM S-460
PFD-61712-A403

461

OFFGAS
FROM S-410
PFD-61712-A401

411

PSA OFFGAS
FROM M-385
PFD-61712-A304

389

389B

512

K-511

W-K511

REFORMER FEED GAS
TO H-AP-30
PFD-61712-A501-A

REFORMER FEED GAS
TO H-AP-30
PFD-61712-A501-A

515

REFORMER COMB GAS
TO H-BP-9
PFD-61712-A505

REFORMER COMB GAS
FROM H-AP-22
PFD-61712-A505

516

593

PSA OFFGAS
FROM M-575
PFD-61712-A503

589

591

PSA OFFGAS
TO H-BP-7
PFD-61712-A505

PSA OFFGAS
FROM H-AP-19
PFD-61712-A505

592

HYDROPR PURGE
FROM H-459
PFD-61712-A402

452

541

REFORMER COMB GAS
TO R-530
PFD-61712-A501-A

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Rev.	Date	By	Description
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 500: REFORMER

Project No: 30482.00
Drawing: PFD-61712-A501
Rev: 1

PFD-61712-A501		345	389	389B	411	428	452	461	478	502	512	515	516	519	526	536	541	589	591	592	593					
Total Flow	lb/h	1,824	54,620	57,669	0	787	1,281	0	356	125	56,467	56,467	1,203	125	46,210	102,802	84,672	82,271	82,189	82,189	82	0	0	0	0	0
Temperature	F	95	110	109	0	110	110	0	110	60	109	500	500	60	556	526	438	109	109	450	109	0	0	0	0	0
Pressure	Psia	95	22	22	113	53	33	20	53	200	22	118	20	200	130	118	20	22	22	20	22	0	0	0	0	0
Vapor Fraction		1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-3	-158	-163	0	-1	-1	0	-1	0	-160	-152	-3	0	-254	-405	-294	-298	-298	-290	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	2	0	0	0	2	0	2	5	5	5	5	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	213	1,135	1,432	0	56	2	0	27	0	1,402	1,402	30	0	0	1,402	1,534	1,504	1,503	1,503	2	0	0	0	0	0
Ammonia	lb/h	0	0	4	0	4	3	0	0	0	4	4	0	0	0	4	6	3	3	3	0	0	0	0	0	0
H2S	lb/h	0	0	5	0	5	3	0	1	0	5	5	0	0	0	5	12	9	9	9	0	0	0	0	0	0
Water	lb/h	5	514	546	0	18	55	0	9	0	535	535	11	0	45,491	46,027	508	442	441	441	0	0	0	0	0	0
Carbon Monoxide	lb/h	662	3,348	4,078	0	51	2	0	13	0	3,993	3,993	85	0	0	3,993	4,539	4,457	4,452	4,452	4	0	0	0	0	0
Carbon Dioxide	lb/h	553	38,522	39,331	0	139	53	0	42	1	38,511	38,511	820	1	0	38,512	75,367	74,569	74,494	74,494	75	0	0	0	0	0
Methane	lb/h	83	2,354	2,624	0	115	15	0	70	109	2,569	2,569	55	109	0	2,679	966	897	896	896	1	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	167	4,714	4,899	0	11	5	0	7	0	4,797	4,797	102	0	0	4,797	125	18	18	18	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	265	0	147	94	0	118	7	260	260	6	7	0	267	299	199	199	199	0	0	0	0	0	0
Propylene	lb/h	56	1,594	1,650	0	1	1	0	0	0	1,616	1,616	34	0	0	1,616	35	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	14	0	14	15	0	0	3	14	14	0	3	0	17	25	10	10	10	0	0	0	0	0	0
Furan	lb/h	7	200	207	0	0	0	0	0	0	203	203	4	0	0	203	4	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	28	790	819	0	1	2	0	0	0	802	802	17	0	0	802	20	1	1	1	0	0	0	0	0	0
Tetrahydrofuran	lb/h	6	169	175	0	0	0	0	0	0	171	171	4	0	0	171	4	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	80	0	80	158	0	0	2	79	79	2	2	0	80	213	53	53	53	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	7	187	193	0	0	0	0	0	0	189	189	4	0	0	189	4	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	22	0	22	70	0	0	0	22	22	0	0	0	22	83	13	13	13	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	22	0	22	96	0	0	0	22	22	0	0	0	22	110	13	13	13	0	0	0	0	0	0
Phenol	lb/h	0	31	31	0	0	0	0	0	0	30	30	1	0	31	61	1	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	686	686	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	1	1	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	24	670	745	0	51	230	0	1	0	729	729	16	0	0	729	276	31	31	31	0	0	0	0	0	0
N-Hexane	lb/h	0	0	59	0	12	180	0	46	0	58	58	1	0	0	58	198	17	17	17	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	2	0	2	13	0	0	0	2	2	0	0	0	2	15	2	2	2	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	3	76	85	0	6	31	0	0	0	83	83	2	0	0	83	36	4	4	4	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	24	0	4	88	0	21	0	24	24	1	0	0	24	95	7	7	7	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	2	0	2	16	0	0	0	2	2	0	0	0	2	18	2	2	2	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	2	2	0	0	0	0	0	0	2	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	1	1	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	4	118	129	0	7	44	0	0	0	126	126	3	0	0	126	52	5	5	5	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	7	194	214	0	14	86	0	0	0	210	210	4	0	0	210	101	10	10	10	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	1	0	1	6	0	0	0	1	1	0	0	0	1	7	1	1	1	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	1	0	1	7	0	0	0	1	1	0	0	0	1	8	1	1	1	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QHAP21	0
QHBP37	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
W-K511	2,915	7
	0	0
	0	0
	0	0

R-530 STEAM REFORMER PACKAGE

H-AP-7 REFORMER FLUE GAS COOLER/ REFORMER FEED HIGH TEMP PREHEAT

H-AP-26 REFORMER FLUE GAS COOLER/ INTER-TURBINE STEAM REHEAT

H-AP-27 REFORMER FLUE GAS COOLER/DISTILLATE COLUMN REBOILER

H-AP-28 REFORMER FLUE GAS COOLER/NAPHTHA COLUMN REBOILER

H-AP-29 REFORMER FLUE GAS COOLER/REFORMER COMBUSTOR AIR PREHEAT

H-AP-30 REFORMER FLUE GAS COOLER/REFORMER FEED GAS PREHEAT

H-AP-54 REFORMER FLUE GAS COOLER/BOILER FEEDWATER PREHEAT

H-AP-42 REFORMER FLUE GAS COOLER/BOILER FEEDWATER PREHEAT

H-AP-36 REFORMER FLUE GAS COOLER/BOILER FEEDWATER PREHEAT

H-BP-2 REFORMER FLUE GAS COOLER/REFORMER COMBUSTOR AIR PREHEAT

K-545 REFORMER COMBUSTOR AIR BLOWER

STEAM TO M-602 PFD-61712-A602

STEAM FROM M-602 PFD-61712-A602

REFORMER FEED GAS FROM PFD-61712-A501

536

537

REFORMER COMB GAS FROM H-AP-19/22/H-459 PFD-61712-A501

541

R-530

546

H-548 QF-H548

H-AP-7 QHAP7

H-AP-26 QHAP26

H-AP-27 QHAP27

H-AP-28 QHAP28

H-AP-29 QHAP29

H-AP-30 QHAP30

H-AP-54 QHAP54

H-AP-42 QHAP42

H-AP-36 QHAP36

H-BP-2 QHBP2

1

D-451 BOTTOMS FROM D-451 PFD-61712-A402

D-451 BOTTOMS TO D-451 PFD-61712-A402

SATURATED WATER TO H-AP-52 PFD-61712-A605

SATURATED WATER FROM H-AP-55/H-AP-56 PFD-61712-A605

SATURATED WATER TO H-AP-51 PFD-61712-A605

SATURATED WATER FROM H-AP-31/33/34/35/36/37 PFD-61712-A605

SATURATED WATER TO H-AP-40/41/42/55/56 PFD-61712-A605

SATURATED WATER FROM H-BP-20/21/22 PFD-61712-A605

549

FLUE GAS TO M-104 PFD-61712-A102

540

REFORMER PRODUCT TO R-565/H-AP-47/50 PFD-61712-A502

D-450 BOTTOMS TO D-450 PFD-61712-A402

D-450 BOTTOMS FROM D-450 PFD-61712-A402

COMBUSTION AIR FROM H-AP-20 PFD-61712-A505

REFORMER FEED GAS TO R-530 PFD-61712-A501

515

REFORMER FEED GAS FROM K-511 PFD-61712-A501

514

COMBUSTION AIR TO H-AP-20 PFD-61712-A505

COMBUSTION AIR TO H-BP-12 PFD-61712-A505

543

542

COMBUSTION AIR

K-545

W-K545

1 NOTE: H-548 NOT PHYSICALLY PRESENT IN R-530 FLUE, BUT IS SHOWN TO ACCOUNT FOR FLUE GASES AND COMBUSTION DUTIES OF H-411 AND H-461

Harris Group

NREL NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 500: REFORMER

Rev.	Date	By	Description
1	12/29/14	JAR	MINOR UPDATES
0	12/12/14	DMS	ADDED HX NETWORK

Project No: 30482.00

Drawing: PFD-61712-A501-A

Rev: 1

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

PFD-61712-A501A		514	515	536	537	540	541	542	543	546	549														
Total Flow	lb/h	56,467	56,467	102,802	102,802	102,802	84,672	136,272	136,272	136,272	220,944	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	467	500	526	1400	1616	438	90	173	600	245	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	120	118	118	118	115	20	15	21	20	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-152	-152	-405	-362	-295	-294	-15	-12	2	-463	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	1,721	1,721	1,721	1,721	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	2	2	5	5	100,907	100,907	100,907	100,912	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	30,918	30,918	30,918	6,218	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	1,402	1,402	1,402	1,402	4,803	1,534	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	4	4	4	4	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	5	5	5	5	5	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	535	535	46,027	46,027	33,046	508	2,659	2,659	2,659	21,487	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	3,993	3,993	3,993	3,993	30,596	4,539	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	38,511	38,511	38,512	38,512	33,927	75,367	67	67	67	90,566	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	2,569	2,569	2,679	2,679	420	966	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	4,797	4,797	4,797	4,797	0	125	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	260	260	267	267	0	299	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	1,616	1,616	1,616	1,616	0	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	14	14	17	17	0	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	203	203	203	203	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	802	802	802	802	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	171	171	171	171	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	79	79	80	80	0	213	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	189	189	189	189	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	22	22	22	22	0	83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	22	22	22	22	0	110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	30	30	61	61	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	686	686	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	729	729	729	729	0	276	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	58	58	58	58	0	198	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	2	2	2	2	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	83	83	83	83	0	36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	24	24	24	24	0	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	2	2	2	2	0	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	126	126	126	126	0	52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	210	210	210	210	0	101	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	1	1	1	1	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	1	1	1	1	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QF-H458	3
QHAP21	44
QHAP26	15
QHAP27	6
QHAP28	5
QHAP29	5
QHAP30	1
QHAP36	5
QHAP42	9
QHAP54	9
QHBP2	4
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
W-K545	1,087	3
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

R-565
WGS
REACTOR

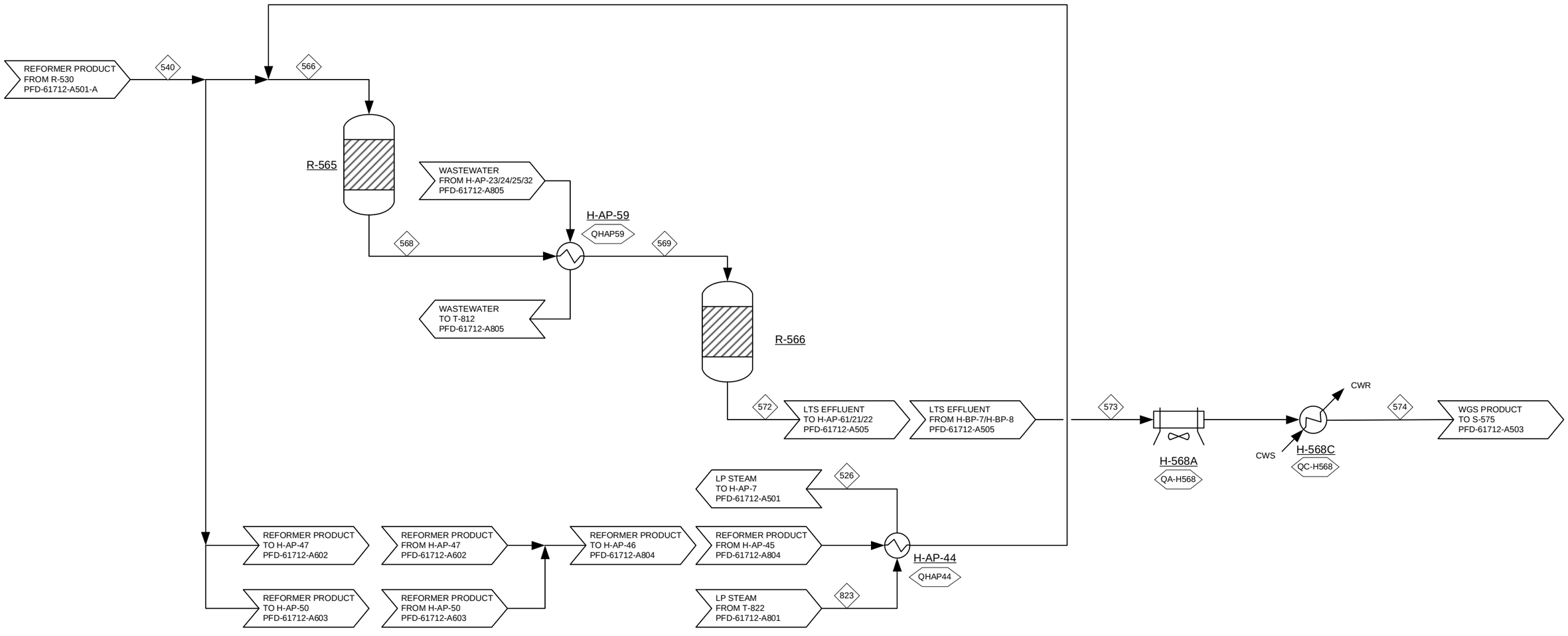
H-AP-59
A500 HIGH TEMP WGS
OUTLET COOLER/
STEAM PRODUCTION
FROM WW FOR WGS

R-566
LTS REACTOR

H-AP-44
REFORMER OUTLET
COOLER/REFORMER
STEAM SUPERHEAT

H-568A
WGS EFFLUENT
ACHE

H-568C
WGS EFFLUENT
COOLER



Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Harris Group

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 500: WATER GAS SHIFT

Rev.	Date	By	Description
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Project No: 30482.00
Drawing: PFD-61712-A502
Rev: 1

PFD-61712-A502		526	540	566	568	569	572	573	574	823															
Total Flow	lb/h	46,210	102,802	102,802	102,802	102,802	102,802	102,802	102,802	46,210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	556	1616	644	835	428	540	185	110	356	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	130	115	113	108	106	101	99	97	135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-254	-295	-347	-347	-368	-368	-393	-405	-258	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	5	5	5	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	4,803	4,803	6,011	6,011	6,686	6,686	6,686	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	5	5	5	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	45,491	33,046	33,046	22,252	22,252	16,218	16,218	16,218	45,491	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	30,596	30,596	13,815	13,815	4,433	4,433	4,433	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	33,927	33,927	60,294	60,294	75,035	75,035	75,035	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	420	420	420	420	420	420	420	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	31	0	0	0	0	0	0	0	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	686	0	0	0	0	0	0	0	686	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QA-H568	8
QC-H568	3
QHAP44	5
QHAP59	21
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0

S-575
COMPRESSOR
SUCTION KO DRUM

K-580
PSA COMPRESSOR
MULTISTAGE

T-576
COMRPESSOR
CONDENSATE TANK

S-586
PSA COMPRESSOR
DISCHARGE KO DRUM

P-576
COMPRESSOR
CONDENSATE PUMP

M-575
PSA

RECYCLE GAS PURGE
FROM S-461
PFD-61712-A403

481

RECYCLE GAS PURGE
FROM S-411
PFD-61712-A401

431

588

M-575

589

PSA OFFGAS
TO K-511/H-BP-7/9
PFD-61712-A501

590

HYDROGEN
TO K-211/K-412/K-462
PFD-61712-A504

577

586

CWR

CWS

WGS PRODUCT
FROM H-568C
PFD-61712-A502

574

S-575

585

S-586

582

587

K-580

W-K580

QC-K580

QA-K580

576A

T-576

576

CONDENSATE
TO T-860
PFD-61712-A804

P-576

W-P576

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 500: PSA

Project No: 30482.00

Drawing: PFD-61712-A503

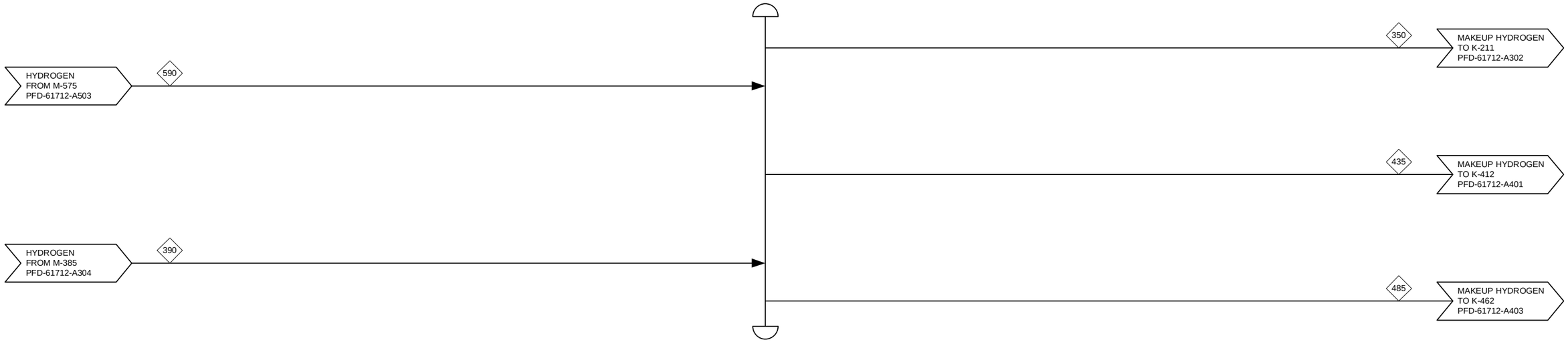
Rev: 2

ENGINEERING-PDH.COM
| CHE-136 |

PFD-61712-A503		431	481	574	576	576A	577	582	585	586	587	588	589	590												
Total Flow	lb/h	2,061	298	102,802	15,788	15,077	87,725	550	87,176	87,014	162	89,373	82,271	7,102	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	110	110	110	110	110	110	110	110	110	110	109	109	109	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	1493	1893	97	102	97	97	97	278	276	276	276	22	266	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	0	0	1	0	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-2	0	-405	-108	-103	-302	-4	-299	-298	-1	-301	-298	-3	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	5	0	0	5	0	5	5	0	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	727	107	6,686	0	0	6,686	0	6,686	6,686	0	7,520	1,504	6,016	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	3	0	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	4	0	5	0	0	5	0	5	5	0	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	9	1	16,218	15,786	15,075	1,143	550	593	432	162	442	442	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	414	32	4,433	0	0	4,433	0	4,433	4,433	0	4,879	4,457	422	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	180	19	75,035	1	1	75,033	0	75,033	75,033	0	75,232	74,569	663	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	397	80	420	0	0	420	0	420	420	0	897	897	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	14	3	0	0	0	0	0	0	0	0	18	18	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	157	42	0	0	0	0	0	0	0	0	199	199	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	10	0	0	0	0	0	0	0	0	0	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	53	0	0	0	0	0	0	0	0	0	53	53	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	13	0	0	0	0	0	0	0	0	0	13	13	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	13	0	0	0	0	0	0	0	0	0	13	13	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	31	0	0	0	0	0	0	0	0	0	31	31	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	8	9	0	0	0	0	0	0	0	0	17	17	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	2	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	4	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	2	4	0	0	0	0	0	0	0	0	7	7	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	2	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	5	0	0	0	0	0	0	0	0	0	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	10	0	0	0	0	0	0	0	0	0	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QC-K580	4
QA-K580	5
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
WK-580	3,249	8
W-P576	0	0
	0	0
	0	0



Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 500: HYDROGEN DISTRIBUTION

Project No: 30482.00
Drawing: PFD-61712-A504
Rev: 1

PFD-61712-A504		350	390	435	485	590																			
Total Flow	lb/h	11,217	7,032	2,154	764	7,102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	100	110	110	110	109	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	110	202	245	245	266	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-4	-3	-1	0	-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	9,502	5,957	1,825	647	6,016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	667	418	128	45	422	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	1,048	657	201	71	663	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

H-AP-22
A500 LOW TEMP WGS OUTLET COOLER/REFORMER COMBUSTOR GAS PREHEAT

H-AP-20
A500 LOW TEMP WGS OUTLET COOLER/REFORMER COMBUSTOR AIR PREHEAT

H-AP-19
A500 LOW TEMP WGS OUTLET COOLER/PSA OFFGAS TO REFORMER COMBUSTOR PREHEAT

H-BP-15
LOW TEMP WGS OUTLET COOLER/PSA EXH TO REFORMER COMB PREHEAT

H-BP-9
LOW TEMP WGS OUTLET COOLER/REFORMER COMB GAS PREHEAT

H-BP-12
LOW TEMP WGS OUTLET COOLER/REFORMER COMB AIR PREHEAT

H-BP-7
LOW TEMP WGS OUTLET COOLER/REFORMER COMBUSTOR AIR PREHEAT

COMBUSTION AIR FROM H-BP-2 PFD-61712-A501-A

COMBUSTION AIR FROM K-545 PFD-61712-A501-A

592 PSA OFFGAS TO R-530 PFD-61712-A501

591 PSA OFFGAS FROM M-575 PFD-61712-A501

LTS EFFLUENT FROM R-566 PFD-61712-A502

572

LTS EFFLUENT TO H-AP-61 PFD-61712-A805

LTS EFFLUENT FROM H-AP-61 PFD-61712-A805

LTS EFFLUENT TO H-AP-21 PFD-61712-A501

LTS EFFLUENT FROM H-AP-21 PFD-61712-A501

H-AP-20
QHAP20

H-BP-12
QHBP12

H-BP-7
QHBP7

573 LTS EFFLUENT TO H-568A PFD-61712-A502

H-AP-19
QHAP19

REFORMER COMB GAS TO R-530 PFD-61712-A501

516

H-BP-15
QHBP15

LTS EFFLUENT TO H-BP-8 PFD-61712-A604

LTS EFFLUENT FROM H-BP-8 PFD-61712-A604

H-AP-22
QHAP22

LTS EFFLUENT TO H-BP-25 PFD-61712-A604

LTS EFFLUENT FROM H-BP-28 PFD-61712-A604

513 REFORMER COMB GAS FROM HEADER PFD-61712-A501

H-BP-9
QHBP9

COMBUSTION AIR TO H-AP-29 PFD-61712-A501-A

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Harris Group

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
0	12/12/14	DMS	ADDED HX NETWORK

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 500: A500 HEAT RECOVERY

Project No: 30482.00
Drawing: PFD-61712-A505
Rev: 0

PFD-61712-A505		513	516	572	573	591	592																			
Total Flow	lb/h	1,203	1,203	102,802	102,802	82,189	82,189	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	109	500	540	185	109	450	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	22	20	101	99	22	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-3	-3	-368	-393	-298	-290	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	5	5	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0			0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	30	30	6,686	6,686	1,503	1,503	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	5	5	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	11	11	16,218	16,218	441	441	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	85	85	4,433	4,433	4,452	4,452	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	820	820	75,035	75,035	74,494	74,494	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	55	55	420	420	896	896	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	102	102	0	0	18	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	6	6	0	0	199	199	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	34	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	17	17	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	2	2	0	0	53	53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	13	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	13	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	16	16	0	0	31	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	1	1	0	0	17	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	2	2	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	1	1	0	0	7	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	3	3	0	0	5	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	4	4	0	0	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QHAP19	4
QHAP20	6
QHAP22	0
QHBP12	0
QHBP15	2
QHBP7	2
QHBP9	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0

P-601 MAKE-UP PUMP | H-BP-44 ABSORBER 1 BOTTOMS COOLER/RECYCLED BFW PREHEAT | H-BP-45 BFW BLOWDOWN COOLER/RECYCLED BFW PREHEAT | H-BP-46 HC OUTLET COOLER/ RECYCLED BFW PREHEAT | H-BP-32 BFW BLOWDOWN COOLER/RECYCLED BFW PREHEAT | H-BP-40 EX-SITU CAT REGEN FLUE GAS COOLER/RECYCLED BFW PREHEAT | H-603 BLOWDOWN COOLER | T-601 CONDENSATE COLLECTION TANK | P-605 CONDENSATE COLLECTION PUMP | T-602 CONDENSATE SURGE TANK | P-603 EDI PUMP | M-601 BFW ELECTRODEIONIZATION (EDI) + POLISHING | T-603A DEAERATOR PACKED COLUMN | T-603 DEAERATOR | P-604 BOILER FEEDWATER PUMP

CONDENSATE FROM USERS

CONDENSATE FROM P-602 PFD-61712-A602

616

617

ATM

T-601

626

627

T-602

P-605

P-603

WP603

M-601

630

POLISHED COND TO H-BP-1/H-BP-8 PFD-61712-A604

POLISHED COND FROM PFD-61712-A604

631

ATM

T-603A

FLASH STEAM FROM S-601 PFD-61712-A603

AMMONIA FROM P-704 PFD-61712-A702

BFW CHEMICALS FROM P-707 PFD-61712-A702

T-603

638

639

P-604

WP604

BOILER FEEDWATER TO H-BP-20/21/22 PFD-61712-A605

BOILER FEEDWATER TO M-603 PFD-61712-A602

ABSORBER BOTTOMS FROM H-BP-31 PFD-61712-A305

H-BP-44

QHBP44

BLOWDOWN FROM H-BP-33/37/39 PFD-61712-A603

MAKEUP WATER FROM PFD-61712-A701

618

P-601

WP601

319

ABSORBER BOTTOMS TO S-319 PFD-61712-A305

H-BP-32

QHBP32

VPU FLUE GAS FROM H-AP-37 PFD-61712-A203

H-BP-45

QHBP45

H-BP-40

QHBP40

VPU FLUE GAS TO H-BP-17 PFD-61712-A203

CWR

600

BLOWDOWN TO M-701 PFD-61712-A701

CWS

H-603

QH603

MAKEUP WATER TO H-BP-47 PFD-61712-A404

MAKEUP WATER FROM H-BP-47 PFD-61712-A404

HC EFFLUENT FROM H-BP-19 PFD-61712-A604

H-BP-46

QHBP46

HC EFFLUENT TO H-463A PFD-61712-A404

ENGINEERING-PDH.COM
| CHE-136 |

Harris Group

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 600: STEAM SYSTEM & POWER GENERATION

Project No: 30482.00 | Drawing: PFD-61712-A601 | Rev: 1

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design+Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

PFD-61712-A601		319	600	616	617	618	626	627	630	631	638	639													
Total Flow	lb/h	19,671	6,475	317,274	317,274	6,473	6,473	323,747	323,747	323,747	323,749	323,749	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	175	113	136	136	60	212	138	138	232	232	235	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	123	15	25	15	15	15	15	25	22	22	1401	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-10	-44	-2145	-2145	-44	-43	-2189	-2189	-2158	-2158	-2156	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	43	6,475	317,274	317,274	6,473	6,473	323,747	323,747	323,747	323,749	323,749	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	373	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	333	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	185	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	163	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	427	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	4,923	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	3,421	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	7,751	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	1,788	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QH603	0
QHBP32	0
QHBP40	0
QHBP44	0
QHBP45	0
QHBP46	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
WP601	0	0
WP603	13	0
WP604	740	2
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

M-603
STARTUP BOILER

H-AP-9
CHAR COMBUSTOR FLUE GAS COOLER/INTER-TURBINE STEAM REHEAT

H-AP-47
REFORMER OUTLET COOLER/INTER-TURBINE STEAM REHEAT

M-602
TURBINE GENERATOR

H-BP-10
STEAM TURBINE EXHAUST COOLER/WW PREHEAT FOR STEAM PRODUCTION

H-601
STEAM TURBINE CONDENSER

T-606
STEAM TURBINE CONDENSATE TANK

P-602
CONDENSATE PUMP

BOILER FEEDWATER
FROM P-604
PFD-61712-A601

M-603

LP STEAM
TO USERS

SUPERHEATED STEAM
FROM H-AP-2/4/6/49/50
PFD-61712-A603

607

M-602

W-602A

QH602B

FLUE GAS
FROM S-214
PFD-61712-A203

232P

H-AP-9

QHAP9

FLUE GAS
TO H-AP-8
PFD-61712-A203

STEAM
TO H-AP-26
PFD-61712-A501-A

STEAM
FROM H-AP-26
PFD-61712-A501-A

REFORMER PRODUCT
FROM R-530
PFD-61712-A502

H-AP-47

QHAP47

REFORMER PRODUCT
TO H-AP-46
PFD-61712-A502

WASTEWATER
FROM P-810
PFD-61712-A805

811

614A

H-BP-10

QHBP10

H-601

QAH601

T-606

WASTEWATER
TO H-BP-26/H-BP-33
PFD-61712-A805

616

CONDENSATE
TO T-601
PFD-61712-A601

P-602

WP602

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

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Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 600: STEAM SYSTEM & POWER GENERATION

Rev.	Date	By	Description
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

Project No: 30482.00

Drawing: PFD-61712-A602

Rev: 1

PFD-61712-A602		232P	607	614A	615	616	811																			
Total Flow	lb/h	258,265	317,274	317,274	317,274	317,274	77,811																			
Temperature	F	1328	1000	234	136	136	86																			
Pressure	Psia	115	1321	4	3	25	160																			
Vapor Fraction		1	1	1	0	0	0																			
Enthalpy Flow	MMBtu/h	-208	-1704	-1809	-2145	-2145	-523																			
Argon	lb/h	3,005	0	0	0	0	0																			
Nitrogen	lb/h	176,443	0	0	0	0	0																			
Oxygen	lb/h	8,996	0	0	0	0	0																			
SO2	lb/h	85	0	0	0	0	0																			
NO2	lb/h	0	0	0	0	0	0																			
Hydrogen	lb/h	0	0	0	0	0	0																			
Ammonia	lb/h	0	0	0	0	0	0																			
H2S	lb/h	0	0	0	0	0	0																			
Water	lb/h	13,826	317,274	317,274	317,274	317,274	75,955																			
Carbon Monoxide	lb/h	0	0	0	0	0	0																			
Carbon Dioxide	lb/h	55,910	0	0	0	0	2																			
Methane	lb/h	0	0	0	0	0	0																			
Methanol	lb/h	0	0	0	0	0	0																			
Formic Acid	lb/h	0	0	0	0	0	0																			
Glyoxal	lb/h	0	0	0	0	0	0																			
Ethylene	lb/h	0	0	0	0	0	0																			
Acetaldehyde	lb/h	0	0	0	0	0	0																			
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0																			
Acetic Acid	lb/h	0	0	0	0	0	0																			
Ethane	lb/h	0	0	0	0	0	0																			
Propylene	lb/h	0	0	0	0	0	0																			
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0																			
Propionic Acid	lb/h	0	0	0	0	0	0																			
Propane	lb/h	0	0	0	0	0	0																			
Furan	lb/h	0	0	0	0	0	0																			
1-Butene	lb/h	0	0	0	0	0	0																			
Tetrahydrofuran	lb/h	0	0	0	0	0	0																			
N-Butane	lb/h	0	0	0	0	0	0																			
Furfural	lb/h	0	0	0	0	0	0																			
2-methylfuran	lb/h	0	0	0	0	0	0																			
Furfuryl Alcohol	lb/h	0	0	0	0	0	0																			
n-Pentane	lb/h	0	0	0	0	0	0																			
Pentenone	lb/h	0	0	0	0	0	0																			
Benzene	lb/h	0	0	0	0	0	0																			
Phenol	lb/h	0	0	0	0	0	73																			
1,2-Benzenediol	lb/h	0	0	0	0	0	1,778																			
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0																			
2,5-dimethylfuran	lb/h	0	0	0	0	0	0																			
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0																			
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0																			
Cyclohexanone	lb/h	0	0	0	0	0	0																			
Levoglucosan	lb/h	0	0	0	0	0	0																			
1-Hexanal	lb/h	0	0	0	0	0	0																			
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0																			
Cyclohexane	lb/h	0	0	0	0	0	0																			
N-Hexane	lb/h	0	0	0	0	0	0																			
Hexanol	lb/h	0	0	0	0	0	0																			
Toluene	lb/h	0	0	0	0	0	0																			
2-Methylphenol	lb/h	0	0	0	0	0	0																			
3-Methyl-phenol	lb/h	0	0	0	0	0	0																			
Guaiacol	lb/h	0	0	0	0	0	0																			
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0																			
2-Methylhexane	lb/h	0	0	0	0	0	0																			
VinylPhenol	lb/h	0	0	0	0	0	0																			
O-Xylene	lb/h	0	0	0	0	0	0																			
Ethylbenzne	lb/h	0	0	0	0	0	0																			
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	1																			
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0																			
Vanillyl alcohol	lb/h	0	0	0	0	0	3																			
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0																			
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0																			
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0																			
Ethylcyclohexane	lb/h	0	0	0	0	0	0																			
4-Methylheptane	lb/h	0	0	0	0	0	0																			
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0																			
Indane	lb/h	0	0	0	0	0	0																			
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0																			
Syringaldehyde	lb/h	0	0	0	0	0	0																			
n-Propylbenzene	lb/h	0	0	0	0	0	0																			
Naphthalene	lb/h	0	0	0	0	0	0																			
1-Naphthalenol	lb/h	0	0	0	0	0	0																			
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0																			
Tetralin	lb/h	0	0	0	0	0	0																			
Isoeugenol	lb/h	0	0	0	0	0	0																			
Decalin	lb/h	0	0	0	0	0	0																			
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0																			
1-Methyl naphthalene	lb/h	0	0	0	0	0	0																			
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0																			
Dibenzothiophene	lb/h	0	0	0	0	0	0																			
Biphenyl	lb/h	0	0	0	0	0	0																			
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0																			
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0																			
C14H20-N35	lb/h	0	0	0	0	0	0																			
C14H24-N5	lb/h	0	0	0	0	0	0																			
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0																			
C15H26-N4	lb/h	0	0	0	0	0	0																			
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0																			
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0																			
N-Cetane	lb/h	0	0	0	0	0	0																			
C18H26O	lb/h	0	0	0	0	0	0																			
C18H28	lb/h	0	0	0	0	0	0																			
C21H26O2	lb/h	0	0	0	0	0	0																			
C21H34	lb/h	0	0	0	0	0	0																			
C22H28O2	lb/h	0	0	0	0	0	0																			
Carbon	lb/h	0	0	0	0	0	0																			
Sulfur	lb/h	0	0	0	0	0	0																			
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0																			
Ash	lb/h	0	0	0	0	0	0																			
Wood	lb/h	0	0	0	0	0	0																			
Char	lb/h	0	0	0	0	0	0																			
Coke	lb/h	0	0	0	0	0	0																			

Heat	MMBtu/h
QAH601	327
QH602B	-51
QHAP47	28
QHAP9	8
QHBP10	9
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
W-602A	-59,336	-151
WP602	11	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

T-605
STEAM
DRUM

S-601
BLOWDOWN
FLASH DRUM

H-AP-48
PRE-ABSORBER UPGRADED
VAPOR COOLER/STEAM
SUPERHEAT

H-AP-49
EX-SITU CATALYST REGEN
FLUE GAS COOLER/STEAM
SUPERHEAT

H-AP-50
REFORMER OUTLET
COOLER/STEAM
SUPERHEAT

H-AP-10
BOILER FEEDWATER
BLOWDOWN COOLER/
CATALYST STRIPPER WATER
PREHEAT FOR STEAM

H-AP-11
BOILER FEEDWATER
BLOWDOWN COOLER/
WATER PREHEAT FOR MIX
WITH WW FOR STEAM

H-BP-33
BOILER FEEDWATER
BLOWDOWN COOLER/
WASTEWATER PREHEAT FOR
STEAM PRODUCTION

H-BP-39
BOILER FEEDWATER
BLOWDOWN COOLER/
CATALYST STRIPPER WATER
PREHEAT FOR STEAM

SATURATED WATER
FROM H-AP-51
PFD-61712-A605

641

SATURATED WATER
TO H-AP-1
PFD-61712-A201

SATURATED WATER
TO H-AP-3/H-AP-5
PFD-61712-A202

SATURATED STEAM
FROM H-AP-1
PFD-61712-A201

SATURATED STEAM
FROM H-AP-3/H-AP-5
PFD-61712-A202

644

T-605

SATURATED STEAM
TO H-AP-2
PFD-61712-A201

SATURATED STEAM
TO H-AP-4/H-AP-6
PFD-61712-A202

PYROLYSIS VAPOR
FROM S-262/T-261
PFD-61712-A305

300

H-AP-48

QHAP48

PYROLYSIS VAPOR
TO H-AP-51
PFD-61712-A605

SUPERHEATED STEAM
FROM H-AP-2
PFD-61712-A201

SUPERHEATED STEAM
FROM H-AP-4/H-AP-6
PFD-61712-A202

VPU FLUE GAS
FROM S-264
PFD-61712-A203

289

H-AP-49

QHAP49

VPU FLUE GAS
TO H-AP-38/H-AP-39
PFD-61712-A203

607

SUPERHEATED STEAM
TO M-602
PFD-61712-A602

REFORMER PRODUCT
FROM R-530
PFD-61712-A502

H-AP-50

QHAP50

REFORMER PRODUCT
TO H-AP-46
PFD-61712-A502

FLASH STEAM
TO T-603
PFD-61712-A601

S-601

CLEAN WATER
FROM H-BP-39/H-BP-41
PFD-61712-A804

H-AP-10

QHAP10

CLEAN WATER
TO H-AP-45
PFD-61712-A804

MAKEUP WATER
FROM H-BP-42/H-BP-43
PFD-61712-A801

H-AP-11

QHAP11

MAKEUP WATER
TO T-814
PFD-61712-A801

BLOWDOWN
TO H-AP-55
PFD-61712-A605

BLOWDOWN
FROM H-AP-35
PFD-61712-A605

WASTEWATER
FROM H-BP-10
PFD-61712-A805

H-BP-33

QHBP33

WASTEWATER
TO H-AP-23/24/25/32
PFD-61712-A805

BLOWDOWN
TO H-BP-32
PFD-61712-A601

BLOWDOWN
TO H-BP-37
PFD-61712-A501

BLOWDOWN
FROM H-BP-37
PFD-61712-A501

CLEAN WATER
FROM H-BP-48
PFD-61712-A804

H-BP-39

QHBP39

CLEAN WATER
TO H-AP-10
PFD-61712-A804

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 600: STEAM SYSTEM & POWER GENERATION

Project No: 30482.00

Drawing: PFD-61712-A603

Rev: 1

PFD-61712-A603		289	300	607	641	644																				
Total Flow	lb/h	210,963	310,342	317,274	323,749	323,749	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	1202	931	1000	582	581	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	111	115	1321	1346	1336	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-160	-638	-1704	-2031	-1845	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	2,478	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	145,311	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	7,421	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	21,258	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	3,830	76,670	317,274	323,749	323,749	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	66,248	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	51,924	55,426	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	8,325	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	16,692	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	5,682	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	845	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	2,919	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	1,046	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	1,144	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	2,161	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	1,872	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	5,348	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	990	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	2,627	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	898	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	870	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	333	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	3,060	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	4,153	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	463	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	353	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	381	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	417	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	73	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	4,709	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	3,313	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	3,555	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	427	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	4,923	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	3,421	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	7,754	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	1,788	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QHAP10	0
QHAP11	0
QHAP48	6
QHAP49	17
QHAP50	16
QHBP33	0
QHBP39	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

H-BP-1
A300 WGS OUTLET COOLER/CONDENSER/ BOILER FEEDWATER PREHEAT 1

H-BP-8
LOW TEMP WGS OUTLET COOLER/ CONDENSER/BOILER FEEDWATER PREHEAT 1

H-BP-16
CHAR COMBUSTOR FLUE GAS COOLER/ BOILER FEEDWATER PREHEAT 1

H-BP-25
LOW TEMP WGS OUTLET COOLER/ BOILER FEEDWATER PREHEAT 1

H-BP-28
LOW TEMP WGS OUTLET COOLER/ BOILER FEEDWATER PREHEAT 1

H-BP-35
A300 WGS OUTLET COOLER/BOILER FEEDWATER PREHEAT 1

H-BP-27
A300 WGS OUTLET COOLER/BOILER FEEDWATER PREHEAT 1

H-BP-23
HYDROTREATER OUTLET COOLER/ BOILER FEEDWATER PREHEAT 1

H-BP-18
HYDROTREATER OUTLET COOLER/ BOILER FEEDWATER PREHEAT 1

H-BP-24
HYDROCRACKER OUTLET COOLER/ BOILER FEEDWATER PREHEAT 1

H-BP-19
HYDROCRACKER OUTLET COOLER/ BOILER FEEDWATER PREHEAT 1

H-BP-11
POST-ABSORBER 1 VAPOR COOLER/ BOILER FEEDWATER PREHEAT 1

H-BP-13
RTO LOW TEMP EXHAUST COOLER/ BOILER FEEDWATER PREHEAT 1

H-BP-17
EX-SITU CATALYST REGEN FLUE GAS COOLER/BOILER FEEDWATER PREHEAT 1

H-BP-34
ABSORBER 1 BOTTOMS COOLER/ BOILER FEEDWATER PREHEAT 1

H-BP-31
ABSORBER 1 BOTTOMS COOLER/ BOILER FEEDWATER PREHEAT 1

H-BP-29
DISTILLATE PRODUCT COOLER/ BOILER FEEDWATER PREHEAT 1

WGS OUTLET FROM H-BP-14/H-BP-27 PFD-61712-A303

POLISHED COND FROM M-601C PFD-61712-A601

630

H-BP-1
QHBP1

WGS OUTLET TO H-373 PFD-61712-A303

LTS EFFLUENT FROM H-BP-12/15/28/9 PFD-61712-A505

H-BP-8
QHBP8

LTS EFFLUENT TO H-568A PFD-61712-A505

FLUE GAS FROM H-BP-21 PFD-61712-A203

H-BP-16
QHBP16

239P

FLUE GAS TO M-104 PFD-61712-A203

LTS EFFLUENT FROM H-AP-19/H-AP-20 PFD-61712-A505

H-BP-25
QHBP25

H-BP-28
QHBP28

LTS EFFLUENT TO H-BP-7/H-BP-8 PFD-61712-A505

WGS OUTLET FROM H-AP-14/32/33 PFD-61712-A303

H-BP-35
QHBP35

H-BP-27
QHBP27

WGS OUTLET TO H-BP-4/36/1 PFD-61712-A303

HT EFFLUENT FROM H-AP-12/H-AP-24 PFD-61712-A404

H-BP-23
QHBP23

H-BP-18
QHBP18

HT EFFLUENT TO H-BP-47/48/49 PFD-61712-A404

HC EFFLUENT FROM H-AP-34 PFD-61712-A404

H-BP-24
QHBP24

H-BP-19
QHBP19

HC EFFLUENT TO H-BP-46 PFD-61712-A601

ABSORBER VAPOR FROM H-BP-20 PFD-61712-A605

H-BP-11
QHBP11

ABSORBER VAPOR TO H-313 PFD-61712-A305

FLUE GAS FROM H-840 PFD-61712-A802

840

H-BP-13
QHBP13

841

FLUE GAS TO M-104 PFD-61712-A802

VPU FLUE GAS FROM H-BP-40/22/41/42 PFD-61712-A203

H-BP-17
QHBP17

297

VPU FLUE GAS TO M-104 PFD-61712-A203

ABSORBER BOTTOMS FROM H-AP-23 PFD-61712-A305

H-BP-34
QHBP34

ABSORBER BOTTOMS TO H-BP-31 PFD-61712-A305

ABSORBER BOTTOMS FROM H-BP-34/H-BP-43 PFD-61712-A305

H-BP-31
QHBP31

ABSORBER BOTTOMS TO H-BP-44 PFD-61712-A305

DIESEL PRODUCT FROM H-AP-16/H-AP-25 PFD-61712-A404

H-BP-29
QHBP29

631

POLISHED COND TO T-603 PFD-61712-A601

DIESEL PRODUCT TO H-BP-30 PFD-61712-A404

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Harris Group

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 600: BOILER FEEDWATER PREHEAT 1

Rev.	Date	By	Description
1	12/29/14	JAR	MINOR UPDATES
0	12/12/14	DMS	ADDED HX NETWORK

Project No: 30482.00
Drawing: PFD-61712-A604
Rev. 1

PFD-61712-A604		239P	297	630	631	840	841																			
Total Flow	lb/h	258,265	210,963	323,747	323,747	80,265	80,265	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	245	245	138	232	269	245	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	109	105	25	22	19	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-284	-213	-2189	-2158	-28	-28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	3,005	2,478	0	0	979	979	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	176,443	145,311	0	0	57,382	57,382	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	8,996	7,421	0	0	15,606	15,606	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	13,826	3,830	323,747	323,747	3,752	3,752	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	55,910	51,924	0	0	2,547	2,547	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QHBP1	5
QHBP11	5
QHBP13	0
QHBP16	1
QHBP17	1
QHBP18	2
QHBP19	0
QHBP23	2
QHBP24	0
QHBP25	2
QHBP27	1
QHBP28	1
QHBP29	2
QHBP31	1
QHBP34	0
QHBP35	1
QHBP8	7
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

H-BP-20
POST-ABSORBER 1
VAPOR COOLER/
BOILER FEEDWATER
PREHEAT 2

H-BP-21
CHAR COMBUSTOR
FLUE GAS COOLER/
BOILER FEEDWATER
PREHEAT 2

H-BP-22
EX-SITU CATALYST
REGEN COOLER/
BOILER FEEDWATER
PREHEAT 2

H-AP-31
POST-ABSORBER 1
VAPOR COOLER/
BOILER FEEDWATER
PREHEAT

H-AP-33
A300 WGS OUTLET
COOLER/BOILER
FEEDWATER
PREHEAT

H-AP-34
HYDROTREATER
OUTLET COOLER/
BOILER FEEDWATER
PREHEAT

H-AP-35
BOILER FEEDWATER
BLOWDOWN COOLER/
BOILER FEEDWATER
PREHEAT

H-AP-37
EX-SITU CATALYST
REGEN FLUE GAS
COOLER/BOILER
FEEDWATER PREHEAT

H-AP-40
BOILER FEEDWATER
BLOWDOWN COOLER/
BOILER FEEDWATER
PREHEAT

H-AP-41
HYDROTREATER
OUTLET COOLER/
BOILER FEEDWATER
PREHEAT

H-AP-55
BOILER FEEDWATER
BLOWDOWN COOLER/
BOILER FEEDWATER
PREHEAT

H-AP-56
PRE-ABSORBER
UPGRADED VAPOR
COOLER/BOILER
FEEDWATER PREHEAT

H-AP-52
A300 WGS OUTLET
COOLER/BOILER
FEEDWATER
PREHEAT

H-AP-51
PRE-ABSORBER
UPGRADED VAPOR
COOLER/BOILER
FEEDWATER PREHEAT

ABSORBER VAPOR
FROM H-AP-17/18/31
PFD-61712-A305

BOILER FEEDWATER
FROM P-604
PFD-61712-A601

639

FLUE GAS
FROM H-AP-8
PFD-61712-A203

VPU FLUE GAS
FROM H-AP-37
PFD-61712-A203

H-BP-20
QHBP20

ABSORBER VAPOR
TO H-BP-11
PFD-61712-A604

H-BP-21
QHBP21

FLUE GAS
TO H-BP-16
PFD-61712-A203

H-BP-22
QHBP22

VPU FLUE GAS
TO H-BP-17
PFD-61712-A203

ABSORBER VAPOR
FROM D-301
PFD-61712-A305

H-AP-31
QHAP31

ABSORBER VAPOR
TO H-BP-20/H-BP-3
PFD-61712-A305

WGS OUTLET
FROM H-AP-15
PFD-61712-A303

H-AP-33
QHAP33

WGS OUTLET
TO H-BP-14/H-BP-35
PFD-61712-A303

H-AP-34
QHAP34

HC EFFLUENT
TO H-BP-6
PFD-61712-A404

H-AP-35
QHAP35

BLOWDOWN
TO H-BP-33/37/39
PFD-61712-A603

SATURATED WATER
TO H-AP-36
PFD-61712-A501-A

SATURATED WATER
FROM H-AP-36
PFD-61712-A501-A

VPU FLUE GAS
TO H-AP-38/H-AP-39
PFD-61712-A203

H-AP-37
QHAP37

VPU FLUE GAS
TO H-BP-40/22/41/42
PFD-61712-A203

H-AP-40
QHAP40

HC EFFLUENT
FROM H-AP-57/H-AP-43
PFD-61712-A404

H-AP-41
QHAP41

SATURATED WATER
TO H-AP-42
PFD-61712-A501-A

SATURATED WATER
FROM H-AP-42
PFD-61712-A501-A

H-AP-55
QHAP55

SATURATED WATER
TO H-AP-54
PFD-61712-A501-A

SATURATED WATER
FROM H-AP-54
PFD-61712-A501-A

BLOWDOWN
FROM S-601
PFD-61712-A603

PYROLYSIS VAPOR
FROM H-AP-51
PFD-61712-A305

H-AP-56
QHAP56

PYROLYSIS VAPOR
TO D-301
PFD-61712-A301

PYROLYSIS VAPOR
FROM H-AP-48
PFD-61712-A603

H-AP-51
QHAP51

641

SATURATED WATER
TO H-AP-1/3/5
PFD-61712-A603

PYROLYSIS VAPOR
TO H-AP-53/56/60
PFD-61712-A305

H-AP-52
QHAP52

372

WGS OUTLET
FROM R-365
PFD-61712-A303

WGS OUTLET
TO H-AP-15
PFD-61712-A303

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/29/14	JAR	MINOR UPDATES
0	12/12/14	DMS	ADDED HX NETWORK

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 600: BOILER FEEDWATER PREHEAT 2

Project No: 30482.00

Drawing: PFD-61712-A605

Rev: 1

ENGINEERING-PDH.COM
| CHE-136 |

PFD-61712-A605		372	639	641																						
Total Flow	lb/h	82,376	323,749	323,749	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	637	235	582	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	84	1401	1346	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-253	-2156	-2031	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	7,092	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	21,172	323,749	323,749	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	3,766	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	39,180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	2,354	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	4,714	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	1,594	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	790	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	169	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	187	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	670	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	118	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	194	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QHAP31	10
QHAP33	0
QHAP34	1
QHAP35	0
QHAP37	4
QHAP40	1
QHAP41	3
QHAP51	43
QHAP52	8
QHAP55	0
QHAP56	16
QHBP20	10
QHBP21	4
QHBP22	2
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0

P-708
FLUE GAS SCRUBBER
CIRCULATION PUMP

M-703
FLUE GAS
SCRUBBER

M-704
FLUE GAS
STACK

M-701
COOLING
TOWER SYSTEM

P-701
COOLING
WATER PUMP

124
BLOWDOWN
TO T-860
PFD-61712-A804

ATM

M-704

FLUE GAS
FROM K-101
PFD-61712-A102

110

M-703

P-708

ATM

ATM

DRIFT

EVAP

718

M-701

WM701

BLOWDOWN
FROM H-603
PFD-61712-A601

600

COOLING TOWER
CHEMICALS

NAOH
FROM P-705
PFD-61712-A702

715

CWS
TO HEADER

CWR
FROM HEADER

P-701

WP701

CW USERS

H-314	H-459
H-374	H-463C
K-390	H-494
H-413C	H-495
H-444	H-568C
H-445	K-580
H-454	H-603
H-457C	M-708

QM701

SAND FILTER FILTRATE
FROM M-807
PFD-61712-A803

713

CT BLOWDOWN
TO T-860
PFD-61712-A804

618

MAKE-UP WATER
TO P-601
PFD-61712-A601

MAKE-UP WATER

815

MAKE-UP WATER
TO P-815
PFD-61712-A801

Plot date: 12/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 700: COOLING WATER & FLUE GAS SCRUBBER

Project No: 30482.00

Drawing: PFD-61712-A701

Rev: 2

PFD-61712-A701		110	124	600	618	713	715	718	815																
Total Flow	lb/h	770,436	23,429	6,475	6,473	10,937	2,618,485	2,618,485	1,926	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	160	123	113	60	90	90	110	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	16	15	15	15	15	75	60	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-1005	-160	-44	-44	-75	-17932	-17876	-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	8,183	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	480,047	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	38,240	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	107	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	42,895	23,429	6,475	6,473	10,937	2,618,485	2,618,485	1,926	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	200,947	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QM701	56
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
WM701	147	0
WP701	252	1
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

T-702
FIREWATER
STORAGE TANK

T-703
PURCHASED DIESEL
STORAGE TANK

T-704
AMMONIA
STORAGE TANK

T-705
CAUSTIC
STORAGE TANK

T-708
BFW CHEMICAL
STORAGE TANK

M-702
HYDRAULIC TRUCK DUMP
WITH SCALE

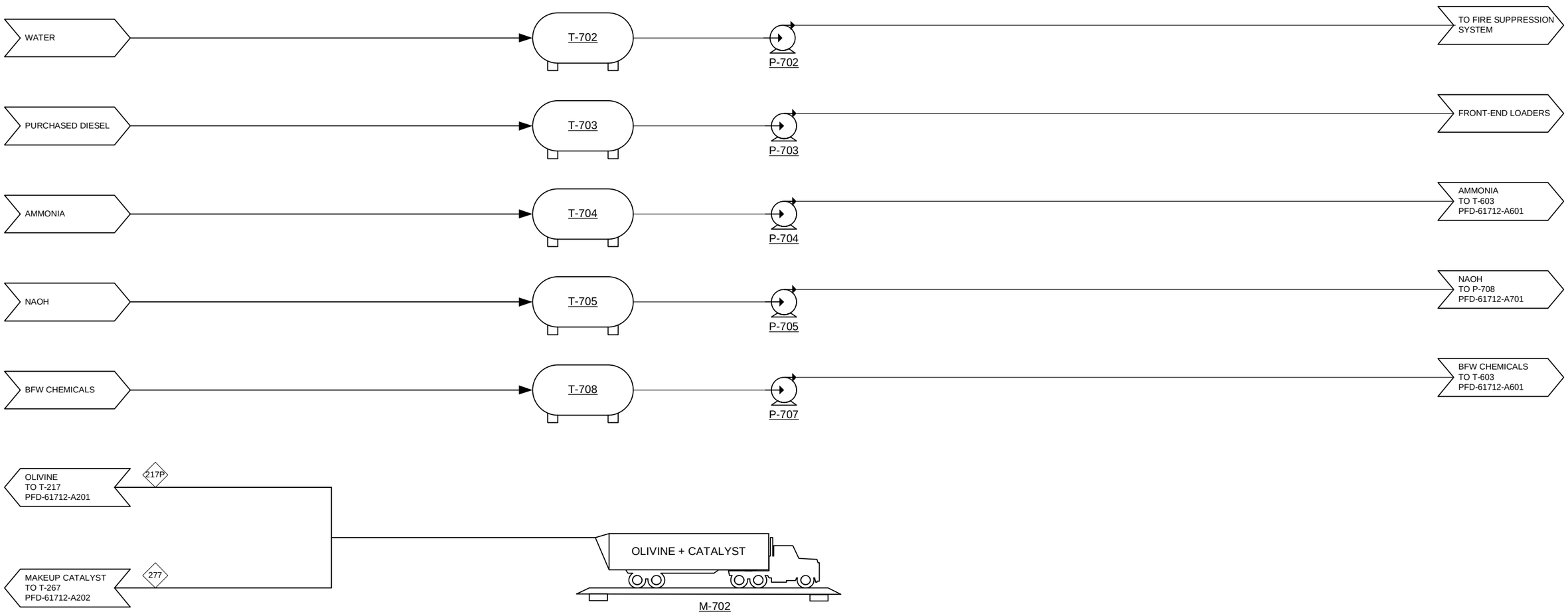
P-702
FIREWATER
PUMP

P-703
DIESEL
PUMP

P-704
AMMONIA
PUMP

P-705
CAUSTIC
PUMP

P-707
BFW CHEMICAL
PUMP



Plot date: 3/16/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150316.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 700: MATERIALS STORAGE

Project No: 30482.00
Drawing: PFD-61712-A702
Rev: 1

PFD-61712-A702																										
Total Flow	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

K-701
PLANT AIR
COMPRESSOR

S-701
INSTRUMENT
AIR DRYER

T-701
PLANT AIR
RECEIVER

T-792
DIESEL PRODUCT
STORAGE TANK

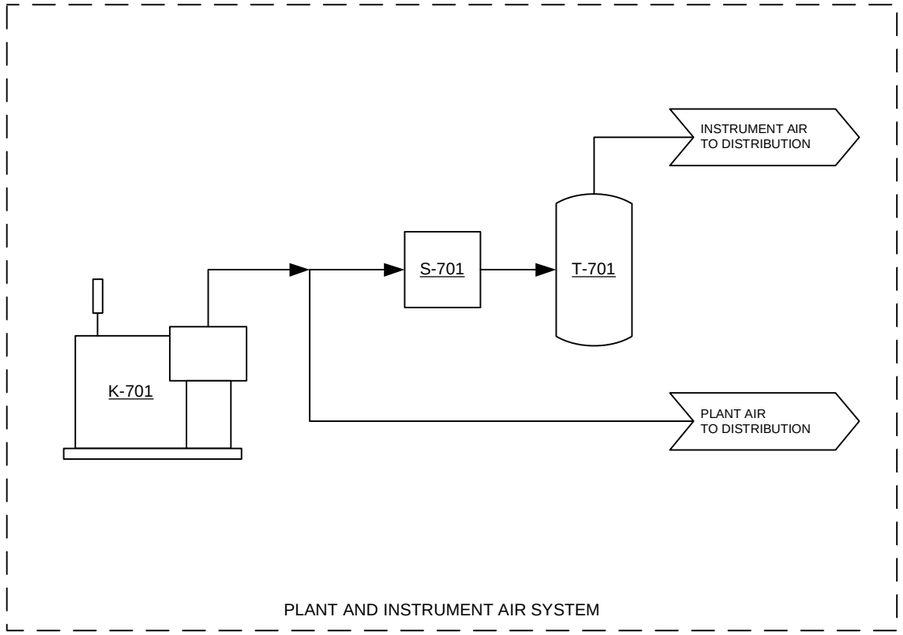
P-792
DIESEL PRODUCT
PUMP

T-790
GASOLINE PRODUCT
STORAGE TANK

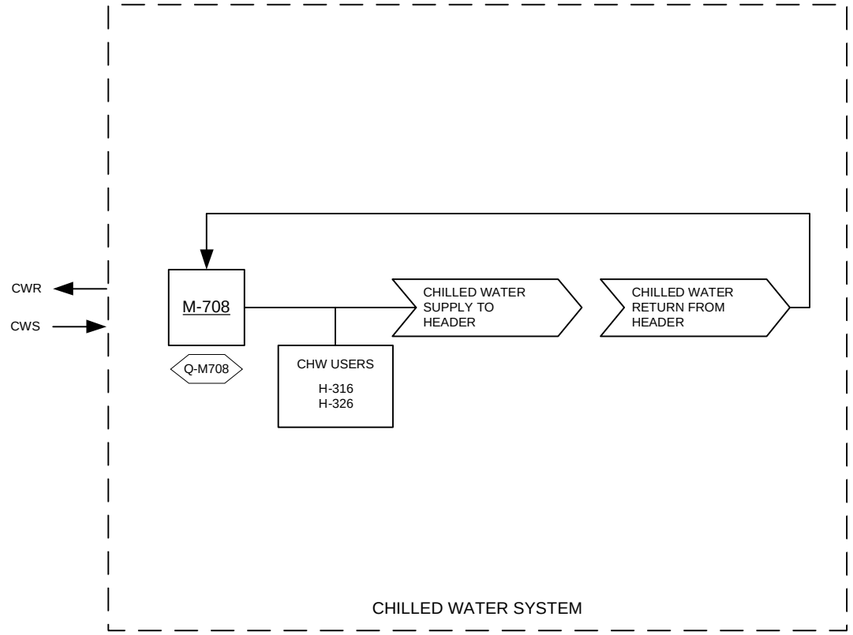
P-790
GASOLINE PRODUCT
PUMP

M-710
PRODUCT
LOADING RACK

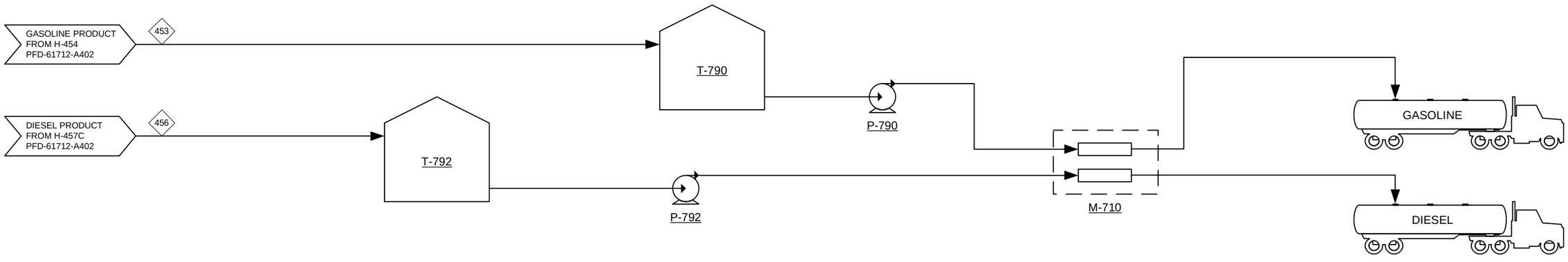
M-708
CHILLED WATER
SYSTEM



PLANT AND INSTRUMENT AIR SYSTEM



CHILLED WATER SYSTEM



Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 700: UTILITIES AND PRODUCT LOADOUT

Project No: 30482.00
Drawing: PFD-61712-A703
Rev: 2

PFD-61712-A703		453	456																						
Total Flow	lb/h	20,408	24,739	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	60	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	15	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-15	-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	168	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	311	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	321	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	1,321	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	3,526	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	1,942	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	445	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	829	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	1,645	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	1,501	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	2,524	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	4,156	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	384	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	301	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	120	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	58	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	200	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	114	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	5	191	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	222	76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	22	4,440	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	1	933	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	1	3,309	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	65	4,632	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	2	3,177	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	2,946	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	162	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	4,656	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
Q-M708	23
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

T-810
BOILER FEED TANK

P-810
BOILER
CHARGE PUMP

P-815
BOILER MAKEUP
PUMP

H-BP-42
EX-SITU CATALYST REGEN
FLUE GAS COOLER/WATER
PREHEAT FOR MIX WITH
WW FOR STEAM

H-BP-43
ABSORBER 1 BOTTOMS
COOLER/WATER PREHEAT
FOR MIX WITH WW FOR
STEAM

T-812
STEAM
DRUM

P-812
CONDENSATE
PUMP

T-814
BOILER FEED TANK

P-814
BOILER
CHARGE PUMP

T-822
STEAM
DRUM

P-822
CONCENTRATED
WASTEWATER PUMP

AQUEOUS PHASE
FROM S-329
PFD-61712-A302

334

T-810

811

WASTEWATER
TO H-BP-10
PFD-61712-A805

P-810

W-P810

WASTEWATER
FROM H-AP-59/61/62
PFD-61712-A805

T-812

813

LP STEAM
TO H-AP-53
PFD-61712-A303

814

P-812

W-P812

MAKEUP WATER
FROM
PFD-61712-A701

815

P-815

W-P815

MAKEUP WATER
TO H-BP-49
PFD-61712-A404

MAKEUP WATER
FROM H-BP-49
PFD-61712-A404

VPU FLUE GAS
FROM H-AP-37
PFD-61712-A203

H-BP-42

QHBP42

MAKEUP WATER
TO H-AP-11
PFD-61712-A603

MAKEUP WATER
FROM H-AP-11
PFD-61712-A603

816B

T-814

822

P-814

W-P814

BOILER FEEDWATER
TO H-AP-57/58/60/63
PFD-61712-A805

BOILER FEEDWATER
FROM H-AP-57/58/60/63
PFD-61712-A805

T-822

823

LP STEAM
TO H-AP-44
PFD-61712-A502

VPU FLUE GAS
TO H-BP-17
PFD-61712-A203

ABSORBER BOTTOMS
FROM H-AP-23
PFD-61712-A305

H-BP-43

QHBP43

ABSORBER BOTTOMS
TO H-BP-31
PFD-61712-A305

825

CONC WASTEWATER
TO K-831
PFD-61712-A802

P-822

W-P822

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

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Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 800: WASTEWATER MANAGEMENT

Project No: 30482.00

Drawing: PFD-61712-A801

Rev: 1

PFD-61712-A801		334	811	812	813	814	815	816B	822	823	825															
Total Flow	lb/h	77,811	77,811	77,811	30,755	47,057	1,926	1,926	48,983	46,210	2,772	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	86	86	359	354	354	60	350	354	356	356	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	100	160	150	140	145	15	150	145	135	140	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-523	-523	-500	-174	-299	-13	-13	-312	-258	-13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	75,955	75,955	75,955	30,663	45,292	1,926	1,926	47,218	45,491	1,727	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	73	73	73	40	33	0	0	33	31	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	1,778	1,778	1,778	49	1,729	0	0	1,729	686	1,043	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	3	3	3	0	2	0	0	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

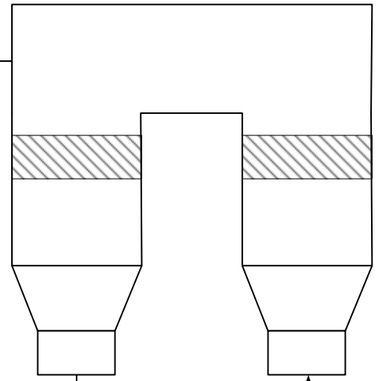
Heat	MMBtu/h
QHBP42	0
QHBP43	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
WP810	10	0
WP815	1	0
WP812	1	0
WP814	1	0
WP822	0	0
	0	0
	0	0

K-831
RTO
BLOWER

M-833
AQUEOUS REGENERATIVE
THERMAL OXIDIZER

H-840
RTO FEED/EFFLUENT
EXCHANGER



838

FLUE GAS
TO H-AP-62/H-AP-63
PFD-61712-A805

FLUE GAS
FROM H-AP-62/H-AP-63
PFD-61712-A805

840

FLUE GAS
TO H-BP-13
PFD-61712-A604

FLUE GAS
FROM H-BP-13
PFD-61712-A604

841

FLUE GAS
TO M-104
PFD-61712-A102

M-833

H-840

QH840

CONC WASTE WATER
FROM P-822
PFD-61712-A801

825

COMBUSTION AIR

832

K-831

W-K831

NATURAL GAS
FROM UTILITY

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 800: AQUEOUS RTO

Project No: 30482.00

Drawing: PFD-61712-A802

Rev. 1

PFD-61712-A802		825	832	838	840	841																				
Total Flow	lb/h	2,772	77,492	80,265	80,265	80,265	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	356	90	863	269	245	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	140	15	22	19	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-13	-9	-15	-28	-28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	979	979	979	979	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	57,382	57,382	57,382	57,382	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	17,582	15,606	15,606	15,606	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	1,727	1,512	3,752	3,752	3,752	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	38	2,547	2,547	2,547	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	1,043	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QH840	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
W-K831	1,032	3
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

T-801
CLARIFIER
OVERFLOW TANK

P-801
CLARIFIER
OVERFLOW PUMP

M-807
SAND
FILTER

M-805
CLARIFIER

T-809
SLURRY
TANK

P-809
SLURRY
PUMP

M-806
BELT
PRESS

SOLIDS
FROM S-319/S-324/S-329
PFD-61712-A302

335

WASTE WATER
FROM S-411/S-461/M-861
PFD-61712-A804

880

FLOCCULANT/
COAGULANT

SOLIDS TO DISPOSAL

M-806

M-805

T-809

P-809

T-801

P-801

M-807

BACKWASH

SAND FILTER FILTRATE
TO M-701/P-708
PFD-61712-A701

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
2	12/29/14	JAR	MINOR UPDATES
1	12/12/14	DMS	ADDED HX NETWORK
0	9/29/14	JAR	ISSUED FOR DESIGN REPORT

THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 800: CLARIFIER AND SAND FILTER

Project No: 30482.00

Drawing: PFD-61712-A803

Rev: 2

PFD-61712-A803		335	880																						
Total Flow	lb/h	36	20,759	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	90	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	100	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	0	-141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	5	20,708	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N3S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

T-860
RO FEED TANK

P-860
RO FEED PUMP

M-861
REVERSE
OSMOSIS UNIT

T-866
CLEAN WATER
TANK

P-866
CLEAN WATER
PUMP

H-BP-41
EX-SITU CATALYST REGEN
COOLER/CATALYST
STRIPPER WATER
PREHEAT FOR STEAM

H-AP-46
REFORMER OUTLET
COOLER/CATALYST
COOLER STEAM
PRODUCTION

H-AP-45
REFORMER OUTLET
COOLER/CATALYST
STRIPPER STEAM
PRODUCTION

AQUEOUS PHASE
FROM S-411
PFD-61712-A401

424

AQUEOUS PHASE
FROM S-461
PFD-61712-A403

474

880

WASTE WATER
TO M-805
PFD-61712-A803

BLOWDOWN
FROM P-708
PFD-61712-A701

124

CONDENSATE
FROM P-377
PFD-61712-A304

377

AQUEOUS PHASE
FROM S-412
PFD-61712-A401

430

CONDENSATE
FROM P-576
PFD-61712-A503

576

CT BLOWDOWN
FROM P-701
PFD-61712-A701

713

T-860

860

P-860

W-P860

864

RO BRINE

RO

M-861

865

T-866

P-866

W-P866

CLEAN WATER
TO H-BP-48
PFD-61712-A404

CLEAN WATER
FROM H-BP-48
PFD-61712-A404

CLEAN WATER
TO H-BP-39
PFD-61712-A603

CLEAN WATER
FROM H-BP-39
PFD-61712-A603

CLEAN WATER
TO H-AP-10
PFD-61712-A603

CLEAN WATER
FROM H-AP-10
PFD-61712-A603

VPU FLUE GAS
FROM H-AP-37
PFD-61712-A203

H-BP-41

QHBP41

VPU FLUE GAS
TO H-BP-17
PFD-61712-A203

H-AP-45

QHAP45

REFORMER PRODUCT
TO H-AP-44
PFD-61712-A502

REFORMER PRODUCT
FROM H-AP-47/H-AP-50
PFD-61712-A502

H-AP-46

QHAP46

270

STEAM
TO T-261
PFD-61712-A202

CLEAN WATER
HEADER

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Harris Group

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Rev.	Date	By	Description
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1	12/12/14	DMS	ADDED HX NETWORK
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THERMOCHEMICAL CONVERSION OF BIOMASS
TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 800: WASTEWATER REVERSE OSMOSIS

Project No: 30482.00

Drawing: PFD-61712-A804

Rev: 2

PFD-61712-A804		124	270	377	424	430	474	576	713	860	864	865	880												
Total Flow	lb/h	23,429	2,756	20,723	2,912	0	129	15,788	10,937	70,877	17,719	53,158	20,759	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	123	555	110	110	0	110	110	90	111	112	112	112	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	15	135	83	1493	0	1893	102	15	15	15	15	15	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-160	-15	-141	-20	0	-1	-108	-75	-483	-121	-363	-141	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	34	0	0	0	0	0	0	0	35	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	23,429	2,756	20,658	2,877	0	129	15,786	10,937	70,810	17,702	53,107	20,708	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	0	0	1	0	0	0	1	0	2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	0	0	15	0	0	0	0	0	15	4	11	4	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	0	0	49	0	0	0	0	0	49	12	37	12	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QHAP45	2
QHAP46	0
QHBP41	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
WP866	2	0
WP860	10	0
	0	0
	0	0
	0

H-AP-60
PRE-ABSORBER UPGRADED VAPOR COOLER/STEAM PRODUCTION FROM WW FOR REFORMER

H-AP-63
RTO HIGH TEMP EXHAUST COOLER/STEAM PRODUCTION FROM WW FOR REFORMER

H-AP-61
A500 LOW TEMP WGS OUTLET COOLER/STEAM PRODUCTION FROM WW FOR WGS

H-AP-62
RTO HIGH TEMP EXHAUST COOLER/STEAM PRODUCTION FROM WW FOR WGS

WASTEWATER FROM P-810 PFD-61712-A801

811

WASTEWATER TO H-BP-10 PFD-61712-A602

WASTEWATER FROM H-BP-10 PFD-61712-A602

WASTEWATER TO H-BP-33 PFD-61712-A603

WASTEWATER FROM H-BP-33 PFD-61712-A603

WASTEWATER TO H-BP-26 PFD-61712-A402

WASTEWATER FROM H-BP-26 PFD-61712-A402

WASTEWATER TO H-AP-23 PFD-61712-A305

WASTEWATER FROM H-AP-23 PFD-61712-A305

WASTEWATER TO H-AP-24 PFD-61712-A404

WASTEWATER FROM H-AP-24 PFD-61712-A404

WASTEWATER TO H-AP-25 PFD-61712-A404

WASTEWATER FROM H-AP-25 PFD-61712-A404

WASTEWATER TO H-AP-32 PFD-61712-A303

WASTEWATER FROM H-AP-32 PFD-61712-A303

WASTEWATER TO H-AP-59 PFD-61712-A502

WASTEWATER FROM H-AP-59 PFD-61712-A502

812

WASTEWATER TO T-812 PFD-61712-A801

LTS EFFLUENT FROM R-566 PFD-61712-A505

H-AP-61

QHAP61

LTS EFFLUENT TO H-AP-19/H-AP-20 PFD-61712-A505

H-AP-62

QHAP62

FLUE GAS FROM M-833 PFD-61712-A802

838

H-AP-63

QHAP63

BOILER FEEDWATER FROM P-814 PFD-61712-A801

822

BOILER FEEDWATER TO T-822 PFD-61712-A801

839

FLUE GAS TO H-840 PFD-61712-A802

CONC WASTEWATER TO H-AP-57 PFD-61712-A404

CONC WASTEWATER FROM H-AP-57 PFD-61712-A404

CONC WASTEWATER TO H-AP-58 PFD-61712-A402

CONC WASTEWATER FROM H-AP-58 PFD-61712-A402

PYROLYSIS VAPOR FROM H-AP-51 PFD-61712-A305

H-AP-60

QHAP60

PYROLYSIS VAPOR TO D-301 PFD-61712-A305

Plot date: 1/29/2015 J:\1A - Process Solutions\30482 NREL Thermochemical Conv - Design-Model\Drawings\ 30482 Pyrolysis Ex-Situ PFDs 61712 150128.vsd

Rev.	Date	By	Description
0	12/12/14	DMS	ADDED HX NETWORK

Harris Group

NREL NATIONAL RENEWABLE ENERGY LABORATORY

THERMOCHEMICAL CONVERSION OF BIOMASS TO HYDROCARBON FUEL
FAST PYROLYSIS AND VAPOR PHASE UPGRADING

PROCESS FLOW DIAGRAM
AREA 800: A800 HEAT RECOVERY

Project No: 30482.00

Drawing: PFD-61712-A805

Rev: 0

PFD-61712-A805		811	812	822	838	839																			
Total Flow	lb/h	77,811	77,811	48,983	80,265	80,265	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Temperature	F	86	359	354	863	437	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure	Psia	160	150	145	22	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vapor Fraction		0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy Flow	MMBtu/h	-523	-500	-312	-15	-24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argon	lb/h	0	0	0	979	979	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrogen	lb/h	0	0	0	57,382	57,382	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oxygen	lb/h	0	0	0	15,606	15,606	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NO2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ammonia	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2S	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water	lb/h	75,955	75,955	47,218	3,752	3,752	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Monoxide	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon Dioxide	lb/h	2	2	0	2,547	2,547	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Formic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Glyoxal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxyacetaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hydroxy-2-propanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propionic Acid	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Propane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Butene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Butane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Furfuryl Alcohol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Pentane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Benzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phenol	lb/h	73	73	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,2-Benzenediol	lb/h	1,778	1,778	1,729	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylfurfural	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-dimethylfuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl Cyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydroxymethylcyclopentenone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexanone	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Levoglucosan	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Hexanal	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dimethoxytetrahydrofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Hexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hexanol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Toluene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3-Methyl-phenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Guaiacol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Methyl-Cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methylhexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
VinylPhenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O-Xylene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylbenzne	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,3-Dimethyl-phenol	lb/h	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,6-dimethoxyphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vanillyl alcohol	lb/h	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,4,6-Trimethylpyridine	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cis-1,2-dimethyl cyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Trans-1,2-dimethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ethylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4-Methylheptane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Methyl-Benzofuran	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Indane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2-methoxy-4-vinylphenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syringaldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Propylbenzene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Naphthalenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferyl Aldehyde	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetralin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isoeugenol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Decalin	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2,5-Dimethyloctane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Methyl naphthalene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1-methyl decahydronaphthene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibenzothiophene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Biphenyl	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5-hexyl-O-cresol	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
n-Heptylcyclohexane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H20-N35	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14H24-N5	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3,5-Dimethyldodecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15H26-N4	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6,8-Dimethyltridecane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1,4-Dimethyl-Phenanthrene	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N-Cetane	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H26O	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18H28	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H26O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21H34	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C22H28O2	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Carbon	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sulfur	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sand/Catalyst Solids	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ash	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wood	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Char	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Coke	lb/h	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Heat	MMBtu/h
QHAP60	29
QHAP61	2
QHAP62	4
QHAP63	5
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0
	0

Work	hp	MMBtu/h
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0
	0	0

Appendix H. Heat Exchanger Costs for the *Ex Situ* Case

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HX Name	Description	Belongs to Area	Hot In	Hot Out	Cold In	Cold Out	LMTD	Duty	Pres. Stream 1	Pres. Stream 2	Shell	Tube	Shell Material	Tube Material	Shell Design Pres.	Tube Design Pres.	U	Area	Equip. Cost (Q1 2009 Basis)	Direct Cost (Q1 2009 Basis)	Ratio (Direct Cost/Equipment
	Stream 1 /Stream 2		F	F	F	F	ΔT	Btu/h	(psia)	(psia)					psig (20% Excess, Min. = 50 psig)	psig (20% Excess, Min. = 50 psig)	Btu/(hr ft^2 °F)	ft^2	$	$	
Network Above Pinch																					
H-AP-7	Reformer Flue Gas Cooler / Reformer Feed High Temp Preheat	A500	1804.2	1134.2	525.6	1400.0	499.5	43,837,566	19	118	Reformer Flue Gas Cooler	Reformer Feed High Temp	CS	CS	50	130	10	8777	165,100.00	326,100.00	1.98
H-AP-8	Char Combustor Flue Gas Cooler / Fast Pyrolysis Fluidizing Gas Preheat	A211	1212.4	309.9	285.0	800.0	138.0	64,162,490	115	125	Char Combustor FG Cooler	FP Fluidizing Gas	CS	CS	120	140	10	46481	804,700.00	1,275,600.00	1.59
H-AP-9	Char Combustor Flue Gas Cooler / Inter-Turbine Steam Reheat	A600	1328.0	1212.4	698.3	1000.0	414.1	8,222,305	115	350	Char Combustor FG Cooler	Inter-Turbine Steam Preheat	CS	CS	120	410	10	1986	45,500.00	146,200.00	3.21
H-AP-10	Boiler Feed Water Blowdown Cooler / Catalyst Stripper Water Preheat for Steam	A600	581.0	309.9	285.0	356.0	90.9	225,383	1336	145	Catalyst Stripper Water Preheat	BFW Blowdown Cooler	CS	SS304L	160	1,590	100	25	13,200.00	129,200.00	9.79
H-AP-11	Boiler Feed Water Blowdown Cooler / Water Preheat for Mix with WW for Steam	A600	581.0	309.9	285.0	350.0	92.5	143,809	1336	155	Water Preheat for Mix	BFW Blowdown Cooler	CS	SS304L	170	1,590	100	16	13,000.00	129,000.00	9.92
H-AP-12	Hydrotreater Outlet Cooler / HT Product to Naphtha Column Preheat	A450	415.5	309.9	285.0	375.0	32.1	3,492,816	1510	48	HT Product	Hydrotreater	SS316	A199-T22 or A199D (2.5 Cr-1 Mo)	50	1,800	80	1361	112,200.00	312,200.00	2.78
H-AP-13	Distillate Column Condenser / HT Product to Naphtha Column Preheat	A450	550.3	490.9	375.0	450.0	107.9	2,912,097	15	48	Distillate Column Condenser	HT Product	SS316	CS	50	50	5	5398	106,900.00	247,500.00	2.32
H-AP-14	A300 WGS Outlet Cooler / A300 Pyrolysis Off-Gas to WGS Preheat	A360	425.0	309.9	285.0	400.0	25.0	4,039,336	84	93	A300 WGS Outlet Cooler	A300 Pyrolysis Off-Gas	A204C	CS	90	100	10	16188	275,400.00	474,300.00	1.72
H-AP-15	A300 WGS Outlet Cooler / A300 WGS Feed Preheat	A360	490.4	425.0	396.8	464.0	27.3	3,382,516	84	91	A300 WGS Outlet Cooler	A300 WGS Feed Preheat	A204C	CS	90	90	10	12411	200,200.00	385,000.00	1.92
H-AP-16	Distillate Product Cooler / HC Product to Naphtha Column Preheat	A450	491.1	309.9	285.0	466.1	25.0	2,373,485	35	48	Distillate product cooler	HC Product	SS316	CS	50	50	80	1189	34,100.00	146,000.00	4.28
H-AP-17	Post-Absorber 1 Vapor Cooler / Char Combustor Air Preheat	A310	358.2	309.9	287.2	336.2	22.4	2,934,814	110	123	Post Absorber 1 Vapor Cooler	Char Combustor Air Preheat	CS	CS	120	130	10	13131	247,500.00	458,100.00	1.85
H-AP-18	Post-Absorber 1 Vapor Cooler / Ex Situ Catalyst Regen Air Preheat	A310	358.2	309.9	285.0	336.2	23.4	2,528,606	110	117	Post Absorber 1 Vapor Cooler	Ex Situ Catalyst Regen Air Preheat	CS	CS	120	130	10	10795	190,300.00	386,900.00	2.03
H-AP-19	A500 Low Temp WGS Outlet Cooler / PSA Off-Gas to Reformer Combustor Preheat	A500	503.0	309.9	285.0	450.0	37.2	4,124,363	101	21	PSA Off-Gas	A500 Low Temp WGS Outlet	CS	CS	50	110	10	11086	170,400.00	353,900.00	2.08
H-AP-20	A500 Low Temp WGS Outlet Cooler / Reformer Combustor Air Preheat	A500	503.0	309.9	285.0	450.0	37.2	5,634,861	101	21	Combustor Air Preheat	A500 Low Temp WGS Outlet	CS	CS	50	110	10	15145	240,900.00	439,300.00	1.82
H-AP-21	A500 Low Temp WGS Outlet Cooler / Natural Gas to Reformer Preheat	A500	540.0	503.0	285.0	500.0	105.0	17,663	101	198	A500 Low Temp WGS Outlet	Natural Gas to Reformer	A204C	CS	110	220	10	17	9,500.00	62,500.00	6.58
H-AP-22	A500 Low Temp WGS Outlet Cooler / Reformer Combustor Gas Preheat	A500	540.0	503.0	285.0	500.0	105.0	100,164	101	21	Reformer Combustor Gas	A500 Low Temp WGS Outlet	CS	CS	50	110	10	95	11,300.00	64,500.00	5.71
H-AP-23	Absorber 1 Bottoms Cooler / WW Preheat for Steam Production	A310	461.2	309.9	285.0	358.6	54.9	1,597,418	133	155	Absorber 1 Bottoms	WW Preheat	CS	SS316	140	170	80	364	22,700.00	112,800.00	4.97
H-AP-24	Hydrotreater Outlet Cooler / WW Preheat for Steam Production	A500	415.5	309.9	285.0	358.6	38.7	3,230,771	1510	155	WW Preheat	Hydrotreater Outlet Cooler	SS316	A199-T22 or A199D (2.5 Cr-1 Mo)	170	1,800	80	1043	95,500.00	299,200.00	3.13
H-AP-25	Distillate Product Cooler / WW Preheat for Steam Production	A450	491.1	309.9	285.0	358.6	64.4	384,860	35	155	Distillate Product Cooler	WW Preheat	CS	SS316	50	170	80	75	14,000.00	82,600.00	5.90
H-AP-26	Reformer Flue Gas Cooler / Inter-Turbine Steam Reheat	A600	1134.2	911.6	698.3	1000.0	170.7	14,562,462	19	350	Reformer Flue Gas Cooler	Inter-Turbine Steam Reheat	CS	CS	50	410	10	8531	168,000.00	328,700.00	1.96
H-AP-27	Reformer Flue Gas Cooler / Distillate Column Reboiler	A450	911.6	819.0	705.0	711.6	153.0	6,062,749	19	20	Reformer Flue Gas Cooler	Distillate Column Reboiler	CS	CS	50	50	35	1132	27,100.00	122,100.00	4.51
H-AP-28	Reformer Flue Gas Cooler / Naphtha Column Reboiler	A450	819.0	741.5	595.8	626.5	168.0	5,072,974	19	40	Reformer Flue Gas Cooler	Naphtha Column Reboiler	CS	CS	50	50	35	863	23,400.00	101,500.00	4.34
H-AP-29	Reformer Flue Gas Cooler / Reformer Combustor Air Preheat	A500	741.5	663.1	450.0	600.0	174.9	5,123,961	19	21	Reformer Flue Gas Cooler	Reformer Combustor Air	CS	CS	50	50	5	5861	88,000.00	227,900.00	2.59
H-AP-30	Reformer Flue Gas Cooler / Reformer Feed Gas Preheat	A500	663.1	651.6	466.8	500.0	173.7	757,539	19	120	Reformer Flue Gas Cooler	Reformer Feed Gas Preheat	CS	CS	50	130	10	436	18,700.00	85,000.00	4.55

HX Name	Description	Belongs to Area	Hot In	Hot Out	Cold In	Cold Out	LMTD	Duty	Pres. Stream 1	Pres. Stream 2	Shell	Tube	Shell Material	Tube Material	Shell Design Pres.	Tube Design Pres.	U	Area	Equip. Cost (Q1 2009 Basis)	Direct Cost (Q1 2009 Basis)	Ratio (Direct Cost/Equipment
	Stream 1 /Stream 2		F	F	F	F	ΔT	Btu/h	(psia)	(psia)					psig (20% Excess, Min. = 50 psig)	psig (20% Excess, Min. = 50 psig)	Btu/(hr ft^2 °F)	ft^2	$	$	
H-AP-31	Post-Absorber 1 Vapor Cooler / Boiler Feed Water Preheat	A310	358.2	309.9	285.0	340.0	21.4	9,708,179	110	1346	Post Absorber 1 Vapor Cooler	Boiler Feed Water Preheat	CS	SS304L	120	1,600	40	11349	902,000.00	1,982,200.00	2.20
H-AP-32	A300 WGS Outlet Cooler / WW Preheat for Steam Production	A360	425.0	309.9	285.0	358.6	42.3	1,437,623	84	155	A300 WGS Outlet Cooler	WW Preheat	A204C	SS316	90	170	35	971	41,200.00	181,800.00	4.41
H-AP-33	A300 WGS Outlet Cooler / Boiler Feed Water Preheat	A360	425.0	309.9	285.0	340.0	49.0	477,847	84	1346	A300 WGS Outlet Cooler	BFW Preheat	A204C	SS304L	90	1,600	40	244	33,300.00	233,100.00	7.00
H-AP-34	Hydrotreater Outlet Cooler / Boiler Feed Water Preheat	A410	360.0	309.9	285.0	340.0	22.4	1,055,021	1910	1346	BFW Preheat	Hydrotreater Outlet Cooler	SS304L	A199-T22 or A199D (2.5 Cr-1 Mo)	1,600	2,280	80	590	113,700.00	322,700.00	2.84
H-AP-35	Boiler Feed Water Blowdown Cooler / Boiler Feed Water Preheat	A600	360.0	309.9	285.0	340.0	22.4	300,243	1336	1336	BFW Preheat	BFW Blowdown Cooler	SS304L	SS304L	1,590	1,590	100	134	55,300.00	192,900.00	3.49
H-AP-36	Reformer Flue Gas Cooler / Boiler Feed Water Preheat	A600	380.0	309.9	285.0	340.0	31.9	4,583,506	19	1346	Reformer Flue Gas Cooler	BFW Preheat	CS	SS304L	50	1,600	35	4110	327,000.00	875,100.00	2.68
H-AP-37	Ex Situ Catalyst Regen Flue Gas Cooler / Boiler Feed Water Preheat	A261	380.5	309.9	285.0	340.0	32.1	3,939,780	111	1346	Ex Situ Catalyst Regen FG Cooler	BFW Preheat	CS	SS304L	120	1,600	35	3509	283,400.00	830,900.00	2.93
H-AP-38	Ex Situ Catalyst Regen Flue Gas Cooler / Char Combustor Air Preheat	A261	897.2	380.5	336.2	600.0	132.9	15,809,168	111	123	Ex Situ Catalyst Regen FG Cooler	Char Combustor Air	CS	CS	120	130	10	11897	202,900.00	400,100.00	1.97
H-AP-39	Ex Situ Catalyst Regen Flue Gas Cooler / Ex Situ Catalyst Regen Air Preheat	A261	897.2	380.5	336.2	600.0	132.9	13,035,111	111	117	Ex Situ Catalyst Regen FG Cooler	Ex Situ Catalyst Regen	CS	CS	120	130	10	9810	176,300.00	338,000.00	1.92
H-AP-40	Boiler Feed Water Blowdown Cooler / Boiler Feed Water Preheat	A600	500.0	360.0	340.0	465.0	26.8	839,835	1336	1346	BFW Blowdown	BFW Preheat	SS304L	SS304L	1,590	1,600	100	313	84,700.00	314,200.00	3.71
H-AP-41	Hydrotreater Outlet Cooler / Boiler Feed Water Preheat	A410	520.0	360.0	340.0	465.0	34.6	3,372,674	1910	1346	BFW Preheat	Hydrotreater Outlet Cooler	SS304L	A199-T22 or A199D (2.5 Cr-1 Mo)	1,600	2,280	80	1218	197,900.00	524,000.00	2.65
H-AP-42	Reformer Flue Gas Cooler / Boiler Feed Water Preheat	A600	520.0	380.0	340.0	465.0	47.1	9,160,429	19	1346	Reformer Flue Gas Cooler	BFW Preheat	CS	SS304L	50	1,600	35	5557	439,700.00	989,200.00	2.25
H-AP-43	Hydrotreater Outlet Cooler / HC Product to Naphtha Column Preheat	A410	717.4	520.0	466.1	550.0	100.1	1,099,410	1910	48	HC Product	Hydrotreater Outlet Cooler	CS	A199-T22 or A199D (2.5 Cr-1 Mo)	50	2,280	80	137	28,600.00	106,400.00	3.72
H-AP-44	Refomer Outlet Cooler / Reformer Steam Superheat	A500	728.9	644.0	356.2	556.2	225.4	4,505,467	115	135	Reformer Outlet Cooler	Reformer Steam Superheat	CS	SS316	120	150	10	1999	67,000.00	209,700.00	3.13
H-AP-45	Refomer Outlet Cooler / Catalyst Stripper Steam Production	A261	775.4	728.9	356.0	356.0	395.7	2,467,430	115	145	Reformer Outlet Cooler	Catalyst Stripper Steam	CS	CS	120	160	35	178	13,800.00	79,000.00	5.72
H-AP-46	Refomer Outlet Cooler / Catalyst Cooler Steam Superheat	A261	780.5	775.4	355.0	555.0	312.9	269,714	115	140	Reformer Outlet Cooler	Catalyst Cooler Steam	CS	CS	120	150	10	86	12,000.00	66,000.00	5.50
H-AP-47	Refomer Outlet Cooler / Inter-Turbine Steam Reheat	A600	1616.0	780.5	698.3	1000.0	265.0	27,890,753	115	350	Reformer Outlet Cooler	Inter-Turbine Steam Reheat	CS	CS	120	410	10	10525	196,200.00	392,800.00	2.00
H-AP-48	Pre-Absorber Upgraded Vapor Cooler / Steam Superheat	A600	930.9	902.5	580.0	641.3	305.8	5,711,881	115	1326	Pre-Absorber Upgraded Vapor Cooler	Steam Superheat	CS	SS304L	120	1,580	50	374	48,800.00	249,200.00	5.11
H-AP-49	Ex Situ Catalyst Regen Flue Gas Cooler / Steam Superheat	A600	1202.0	897.2	641.3	1000.0	227.9	17,014,851	111	1326	Ex-Situ Catalyst Regen Flue Gas Cooler	Steam Superheat	CS	SS304L	120	1,580	50	1493	125,700.00	528,700.00	4.21
H-AP-50	Refomer Outlet Cooler / Steam Superheat	A600	1616.0	780.5	641.3	1000.0	320.6	16,442,228	115	1326	Reformer Outlet Cooler	Steam Superheat	CS	SS304L	120	1,580	50	1026	85,800.00	488,000.00	5.69
H-AP-51	Pre-Absorber Upgraded Vapor Cooler / Boiler Feed Water Preheat	A310	902.5	690.4	465.0	582.0	270.2	42,704,554	115	1346	Upgraded Vapor Cooler	BFW Preheat	CS	SS304L	120	1,600	40	3951	312,400.00	860,300.00	2.75
H-AP-52	A300 WGS Outlet Cooler / Boiler Feed Water Preheat	A360	637.0	490.4	435.6	465.0	102.4	7,591,348	84	1346	A300 WGS Outlet Cooler	BFW Preheat	A204C	SS304L	90	1,600	40	1853	148,800.00	553,400.00	3.72

HX Name	Description	Belongs to Area	Hot In	Hot Out	Cold In	Cold Out	LMTD	Duty	Pres. Stream 1	Pres. Stream 2	Shell	Tube	Shell Material	Tube Material	Shell Design Pres.	Tube Design Pres.	U	Area	Equip. Cost (Q1 2009 Basis)	Direct Cost (Q1 2009 Basis)	Ratio (Direct Cost/Equipment
	Stream 1 /Stream 2		F	F	F	F	ΔT	Btu/h	(psia)	(psia)					psig (20% Excess, Min. = 50 psig)	psig (20% Excess, Min. = 50 psig)	Btu/(hr ft^2 °F)	ft^2	$	$	
H-AP-53	Pre-Absorber Upgraded Vapor Cooler / A300 WGS Steam Superheat	A310	690.4	466.4	353.8	403.8	186.2	760,513	115	140	Upgraded Vapor Cooler	A300 WGS Steam Superheat	CS	SS316	120	150	10	408	25,100.00	115,100.00	4.59
H-AP-54	Reformer Flue Gas Cooler / Boiler Feed Water Preheat	A600	651.6	520.0	402.2	435.6	161.9	8,608,504	19	1346	Reformer Flue Gas Cooler	BFW Preheat	CS	SS304L	50	1,600	40	1329	106,900.00	509,500.00	4.77
H-AP-55	Boiler Feed Water Blowdown Cooler / Boiler Feed Water Preheat	A600	581.0	500.0	340.0	402.2	169.2	485,893	1336	1346	BFW Blowdown Cooler	BFW Preheat	SS304L	SS304L	1,590	1,600	100	29	27,200.00	163,500.00	6.01
H-AP-56	Pre-Absorber Upgraded Vapor Cooler / Boiler Feed Water Preheat	A310	690.4	466.4	340.0	402.2	196.3	15,578,969	115	1346	Pre-Absorber Upgraded Vapor Cooler	BFW Preheat	CS	SS304L	120	1,600	40	1984	155,100.00	559,900.00	3.61
H-AP-57	Hydrotreater Outlet Cooler / Steam Production from WW for Reformer	A800	717.4	520.0	353.7	361.5	249.2	3,061,157	1910	145	Steam Production	HT Outlet Cooler	CS	A199-T22 or A199D (2.5 Cr-1 Mo)	160	2,280	80	154	27,900.00	106,000.00	3.80
H-AP-58	Distillate Column Condenser / Steam Production from WW for Reformer	A800	550.3	490.9	353.7	361.5	161.6	4,524,433	15	145	Distillate Column Condenser	Steam Production from WW	CS	SS316	50	160	35	800	32,300.00	145,800.00	4.51
H-AP-59	A500 High Temp WGS Outlet Cooler / Steam Production from WW for WGS	A500	835.4	428.0	358.6	359.1	211.2	20,869,597	108	150	A500 High Temp WGS Outlet	Steam Production from WW	A204C	SS316	110	170	35	2823	101,300.00	281,800.00	2.78
H-AP-60	Pre-Absorber Upgraded Vapor Cooler / Steam Production from WW for Reformer	A310	690.4	466.4	353.7	361.5	201.9	28,749,167	115	145	Upgraded Vapor Cooler	Steam Production from WW	CS	SS316	120	160	35	4069	125,300.00	307,100.00	2.45
H-AP-61	A500 Low Temp WGS Outlet Cooler / Steam Production from WW for WGS	A500	540.0	503.0	358.6	359.1	162.0	1,752,794	101	150	A500 Low Temp WGS Outlet	Steam Production from WW	A204C	SS316	110	170	35	309	22,000.00	111,700.00	5.08
H-AP-62	RTO High Temp Exhaust Cooler / Steam Production from WW for WGS	A800	863.4	436.7	358.6	359.1	228.5	4,331,122	22	150	RTO High Temp Exhaust Cooler	Steam Production from WW	CS	SS316	50	170	35	542	26,700.00	139,900.00	5.24
H-AP-63	RTO High Temp Exhaust Cooler / Steam Production from WW for Reformer	A800	863.4	436.7	353.7	361.5	232.8	4,695,177	22	145	RTO High Temp Exhaust Cooler	Steam Production from WW	CS	SS316	50	160	35	576	26,900.00	140,100.00	5.21
Network Below Pinch																					
H-BP-1	A300 WGS Outlet Cooler/Condenser / Boiler Feed Water Preheat 1	A360	218.7	185.0	138.1	175.6	44.9	4,911,418	83	25	WGS Outlet	BFW Preheat 1	A204C	CS	80	50	35	3124	51,200.00	173,100.00	3.38
H-BP-2	Reformer Flue Gas Cooler / Reformer Combustor Air Preheat	A500	309.9	244.8	173.1	285.0	44.3	3,736,136	18	21	Air Preheat	Reformer Flue Gas	CS	CS	50	50	5	16885	173,100.00	353,400.00	2.04
H-BP-3	Post-Absorber 1 Vapor Cooler / Fast Pyrolysis Fluidizing Gas Preheat	A211	309.9	220.0	200.7	285.0	22.0	10,024,571	109	127	FG Preheat	Post Absorber 1 Vapor	CS	SS304L	140	120	10	45578	865,900.00	1,379,600.00	1.59
H-BP-4	A300 WGS Outlet Cooler/Condenser / Pyrolysis Off-Gas Feed to WGS Preheat	A360	218.7	185.0	95.0	200.7	44.7	3,585,841	83	95	WGS Outlet	Pyrolysis Off Gas Feed	A204C	CS	80	100	10	8016	111,900.00	257,900.00	2.30
H-BP-5	Hydrotreater Outlet Cooler / HT Product to Naphtha Column Preheat	A450	309.9	175.0	120.4	285.0	37.8	3,812,615	1,508	53	HT Product	HT Outlet Cooler	SS316	A199-T22 or A199D (2.5 Cr-1 Mo)	50	1,790	70	1440	121,900.00	322,100.00	2.64
H-BP-6	Hydrocracker Outlet Cooler / HC Product to Naphtha Column Preheat	A450	309.9	175.0	110.0	285.0	41.8	1,527,541	1,908	53	HC Product	HC Outlet Cooler	SS316	A199-T22 or A199D (2.5 Cr-1 Mo)	50	2,270	70	522	56,500.00	206,800.00	3.66
H-BP-7	Low Temp WGS Outlet Cooler/Condenser / PSA Exh. to Ref. Comb. Preheat	A500	213.3	185.0	109.4	199.3	36.5	2,116,466	100	21	PSA Exchanger	Low Temp WGS	CS	A209 (C - 0.5 Mo)	50	110	10	5793	121,900.00	266,000.00	2.18
H-BP-8	Low Temp WGS Outlet Cooler/Condenser / Boiler Feed Water Preheat 1	A500	213.3	185.0	138.1	175.6	42.1	7,255,229	100	25	BFW Preheat 1	Low Temp WGS	CS	A209 (C - 0.5 Mo)	50	110	35	4926	107,000.00	230,700.00	2.16
H-BP-9	Low Temp WGS Outlet Cooler / Reformer Combustor Gas Preheat	A500	309.9	213.3	108.8	285.0	55.5	74,879	100	22	Reformer Combustor Gas	Low Temp WGS	CS	A209 (C - 0.5 Mo)	50	110	10	135	14,000.00	67,400.00	4.81
H-BP-10	Steam Turbine Exhaust Cooler / WW Preheat for Steam Production	A600	234.3	170.0	86.5	174.7	70.9	9,250,080	4	160	Steam Turbine Exhaust	WW Preheat	CS	SS316	50	180	150	870	31,600.00	122,800.00	3.89
H-BP-11	Post-Absorber 1 Vapor Cooler / Boiler Feed Water Preheat 1	A310	250.0	220.0	175.6	232.3	29.0	5,196,218	109	25	BFW Preheat 1	Post Absorber 1 Vapor	CS	SS304L	50	120	35	5117	107,000.00	277,400.00	2.59
H-BP-12	Low Temp WGS Outlet Cooler / Reformer Combustor Air Preheat	A360	309.9	213.3	173.1	285.0	31.9	19,735	100	21	Reformer Combustor Air	Low Temp WGS	CS	CS	50	110	10	62	9,700.00	62,400.00	6.43

HX Name	Description	Belongs to Area	Hot In	Hot Out	Cold In	Cold Out	LMTD	Duty	Pres. Stream 1	Pres. Stream 2	Shell	Tube	Shell Material	Tube Material	Shell Design Pres.	Tube Design Pres.	U	Area	Equip. Cost (Q1 2009 Basis)	Direct Cost (Q1 2009 Basis)	Ratio (Direct Cost/Equipment
	Stream 1 /Stream 2		F	F	F	F	ΔT	Btu/h	(psia)	(psia)					psig (20% Excess, Min. = 50 psig)	psig (20% Excess, Min. = 50 psig)	Btu/(hr ft^2 °F)	ft^2	$	$	
H-BP-13	RTO Low Temp Exhaust Cooler / Boiler Feed Water Preheat 1	A800	269.1	244.8	175.6	232.3	51.3	490,867	19	25	BFW Preheat 1	RTO Low Temp EC	CS	SS304L	50	50	35	274	16,800.00	102,000.00	6.07
H-BP-14	A300 WGS Outlet Cooler / Pyrolysis Off-Gas Feed to WGS Preheat	A360	309.9	218.7	200.7	285.0	21.3	2,862,490	83	95	WGS Outlet	Pyrolysis Off-Gas Feed	CS	CS	80	100	10	13460	150,600.00	329,000.00	2.18
H-BP-15	Low Temp WGS Outlet Cooler / PSA Exh. to Ref. Comb. Preheat	A500	309.9	213.3	199.3	285.0	18.9	2,019,392	83	25	BFW Preheat	A300 WGS O/L	CS	A209 (C - 0.5 Mo)	50	80	35	3048	68,400.00	190,100.00	2.78
H-BP-16	Char Combustor Flue Gas Cooler / Boiler Feed Water Preheat 1	A211	255.0	244.8	175.6	232.3	41.7	676,950	112	25	BFW Preheat 1	Char Combustor FG	CS	CS	50	120	35	464	17,000.00	81,900.00	4.82
H-BP-17	Ex Situ Catalyst Regen Flue Gas Cooler / Boiler Feed Water Preheat 1	A261	255.0	244.8	175.6	232.3	41.7	534,946	245	25	BFW Preheat 1	Ex-situ Catalyst Regen FG	CS	CS	50	280	40	321	16,100.00	82,200.00	5.11
H-BP-18	Hydrotreater Outlet Cooler / Boiler Feed Water Preheat 1	A410	250.3	193.6	175.6	232.3	18.0	1,937,436	1,508	25	BFW Preheat 1	HT Outlet Cooler	CS	A199-T22 or A199D (2.5 Cr-1 Mo)	50	1,790	100	1076	83,300.00	266,400.00	3.20
H-BP-19	Hydrocracker Outlet Cooler / Boiler Feed Water Preheat 1	A460	250.3	193.6	175.6	232.3	18.0	346,619	1,908	25	BFW Preheat 1	HC Outlet Cooler	CS	A199-T22 or A199D (2.5 Cr-1 Mo)	50	2,270	120	160	29,100.00	132,200.00	4.54
H-BP-20	Post-Absorber 1 Vapor Cooler / Boiler Feed Water Preheat 2	A310	309.9	250.0	235.2	285.0	19.4	10,383,723	109	1,351	PA 1 Vapor Cooler	BFW Preheat 2	CS	SS304L	120	1,610	40	13389	792,100.00	1,803,000.00	2.28
H-BP-21	Char Combustor Flue Gas Cooler / Boiler Feed Water Preheat 2	A211	309.9	255.0	235.2	285.0	22.2	3,635,193	112	1,351	Char Combustor FG	BFW Preheat 2	CS	SS304L	120	1,610	40	4088	234,000.00	788,300.00	3.37
H-BP-22	Ex Situ Catalyst Regen Flue Gas Cooler / Boiler Feed Water Preheat 2	A261	309.9	255.0	235.2	285.0	22.2	2,261,634	108	1,351	Regen Flue Gas	BFW Preheat 2	CS	SS304L	110	1,610	40	2543	144,300.00	695,300.00	4.82
H-BP-23	Hydrotreater Outlet Cooler / Boiler Feed Water Preheat 1	A410	309.9	250.3	175.6	232.3	76.1	2,039,539	1,508	25	BFW Preheat 1	HT Outlet Cooler	CS	A199-T22 or A199D (2.5 Cr-1 Mo)	50	1,790	100	268	36,100.00	133,300.00	3.69
H-BP-24	Hydrocracker Outlet Cooler / Boiler Feed Water Preheat 1	A460	309.9	250.3	175.6	232.3	76.1	364,886	1,908	25	BFW Preheat 1	HC Outlet Cooler	CS	A199-T22 or A199D (2.5 Cr-1 Mo)	50	2,270	100	48	15,800.00	92,500.00	5.85
H-BP-25	Low Temp WGS Outlet Cooler / Boiler Feed Water Preheat 1	A500	309.9	250.0	175.6	232.3	76.0	1,641,492	83	25	A300 WGS Outlet	BFW Preheat 1	A204C	CS	80	50	35	617	19,000.00	96,400.00	5.07
H-BP-26	Naphtha Column Condenser / WW Preheat for Steam Production	A450	298.0	200.2	174.7	285.0	18.5	7,190,523	35	160	WW Preheat	Naphtha Column	SS316	SS316	180	50	35	11097	319,100.00	627,000.00	1.96
H-BP-27	A300 WGS Outlet Cooler / Boiler Feed Water Preheat 1	A360	250.0	218.7	175.6	232.3	28.5	573,334	83	25	A300 WGS	BFW Preheat 1	A204C	CS	80	50	35	574	18,800.00	96,200.00	5.12
H-BP-28	Low Temp WGS Outlet Cooler / Boiler Feed Water Preheat 1	A500	250.0	213.3	175.6	232.3	26.4	1,005,597	100	25	BFW Preheat 1	Low T WGS	CS	A209 (C - 0.5 Mo)	110	50	35	1087	33,500.00	128,700.00	3.84
H-BP-29	Distillate Product Cooler / Boiler Feed Water Preheat 1	A450	309.9	193.6	175.6	232.3	40.8	1,500,727	30	25	BFW Preheat 1	Distillate Product	CS	SS316	50	50	80	460	20,100.00	85,000.00	4.23
H-BP-30	Distillate Product Cooler / HT Product to Naphtha Column Preheat	A450	193.6	175.0	110.0	120.4	69.0	240,551	30	53	Distillate Product	HT product	SS316	SS316	50	50	80	44	11,800.00	82,900.00	7.03
H-BP-31	Absorber 1 Bottoms Cooler / Boiler Feed Water Preheat 1	A310	255.0	193.6	175.6	232.3	20.3	556,211	129	25	BFW Preheat 1	Absorber 1	CS	SS316	50	140	80	343	21,000.00	110,700.00	5.27
H-BP-32	Boiler Feed Water Blowdown Cooler / Recycled Boiler Feed Water Preheat	A600	255.0	193.6	153.4	239.4	26.0	400,090	1,326	30	Recycled BFW	BFW Blowdown Cooler	CS	SS304L	50	1,580	100	154	30,200.00	147,300.00	4.88
H-BP-33	Boiler Feed Water Blowdown Cooler / WW Preheat for Steam Production	A600	309.9	255.0	174.7	285.0	47.3	203,262	1,326	160	WW Preheat	BFW Blowdown Cooler	SS316	SS304L	180	1,580	100	43	19,000.00	141,200.00	7.43
H-BP-34	Absorber 1 Bottoms Cooler / Boiler Feed Water Preheat 1	A310	309.9	255.0	175.6	232.3	78.5	419,621	128	25	BFW Preheat 1	Absorber 1	CS	SS304L	50	140	80	67	13,400.00	82,000.00	6.12
H-BP-35	A300 WGS Outlet Cooler / Boiler Feed Water Preheat 1	A360	309.9	250.0	175.6	232.3	76.0	1,097,460	83	25	BFW Preheat 1	A300 WGS Outlet	CS	A209 (C - 0.5 Mo)	50	80	35	413	20,300.00	85,200.00	4.20
H-BP-36	A300 WGS Outlet Cooler/Condenser / Fast Pyrolysis Fluidizing Gas Preheat	A360	218.7	185.0	159.7	200.7	21.4	4,868,699	82.84	127	WGS Outlet Cooler	FP Fluidizing Gas	A204C	CS	80	140	10	22709	279,400.00	511,900.00	1.83

HX Name	Description	Belongs to Area	Hot In	Hot Out	Cold In	Cold Out	LMTD	Duty	Pres. Stream 1	Pres. Stream 2	Shell	Tube	Shell Material	Tube Material	Shell Design Pres.	Tube Design Pres.	U	Area	Equip. Cost (Q1 2009 Basis)	Direct Cost (Q1 2009 Basis)	Ratio (Direct Cost/Equipment
	Stream 1 /Stream 2		F	F	F	F	ΔT	Btu/h	(psia)	(psia)					psig (20% Excess, Min. = 50 psig)	psig (20% Excess, Min. = 50 psig)	Btu/(hr ft^2 °F)	ft^2	$	$	
H-BP-37	Boiler Feed Water Blowdown Cooler / Natural Gas to Reformer Preheat	A500	309.9	255.0	60.0	285.0	82.7	15,859	1331	200	Natural Gas	BFW Blowdown	CS	SS304L	230	1580	40	5	9,900.00	72,000.00	7.27
H-BP-39	Boiler Feed Water Blowdown Cooler / Catalyst Stripper Water Preheat for Steam	A600	309.9	255.0	153.4	285.0	54.6	139,187	1331	150	Catalyst Stripper WW	BFW Blowdown	CS	SS304L	170	1580	40	64	13,300.00	80,600.00	6.06
H-BP-40	Ex Situ Catalyst Regen Flue Gas Cooler / Recycled Boiler Feed Water Preheat	A261	309.9	255.0	153.4	239.4	85.2	156,535	107.84	29.696	Recycled BFW	Ex-Situ Catalyst Regen	CS	CS	50	110	35	53	9,400.00	62,100.00	6.61
H-BP-41	Ex Situ Catalyst Regen Flue Gas Cooler / Catalyst Stripper Water Preheat for Steam	A261	309.9	255.0	153.4	285.0	54.6	256,387	107.84	150	Ex Situ Regen Flue	Catalyst Stripper WW	CS	CS	110	170	35	134	13,700.00	68,000.00	4.96
H-BP-42	Ex Situ Catalyst Regen Flue Gas Cooler / Water Preheat for Mix with WW for Steam	A261	309.9	255.0	153.4	285.0	54.6	198,081	107.84	160	Ex Situ Regen Flue	Water preheat	CS	SS316	110	180	35	104	14,600.00	83,600.00	5.73
H-BP-43	Absorber 1 Bottoms Cooler / Water Preheat for Mix with WW for Steam	A310	309.9	255.0	153.4	285.0	54.6	78,505	127.84	160	Water Preheat	Absorber 1 Bottoms	SS316	SS304L	180	140	80	18	10,700.00	84,900.00	7.93
H-BP-44	Absorber 1 Bottoms Cooler / Recycled Boiler Feed Water Preheat	A310	193.6	175.0	60.1	153.4	71.2	168,999	123	29.696	Recycled BFW	Absorber 1 Bottoms	CS	SS304L	50	130	80	30	10,500.00	78,500.00	7.48
H-BP-45	Boiler Feed Water Blowdown Cooler / Recycled Boiler Feed Water Preheat	A600	193.6	170.0	60.1	153.4	69.3	154,167	1331	29.696	Recycled BFW	Boiler Feedwater Blowdown	CS	SS304L	50	1580	100	22	13,000.00	128,700.00	9.90
H-BP-46	Hydrocracker Outlet Cooler / Recycled Boiler Feed Water Preheat	A460	193.6	175.0	60.1	153.4	71.2	114,047	1907.5	29.696	Recycled BFW	HC Outlet	CS	A199-T22 or A199D (2.5 Cr-1 Mo)	50	2270	100	16	12,100.00	88,600.00	7.32
H-BP-47	Hydrotreater Outlet Cooler / Recycled Boiler Feed Water Preheat	A410	193.6	175.0	60.1	153.4	71.2	166,633	1507.5	29.696	Recycled BFW	HT Outlet	CS	A199-T22 or A199D (2.5 Cr-1 Mo)	50	1790	100	23	12,300.00	88,800.00	7.22
H-BP-48	Hydrotreater Outlet Cooler / Catalyst Stripper Water Preheat for Steam	A410	193.6	175.0	61.1	153.4	70.8	277,242	1507.5	150	Catalyst Stripper WW	HT Outlet	CS	A199-T22 or A199D (2.5 Cr-1 Mo)	170	1790	100	39	15,500.00	92,200.00	5.95
H-BP-49	Hydrotreater Outlet Cooler / Water Preheat for Mix with WW for Steam	A410	193.6	175.0	61.2	153.4	70.8	193,593	1507.5	160	Water Preheat for Mix	HT Outlet	SS316	A199-T22 or A199D (2.5 Cr-1 Mo)	180	1790	100	27	13,300.00	91,900.00	6.91
	Total							568,440,588											12,000,000	31,624,400	2.64

General Guidelines Used:

1. Steam Turbine Exhaust / WW Preheat considered a water/steam heat exchange and allocated a U of 150 BTU/hr ft2 F
2. High pressure gas heat exchange , U = 10 BTU/hr ft2 F
3. Low Pressure gas heat exchange , U=5 Btu/hr ft 2 F
4. Water / Gas (100 psi) heat exchange , U =35 Btu/hr ft2 F
5. High pressure liquid-liquid heat exchange(~1000 psi), U = 100 Btu/hr ft2 F
6. Water and distillate product (~100 psi) , U = 80 Btu/hr ft2 F
7. Pressures (<800 psig: CS; 800-1400 psig: SS304L; >1400 psig A199-T22 or A199D (2.5 Cr-1 Mo))
8. Default Corrosion allowance for Tube (CS): 0.0025 inches(0.06 mm) and Shell (CS) :0.125 inches (3 mm) in ASPEN ICARUS

Appendix I. Plant Footprint and Land Cost Calculation From Harris Group Inc.

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Table I-1. Plant Footprint and Land Cost Calculation From Harris Group Inc.

	Area	Width ft	Length ft	Area ft^2	acre
1	Truck staging, scales, scale shack, guard shack, etc.	250	500	125,000	2.9
2	Feedstock handling and storage: x2-truck dumps/hoppers, x2 scalping screens/hogs, x2-400' diameter stacker reclaimers, and conveyors	800	1,000	800,000	18.4
3	Feedstock drying and storage: x2-dryers/WESPs/RTOs and x2-dry feedstock silos	200	500	100,000	2.3
4	Pyrolysis island: x2-reactors, x2-regenerators, bed/sorbent media handling w/ silos, ash handling w/ silo(s), air compressors, solids cooler, instrument air system, etc.	125	150	18,750	0.4
5	Vapor phase upgrading island: reactor, regenerator, bed media handling w/ silos, air compressor, solids cooler, steam stripper, instrument air system, etc.	75	100	7,500	0.2
6	Condensers: two absorber condensers, decanters, filters, WGS reactor, PSA, compressor	100	100	10,000	0.2
7	Hydrotreating/hydrocracking reactors, hydrogen compressors	50	100	5,000	0.1
8	Product separation: distillation columns	75	100	7,500	0.2
9	SMR: reformer and PSA	200	200	40,000	0.9
10	Wastewater treatment, boiler water treatment, condensate treatment, DA, steam distribution, power generation, reboiler stripper, RTO, etc.	200	250	50,000	1.1
11	Cooling towers, pumps, etc.	100	150	15,000	0.3
12	Tank farm: product tanks, fuel, chemicals, fire water, process water, etc.	500	500	250,000	5.7
13	Air separation plant, compressors, tanks, etc.	50	50	2,500	0.1
14	Storm water system: retention pond, etc.	200	200	40,000	0.9
15	Electrical feed, transformers, etc.	100	100	10,000	0.2
16	Electrical building	25	100	2,500	0.1
17	Control room	25	50	1,250	0.0
18	Offices, etc.	100	100	10,000	0.2
19	Maintenance shop, maintenance warehouse/yard	200	200	40,000	0.9
20	Parking, roads, etc.	500	500	250,000	5.7
21	Buffer			871,200	20.0
22	Unusable land (topography and environmentally)			1,306,800	30.0
23	Other: space in-between process areas, etc. (10% of process areas and buildings)			153,500	3.5
24	Easement (10% of all above)			411,650	9.5
25	Contingency (10% of all above)			452,815	10.4
			Total	**4,980,965**	**114.3**
	Specific Land Cost*	$/acre	14,000		
	Site Area	acres	114.3		
	Total Land Cost	**$**	**1,600,861**		

*Specific land cost assumption based on USDA (2012) and Dutta et al. (2011). Basis: 2,000 dry metric tons/day feedstock basis or 2,205 dry short tons/day. Most estimates derived from Dutta et al. (2011).

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Appendix I References

Dutta, A.; Talmadge, M.; Hensley, J.; Worley, M.; Dudgeon, D.; Barton, D.; Groendijk, P.; Ferrari, D.; Stears, B.; Searcy, E.M.; Wright, C.T.; Hess, J.R. (2011). *Process Design and Economics for Conversion of Lignocellulosic Biomass to Ethanol: Thermochemical Pathway by Indirect Gasification and Mixed Alcohol Synthesis.* NREL/TP-5100-51400. Golden, CO: National Renewable Energy Laboratory.

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Appendix J. Reviewer Comments on Draft Design Report and Responses

This appendix presents a summary of reviewer comments from draft versions of the report, issued for peer review in June 2014 and in August 2014. Comments from the peer review panel are summarized below and followed by a response from the authors. Some of the comments are paraphrased along with added context for clarity. Comments were combined when there were commonalities among observations from multiple reviewers. Minor/editorial comments were addressed, but left out of this appendix. The responses also describe any actions taken to address the comments in this final version.

Area A100: Feed Handling and Drying

1. **Comment:** Feedstock handling capital, including drying and sizing, should be included in the analysis. The $80/dry ton cost may be too low.

   Response: Details about feedstock logistics and cost breakdown are included in Jacobson et al. (2014). All the above costs are included in the $80/dry ton. This report focuses on the conversion aspects and includes the feedstock cost input as an operating expense. Sensitivity analysis showing the impact of more expensive feedstock is included in Figure 15.

2. **Comment:** Use of blended feedstock material can be a challenge in actual plants from a handling perspective. Additional equipment may be necessary.

   Response: Further experiments and validation efforts led by the Idaho National Laboratory will study the details of feed systems for the blended material.

3. **Comment:** For grinding to 2mm, what portion of it happens within the plant? What is the form of the feedstock and which operations happen onsite. The effect of particle size on conversion needs to be studied.

   Response: The assumption of the particle size in this report is consistent with Jones et al. (2013). For the 2022 target case presented in this report, it is anticipated that pelletized material will be brought to the plant and crushed on-site before feeding to the reactor. An additional cross-flow dryer for warming up the feed using waste heat is included within plant operations in this design.

4. **Comment:** The low cost of feedstock at $80/dry ton is partially justified by the use of substantial residue (30%) and waste materials (20%). Such biomass materials come with significant quality/consistency issues that impact operating efficiency. These issues the authors abstract away using the n^{th} plant framework. More fundamentally, by assuming that a mature industry with multiple operating plants has been achieved, the authors should recognize that within such a context there will be competition for biomass resources. Such competition implies that the availability of residue/waste at low cost is very questionable. The authors would be on more solid ground in assuming a mature industry uses plantation wood dedicated to feed these plants.

   Response: As observed by the reviewer, the assumption of diversified material was deliberate for cost reduction purposes. The cost impacts of the inclusion of the various constituents of the blend, at different volumes, were also included by Jacobson et al. (2014).

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The marginal cost of each constituent is shown to go up for higher volume demands. The cost of large volumes of plantation wood is expected to be higher than the blended material.

5. **Comment:** One of the startups using catalytic fast pyrolysis technology stated in their public report that their wood yard design were a significant part of their inability to achieve target rates. This area should not be neglected.

   Response: We included areas for "Feedstock handling and storage" and "Feedstock drying and storage" in our design (shown in Appendix I).

6. **Comment:** I was surprised to see C&D waste as 20 % of the blended feed. C&D waste usually contains significant metal and ash contamination (e.g., iron from nails, gypsum from sheetrock). Is the INL blended feedstock clean of contaminants? If not, those contaminants should be mentioned as a risk to Area 200. Multiple reviewers questioned the impacts of contaminants and additional ash in the blended material (usually much higher than wood), along the same lines as this comment; they expressed their concerns about the impacts of mineral matter/ash on the organic yields.

   Response: The feedstock logistics design proposed by the Idaho National Laboratory has specifications for ash. They discuss operations for ash removal in order to meet the elemental analysis specifications of the feedstock in Jacobson et al. (2014). In addition there are experimental plans to quantify the impacts of using the blended material on the yields from the various conversion pathways (including those detailed in this report). Findings from these experiments will be factored into future techno-economic assessments.

Area A200: Fast Pyrolysis and Vapor Upgrading

7. **Comment:** What was the reason for the choice of 120 psia (~8 bars) with a hydrogen partial pressure of approximately 75-95 psia (5-6.6 bars) in the inlet fluidizing gas for the fast pyrolysis reactors? These are not conventional fast pyrolysis or hydropyrolysis conditions. This assumption should be emphasized upfront, otherwise people do not see that there is a deviation from conventional pyrolysis at near atmospheric conditions.

   Response: Based on this and similar comments, we made these assumptions very conspicuous in the Executive Summary and the Introduction sections, as well as Section 3.2.1.5 dedicated to this aspect.

8. **Comment:** The liquid yield and oxygen content for the organic phase in this report do not coincide with Figure 1. For that oxygen content the yield would be near 20% and here your yield is near 30%. I understand you are looking at a process that uses hydrogen and elevated pressure, but it would be great if you could state where these yields came from, either experimental data or a projection, somewhere clearly in the Area 200 description. Figure 11 shows that >50% of the LHV is recovered as fuel-range hydrocarbon products in each case. Again, this is very dependent on process yields, so it is good to be very clear on where you obtain those.

   Response: We have since made it very clear that this design report details target cases for 2022. Figure 1 is reflective of the current state of technology. We have separately developed a state of technology assessment, and initial annual targets leading up to 2022, based on the process designs detailed in this report; those results are expected to be published in BETO's Multi-Year Program Plan.

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9. **Comment:** There were several comments about Figure 1, including (a) reasons for differences among data points and whether they were caused by differences in catalysts or different reaction conditions, (b) the draft version had a discussion using catalyst to biomass ratios, while the figure shows the inverse (biomass to catalyst ratio) on the x-axis, (c) whether the results are for *in situ* or *ex situ*, (d) more clarity in the text surrounding the discussion of the figure.

   Response: Figure 1 was previously published in a journal article. Details about the individual data points are available in the cited literature. We have modified some of the text around the figure based on reviewer comments. The main purpose of the figure is to show that we tend to lower yields as we deoxygenate the organic product. This is a key challenge for us in meeting our 2022 goals with both high yields and significant deoxygenation. This figure highlights the need for catalyst research and exploring new catalyst materials and chemistry to accomplish our goals.

10. **Comment:** Many comments reflected that the draft version did not sufficiently emphasize that we are showing designs for target cases, rather than the current state of research.

    Response: Please see the response to Comment 8. Based on this recommendation, the title of this report was modified to include "Research Pathways," and key table captions were also modified to state that these are 2022 targets.

11. **Comment:** Multiple reviewers of the draft report wanted to see more discussion about catalysts. Their comments included (a) the likely necessity to use catalysts with different functionality compared to zeolites like ZSM-5, which produce aromatics, (b) mentioning new chemistries that can promote lower oxygen at higher yield, (c) queries whether confidentiality constraints were stopping the authors from disclosing more about the catalysts, (d) requests for the inclusion of some catalyst background for the reader to be able to appreciate the relevance of these conversion pathways.

    Response: Section 3.2.1.6 was added to discuss some of these aspects. Since this report is focused on the process design and techno-economics, we limited the discussion and pointed out review articles as additional resources on this topic.

12. **Comment:** The use of a hot gas filter (HGF) may be necessary, even in the case of a circulating fluidized bed (CFB) *ex situ* reactor. The two preceding cyclones may not be sufficient to remove finer entrained mineral matter that can deactivate catalysts. The current design assumes two cyclones prior to the CFB *ex situ* reactor. It was pointed out that the statement in the draft version about "only a small proportion of fine solids" needed to be qualified.

    Response: Irreversible deactivation from contaminants is mentioned in the current version. We also mention that an HGF may be necessary based on future experimental data.

13. **Comment:** The draft report used the term ash to refer to all biomass inorganic content. It was pointed out that there is a difference between mineral matter and ash. Ash is the product after biomass combustion.

    Response: We adopted the suggestion and made changes to the text to reflect this. However, it should be noted that much of the literature on this subject uses the term ash for biomass inorganic content in all contexts, because ash is the eventual measurement of inorganic content.

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14. **Comment:** It should be pointed out that mineral matter is contained in the char from the pyrolysis reactor.

    Response: We added this to the text in Section 3.2.1.

15. **Comment:** Call out the content of char entering the char combustor and mention that the char/sand mixture flowrate has been adjusted to maintain thermal balance so that the heat supplied by char combustion is equal (more or less) to the heat required for the pyrolysis step.

    Response: In order to further convey this point we added text to say that pyrolysis is endothermic. Char and all other component flow rates are included in the stream summary tables in Appendix G. Percent char produced is shown in Table ES-1.

16. **Comment:** How much coke is deposited on the catalyst in the *in situ* case? FCC catalysts come out of the riser with 1-2% coke.

    Response: In the 2022 target case there is 1.1% coke on the catalyst leaving the *in situ* catalytic fast pyrolysis reactor. Details are available in the steam summaries in Appendix G.

17. **Comment:** Attrition rates assumed in the draft report were too low.

    Response: We feel the catalyst replacement rates assumed in the final draft cover this concern adequately. A total of 3.6% of the catalyst inventory is assumed to be replaced per day in both the *in situ* and *ex situ* cases.

18. **Comment:** It was noted that some of the key catalyst performance goals are competing. For example, increased coupling may lead to more liquids, but may also lead to more coke formation. Furthermore, increased liquid yield may decrease hydrogen efficiency.

    Response: The goal of the research is to overcome these obstacles. Also, the use of separate reactors operating with different catalysts and different reaction conditions will be considered as we consider additional process options in the future.

19. **Comment:** The catalyst cost at $6,500/ton in the draft seemed 3 to 8 times low.

    Response: We increased the unit cost of the catalyst three times to $19,500/ton or $9.75/lb. Note that the actual cost will depend on modifications made to the catalyst based on research. This unit cost is higher than FCC catalyst costs, which was the basis of our initial assumption of $6,500/ton or $3.25/lb. We also allow for 3.6% of the catalyst inventory to be replaced per day. This leaves room for the research to develop less expensive catalysts with higher losses, or more expensive catalysts with lower losses to meet the cost targets.

20. **Comment:** With the recent commercial challenges, it may be difficult to accept the utilization of FCC upgrading equipment (circulating fluidized bed reactors).

    Response: The research will have to experimentally justify and demonstrate achieving some of the target metrics using circulating fluidized bed reactors. This technology has been successfully scaled up for biomass fast pyrolysis; we chose this option in our design for that reason. The *ex situ* upgrading case will have additional fixed bed options as mentioned in the text.

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21. **Comment:** Total capital costs in the initial draft seemed high in both the *in situ* and *ex situ* cases. Some Catalytic Fast Pyrolysis systems have been reported for 50% of the costs shown in the draft report.

    Response: The equipment costs were since adjusted in the final version, especially for the use of higher than ambient pressures. There were savings from the use of 120 psia pressures because of reduced reactor volumes (estimated by the Harris Group). We were careful to not underestimate the costs, and used higher installation factors of ~4 for the reactor and the regenerator in the final version.

22. **Comment:** For the *ex situ* case the benefit of adding hydrogen to the fast pyrolysis reactor is negligible, so why not add hydrogen only to the *ex situ* vapor upgrading reactor?

    Response: The reason we chose to add hydrogen to the front end instead of the *ex situ* reactor only was because of concerns about the dilution of hydrogen and lowering the partial pressure. We do need a certain amount of fluidizing gases, so inclusion of hydrogen in the mix allows us to not add other gases for fluidization in the fast pyrolysis reactor.

23. **Comment:** The initial design specified a pressurized (~120 psia) reactor and a near atmospheric combustor, with intermediate lock hoppers in order to lower compression costs for air fed to the combustor. There were many comments about this design, especially with respect to costs and reliability of such a system, and it was recommended that the system should be designed with similar reactor and combustor pressures.

    Response: The recommendation to operate the reactor and combustor at comparable pressures was adopted in the final design. The electricity credit was reduced because of higher compression requirements, but we agreed that this is a more reliable design.

24. **Comment:** The simplified flow diagrams in the report do not adequately reflect the complexity of the systems described such as solids coolers and lock hoppers (in the previous draft). More details should be presented.

    Response: Appendix G includes detailed process flow diagrams along with stream tables.

25. **Comment:** How was the 5:1 catalyst to biomass ratio concluded?

    Response: This is an initial assumption, and will likely be modified with more experimental results. This ratio will depend on the steady state activity of the catalyst, which is affected significantly by the reactor configuration and whether the system is a truly circulating fluidized bed system. Although Figure 1 shows results from different experimental configurations, it indicates that ~6% oxygen content oil can be produced with an approximate 5:1 catalyst to biomass ratio (0.2 biomass to catalyst ratio). As mentioned in this report, significant yield improvements will be necessary via catalyst research to achieve our 2022 yield targets, even as we achieve an oxygen content of 6%. Our choice for this design was influenced by this consideration.

26. **Comment:** In both cases, stripping steam is used to recover additional product. How much extra yield is assumed? How was this concluded? And is it really worth the extra yield to add this extra unit operation?

    Response: This assumption was consistent with FCC systems where steam helps recover additional hydrocarbons from the catalyst before regeneration. The tradeoff between capital

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costs, product recovery, and impacts on catalyst maintenance will need to be assessed experimentally for biomass systems during our research.

27. **Comment:** What is the organic yield and composition (CHON) for both the *in situ* and *ex situ* cases? What is the basis for this yield?

    Response: The organic liquid yields are shown in Table ES-1, and mass percent C, H, O are shown in Table 6 under Area 300. These are targets to achieve cost-competitive fuels production from biomass by 2022. The yield bases for 2022 were derived using these considerations: (1) organic yield maximization while still allowing reasonable coke and gas losses, (2) the yields needed to be in the range where the process was economically feasible, and (3) the *ex situ* case had the added target for higher diesel-range product.

28. **Comment:** What is the non-condensable gas composition from the *in situ* and *ex situ* reactors?

    Response: We have included detailed flow diagrams and stream summaries in Appendix G, where the gas composition information is also included.

29. **Comment:** What is the hydrogen consumption in the *in situ* and *ex situ* process?

    Response: Hydrogen consumption by difference of reactor inlet and outlet gas composition in the *in situ* and *ex situ* 2022 target cases are 1.3 and 1.8 wt.% of dry biomass, respectively. Please note that this consumption can be significantly impacted by water gas shift assumptions. The other metrics such as H/C ratio, oxygen content, and organic liquid yields provided in Table ES-1 are more reflective of the extent of desirable reactions involving hydrogen.

30. **Comment:** Why is the *ex situ* case bio-oil oxygen content lower than in the *in situ* case?

    Response: The catalyst performance assumptions are more aggressive for the *ex situ* case, based on some of the potential advantages outlined in Table 3.

31. **Comment:** Why is the *in situ* yield (75 gge/ton) lower than the *ex situ* yield (78 gge/ton)?

    Response: In this 2022 target design, the yield differences are primarily because of the higher losses during the hydrotreating of the *in situ* process bio-oil. The *in situ* process bio-oil has higher oxygen content and losses are estimated based on Figure 8.

32. **Comment:** Why is the catalyst loss rate lower for *ex situ* compared to *in situ*?

    Response: Although both the *in situ* and *ex situ* cases assume total catalyst replacement rates of 3.6% of the inventory per day, the catalyst (bed solids) inventory itself is assumed to be larger for the *in situ* case (Table 4) because of the disadvantages of the catalyst mixing with bulk solids such as biomass, char, and mineral matter/ash within the reactor, as outlined in Table 3.

33. **Comment:** Add a sensitivity case for 20% oxygen content in the organic liquid with atmospheric pressure and 5 bars pressure, using hydrogen only downstream. Outline the impact on capital costs (because of larger volumes) in such a case.

    Response: We will consider adding such a case during our future analysis. We could not include the case in this report because of time constraints. We did add a discussion about hydrogen and pressure in Section 3.2.1.5. Even without any consideration of potential

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benefits to the chemistry (which will need to be experimentally proven with future catalyst development), we anticipate some negative impacts on the economics because of larger reactors.

34. **Comment:** Show how you can bring down the cost further from less than $3.5/GGE to $3/GGE.

    Response: Figure 15 shows sensitivity cases and the key areas where we can make further impacts. As pointed out by another reviewer, we can optimize the operating scales and related handling of intermediates after some maturation of the technology, and our n^{th}-plant assumption *in this regard* may be sub-optimal; economies of scale alone can bring down the cost significantly. There is some conservatism in the assumption of catalyst losses of 3.6% of the inventory per day (especially for the *ex situ* case); this may be another area of further cost reduction.

35. **Comment:** Show sensitivity to the modeled dew point in the condensation train and how much of an impact changes in this temperature impact the process and economics.

    Response: The reviewer's comment was based on the assumption in the initial design that we can have indirect heat exchange down to the dew point of the pyrolysis vapors. In the final design we assumed direct quench below the dew point to avoid fouling heat exchangers. The impact is shown in sensitivity Case 22 in Figure 15.

36. **Comment:** Discuss the basis for sizing and scaling of the combustor. Parameters that should be discussed include superficial velocity, % of stoichiometric air used, scaling variable used (should be related to superficial velocity).

    Response: We have added this discussion in Section 3.2.

37. **Comment:** From the perspective of solids carryover to the quench system, it may not be necessary to have a hot gas filter (HGF) provided the cyclone efficiencies match the Particle Size Distribution (PSD) of the catalyst. In this context it may be useful to remove fines from fresh catalyst before introducing into the reactor. Granted some char will carry over, especially for the *in situ* case, but that alone will not necessitate a hot gas filter.

    Response: Thank you for your valuable insights.

38. **Comment:** Hydrogen embrittlement considerations for the reactors should be mentioned in the text.

    Response: We have included this along with a reference.

39. **Comment:** It is important to pay close attention to siting, economies of scale, use of merchant hydrogen taking advantage of economies of scale to reduce costs.

    Response: This is a generic design for a standalone plant at a U.S. location. We do understand that there are numerous advantages to be had from an optimal location, but we did not want to make this design too specific and tied to other considerations; those factors will likely be leveraged more efficiently by commercial entities.

40. **Comment:** The incentives for *ex situ* should be bigger than the *in situ* case, leveraging hydrogen addition; it is less clear whether hydrogen addition will be possible in the *in situ* case. For a yield of 29%, the trend line in Figure 1 in the study design would suggest a pyrolysis oil oxygen level closer to 20 % vs. 10.8% assumed in the study; if these numbers

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are confirmed then it seems that the benefits in this process are derived primarily from the introduction of hydrogen.

Response: The anticipated benefits from hydrogen addition are larger for the *ex situ* case, as reflected by the more aggressive 2022 targets compared to the *in situ* case. It has been further clarified in this final version of this report that the cases shown here reflect target cases, and not the current state of catalyst performances as reflected by Figure 1. The 2022 case is targeted to significantly improve on the performances shown in Figure 1. The benefits through research is expected from not just the introduction of hydrogen, but also through the use of developed catalysts that are capable of beneficially using the hydrogen at the reaction conditions during vapor upgrading.

41. **Comment:** It is not at all clear why the two cases produce such differing amounts of gasoline vs. diesel. This raises questions about the product distillation curve and the hydrocracker design.

    Response: Targeted coupling reactions will be one of the objectives of *ex situ* catalyst development. Coupling reactions are expected to allow the production of larger molecules, including more molecules in the diesel range. This is the reason for a larger proportion of diesel in the *ex situ* product as the 2022 target.

42. **Comment:** Is the distillation curve for the 10.5 % oxygen (*in situ*) product assumed to be significantly different than for the 6.4 % (*ex situ*) product? Data from previous work suggested that significant boiling point changes occur below 5% oxygen in the case of fast pyrolysis. Here the oxygen level for the hydrocarbon feed is assumed to be higher than for the hydrotreated product (in the previous cases with 5% oxygen after hydrotreating of raw pyrolysis oil). Why is this assumption made? Is there data to support this?

    Response: Note that we are not aiming to directly blend the material targeted at 10.5% and 6.4% oxygen for the *in situ* and *ex situ* 2022 cases, respectively, into fuel products. The downstream hydroprocessing is aimed to further reduce the oxygen content to below 1% before it can be considered for blending into gasoline and diesel. The 2022 targets for the final product in this report are close to the low oxygen content (LOC) products characterized by Christensen et al. (2011), which were considered blendable into gasoline and diesel.

43. **Comment:** It is noted that the design calls for the diesel fraction from the hydrotreater to be sent to the diesel pool. Given what is known about the poor quality of pyrolysis oil diesel, we would think it will require upgrading via hydrocracking. Specific data about diesel product quality should be provided, given that a substantial portion of *ex situ* economic advantage derives from producing more diesel and less gasoline range material.

    Response: As noted in the Conclusions section, product characterization and quality specifications specific to these processes will become important with advances in the research for these pathways. We expect that in the post-2017 timeframe significant attention will be paid to quality aspects and the development of associated targets for refinery integration. This may include targeting the hydrocracking operations, already included in this design, toward better quality products, including the possibility of ring-opening chemistry.

44. **Comment:** The riser diameter on the ex-situ pyrolysis reactor was limited to 1000 tons/day. What limits the riser diameter?

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Response: The limitation of 1,000 tons/day per fast pyrolysis reactor train was based on biomass feeding constraints and not the riser diameter.

45. **Comment:** FCC units that can operate with only two cyclones on their regenerators do not usually meet U.S. emissions standards for particulate matter. Typically, a wet-gas scrubber (preferred), electrostatic precipitator, or baghouse is required. Perhaps a tertiary separation is not necessary for sand, but one will be required for ZSM-5. A flue-gas scrubber was mentioned with a reverse-osmosis system for the water product, but there was no other description of the equipment.

    Response: We do not describe the system in the main report because it is mature technology, but have included the source of the scrubber information used for our costs in Appendix A. The information was originally obtained for use in Dutta et al. (2011).

46. **Comment:** Will the regenerators handling ZSM-5 be operated in full or partial-burn mode? Partial burn requires a separate CO boiler.

    Response: We assumed full burn with 20% excess air, along with an associated catalyst cooler.

47. **Comment:** In the draft version it was mentioned that the *ex situ* catalyst operates in a "more benign reaction environment". It should be further stated that irreversible catalyst deactivation from impurities such as alkali can be reduced by the upstream removal of solids. In addition it is important to point out the flexibility to operate at different conditions compared to the fast pyrolysis reactor in the *ex situ* approach; this can have advantages in carbon efficiency, higher selectivity to target products and reduced deactivation.

    Response: Thank you for the valuable comments. All the points were included in this final version.

48. **Comment:** It was not clear if there was a continuous feed of steam (mentioned for stripping the catalyst) to the reactors or a feed to the regeneration cycle.

    Response: In this conceptual design the stripping steam is fed after the catalyst is separated from the vapors, similar to FCC units. The function is to strip out any volatiles from the catalyst that would otherwise go to the regenerator and be combusted.

49. **Comment:** In terms of deoxygenation, does your model suggest that hydrodeoxygenation pathways would be preferred to decarboxylation / decarbonylation reactions.

    Response: Carbon efficiency is of prime importance for increasing fuel yields. Unlike in syngas-based processes, any carbon not already incorporated in liquid-range molecules after vapor upgrading (in these *in situ* and *ex situ* conceptual process designs) cannot be reincorporated into liquid phase products. Thus hydrodeoxygenation is the preferred route for deoxygenation to avoid carbon losses as CO and CO_2.

50. **Comment:** What is meant by "more favorable reaction chemistry" in the context of *ex situ* vapor upgrading?

    Response: We meant desirable reactions such as hydrodeoxygenation, hydrogenation, and coupling. We have added this to the text.

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51. **Comment:** What are the purported benefits of reducing oxygen content to 6.4% in the *ex situ* case? Does this allow dropping into an existing refinery, or does it allow removing extra hydrodeoxygenation units?

    Response: Compared to raw pyrolysis oil hydrotreating (Jones et al. 2013) where three hydrotreating steps are included in the design, this conceptual process assumes a single step hydrotreater, which is assumed to be made possible by the lower oxygen content in the bio-oil; this will be experimentally verified with progress in research. The 6.4% oil is not deemed suitable for blending into refinery products; it may however be possible to feed this intermediate into a petroleum refinery for further processing (Christensen et al. 2011).

52. **Comment:** Inclusion of a comparison between *in situ* and *ex situ* will be useful.

    Response: We included this in this final version (Table 3).

53. **Comment:** Need to be consistent with the use of the terms "vapor upgrading" and "vapor phase upgrading". At one point it says "vapor phase upgrading" is for *ex situ*.

    Response: We made them consistent in the final version.

54. **Comment:** It was mentioned that the pyrolysis reactor has sizing constraints due to biomass feeding. It is unclear why those constraints are gone just by switching to an *ex situ* configuration. The system is still using a pyrolysis reactor upstream of the *ex situ* reactor. Are you saying 2 pyrolysis reactors feed into 1 upgrading reactor? If so, you have 3 total reactors for *ex situ* and 2 for *in situ*…how does that reduce cost for the *ex situ* system? Please make this clearer.

    Response: The reviewer correctly pointed out that there are more reactors in the *ex situ* system, hence the total capital costs are higher compared to the *in situ* system. However, the single larger *ex situ* reactor is less expensive compared to the combined cost of two-train reactors necessary for fast pyrolysis (Table 5). The language in the text was modified in an attempt to make this more apparent.

55. **Comment:** Is the inclusion of metals factored into the catalyst costs?

    Response: We did factor the inclusion of metals into the cost. Also, based on reviewer comments we made significant upward revisions to the assumed catalyst costs for *in situ* and *ex situ* vapor upgrading.

56. **Comment:** The regeneration temperature for zeolites is typically < 650°C.

    Response: We reduced the regeneration temperature in the versions after the June 2014 draft. The temperature was higher in the June 2014 draft version, based on FCC catalyst regeneration temperatures from literature.

57. **Comment:** Do you have any olefins in the gases? Are they all utilized in coupling reactions? Typically quite significant fractions of olefins are formed.

    Response: We did not use coupling reactions for light olefins in the gases for the 2022 cases. Additional coupling of olefins can be beneficial to yields.

58. **Comment:** Why is the assumed heat loss lower for the *ex situ* reactor compared to the fast pyrolysis reactors? Is it because of the assumption of a single train for the *ex situ* reactor?

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Response: Yes, the rationale was lower losses in the single train *ex situ* reactor compared to two trains for the fast pyrolysis reactor.

59. **Comment:** When mentioning "better quality oil" in Figure 1, it should be mentioned that oxygen content alone does not dictate the quality of oil. It is a function of functional groups. For example phenols are preferable to acids. Some catalytic pyrolysis oils still contain some of the reactive species.

    Response: We added the mention of reactive functional groups to the section around Figure 1.

60. **Comment:** "Efficient hydrogen utilization, which ties into reduced aromatics in the product, reduced coke formation, and greater hydrodeoxygenation to allow higher carbon efficiency". How is hydrogen efficiency measured?

    Response: The effectiveness of hydrogen use during vapor upgrading is measured by the combination of the three metrics: H/C ratio, oxygen content, and yield of the organic liquid product.

61. **Comment:** Is there a problem of having hydrogen in the reactor of the circulating fluidized bed (CFB) system with the presence of oxygen in the combustor?

    Response: Gases and vapors from the reactor do not flow into the combustor side of the CFB system. In a typical system, solids such as char are separated in a cyclone and then sent to the combustor, with a seal created by the solids in a standpipe. The oxygen reacts with the solids and the hydrogen-rich gases on the reactor side should not flow into the combustor.

62. **Comment:** Is stripping supposed to be within the continuous process or is it separate? It doesn't appear on the process flow diagram.

    Response: Stripping steam is part of the continuous process. It is not shown in the simplified process flow diagrams in the main report. However the detailed process flow diagrams and stream summaries in Appendix G include this information.

63. **Comment:** What types of reactions cause the heat balance in the *ex situ* reactor to be exothermic?

    Response: Hydrogenation and hydrodeoxygenation reactions are typically exothermic. Product distributions before and after the *ex situ* upgrading reactor can be found in Appendix G.

64. **Comment:** Explain how the capital cost of the fast pyrolysis reactor compares with Ensyn's published values; those were used by Jones et al., 2013.

    Response: Please see comment 21 for a related response. The costs of the systems in this design are lower because of smaller volumetric flow rates as a result of higher pressures (~6 times Jones et al. 2013). Although a direct comparison is not possible without going back and modifying the design by the Harris Group, a quick check by changing the cost by a factor of 6 (for the larger volume) to the power of 0.5 (scaling exponent) for the reactor and combustor gave an installed cost very close to the one in the Jones et al. 2013 report.

65. **Comment:** "The fluidizing gases are rich in hydrogen because of a deliberate attempt to create a hydrogen-rich atmosphere to impact the chemistry favorably." Please explain what is

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meant by favorable. Is it to reduce coking? At these conditions it is unlikely to cause hydrogenation.

Response: Favorable chemistry includes hydrodeoxygenation and reduced coking as near-term targets. Hydrogenation, although difficult, is not impossible. Hydrogenation will be one of the longer-term targets.

66. **Comment:** It is worth adding more information about the chemistry of all the processes considered, especially of the catalytic pyrolysis and catalytic vapor cracking. What kind of products and with what yields can be obtained from those processes. Mass balances for all the stages should be better visible, in addition to tables within the text; suggest providing stream sizes in the process flowsheets.

    Response: The processes represent 2022 targets. We will develop further understanding of the chemistry with research progress and modify the chemistry accordingly; some of the chemistry assumptions will be specific to catalysts being used. In the simulation we used conversion blocks to represent the key functionalities of hydrodeoxygenation, hydrogenation, and coupling. Detailed stream information is provided in Appendix G of this final version; products and the assumed chemistry can be seen in those stream summaries.

67. **Comment:** It is not quite clear how the size of the pyrolyzers and the vapor cracker were calculated. In Table 4 the weight ratio of the fluidizing gas to biomass is equal to 0.86, which may be too low. Even bubbling beds usually operate at the ratio >2; the entrainment of solids requires significantly more gas (U_t/U_{mf}=72).

    Response: Note that the reactor conditions, especially the slightly elevated pressure and gas properties such as density, and drag coefficient (because of the presence of hydrogen) are different from typical fast pyrolysis systems. In addition the reactor dimension has an impact on the velocities. Based on the reviewer's observation, Anna Trendewicz conducted simulations using the model described in Trendewicz et al. (2014) to validate whether the reactor was in entrained flow mode for the conditions assumed for the model in this report; her results showed that we are in the correct regime.

68. **Comment:** Organic yield of 64 wt % (fast pyrolysis intermediate in *ex situ* case) is certainly high, considering you feedstock ash content. My correlation with the ash content of 0.9 wt% gives me 54.2 wt% (based on dry ash free feed).

    Response: The feedstock ultimate analysis specifications we used are based on woody biomass, and the yield assumption is based on yields reported for such systems and mentioned by Jones et al. (2013). We understand that there are variations in ash within woody biomass samples, which can affect yields. With progress in research the impacts of ash and blended material based on experimental results will need to be factored into the analysis.

69. **Comment:** In the draft report a reference was provided for the design of the combustion section, which is very secondary. A source of the reactor design criteria should be provided.

    Response: Information about superficial velocity and residence time assumptions for the reactor section was added to the text. The tool described in Worley and Yale (2012) was used by the Harris Group for the reactor design.

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Area A300: Pyrolysis Vapor Quench and Product Recovery

70. **Comment:** The initial draft had an indirect heat exchanger condensation train; multiple reviewers questioned the feasibility of such a design because of potential fouling problems. It was called out that even with 6% oxygen content the product may not be stable enough to allow indirect heat exchange.

    Response: We modified the conceptual design to include direct cooling using two absorber/condensers (shown as the high temperature absorber/condenser and low temperature absorber/condenser in Figure 6). Indirect cooling was limited to the portion prior to the onset of vapor condensation, and the section after most of the heavy material was removed from vapor stream. Lighter fraction bio-oil was used for condensing the heavy fractions in the first absorber/condenser. The final cooling of the entire lighter fraction occurs in a second absorber/condenser.

71. **Comment:** Pyrolysis vapor fractions condense at different temperatures. The heavier the fraction the higher the temperature. See some of Professor Robert Brown's work for specific fractions. That means that staged coolers upstream of the flash tank will foul. (Note that the initial draft had a flash tank instead of the first absorber/condenser used to knock out the heavy organic material; this comment was based on the initial draft.) Inherent is an assumption that if you add catalyst (*in situ*) or upgrade the vapors (*ex situ*), the product will be more uniform with respect to condensation temperatures; I don't think this will happen.

    Response: This and other comments were the reason for us to move toward a design with two separate absorber/condensers, first for the heavy fraction and the second for recovering the lighter fraction (shown as the high temperature absorber/condenser and low temperature absorber/condenser in Figure 6).

72. **Comment:** The chilled water heat exchanger cools the process permanent gases. These gases are split into 3 streams (that seems very difficult to accurately control), and the stream directed into the water gas shift reactor with an inlet temperature of 464°F, gases compressed to 214 psia (note temperature and pressure are for the *ex situ* case, and were slightly different in previous draft version). Where does the heat come from for this reactor, is it from steam? The non-condensable gases are also cooled compressed and re-heated. How is the heat provided?

    Response: The non-condensable gases are split into three streams. One of them is a purge of 1%, which will be a bleed and does not need accurate control. In practice this will be a two-way split between water gas shift (WGS) and recycle, after an initial bleed. This should be doable, especially because you can allow a range of pressure drops on the WGS side because that operation is not affected to any significant extent by slight variations in operating pressure. The heat for the WGS preheat comes from process heat exchange (exchanger network for the *ex situ* case is provided in Appendix H of this final version). The gases are cooled in the absorber/condenser and reheated for WGS; recompression to 214 psia happens before the PSA after cooling of the WGS outlet.

73. **Comment:** (This comment was based on the design in the draft version where the first absorber/condenser for recovering the heavy fraction was not present; instead there was a flash drum after indirect heat exchange.) The dew point of water at 116 psia is 339°F per references. Water will be condensing long before reaching the flash drum temperature of

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110°F. Later it is pointed out that there are issues with heavy hydrocarbons present in the Area 200 effluent vapor. “I think you need to plan to cool the effluent to no less than 350°F, which will, unfortunately, push a substantial cooling load into the absorber, adding exchanger surface area and tower diameter. The higher condensation temperature is another challenge introduced in the design by the desire to add hydrogen (at pressure) to the upgrader.”

Response: The dew point consideration was the primary reason for changes in the design and the inclusion of two absorber/condensers as mentioned in response to some of the previous comments. The Aspen Plus model predicts a condensation temperature of 466°F for the vapor stream prior to the high temperature absorber/condenser in Figure 6. Note that this is the dew point of the mixture, and not the pure component dew point of any specific compound; condensation is affected by partial pressures of all constituents. Very little water is condensed in the first absorber/condenser (included for knocking out the heavier components); it has a bottom stream temperature of 461°F (*ex situ* 2022 target case). Less indirect heat recovery is now possible because of the inclusion of this design change with a high cut-off temperature (466°F) on indirect heat recovery (as pointed out by the reviewer: “push a substantial cooling load into the absorber”).

74. **Comment:** The filter for removing particulate matter from the liquid hydrocarbon should be placed in front of the oil/water separator, which will increase its size significantly (the draft report for review had the filter only for the organic phase product stream after condensation of the vapor upgraded stream). Otherwise, particulate matter in the oil/water separator will likely form a stable emulsion (rag layer) and prove exceptionally difficult to separate. The oil/water separator might also require pH control, depending on the presence of residual acidic oxygenates and for emulsion control. Process chemicals for such need to be included in your off-sites basis if not already required for water and wastewater treatment.

    Response: Per this recommendation the entire condensed liquid stream is filtered in this updated final design. Wastewater treatment was significantly modified in the final design, with a separate section (Area 800) for the destruction of organics in the water from the condensers in Area 300. Also, assumed costs for wastewater for the rest of the plant operations were conservative (based on a unit treatment cost for streams that are more difficult to treat). Any additional chemical costs (if necessary) can be absorbed within those treatment costs. Also, from our current experimental results, carboxylic acids are expected to be negligible for organic liquid products with oxygen contents of 15% or less. We assumed stainless steel for most of the equipment to handle anticipated acidity (Appendix A).

75. **Comment:** An understanding of the impurity profile into the water gas shift (WGS) reactor will be important in specifying the catalyst and hence the operating temperature (and hence determining equilibrium limitation on conversion). Copper catalysts are the commercial standard for low temperature water gas shift, but experience short lifetimes in the presence of inorganic impurities such as S and Cl. If impurity levels are high there is the option to use guard beds to absorb these impurities (additional cost). Alternatively, a non-copper catalyst (e.g. iron-based high temperature shift) may be more appropriate, but this would require higher operating temperatures to compensate for the lower activity.

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Response: The design was modified to have a single step "dirty shift" or sour water gas shift catalyst as mentioned Section 3.3.1 of this version. Operating temperature was higher than a low temperature shift reactor, and a positive 35°F approach to equilibrium was assumed.

76. **Comment:** Are there one or two organic phases? Usually you will form two organic phases, with a top fraction (s.g. < 1) and bottom fraction (s.g. > 1). This is the case even with highly deoxygenated product, although there is less of the bottom phase and maybe better catalysts and processes can eliminate the heavy compounds.

    Response: The model does not have the capability to predict three liquid phases (two organics and one aqueous with dissolved hydrocarbons). Hence we are working with the total organic liquid predicted. There is potential for improvements in this area with the progress in research.

77. **Comment:** Was there water in the predicted organic phase?

    Response: There was some water predicted in the organic phase (~0.4% in the *ex situ* version of the simulation). Again this is an area for improvement and we are working on phase equilibrium prediction methods as part of our research.

78. **Comment:** How much steam is fed to the water gas shift reactor in A300?

    Response: A steam to gas (after subtracting hydrogen) molar ratio of 1.2 was assumed for this sour gas shift design. Appendix G shows stream flows.

79. **Comment:** Effective filtering is needed to prevent fines carryover into downstream organic liquid upgrading.

    Response: As noted in response to comment 74, filters were included in all liquid streams. We added a note in the text to emphasize their importance.

80. **Comment:** The possibility of fouling the heat exchangers may also be due to physically entrained aerosols sticking on the surface, not just reacting pyrolysis oils.

    Response: This is another reason we switched to a direct quench absorber/condenser at a relatively high temperature (see comment 73) for the first vapor condensation step.

81. **Comment:** In the previous draft with a flash tank (instead of a heavy organics absorber/condenser in this final version) 92% of the bottoms product was being cooled and pumped in the single absorber/condenser. A reviewer pointed out that one should be aware of the potential high viscosity and the difficulty of pumping the liquid after cooling.

    Response: In the updated design we only use the light organic liquid from the second absorber/condenser as the quench stream in both the heavy and light fraction absorber/condensers (also called the high temperature and low temperature absorber/condenser in Figure 6 to alleviate this concern). The heavy organic fraction is maintained at a relatively high temperature of 140°F until it is mixed with the lighter organic portion.

Area A400: Hydroprocessing and Product Separation

82. **Comment:** "85% carbon efficiency for 20% oxygen content, and 98.5% carbon efficiency for negligible oxygen content as is usually the case in petroleum refineries." Is the yield for the 20% oxygen content feed consistent with current data in the literature?

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Response: There is limited data currently available for large-scale hydrotreating of organic products in the range of oxygen content of interest in this report. As described in Figure 8, we interpolated carbon efficiencies using the oxygen contents in the feed. Additional data points will become available with further experiments in the coming years. Also, note that the carbon efficiency assumption is consistent (and conservative), with respect to hydrotreating of intermediate oxygen content products within the interpolated range in Figure 8 for products obtained from hydrothermal liquefaction of woody biomass, as interpreted from the data made available by Zhu et al. (2014).

83. **Comment:** "A WHSV of 0.5 h^{-1} usually translates to a lower LHSV for most feedstock and catalyst combinations with an example of such conversion provided by Elliott et al." Are the catalysts used in this work along with yields used in the design basis? If not, what are the catalysts? Multiple reviewers wanted to see specific mention of the types of catalysts assumed for hydrotreating and hydrocracking.

    Response: Catalyst assumption information was added in Section 3.4.1. Non-precious metal catalysts were assumed for hydrotreating. The preliminary data point from PNNL shown in Figure 8 was obtained using a non-precious metal catalyst.

84. **Comment:** In Section 3.4 of the draft version the introduction of sulfur was mentioned. Do you talk about this anywhere later in the report?

    Response: Further discussion was added to Section 3.4.

85. **Comment:** Do the number of hydrotreating reactors include swing reactors? This should be stated.

    Response: Swing reactors were not used in the base case. However, cost sensitivity when using swing reactors for hydrotreating is shown in Case 25 of Figure 15.

86. **Comment:** In the draft version it was mentioned in Section 2.2 that the product was "easier to hydrotreat". This is presumably true. But the remaining O when oxygen content gets to low levels is actually more difficult to hydrotreat compared to the "easy" O removed early on. The effect of this O on HDN and HDS is unknown (but is probably not good).

    Response: Based on this and other reviewer comments the assumed hydrotreating severity, both temperature and pressure, were increased in subsequent drafts of this report. Sulfur and nitrogen do not have significant presence in the woody feedstock assumed in this report.

87. **Comment:** Bio-feeds are often high in N, producing NH_3. Is this considered?

    Response: We understand that some biomass feedstocks, such as algae, can contain significant amounts of nitrogen. Woody feedstocks have lower nitrogen content (Table 2 shows our assumption). Ammonia is shown as a product of hydrotreating. Most of the ammonia produced in the pyrolysis and vapor upgrading sections (small amounts may be present, although not included in this report) will likely be removed with the aqueous phase after scrubbing operations in Area 300.

88. **Comment:** Why were the hydrotreating pressures chosen?

    Response: It was assumed, for the 2022 target cases shown, that the *in situ* case would require higher severity (1,800 psia) and the *ex situ* case 1,500 psia based on their oxygen contents of 10.5% and 6.4%, respectively. These pressures are slightly lower than the

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assumption of 2,000 psia in Jones et al. (2013), noting that raw pyrolysis oil has a much higher oxygen content. It is also understood that the pressures may need to be adjusted based on future experimental results. We included sensitivity Case 27 in Figure 15 to show the impact of a higher hydrotreating pressure; the impact is negligible because hydrotreating is a relatively lower cost operation compared to the upstream vapor upgrading (Area 200) in this particular conceptual process design.

89. **Comment:** The amount of hydrogen consumption assumed in the pyrolysis step for both cases is not trivial and seem to be counter to what is intended with this technology. To put these numbers in perspective by expressing them as wt. % hydrogen of pyoil, they would be 2.3 for the in-situ case and 3 for the *ex situ* case. This is compared to about 5.8 for treating fast pyrolysis pyoil to the 0.5% oxygen level.

    Response: In the final version of this report the values of the weight of *makeup* hydrogen to the weight of bio-oil feed for the hydrotreating reactor in the *in situ* and *ex situ* cases are 6.3% and 3.6%, respectively; this is based on the *pure* hydrogen *makeup*. For hydrocracking, the corresponding values are 10.2% and 3.9% for *in situ* and *ex situ,* respectively. It should be noted that the feed to the hydroprocessing reactors are nearly water free. The aqueous fraction is >50% of the liquid products in Area 300. If the aqueous portion was included in the calculation (for a more direct comparison with the hydrotreating of raw pyrolysis oil from non-catalytic fast pyrolysis, where the reaction water is not removed) then the makeup hydrogen to condensation product ratios for hydrotreating are 2.5% for *in situ* and 1.4% for *ex situ*. We included the ratio of the weight of *chemical* hydrogen consumption to the weight of bio-oil feed to the hydroprocessing reactor in Section 3.4.2; the *chemical* consumptions (shown in Table 9 for hydrotreating and Table 10 for hydrocracking) are lower than the *makeup* ratios mentioned above because the makeup ratios factor purge streams required to maintain the 90 mole % hydrogen purity. All the chemical consumption values are on a water-free basis, and the inclusion of (previously removed) water in the calculations would further lower the ratios. The values shown indicate potentially significant hydroprocessing savings (in the 2022 target case) compared to the 5.8% chemical hydrogen consumption shown for raw pyrolysis oil in Jones et al. 2013; this is to be expected because that was the purpose of vapor upgrading with upstream hydrogen utilization.

90. **Comment:** The basis for the hydrotreater operating conditions selected in the study need to be defined more clearly with respect to the choice of pressures, temperatures and space velocity.

    Response: As mentioned, we show the values for 2022 target cases in this report. The operating parameters chosen for this design are relatively severe with respect to conventional hydrotreating, although less so compared to the hydrotreating of oils from non-catalytic fast pyrolysis. We will modify assumptions as further data becomes available. Cost sensitivities to some of these parameters are shown in Figure 15.

91. **Comment:** Catalytic Fast Pyrolysis (CFP) will be “easier to treat” by causing less hydrotreating catalyst deactivation and fouling. There are several independent studies asserting that CFP can be processed with significantly less HT catalyst fouling/coking (this has not been quantified however). We agree that this supports the approach in this study i.e. specifically that of deleting the investments for the stabilizer and 1st reactor in the current PNNL fast pyrolysis + HT configuration (successfully operated for 60 days). It is less clear

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that one can also reduce the pressure because of this lower coking/fouling property, or argue that the *ex situ* material can be operated at an even lower pressure. In the absence of more specific test data, we would recommend staying with 2000 psia at this stage and treating the option for lower pressures as an optimization opportunity. Also the assumption of a two year catalyst life may be optimistic even in an n^{th} plant analysis.

Response: We included sensitivity cases for higher pressure, use of swing reactors, and catalyst costs in Figure 15 to allow the reader to assess the impacts of variations suggested by the reviewers.

92. **Comment:** We would recommend that the target product oxygen level from the hydrotreaters be the same for both the *in situ* and *ex situ* cases by adjusting the space velocity. This keeps the hydrocracker design the same for both cases except for volume, and avoids having to make some assumptions about the hydrocracker design. By the time the material is hydrotreated to near 1% oxygen its properties are "petroleum like," and no unusual hydrocracking conditions should be needed. Another reviewer commented on the higher oxygen content in the feed to the hydrocracker in the previous draft: "I would expect the oxygen content in the resid fraction to be lower than this, and certainly lower than the output of the unit operation above. We have seen the unremoved oxygen from the HT to follow the lower molecular weight species (phenolic oxygen) as some of the higher MW species are formed by condensation where the oxygen is removed as water."

    Response: We made this change in the final design per the reviewers' inputs. The oxygen content at the hydrotreater outlets are 1 wt %.

93. **Comment:** In the case of the hydrotreaters there appears to be a constraint put on the weight and length of the reactors due to logistics. This drives the design to multiple parallel trains of small hydrotreaters. It is not clear what sets these constraints. Single high pressure reactors of significantly larger size are common in the petroleum industry. If this is driven by the vision of remote plants, these plants could be located where these length and weight restrictions would not apply e.g. on a river. Using parallel small reactors sacrifices significant economies of scale that this study could use to improve the economics. A study design with this large number of tiny reactors would not have much credibility with a refiner. Another reviewer stated that the added commentary about transportation limitations to justify the use of smaller reactors was a good addition, given our design decision in the initial draft.

    Response: We used this feedback to move to single large hydrotreaters in the final design. Multiple smaller hydrotreaters in the initial draft is no longer used. We also removed the commentary about transportation limitations because of this decision.

94. **Comment:** You might want to mention what impurities are expected to be in the purge stream from the hydrotreater.

    Response: We provided detailed stream summaries in Appendix G of the final version of the report. Assumptions about light gases formed, which constitute the impurities from the hydrotreating and hydrocracking reactors in both the *in situ* and *ex situ* cases, can be gathered from the information provided.

95. **Comment:** You might want to mention that the hydrocracker recycles to extinction any gas oil (heavier than distillate, e.g., three- and four-ring aromatics) fraction.

    Response: We added this to the text per this suggestion.

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96. **Comment:** Both hydrotreater and hydrocracker have two-stage flashes on the reactor effluent. Where does the low-pressure flash vapor go?

    Response: We included detailed process flow diagrams in Appendix G. All stream destinations can now be traced by the interested reader. In this particular case the high-pressure (HP) flash purge streams go to the pressure swing adsorption (PSA) and the low pressure (LP) one goes to the reformer.

97. **Comment:** A low rate of irreversible catalyst deactivation would make the option for a fixed bed reactor more feasible (assuming this reactor set up would cope with rates of reversible deactivation by carbon laydown). Note also that the use of guard beds may be a strategy in fixed bed operation to minimize the effects of poisoning.

    Response: Note that we included a sensitivity case in Figure 15 showing the cost impact of using swing reactors. This case should capture the impact of more frequent maintenance activities for reversible deactivation (coke laydown).

98. **Comment:** Hydrotreating catalyst: I'm assuming at some point that a sulfided NiMo (or CoMo) catalyst will be used in this stage of the process. Will there be sufficient sulfur species present in the feed to this reactor to maintain the catalyst in a sulfided state, or do you envisage having to add a sulfiding agent?

    Response: We have included justification in the text based on the Aspen Plus simulation predictions, which show that we will have sufficient sulfur at steady state to keep the catalyst sulfided.

99. **Comment:** Hydrotreating catalyst: "Price: $20/lb (2011) based on NREL calculations using metals pricing and costs for manufacturing processes." This cost is a bit on the high side.

    Response: We retained the $20/lb in the final report to allow for any cost escalations because of catalyst modifications to handle the quality of oil after vapor upgrading.

100. **Comment:** For hydroprocessing add information about makeup hydrogen, make clear that purge gas goes to the PSA and not reforming, both lb/lb and Carbon/Carbon yields.

    Response: All these are included in the final version of the report. A related response is included after comment 96.

101. **Comment:** Compare hydrocracker and hydrotreater costs with Jones et al. (2013) report after scaling. Provide sensitivity analysis to show impact of capital cost escalation.

    Response: A quick comparison was made between the first stage hydrotreater in Jones et al. (2013) and the hydrotreater cost assumed in the *ex situ* case of this report using the ratios of the mass flow rates and a scaling exponent of 0.65 (based on Jones et al. 2013). The reactor cost was higher in the *ex situ* case. It is understood that the two cases are not directly comparable because of differences in the quality of feed to the reactors and also the conversion strategies. Sensitivity Cases 19 and 25 in Figure 15 of this report show the impacts of changes in assumptions.

102. **Comment:** The hydrotreater is modeled to operate at 340°C (inlet temperature). This temperature is low for the material being processed. What is the temperature rise in the hydrocracker given an inlet temperature of 380°C? Usually they get to 400-410°C as the max temperature needed for really low deoxygenation (even with low O&N HTL oil from algae).

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I am not sure that you can back off on that temperature even starting with lower oxygen content because of the remaining type of oxygen is just harder to remove.

Response: This temperature was increased to 375°C at the inlet with an outlet temperature of 403°C at the outlet. The hydrocracker inlet temperature was also increased to 392°C, with an outlet temperature of 420°C.

103. **Comment:** What is the chemical consumption across the reactor? This is a key metric and difficult to back calculate from the text. Add this to the table. Also, state the basis for hydrogen consumption.

Response: Chemical hydrogen consumption per feed to the reactor (on a weight basis) for the hydrotreater is 2.1% for *ex situ* and 2.6% for the *in situ* case; for the hydrocracker it is 3.1% for *ex situ* and 5.4% for the *in situ* case. This was added to the tables in Section 3.4.2. The basis for hydrogen consumption is discussed in Section 3.4.

104. **Comment:** The hydrogen feed to the reactor was 14,174 scf/bbl for the *in situ* case and 9,161 scf/bbl (these numbers reflect updates for this final version for context). How was this chosen?

Response: The key factors are reactor temperature control and maintaining 90 mole% purity of the hydrogen feed gas (treat gas). This is discussed in detail in Section 3.4.

105. **Comment:** In the draft version: Process model flow information for hydrotreater based on CHO yields reported: Predicting a 96% carbon yield to the organic liquid product seems too high. Typically a 60 to 65% yield has been achieved with regular (non-catalytic) fast pyrolysis oil that is already a higher average molecular weight. It is possible that catalytic fast pyrolysis oil could have higher yield to non-condensables.

Response: The interpretation of 96% based on the information provided in the draft version may not be accurate (because sufficient information was not provided and some gases were included in the reported stream). This assumption was revisited and modified as shown in Figure 8 for the entire hydroprocessing unit (carbon efficiencies of 91% for *in situ* and 94% for *ex situ*). Individual carbon efficiencies for the hydrotreaters can be derived from CHO analysis and mass flow rates provided in Table 8.

106. **Comment:** In the draft version: Hydrocracker yield in Table 8, based on CHO calcs: 99% carbon yield to the organic is also too high. Very unlikely to achieve this with the best of oils. What is the basis for the yields?

Response: Similar to previous response for the hydrotreater: The interpretation of 99% based on the information provided in the draft version may not be accurate (because sufficient information was not provided and gases were included in the reported stream). Also, assumptions in this regard were subsequently modified as shown in Figure 8 for the entire hydroprocessing unit (carbon efficiencies of 91% for *in situ* and 94% for *ex situ*). Individual carbon efficiencies for the hydrocracker can be derived from CHO analysis and mass flow rates provided in Table 8.

107. **Comment:** Flow rate to hydrocracker: Is there a reference for this estimate? I would expect that the product from the HT would have less resid type material, due to the tendency for CFP to make smaller molecule hydrocarbons rather than the high MW that comes out of HTL and FP.

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Response: The 2022 targets in this design reflect intended research improvements to increase diesel-range molecules via coupling reactions. Research efforts will include catalyst development to move toward these targets. As noted in the text the 2022 target for diesel-range molecules are significantly lower for the *in situ* case.

108. **Comment:** Mass of catalyst in the hydrotreating reactor (Table 9): What is meant by "design" and "actual"? and why is actual>design?

Response: There is a 70% overdesign as noted in this latest version.

109. **Comment:** Hydroprocessing catalyst price in Table 30: $10-12/lb (2011) based on NREL calculations using metals pricing and costs for manufacturing processes (comment based on June 2014 draft). This is rather low for hydrotreating catalyst – perhaps should be ~$20/lb

Response: We increased the cost to $20/lb, although another reviewer pointed out that $20/lb may be on the high side for catalysts without precious metals.

110. **Comment:** If you could get to 5-10% oxygen in catalytic pyrolysis then the hydrotreating likely would work similarly to hydrotreating HTL. I just wonder what kind of carbon recovery you get through the catalytic pyrolysis step when you have only 5-10% oxygen left. Carbon recovery of hydrotreating of CFP oil with 5-10 wt% O would be similar to that of HTL oil, which could reach 0.92-0.98 g carbon in oil per g carbon in feed. That was observed recently with algae HTL oils. The lower end of that range (0.92) is what is seen with lower lipid algae biocrudes. Since the CFP feedstocks won't have lipid, I'd suggest aiming for the 0.92 g/g yield (or maybe even lower).

Response: In the latest version we have a 91% and 94% carbon recovery for the *in situ* and *ex situ* cases with 6.4% and 10.5% oxygen contents, respectively. This is in line with the reviewer comments. Hydroprocessing carbon recovery targets for 2022 for the *in situ* and *ex situ* cases are outlined in Table ES-1.

Area A500: Hydrogen Plant

111. **Comment:** The hydrogen plant investment costs seem out of line WRT the cost of the hydroprocessing: the ratio of H_2 plant cost/Hydroprocessing cost seems much too high, which again provides a pretty significant economic penalty.

Response: The cost was changed to make consistent with Jones et al. (2013). Our initial source had a higher cost estimate.

112. **Comment:** If I read correctly, you're using fuel gas to fire the SMR rather than natural gas. Did you check the adiabatic flame temperature of the fuel gas to ensure that it is capable of providing the radiant heat necessary? My understanding from steam cracking is that high-CO gases cannot provide sufficient temperature to operate a cracking furnace, which runs only a little hotter than an SMR.

Response: Aspen Plus predicts that the adiabatic temp can support the SMR. Historically, we have used a minimum fuel combustor temperature of 1,700°F or higher in our simulations (design specification). However, the temperature is higher than 1,750°F for both the *in situ* and *ex situ* cases. There is hydrogen present in the fuel gas mix. Preheating the combustion air after the air blower helps to raise the temperature significantly.

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113. **Comment:** PSA – Not all PSA processes for air separation require 6-7 bar pressure. Is the 16-18 bar PSA pressure for H_2 firmly established? Also, it does not appear that hydrogen recycle is required…assumption or based on rigorous review of the process for these conditions?

    Response: Here is some information from Miller and Stoecker (1989). It is not the most recent publication, but we assume that the general premise for PSAs has not changed. "The driving force for the separation is the impurity partial pressure difference between the feed and the tail gas. A minimum pressure ratio of approximately 4:1 between the feed and tail gas pressure is usually required for hydrogen separations. However, the absolute pressures of the feed and tail gas are also important, particularly to hydrogen recovery. The optimum feed pressure range for PSA units in refinery applications is 200-400 psig. The optimum tail gas pressure is as low as possible. Since vacuum is normally avoided, tail gas pressures between 2 and 5 psig are typically used when high recovery is needed. The 2 psig pressure can be used when the tail gas is to be compressed, and 5 psig can be used when the tail gas is sent directly to fuel burners, as in steam reforming applications." Our design has ~65% and ~70% hydrogen (volume basis) in the streams fed to the PSA. Recycle is required for low hydrogen concentrations.

Area A600: Steam System and Power Generation

114. **Comment:** From initial draft version: A portion of the economics is dependent on high electricity production with credit of 21 cents (per kW-hr?), which is too high … probably closer to 5 cents in most areas where this plant could be located.

    Response: To clarify the reviewer's interpretation, the 21 cents credit was per GGE of product and not 21 cents/kWh. The unit credit is 5.85 cents/kWh. The per GGE electricity credit has since been reduced after process modifications to address reviewer comments; the reduction was primarily from the removal of lock hoppers in the circulating fluidized bed reactor systems.

115. **Comment:** You should list the pressure levels for the steam headers. I'm not an expert by any means, but I was surprised at the super-high pressure level of 1321 psia. It might just be my personal experience, but I'm used to seeing levels like 900 or 1500 psig. Steam cracker transfer-line exchangers will produce up at the 1500 psig range. FCC waste-heat boilers and catalyst coolers tend to run more like 900 psig. Regardless, some explanation of the determinant of the SHP header level would be nice.

    Response: This was used to maximize electricity generation. We had quotes from the mixed alcohol process (Dutta et al. 2011) for these conditions, so we did not want to go any higher since cost quotes are difficult to get. We did not want to go lower because we have sufficient delta T to operate at 1,321 psia in the catalyst coolers. We requested Harris Group to make sure that the catalyst cooler costs reflect this steam pressure.

116. **Comment:** In the previous draft: I found intra-process heat exchangers listed in the equipment lists of Area 600 for both cases but no mention of its need or specifications in the narrative and no listing of the reformer itself.

    Response: We have provided detailed heat exchanger network information for the *ex situ* case. The heat exchange network is included in Appendix G-2, and details of heat exchangers and costs in Appendix H. The pinch analysis heat exchanger cost line items in the equipment

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list in Appendix B were prorated based on duties in specific areas, given that cross exchanges occur across areas and assignment of exchangers to one specific area would be arbitrary. The *in situ* case was scaled from the *ex situ* case using total duty, which we deemed reasonable because the processes are similar.

117. **Comment:** Power Gen – Why 350 psia extraction pressure for the low pressure turbine (LPT)? Was there any sensitivity analysis to this parameter? My experience would have thought this to be significantly lower (<270 psia) in order to max steam cycle thermal efficiency. Nevertheless, no explanation was given as to the 1st stage expansion pressure. The steam cycle efficiency may not change by more than 1% by going lower in extraction stage pressure, but it really depends on how flat the net efficiency vs. LPT inlet pressure curve is. Are the high pressure turbine (HPT) and LPT turbine expansion efficiencies different? They are in real systems.

    Response: We will study the impact via sensitivity analysis in the future. It was not included in this report because of time constraints; the reviewer pointed out the benefit may be marginal. We do not assume different efficiencies for HPT and LPT; it is good to be made aware of this. We will keep the existing specifications for this report, but retain this comment for future use and modifications.

118. **Comment:** Electricity credit seems to influence also somewhat substantially. Would make sense to evaluate Power Gen cycle efficiency more closely as well as evaluate (if you haven't already) other cycle technology options that might fit.

    Response: This can be done in the future. However, since the focus of the process is fuels production, most of the biomass energy is targeted toward fuels rather than power and the overall impact of electricity is not as significant. The electricity credit was further reduced to ~4 cents/GGE since the draft version that was reviewed.

Area A700: Cooling Water and Other Utilities

119. **Comment:** Chilled water is mentioned as a utility for Area 200, and I found the equipment in the equipment list. I found no discussion of the equipment specifications in the narrative, however.

    Response: We added information in Appendix A. It was derived from Humbird et al. (2011) and the same electricity consumption basis was used in this report.

Area A800: Wastewater Management and Recycle

120. **Comment:** We were pleased to see that the design includes more definition to the utilities part of the plant. In our view, past studies underestimated these costs, particularly for water treatment.

    Response: Thank you for the comment.

121. **Comment:** Comment based on previous draft: I think you need a loading rack for wastewater, or at least a pump, pad, and flex hose, since your plan includes shipping wastewater offsite. Additionally the logistics and costs of shipping so much wastewater offsite is significant. The offsite wastewater treatment number of $0.48/T seems optimistic.

    Response: Clarification is now provided that we were not planning to ship the wastewater. The portion of wastewater that is most challenging will be handled by the regenerative

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thermal oxidizer (RTO). Other wastewater that has known methods of treatment is expected to be treated in the plant vicinity. We assumed an operating cost for this treatment; the assumed cost of $0.022/gallon was conservative (high) and based on Humbird et al. (2011).

122. **Comment:** Comment based on first draft in June: Discuss what will be the fate of wastewater, aerobic digestion (discuss assumed it will not be toxic). Is this discharged to POTW (publicly owned treatment works)? Please specify type of treatment and amount to be treated. 9% carbon is very high.

    Response: The wastewater treatment (WWT) strategy was since modified to use an RTO, as described in this version of the report. The wastewater is not sent to POTW; please see discussion in this version about using an RTO for the challenging streams, and on-site WWT for the rest of the wastewater.

Miscellaneous

123. **Comment:** Is it reasonable to provide costs with the precision of five digits if the uncertainty of yields is more than 20%? Another reviewer suggested reducing the number of significant figures reported.

    Response: This was done in a few of the tables. Please understand that the report and all the numbers needed to be updated multiple times. We found it easier and less error prone to keep all the figures. We do understand the large uncertainties in our analysis, and the inclusion of significant figures is not a reflection of extreme certainty.

124. **Comment:** A reviewer questioned 0% contributions presented in the energy balance pie charts (Figure 11).

    Response: We have since included one place of decimal in that pie chart. The numbers presented still reflect rounding to the nearest tenth.

125. **Comment:** A significant amount (~30%) is lost through air-cooled exchangers. Where will the energy come from for the coolers?

    Response: The air cooled exchangers are driven by electricity and accounted within our simulation. The air cooled exchangers were used to save on water usage, and used for cooling needs down to 140°F, but no lower. Cooling water was used for cooling below 140°F.

126. **Comment:** In the sustainability section there was mention of ZnO and HDS as catalysts in the previous draft. Are they state of the art?

    Response: We changed the nomenclature to indicate that these are not catalysts for hydroprocessing. They are used for sulfur removal from off-gases prior to the reformer.

127. **Comment:** A reviewer was interested in having enough details to reproduce and model some of the operations in the process.

    Response: We had not included the detailed stream tables in the review draft. They are now available in Appendix G. We believe the significant details provided in Appendix G will help answer the reviewer's questions.

128. **Comment:** For the sustainability section providing the SimaPro categories applied to the inputs will help with reproducibility of results.

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Response: The information is provided in Table 25 of this version.

129. **Comment:** It will be helpful to know the assumed composition of all these catalysts for sustainability calculations. Provide the caustic identity.

Response: Most of the catalysts are proprietary in nature and company specific. Approximate composition information can be gleaned from the literature. The SimaPro assumptions (including for caustic) are listed in Table 25.

130. **Comment:** Can you provide the boiler feed water chemicals used?

Response: Chemicals utilized for boiler feed water and/or steam condensate treatment are an oxygen scavenger like sodium sulfite (Na_2SO_3) or hydrazine (N_2H_4) and corrosion inhibitor/neutralizing amine like morpholine (C_4H_9NO). Reference Betz Dearborn Water Management Group, 1998.

131. **Comment:** Can you provide the cooling tower treatment chemical used?

Response: Chemicals utilized for cooling tower water treatment generally contain proprietary combinations of corrosion inhibitor, oxygen scavenger, pH control and biological fouling mitigation. Typical compounds used in treatment programs are phosphates, azoles, copolymers and zinc. Reference Betz Dearborn Water Management Group, 1998.

132. **Comment:** An additional table showing the fossil energy consumption and GHG emissions breakdown will be relevant for this work.

Response: The information is provided in graphical form (Figure 12).

133. **Comment:** On an energy basis and with electricity credits, the GHG emissions at the conversion stage for the *in situ* and *ex situ* cases are negative 2.6 kg CO2e/GJ and negative 1.2 kg CO2e/GJ. It's not clear to me if this includes total HDO to produce a finished fuel. It would be worth comparing this number against the fossil fuel baseline emissions to show that it meets the 60% reduction target for qualification as an advanced cellulosic biofuel.

Response: The conversion step includes all operations included in this process including HDO to finished fuels. The negative values or significant reductions are derived primarily from offsetting electricity from other sources. Comparisons with fossil baseline emissions are also included in this report, with further details in Appendix E.

134. **Comment:** What is the impact of depreciating your plant over 20 years rather than 30? This may find broader acceptance.

Response: The impact is shown (included in this version) in Figure 15 as sensitivity Case 12. There is a 4.1% increase in the 2022 target MFSP for the *ex situ* case.

135. **Comment:** The conclusion of *in situ* and *ex situ* selling price being nearly equal at ~$3.5/GGE is reasonable.

Response: Thank you for the comment.

136. **Comment:** Cold biomass can potentially be used for temperature control instead of preheating it. Is it worth the CapEx to heat it? Provide a sensitivity case.

Response: While we did not include a sensitivity case, the use of low grade process heat for heating the biomass has positive impacts on the overall process efficiency. The cost of

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additional cross flow pellet dryer and a blower are marginal compared to the gains in energy efficiency. This low grade heat would otherwise have no consumers in the process.

137. **Comment:** The title should more accurately reflect the content. These design cases are objectives and not achieved yet.

    Response: We tried to make it clear in multiple places within the text that these design cases reflect 2022 targets. We also changed the title to say that these are research pathways.

138. **Comment:** A reviewer did not agree with definitive statements in the draft version saying that we can achieve cost-competitiveness based on this design report.

    Response: We have since modified the statements to make clear that the design case is an outlined pathway, and achievement of catalyst performances outlined in this report is one way to move toward cost-competitiveness of biomass-derived hydrocarbon fuels.

139. **Comment:** Assessment of cost-competitiveness should include consideration of distribution and marketing costs, before the MFSP can be compared to retail pump prices and for claims of cost competitiveness should be advanced. Additional costs are incurred for blending to meet product specifications.

    Response: We understand the necessity of considering additional costs for marketing, distribution, and blending. The research goals presented are for 2022. We anticipate careful consideration of quality specifications and associated penalties/credits as we develop further understanding via research and obtain experimental results. The aspect of blending is expected to be covered as part of future work. We also show that there are options, such as economies of scale, to significantly improve costs beyond the 2022 target cases outlined here, and some of the other significant impacts shown in Figure 15 can be leveraged to further reduce our minimum fuel selling price (MFSP) and offset additional distribution and marketing costs.

140. **Comment:** The design does not leverage economies of scale that can bring significant benefits. N^{th} plant assumptions should also include performance at an efficient scale.

    Response: We understand that economies of scale can have major impacts as depicted in the sensitivity analysis shown in Figure 15. However, we maintained the design at 2000 dry metric tonnes per day for our base case for consistency and comparison across other pathway design reports funded by BETO. The interested reader can gauge the benefits derived from economies of scale from Case 10 in Figure 15. We also included the reviewers' recommendations for the inclusion of references related to economies of scale.

141. **Comment:** Even with n^{th} plant assumptions, capital costs for the process are 6-8 times the cost of new petroleum refinery capacity. Capital efficiency should be significantly improved. It is understood that further contingencies were not included, and favorable process assumptions (e.g. 2 year catalyst life, 90% capacity utilization) were made because of the assumption of n^{th} plants. Inclusion of additional contingencies would further reduce capital efficiencies, and contingencies for the current state of CFP development should be 50% more.

    Response: Biomass conversion processes involve solids handling, use low energy density feedstocks, and are less mature; hence the economics are difficult at this stage. The significant learnings of the petroleum industry through operational improvements for nearly a

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century can be achieved only through actual implementations of these technologies by industry. While economies of scale are one way to leverage future improvements in capital efficiency, other significant areas of potential improvements include catalyst and yields, process intensification and performance, and optimization of intermediate streams; these opportunities are even beyond those outlined in this report. Hence the n^{th}-plant performance outlined here is one potential way toward feasibility, but many other opportunities remain for further improvements in capital efficiency through actual implementation and learnings. For contingencies, we do understand that pioneer plants require significant additional costs; we have not included pioneer plant analysis in this report because we are studying the potential of the process in a mature stage of development. We agree that pioneer plant studies should include higher contingencies.

142. **Comment:** The authors attribute only a 10% return to invested capital. Moreover, it appears that even this low investment return is "leveraged" – via the use of 60% debt whose interest expense is tax deductible. These assumptions are not attractive to companies. The sensitivity analysis shows that a 15% investment return would raise the MFSP by 15.4% (was slightly higher in the draft for review). Venture capital/private equity will likely seek 20+% returns to offset risks. Studies should include returns which industry would require pushing pioneer scale plants to a mature industry.

    Response: The financial assumptions for the base case are consistent with other design reports funded by the Bioenergy Technologies Office (BETO), and allow comparison across conversion pathways; they outline a basis for cost-improvement based research. Sensitivities to changes in these financial assumptions are captured in Figure 15. Sensitivity analysis in Figure 15 also shows options to offset the demands for higher returns via further improvements in other areas. We have conducted pioneer plant analysis separately in the past; the purpose of such studies is to address the push toward commercialization and understanding of risks, rather than understanding where the research and development can lead us.

143. **Comment:** It is not clear that the "leveraged economics" have been done correctly – the authors need to provide more detailed and accessible spreadsheets.

    Response: Detailed discounted cash flow rate of return (DCFROR) and other financial assumptions are included in the appendices of this report. Note that the financial methods have been used in other detailed reports over the years, and have been reviewed by multiple entities, including academic institutions that use our design reports in some of their courses as examples. We believe any major errors in our methods would be noticed and brought to our attention; we do receive comments (including about correctness) from varied sources after the publication of our reports, and we address them. Some of our spreadsheets are available online, and thus have been used and vetted by others.

144. **Comment:** The search for savings on this order of magnitude should drive researchers to look at different and more specific plant locations. The authors' in-situ and ex-situ plants reside at some generic location geared to Idaho National Lab's (INL) recent feedstock/logistics work. The location seems to be consistent with "distributed pyrolysis plants" found in other literature, seeing as the plant design self-manufactures hydrogen. It is unclear whether this location permits large scale water-borne transport of chipped biomass. It clearly does not allow co-processing product at an adjacent refinery. This leads the authors to

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incorporate a sub-scale 1.4 kbd hydrocracker into the process design. Feeding CFP heavy fractions to a hydrocracker may be the right process solution, but this probably needs to happen within a co-processing approach for CFP to have a reasonable chance at commercialization.

Response: We have not considered the co-location scenario in this particular report. With progress in the research we will become better informed about the quality and feasibility of co-processing. An expansion of the scope for location and specific feedstock transportation was not feasible within the time available. Please note that such integrated studies have been conducted in the past (typically after the conversion-specific design report is released). As an example please see Muth et al. (2014).

145. **Comment:** Follow-up work should focus on process designs and locations which facilitate refinery co-processing, large scale/low cost water transport of biomass, and use of the refinery infrastructure e.g. merchant hydrogen. Ex-situ CFP may be well suited to such an approach, seeing as it may produce higher quality blendstocks that still retain some oxygen. Arbogast et al. (2012) contains information about such locations and the economics of and technical requirements for co-processing.

Response: Thank you for pointing out the reference. We added a limited discussion for this report based on your comment, mostly alluding to this as potential future work for cost reduction. We do plan to leverage the current study for other scenarios as more data becomes available from the research. We feel that this study is a start within the time we had available to prepare this report, mainly focusing on building process model-based scenarios outlining a potential pathway to feasibility of the technology via research in the coming years.

146. **Comment:** We look forward to seeing the data supporting the very promising CFP yields and oxygen removal assumed in the study. If confirmed, these could significantly improve the overall economics of biomass pyrolysis to fuels. This study design should be very valuable in formulating and monitoring progress of your forward program. It might be useful as part of this study design to: (a) Identify the most economically attractive areas for focus and what "killer" factors need to be overcome. Examples of potential "killer" variables are: (i) Catalyst life & equipment fouling, (ii) Metallurgy corrosion, (iii) Yields derived from batch experiments extrapolated to a continuous process with scaled up reactors, (iv) Product quality and necessary further processing required for introduction into refinery equipment and/or final fuel products, (b) Estimate probabilities of success in key research areas & derived benefits, (c) Provide a single, more extensive summary of key assumptions in the study and a sense of how well they are backed up with data.

Response: Thank you for these valuable comments. We are at the early stages of research for these pathways. We will consider these points as more data becomes available; some of these may be futile at this point because of the lack of data and early stages of research. We conduct annual state of technology assessments to track the progress of research. The 2014 assessments, along with our annual improvement targets leading to 2022 are expected to be published soon in BETO's Multi-Year Program Plan (MYPP). All your points are candidates for consideration with further maturity.

147. **Comment:** In the draft version for review: The error bands quoted in the design write up regarding the AACE classification system were a bit misleading.

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Response: We removed references to the AACE classification in the final version of the report based on this comment.

148. **Comment:** Could you mention how many model compounds you used?

Response: The list of compounds used is available in Appendix F of this version of the report.

149. **Comment:** Based on June 2014 draft: Suggest adding sensitivity analysis for: (a) Upgrading yield, (b) Losses to different products (coke, light gases) (which would give better results), (c) Catalyst cost and cat:biomass ratio, residence time in upgrader, (d) Hydrotreating severity.

Response: Sensitivity analyses related to the above were added to the August 2014 and subsequent drafts.

150. **Comment:** How did you calculate the theoretical GGE production and yield (Table ES-2)? Did you just take into account the C and H in the feedstock and calculate how much gasoline and diesel could be made?

Response: Section 4.5 describes how we use LHV from the simulation to come up with the GGE values.

151. **Comment:** What composition did you assume for the upgraded products?

Response: Stream tables in Appendix G of this version show the compositional (surrogate compounds) assumptions.

152. **Comment:** Given the importance of catalyst performance, it may have been valuable to include a dedicated section devoted to catalyst design.

Response: We included a short section (3.2.1.6) on potential vapor upgrading catalysts, primarily referring the reader to other articles. Assumptions regarding hydroprocessing catalysts were also added in Section 3.4. We feel that this design report is focused on techno-economics and we should not interfere with the catalyst researchers' ongoing publications of their work.

153. **Comment:** The sustainability section could benefit from a chart. For example, the chart could compare carbon input/output in the form of feedstock, fuel, char, flue gas.

Response: This specific chart for carbon flow is not provided. However, information about biomass energy distribution upon processing (LHV basis) is provided in Figure 11. The carbon efficiencies to products are shown in Figure ES-1 and the information about char is available in the stream tables (Appendix G), along with flue gas information. Almost all the carbon not converted to fuel will eventually show up in the flue gas in the current process design, because excess gases, char, coke, and aqueous carbon are all combusted.

154. **Comment:** Some discussion of potential planned (scheduled maintenance, feedstock supply schedules, planned holidays...) and unplanned (equipment failure, supply disruptions) would be helpful. In particular, there may be interest in knowing whether there are safety/reliability differences between *in situ*/*ex situ* fast pyrolysis and other technologies. A qualitative assessment of reliability concerns specific to these technologies (coking, reactor operation) would be sufficient.

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Response: We did not include this discussion in this report. However we will address some of these topics in the future, especially with the maturing of the technology.

155. **Comment:** The PSA hydrogen stream in the figures can be labeled as Excess or Export Hydrogen unless it is also utilized in the process.

Response: All hydrogen produced is utilized within the process. Natural gas is imported and steam-reformed when additional hydrogen is required. Surplus process fuel gas, if available, is converted to electricity.

156. **Comment:** Discuss oxygenated species types (phenols are preferred to acids, etc.) after vapor upgrading and condensation.

Response: Details about species and stream compositions are included in Appendices F and G of this version of the report.

157. **Comment:** We notice in both this study and the recent PNNL/NREL fast pyrolysis study that the upper size limit for the pyrolysis reactors is set at 1000t/ day due to "biomass feeding constraints". In our previous (pre-2010) discussions there were considerations of 2000 t/d or larger reactors. What has changed? Is this believed to be a hard upper limit? This will have a significant impact on the economic benefits of economies of scale as we try to move this technology to larger, more economic plants.

Response: As mentioned earlier, we have limited this to 1,000 TPD because of anticipated biomass feeding constraints. We have not seen any information thus far about confidence in building larger reactors than this. We also made the same assumption for our indirect gasification studies (Dutta et al. 2011). However, this does not negate future possibility of further scale-up of biomass reactor systems. Note that all the rest of the equipment beyond the initial fast pyrolysis reactor are assumed to have no scaling constraints.

158. **Comment:** We think additional sensitivities and a fuller discussion of what they reveal about where progress is needed, is the way to go. In addition to scale, we think the biomass cost and capital/contingency/return sensitivity discussion is very important to framing the economics and the progress that needs to be made. Framing this properly will spur more aggressive thinking about research possibilities and ultimately more progress.

Response: We feel we show many of these sensitivities in Figure 15. Additional sensitivities and providing options around specific (or anticipated) challenges encountered in the future will also be keys to the success of the research on these conversion pathways. As outlined in the Conclusions and Future TEA Work sections of this report, looking into further conversion variations and options will be the next focus of the TEA team.

159. **Comment:** Ultimately, we also think this discussion will drive pyrolysis oil plants away from generic distributed locations with hydrogen self-sufficiency towards larger plants integrated logistically or co-located with refineries. Our 2010 study saw big potential savings from such an approach, and we think researchers and techno-economic analysts should favor this model or say why they choose not to do so.

Response: This is definitely an option. However, we feel that it will be premature to propose that as a base case without first gaining a deeper understanding of quality aspects and acceptability of intermediates by petroleum refiners.

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160. **Comment:** There seems to be a number of omissions in the offsites. These include: (a) Wood yard or other storage area for feedstock, (b) Warehouse for catalysts, (c) Product tankage for gasoline and diesel, (d) Loading racks (rail or truck) for finished products, (e) Administration building and laboratory. I looked through the equipment lists and didn't see anything like these. I don't think your factors for direct equipment costs cover these. If the feedstock will be supplied in a weatherproof form, then perhaps you need only plot space. If the fresh and spent catalysts are stored in some kind of bulk containers, then perhaps you need only plot space. If you assume colocation at an existing refinery or biorefinery, then you don't need an administration building, laboratory, or loading racks. All of these assumptions need to be stated if valid.

    Response: The current version provides information about most of these items: (1) we included plant footprint calculations by the Harris Group in Appendix I showing area for storage, (2) warehouse for catalysts is not mentioned specifically; however bed media handling with silos are included in the pyrolysis island and within the equipment list (Appendices A and B), (3) product tanks are included in the equipment list, and land allocated under plant footprint, (4) loading racks are factored into the footprint and included in the equipment list under Area 700, and (5) administrative buildings are included within indirect costs (Table 28) and space is allocated within the footprint. Laboratory space is not specifically mentioned, but will be covered under the category "Offices, etc." in Appendix I. The inclusion of Appendix I should answer most of the remaining queries. We do not assume co-location.

161. **Comment:** I did not find a location basis. Construction in the Midwest will have a different cost than in the Gulf Coast. If you feel the difference is insignificant, then just say so.

    Response: An average U.S. location is appropriate, given many of our costs are derived from that setup within ACCE.

162. **Comment:** In looking at a number of the variable costs, the base-year data are significantly out of date (BFW chemicals were quoted 23 years ago!). Simply inflating these numbers is risky. I do recognize that VOC rarely drive the sensitivity of the economics, but more contemporary quotations are probably in order

    Response: We updated most of the costs mentioned (Table 30).

163. **Comment:** Wage rates seem low, especially given the recent run-up in starting salaries for chemical engineers. Given all of the present and anticipated construction on the Gulf Coast, I suspect even the non-professional wages are low.

    Response: We included a 10% escalation, shown in Table 32.

164. **Comment:** It would be nice to have a comparison basis for the n^{th}-plant assumption of 90 % on-stream factor (same as a gasifier or FCC unit?).

    Response: Refiners have made tremendous improvements in operating reliability of refinery applications as the technologies have matured. John S. Magee states, "It is not uncommon today to have FCC units complete three-to-four-year runs between major turnarounds with nearly 100 percent stream factor" (Magee 1993). Given that solids handling is more challenging, we believe that 90% on-stream factors for an n^{th} plant with our conceptual design is not unreasonable.

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165. **Comment:** The steam plant was depreciated on a 20-year, 150 % declining balance basis. There is a MACRS schedule for the 20-year asset class. The two are not quite the same since the MACRS schedule reverts to straight-line in year 9.

Response: We switched to the 20-year MACRS schedule for the steam plant.

166. **Comment:** I realize that you have been using a leveraged financial basis (debt financing at a lower rate than the IRR) for other studies. Nevertheless, such a basis gives a slight improvement to the economics that has nothing to do with the technology. I don't propose you change it, but perhaps recognizing it in the narrative has merit.

Response: Although not mentioned in the main report, we do recognize the slight improvement in the economics over 100% equity with 10% IRR. In the past we provided sensitivity cases showing the impact of the assumption (see Dutta et al. 2011, Figure 16, Case 20). Since we have maintained the same assumption in following BETO-funded reports, we did not explicitly discuss the impact in this report.

167. **Comment:** Calling the discount rate the IRR bothers me a little. Given you are accounting for debt financing separately, it's more like a cost of equity. This is a minor detail, of course.

Response: We qualified the text (in this version) in places where IRR was mentioned to also say that this is the discount rate.

168. **Comment:** I realize that you had to use a relatively sparse set of model compounds for the mass and energy balances. Nevertheless, it would have been nice to see some compositional data for selected streams, especially the inputs and outputs of each of the reactors. I would've liked to be able to follow the relative production and destruction of aromatics, in particular.

Response: Detailed stream tables and flow diagrams are provided in Appendix G showing model compound flow rates for the 2022 target cases.

169. **Comment:** I found no discussion of product specifications for the gasoline or distillate products. Even if the plant provides only blendstocks and not finished products, the manufacturing targets should be discussed. Since you were hydrotreating the product to remove aromatics, I assume you must've had a target of some kind.

Response: Since we are at the early stages of our research, we deliberately limited quality specifications to oxygen content and H/C ratios. Trying to be more specific at this stage without more experimental data would be misleading. We anticipate that there will be significant focus on quality specifications around the 2017 timeframe and beyond with more maturation of the technology.

170. **Comment:** Over time, many chemical processes get optimized to consume (or contain) their byproducts because finding long-term, steady-value dispositions for those byproducts is difficult. This process, given its lack of maturity, carries significant market exposure to placing the electricity and to disposing of wastewater.

Response: We agree that these will be important considerations in the future, and our research plans include some of these aspects.

171. **Comment:** The onsites and offsites are around 50/50 of the TIC, depending on case. Given that I think some offsites are missing, the balance will tip decidedly to offsites, which fits for a greenfield project. To be economical, subsequent evolutions of the design will need to

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focus on making the design more self-contained. A breakthrough in wastewater treatment is probably required.

Response: We tried to include all the major costs, both on-site and off-site. Wastewater treatment was not modeled in detail, but a conservative (high) operating cost was added for that operation. As mentioned in response to another comment, we will have on-site wastewater treatment and there will not be any off-site wastewater shipping requirements.

172. **Comment:** The assumption of using stainless steel in the oil/water separator is probably okay.

Response: Thank you for the feedback.

173. **Comment:** Based on personal experience with similar systems, Area 300 will require demonstration at some scale to resolve all of the potential fouling and corrosion issues.

Response: We agree that this needs further vetting as experimental results become available.

174. **Comment:** If the RTO technology for wastewater handling finds common and effective use with the kinds of wastewater streams you are producing, then perhaps it will work. If you can cite similar applications where the technology is effective, that would be a good addition.

Response: We were able to contact a reputable vendor to talk about the general feasibility of the stream going to the RTO. We changed the concentration based on their initial reluctance to comment on a much more dilute stream going into the RTO.

175. **Comment:** Power requirement tables: An "additional cross-flow dryer" is described in section 3.1 as being within the plant. To avoid questions and confusion, the power consumption should be listed here. The foot note then explains why it's small. Same comment applies to table 16.

Response: Text was added as recommended by the reviewer.

176. **Comment:** Carbon conversion efficiency in reactors is significant. That makes sense relative to Fischer-Tropsch. How aggressive are the reactor performance assumptions on this parameter?

Response: The carbon conversion efficiency on the vapor upgrading portion is based on research targets for 2022 (and not the current state of technology). For this process to be successful we have to get to high process efficiencies to justify the capital. This is theoretically feasible because of direct versus indirect liquefaction. However, doing the right chemistry during vapor upgrading using catalysts will be the key to success. We provided a planned trajectory for achieving the targets for inclusion in BETO's Multi-Year Program Plan document. The hydrotreating efficiency assumptions are shown in Table ES-1 and Figure 8.

177. **Comment:** It will be nice to broaden the work to include technology risk assessment.

Response: While technology risk assessments were not part of our goals for this design report, we are mindful of that aspect. We separately did some high level assessments in that regard; advancements in technology readiness are expected with advances in our research.

178. **Comment:** Pinch Analysis: This section seems to report results, not improvements to the heat exchange network (HEN) design. Certainly one immediate conclusion is that higher pressure cold streams would lower HX irreversibility. Are the cold stream phase change

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streams in the composite diagrams primarily associated with the steam cycle? If so, certainly more could be done to improve cycle efficiency. Utility HX duties were mentioned but not shown (called out) in the composite curve figures. What are their magnitudes and how are they provided? Was there any attempt at HEN redesign?

Response: Higher pressure in the steam system would help, but we decided to settle on the 1,350 psia for the steam production based on quotes we had from previous reports. We understand that steam turbine system designs/fabrication change and costs get significantly higher with much higher pressures. As you probably inferred, the near horizontal line on the cold side is associated with phase change for steam and moving this up can improve process efficiency at the cost of capital associated with larger heat transfer area requirements, as well as any changes in costs of the steam turbines. There are other cold streams in the process such as air preheat (where going to a very high temperature may not be recommended). We did change the air preheat and reformer preheat temperatures to some extent and saw changes in efficiencies, hydrogen production, natural gas requirement, electricity production, etc. Most of the other streams are pegged to process requirements for specific unit operations. So any optimization will be limited by these constraints. We typically take out the utilities to balance the hot and cold streams. The utilities use is usually determined by the pinch point and approach temperatures on the side below the pinch. We keep adding utilities until the side below the pinch appears feasible. We provided duties for all exchangers (see Appendices G and H).

179. **Comment:** Follow-up to previous comment and response: Okay, seems like you have the right price point vs. steam pressure picked out. But at some point in the future, it might be good to know what the marginal cost of increasing pressure is, as the net benefit might be worth it. Further, given the temperature differences in the composite diagram, I think there is room there for an economic lowering of the pinch in the phase change HX section(s). The main point is that there is an optimal tradeoff between HX surface area and life cycle costs. Huge dT's don't necessarily pay off, since operating efficiency gains are very important to operating cost reductions (vs. capital) over the life cycle of the plant. Here a true Pinch Analysis effort with HEN re-design (or exergy analysis) might make a difference.

Response: We do the heat exchanger network (HEN) at the end of the project after we freeze the models because of the very high levels of effort required for processes of this size. Results are shown in Appendix H. However, we do not modify the steam pressure in an iterative fashion, primarily because we do not have the resources to get actual quotes for various turbine systems to do detailed cost sensitivity with steam pressure. Also, since electricity is not our primary product, we anticipate a minimal impact. Also, we do the HEN manually to avoid proposing a spaghetti and physically infeasible network, usually created by commercial software (unless they are well constrained). As mentioned earlier, we decided to go with a steam pressure which we felt was reasonable and for which we had costs available. We would definitely like to bump up the efficiencies since this is very apparent in the sections where the hot and cold curves diverge significantly, and the steam system is the only major operation where we can change specifications without violating process condition requirements. Again, the objective of this design is to focus on the biomass conversion aspects with reasonable recovery of process heat, which we believe we have accomplished here. Pushing for optimization to higher efficiencies in the steam system with increased pressure will be a different exercise if further resources are available.

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