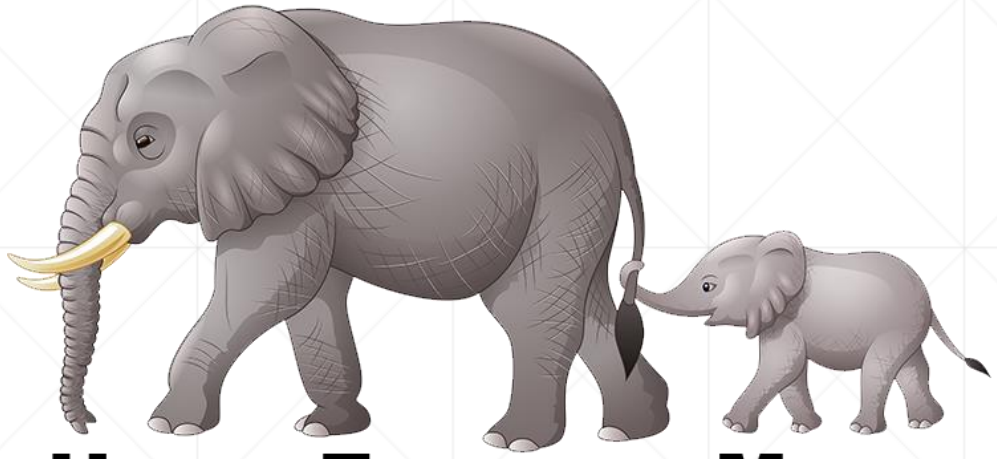
Wednesday, September 23, 2020

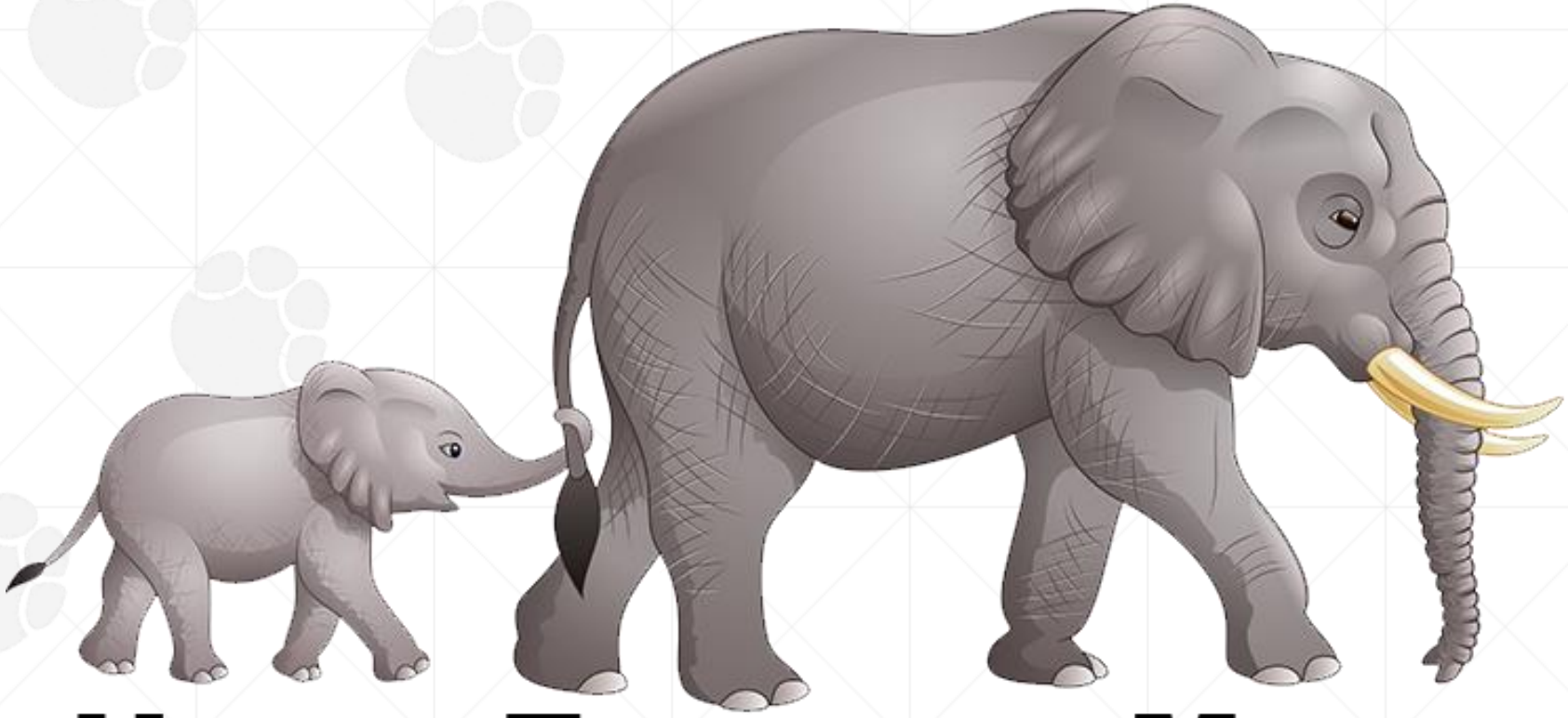


~ PRESENTS ~

Strategies for Upgrading Biogas to RNG

Featuring Jan Scott, Adam Klaas, Eric Wilgenbusch, Kim Murdock-Timmerman

Sponsored by Unison Solutions



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Our Presenters

Jan Scott
Co-owner
Unison Solutions

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Strategies for Upgrading Biogas to RNG

September 23, 2020

Unison Solutions, Inc. Overview

- Company founded on January 1, 2000
- Located in Dubuque, Iowa
- Over 50 employees (10 engineers)
- 65,000 ft^2 manufacturing facility
- Design and fabrication
  - Biogas conditioning and upgrading systems
  - Custom systems and technologies
- Over 325 systems sold worldwide

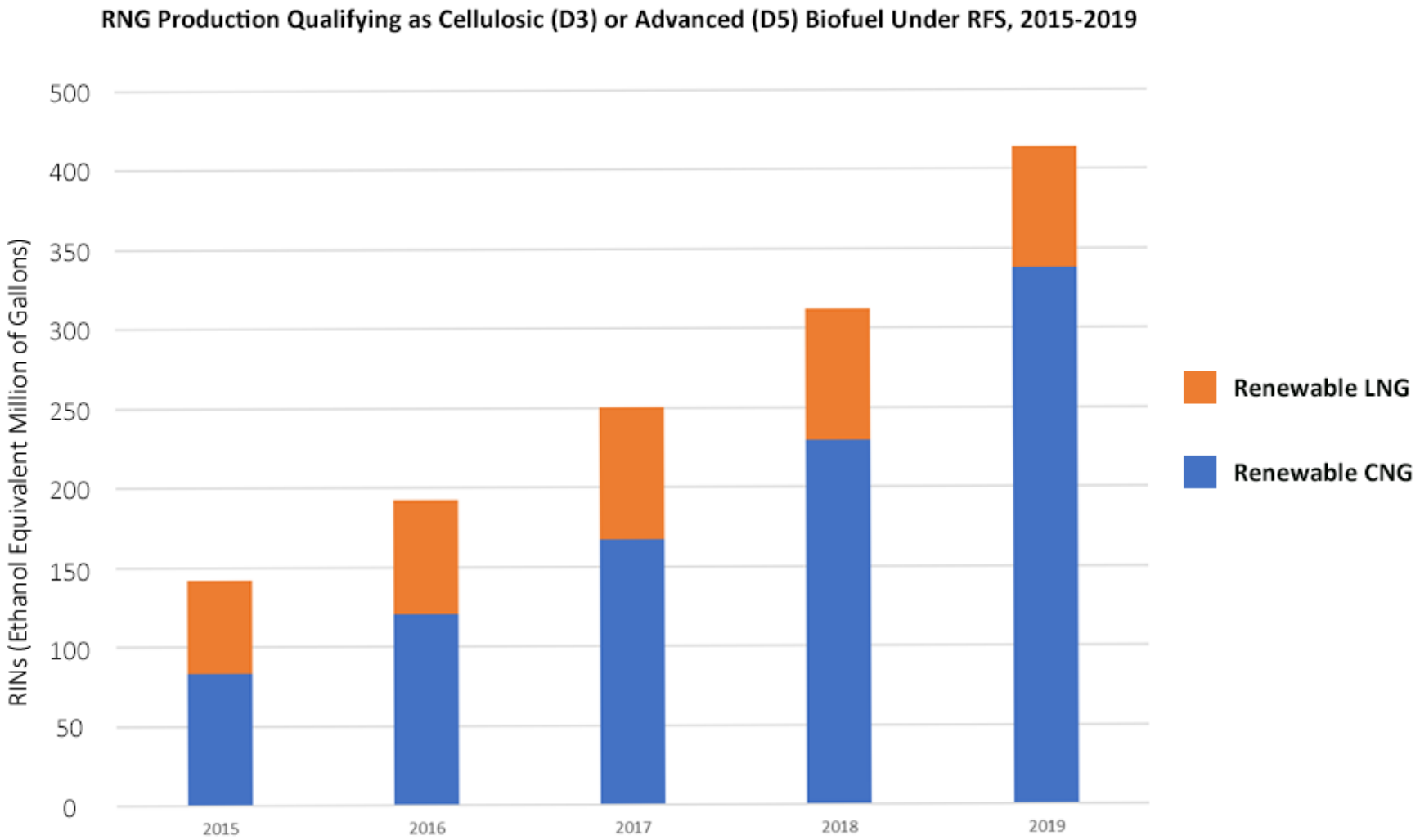
Definitions

- **CNG:** Compressed Natural Gas
- **DGE:** Diesel Gallon Equivalent, 129,500 BTU/gal
- **GGE:** Gasoline Gallon Equivalent, 114,000 BTU/gal
- **LCFS:** Low Carbon Fuel Standard, transportation fuels that reduce CO_2 emissions ($/MT, million tons CO_2)
- **RIN:** Renewable Identification Numbers, biogas that has been upgraded to renewable fuel
- **RFS:** Renewable Fuel Standard, a federal program requiring transportation fuel sold in the United States to contain a minimum volume of renewable fuels.
- **RNG:** Renewable Natural Gas (BioCNG)
- **Wobbe Index:** Used to compare the combustion energy output of different fuels

Getting Started: RIN Basic Information

- EPA monitors compliance for the RFS using a system of tradable credits referred to as renewable identification numbers (RINs)
- A RIN credit is a serial number assigned to each gallon of renewable fuel as it is introduced into U.S. commerce
- Only biogas used as renewable transportation fuel can generate RINs
- RIN Agents: similar to Carbon Credit Exchange Brokers
- Congress has mandated volumes that are in place until 2022
- After 2022, the EPA is expected to continue implementing the RFS without the congressionally mandated schedule of Renewable Volume Obligation (RVO)

RNG Market Growth



RIN generation data https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rins-generated-transactions

RIN Pricing

RIN Type	Description	Greenhouse Gas Reduction Requirement	Price 9/1/2020
Cellulosic Biofuel (D3)	Municipal wastewater plants and landfill biogas qualify (cellulose, hemicellulose, or lignin)	60%	$1.47/RIN $2.20/GGE
Advanced Biofuel (D5)	Produced from non-corn starch, renewable biomass. Includes manure, agricultural and food processing	50%	$0.70/RIN $1.05/GGE

1 RIN = 77,000 BTU/gal

1 GGE = 115,000 BTU/gal

https://www.biocycle.net/2017/11/13/101-for-rins/

"Properties of Fuels" (PDF). Energy Efficiency and Renewable Energy. United States Department of Energy. Alternative Fuels Data Center. October 29, 2014. Retrieved January 1, 2015.

USDOE Property of Fuels

RIN Price Ecoengineer

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Historical RIN Pricing

Fuel (D Code)

D3 D4 D5 D6

QAP Service Type

Q-RIN Unverified

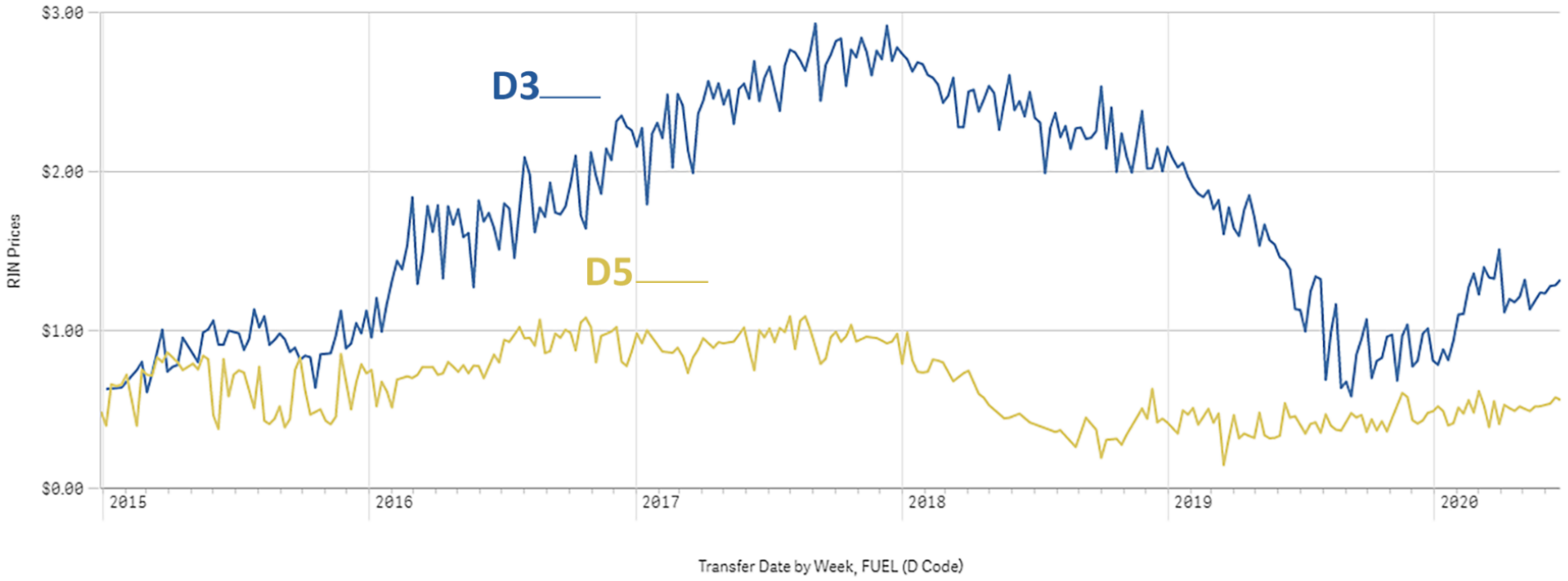
Transfer Years

2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020

Last updated date: Jul, 10, 2020 (Updated monthly)

D-Code	Average Price	
	2019	2020
D3	$1.59	$1.65
D5	$0.56	$0.56

Weekly D3, D4, D5 and D6 RINs Prices



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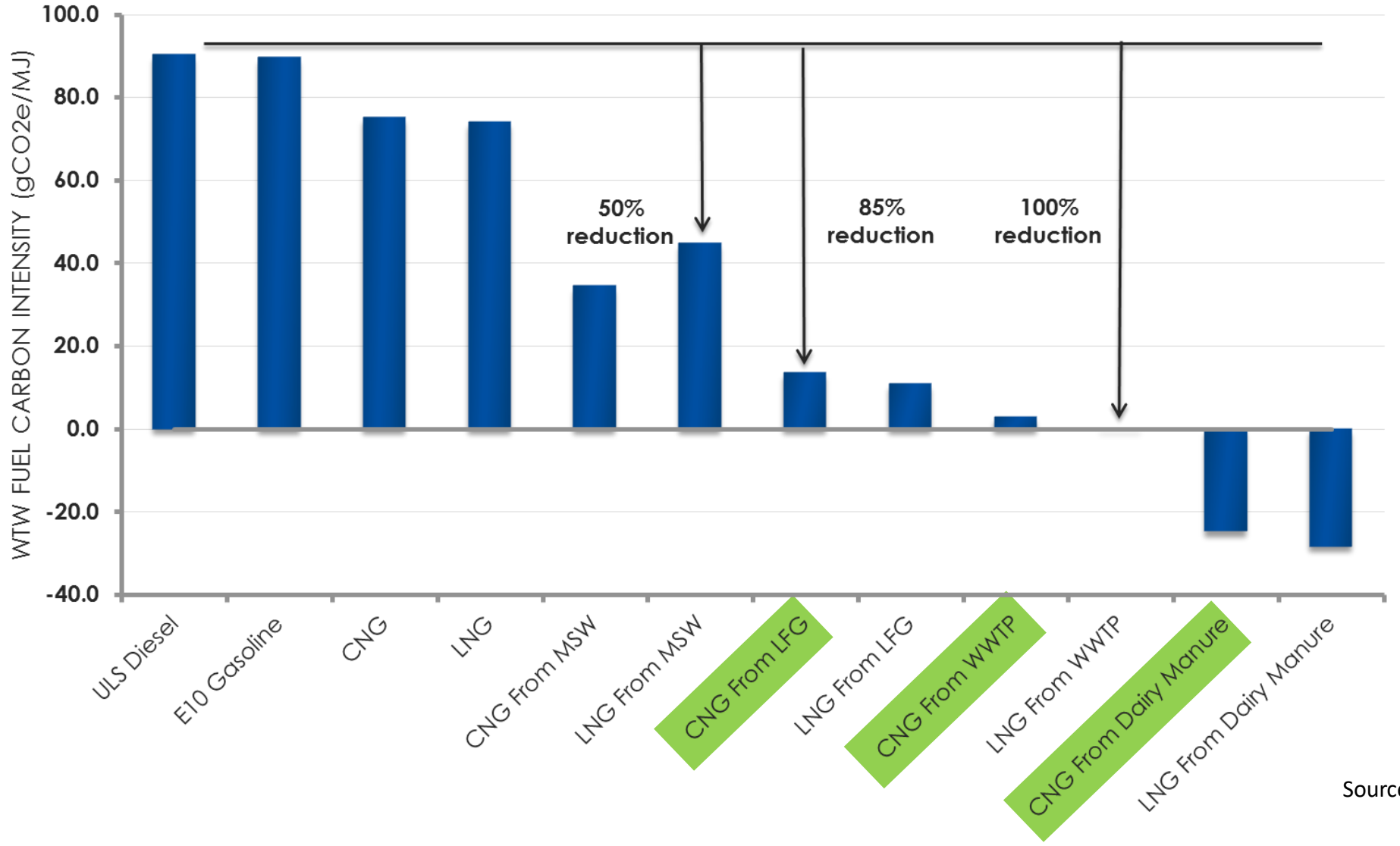
https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rin-trades-and-price-information

Why RNG as Vehicle Fuel?

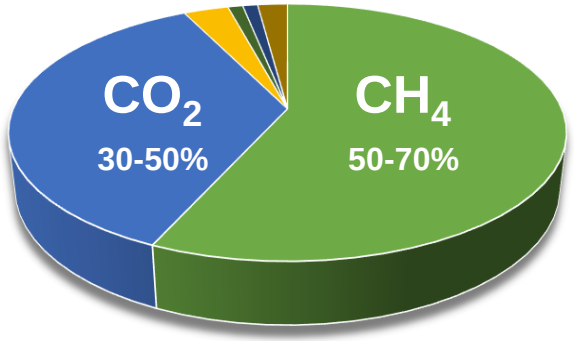


Source: US Dept of Energy

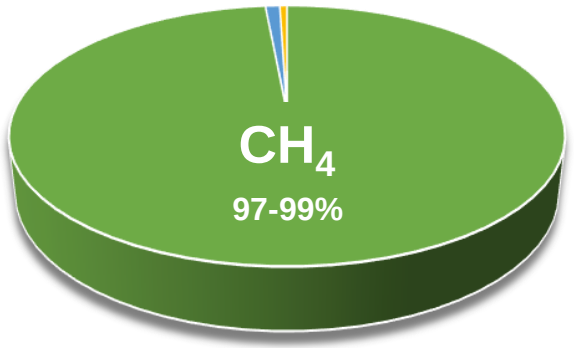
Why RNG as Vehicle Fuel?

Fuel Type	Current Pricing /GGE 9/1/2020	Current Pricing /MMBTU 9/1/2020	Conversions
Natural Gas		$2.30	
CNG	$2.27	$19.97	8.8 GGE=1 MMBTU
RNG (RIN)		$19.36	1 RIN=77,000 BTU/Gal
D3 RIN	$2.20		1.5 RIN/GGE

http://www.cngprices.com/



Biogas



Renewable Natural Gas (RNG)

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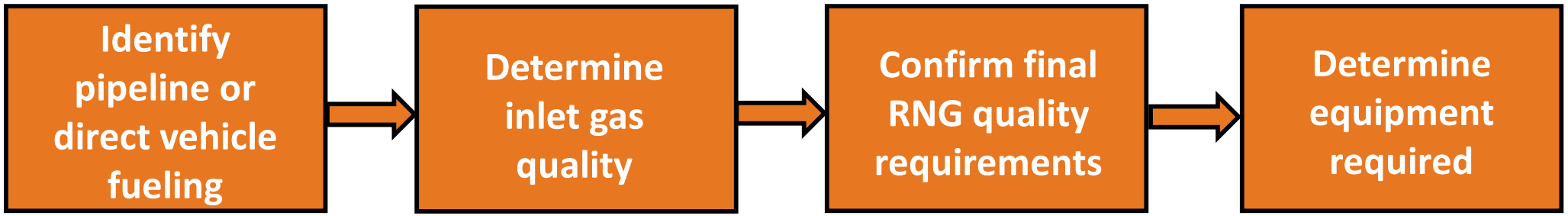
Steps to a Successful RNG Project



Know Your Pipeline Requirements

- **Gas quality requirements***
  - BTU Content
    - Methane
  - Carbon dioxide
  - Oxygen
  - Nitrogen
  - Hydrogen sulfide
  - Siloxanes and VOCs
  - Bacteria
  - Water content

- **Tie-in location and requirements**
  - Interconnect fees
  - Pressure
  - Flow
  - Transport to offloading station (virtual pipeline)
    - Compression
    - Tube trailers
- **What RNG monitoring is required?**
  - Online
  - Monthly
  - Yearly
  - Single validation test

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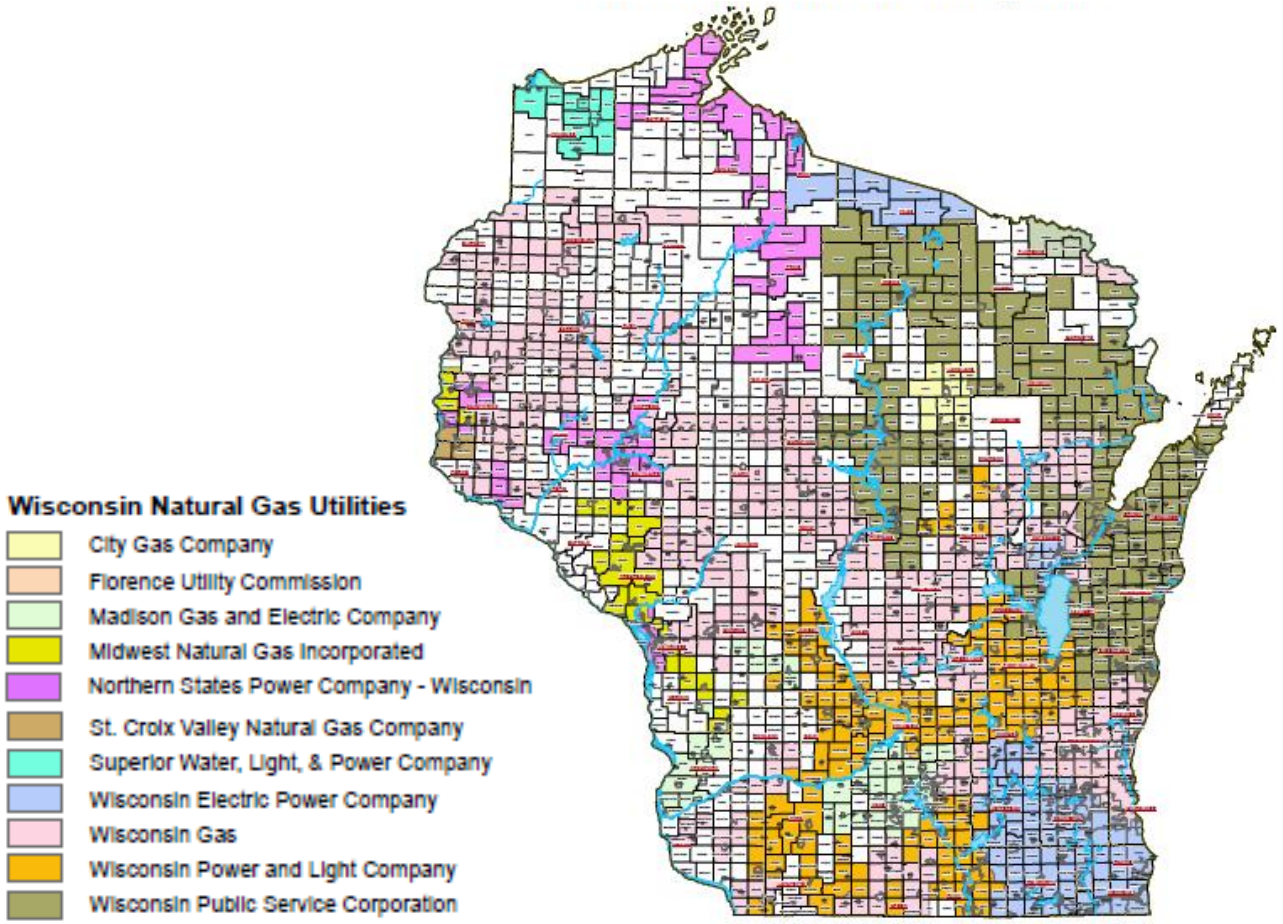
*Requirements vary depending on pipeline tariff

Example: Natural Gas Utilities

Wisconsin Natural Gas System



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Fuel Quality Specification

Biogas Constituents	Raw Biogas	Natural Gas Pipeline*	Midwest Pipeline 1	Midwest Pipeline 2
Methane	50–80%			
Wobbe Index		1,400 BTU/ft^3 max		
Higher Heating Value (HHV)		950-990 BTU/ft^3	950 BTU/ft^3	967–1,200 BTU/ft^3
Carbon Dioxide (CO_2) and Nitrogen (N_2)	20–50%	<2%	<2%	CO_2 <2% N_2 <3%
Oxygen (O_2)	0–1%	0.0005% to 0.2%	0.2%	<1%
Hydrogen Sulfide (H_2S)	<1,000 ppm	≤4 ppm	<4 ppm	< 4 ppmv Total sulfur <320 ppm
Water Content		3–7 lb/MMcf	6 lb/MMcf	< 7 lb/MMcf
Siloxanes and VOCs	<2,000 ppm	ND to 1 ppm	Siloxanes 4 mg Si/m^3 Specific Compounds Identified	
Ammonia			10 ppmv	
Mercury			80 ug Hg/m^3	
Biologicals			4x10^4/Scf	
Pressure	0–2 psig	50–900+ psig		600–975 psig

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*Varies depending on the utility & tariff agreement

Sample Pipeline located in the Western U.S.

Constituents/Properties	Limit	Units
Higher Heating Value	965 - 1100	Btu/scf
Wobbe (based on HHV)	1185 - 1285	
Carbon Dioxide (mol %)	3.0	mol %
Oxygen	2.0	mol %
Total Inerts	14.3	mol %
Hydrogen Sulfide H_2S Total Sulfur	0.25 (4) 5.0 (85)	gr/Cscf (ppmv)
Hydrocarbon Dew Point, Cricondentherm	15	°F
Water Vapor Content	3	lb/ MMscf
Dust, dirt, gum and other solids	Free of	
Water & hydrocarbons in liquid form	Free of	
Temperature	32 – 110	°F

Hazardous Substances/ Objectionable Matter*		
Constituents/Properties	Proposed Limit	Units
Volatile Organic Compounds (VOCs)		
Siloxanes (Total Si)	0.1	mg/m^3
Vinyl Chloride	1170	ppbv
Chorinated/Halogenated Hydrocarbons: Chlorobenzene, trichlorofluoromethane, etc.	100	ppbv
Organic Sulfur: Carbonyl sulfide, Carbon Disulfide, Dimethyl Sulfide, etc.	1	ppmv
BTEX and other aromatics	50	ppmv
Hexanes+ Alkanes	100	ppmv
Formaldehyde/Aldehydes and Ketones	100	ppbv
Other VOCs	100	ppbv
Semi-Volatile Organic Compounds	100	ppbv
Polycyclic Aromatic Hydrocarbons	100	ppbv
Volatile Fatty Acids	10	ppbv
Polychlorinated Biphenyls	0.1	ppbv
Pesticides	1	ppbv
Products	1	ppbv
Inorganic Compounds/Metals		
Mercury	0.01	$\mu g/m^3$
Hydrogen	0.1	mol %
Arsenic, Zinc, Antimony	0.01	$\mu g/m^3$
Ammonia	10	ppmv
Biologicals	0.2	micron

Requirements to Deliver RNG: Natural Gas Pipeline

- Final product gas quality is dependent on utility's specific requirements
- Required equipment varies
- Monitoring of gas quality varies
- Work with the utility at the beginning of a project

West Texas Pipeline Injection Monitoring

Optima KV equipment

Know Your Vehicle Fuel Requirements

- **Gas quality requirements: SAE J1616**
  - Wobbe Index
    - Methane
    - Carbon dioxide
  - Oxygen
  - Nitrogen
  - Hydrogen sulfide
  - Siloxane and VOCs
- **Location for dispensing**
  - Near the upgrading system
  - Dedicated pipeline
  - Virtual pipeline
- **Dispensing requirements**
  - Fast-fill
    - Storage requirements
  - Time-fill
    - Location for fueling vehicles

Fuel Quality Specification

Biogas Constituents	Raw Biogas	SAE J1616 CNG Fuel Quality Specification	Natural Gas Pipeline Fuel Quality*
Methane	50–80%	88% or greater	
Wobbe Index		1,250–1,420 BTU/ft^3	1,400 BTU/ft^3 max
Higher Heating Value (HHV)			950–990 BTU/ft^3
Carbon Dioxide (CO_2) and Nitrogen (N_2)	20–50%		<2%
Oxygen (O_2)	0–1%		0.0005% to 0.2%
Hydrogen Sulfide (H_2S)	<1,000 ppm	≤4 ppm	≤4 ppm
Water Content		PWDP 10˚F below lowest recorded temp	3–7 lb/MMcf
Siloxanes and Volatile Organic Compounds	<2,000 ppm	ND (Silicon)	ND to 1 ppm
Pressure	0–2 psig	3,000–3,600 psig	50–900+ psig

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*Varies depending on the utility

Methods to Deliver RNG: Direct Vehicle Use

Landfill or Digester

Biogas Upgrading System

RNG
for Vehicles

On-site Fueling
Fast-fill & Time-fill

Dedicated Pipeline

Virtual Pipeline

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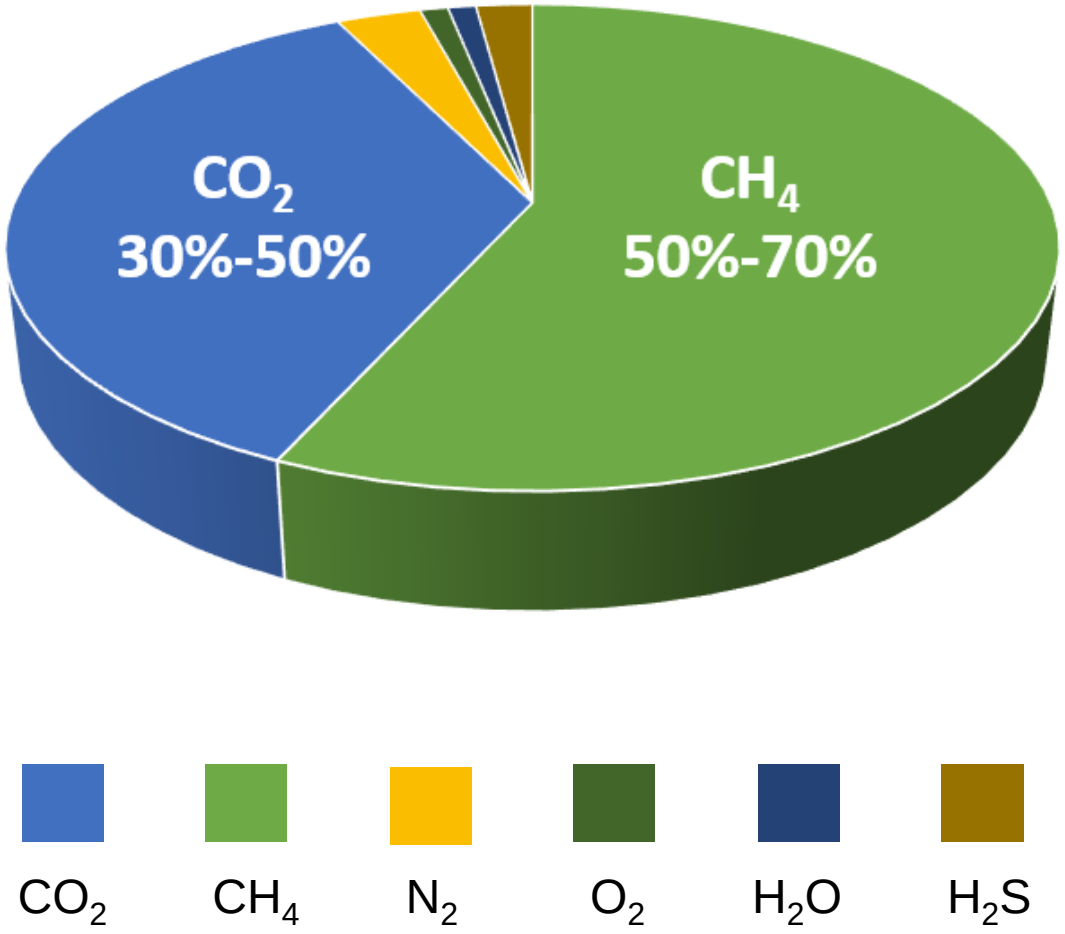
Know Your Biogas Quality

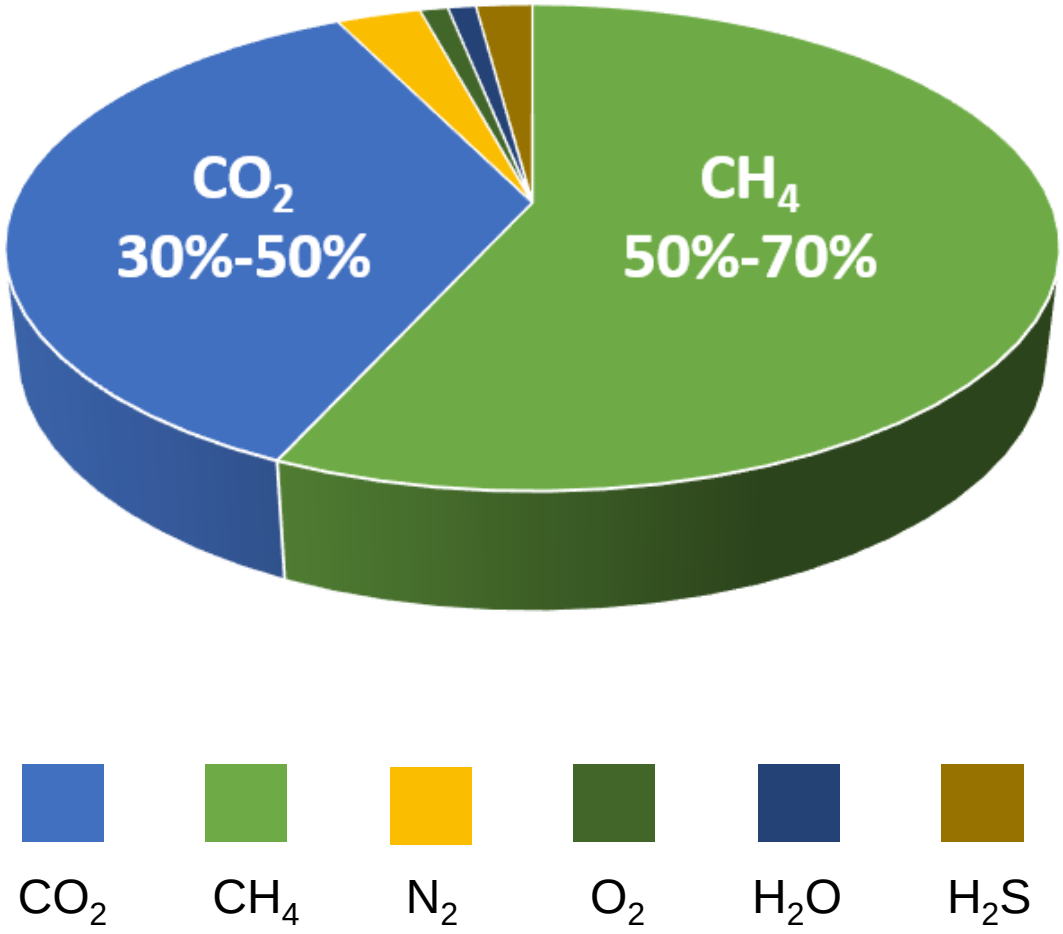
bi·o·gas, ˈbīōˌgas/, *noun,* gaseous fuel, especially methane, produced by the fermentation of organic matter.

- Methane (CH_4)
- Carbon dioxide (CO_2)
- Nitrogen (N_2)
- Oxygen (O_2)
- Hydrogen sulfide (H_2S)
- Moisture
- Particulates
- Siloxanes
- Volatile organic compounds (VOCs)



Know Your Raw Biogas Quality

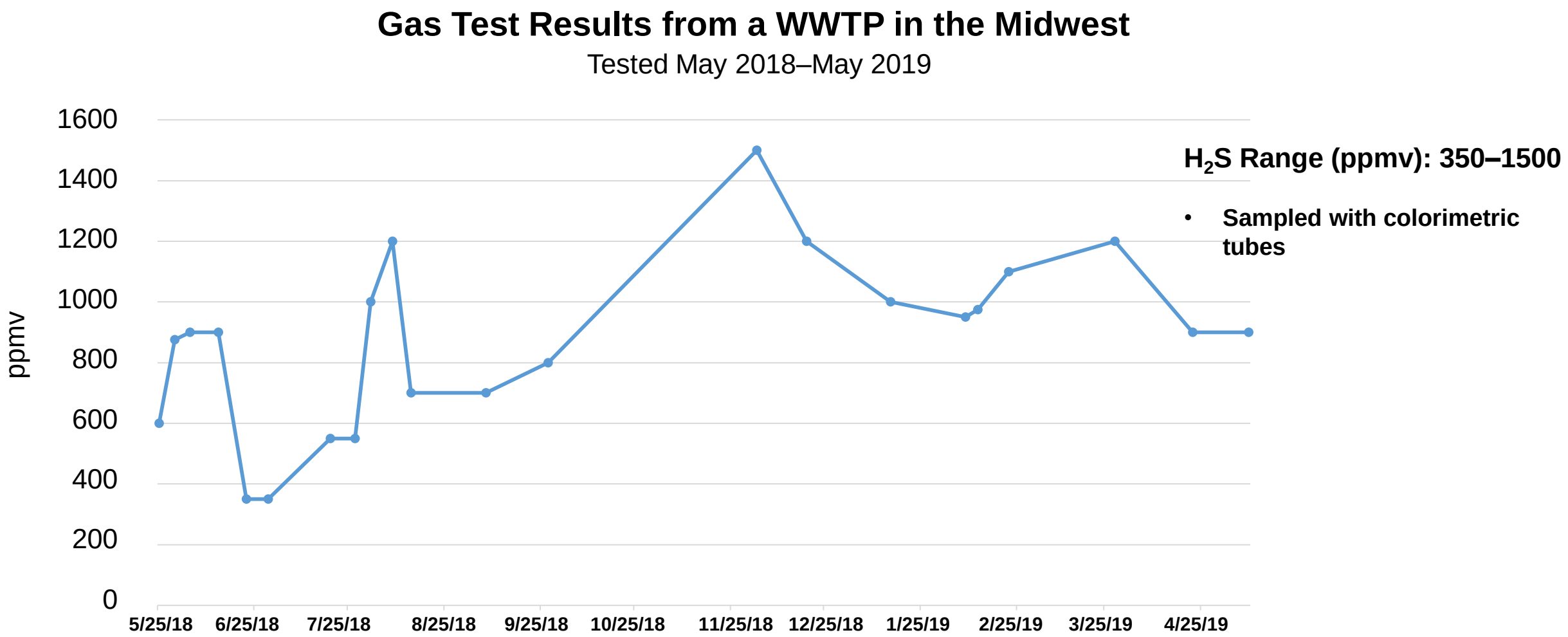
- Methane (CH_4)
  - 50–70%
- Carbon dioxide (CO_2)
  - 30–50%
- Nitrogen (N_2)
  - 1–5%
- Oxygen (O_2)
  - 0–2%
- Hydrogen sulfide (H_2S)
  - 0–10,000 ppm
- Moisture
  - 30–100% R.H.
- Siloxanes
- Volatile organic compounds (VOCs)



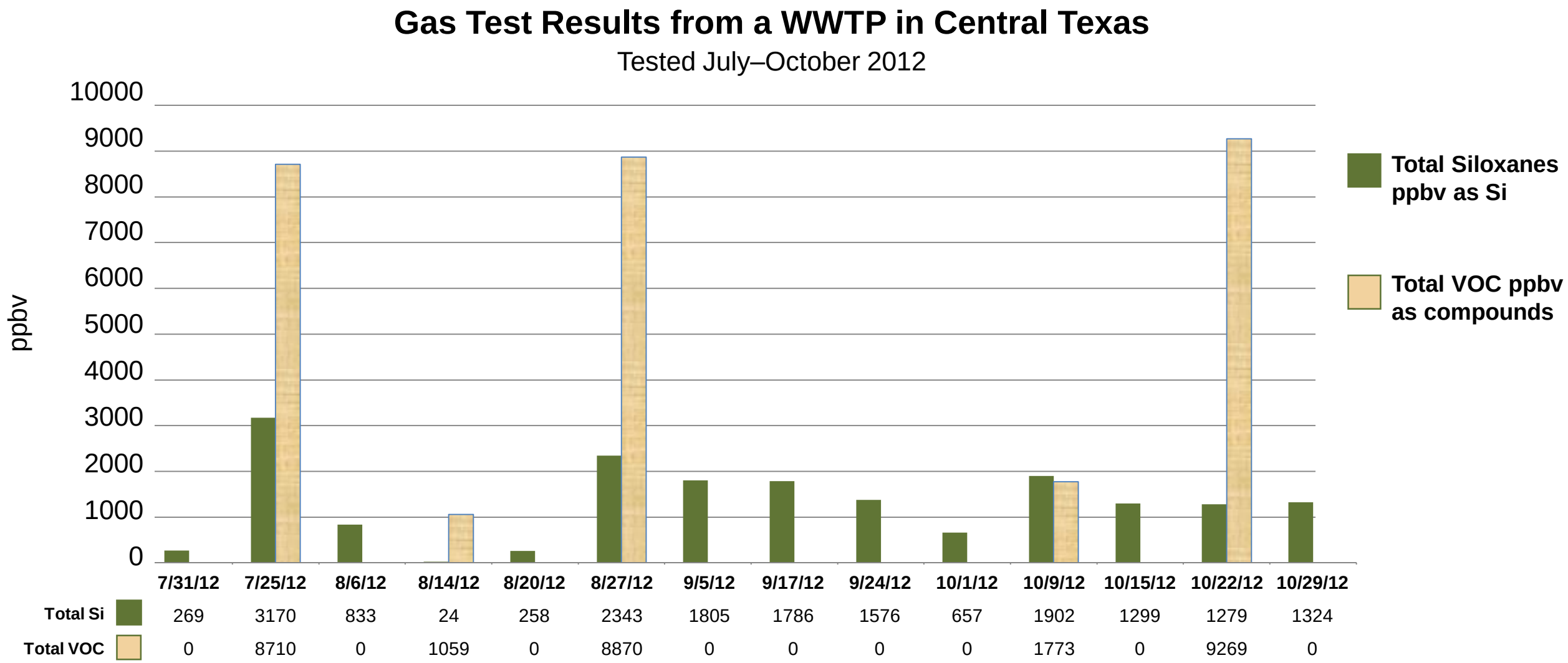
Hydrogen Sulfide (H_2S)

- Where does H_2S come from?
  - Landfills: the breakdown of calcium sulfate used in building materials
  - Digesters: sulfate-reducing bacteria (SRBs) convert the sulfate ion to sulfide
- Equipment damage from corrosion (hydrosulfuric acid)
- SO_x emissions
- Health and safety issues
- Odor control
- **Causes fouling of siloxane/VOC removal media**
- Measure levels with either lab testing, colorimetric tubes, or on-site meter

H_2S Levels: Raw Gas Testing



Siloxane and VOC Levels: Raw Gas Testing



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Siloxane and VOC Levels: Raw Gas Testing

Gas Test Results from a WWTP with Multiple Industrial Clients

Tested January 2017–December 2019

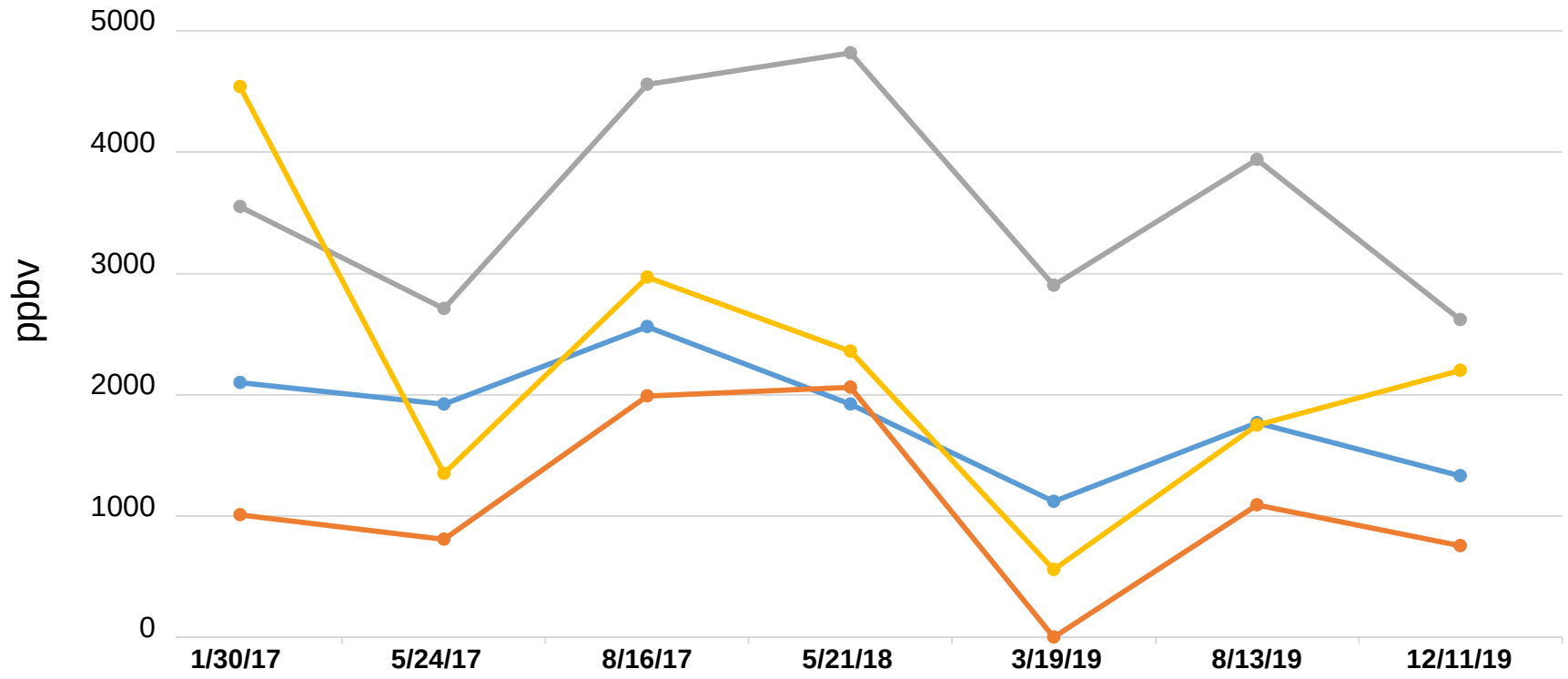
Total VOC Range (ppbv)

(MEK) 2-Butanone: 1,120–2,560

Isopropyl Alcohol: 0–1,990

Acetone: 2,620–4,820

Toluene: 557–4,540



	1/30/17	5/24/17	8/16/17	5/21/18	3/19/19	8/13/19	12/11/19
(MEK) 2-Butanone	2100	1920	2560	1920	1120	1770	1330
Isopropyl Alcohol	1010	805	1990	2060	0	1090	753
Acetone	3550	2710	4560	4820	2900	3940	2620
Toluene	4540	1350	2970	2360	557	1750	2200

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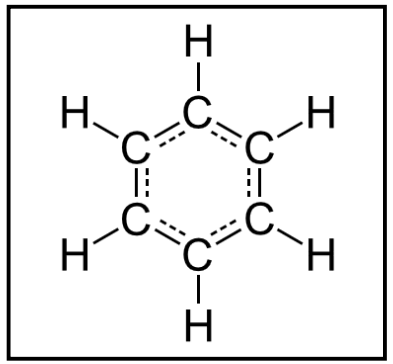
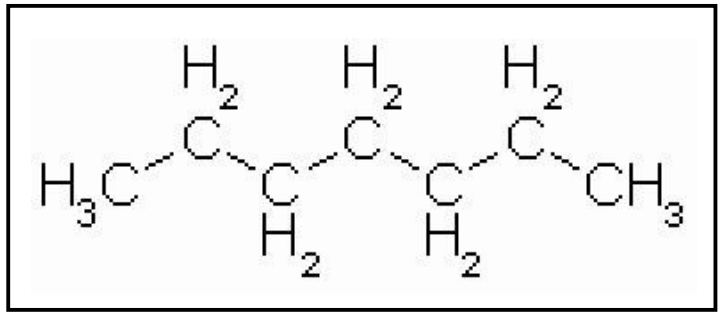
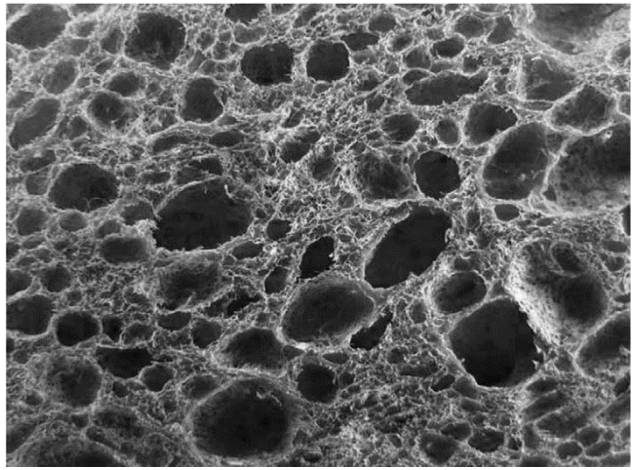
Suitability Factors for Media Systems: Siloxanes, Hydrocarbons, and VOCs

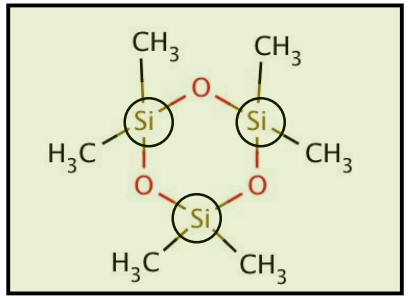


Benzene (C_6H_6)

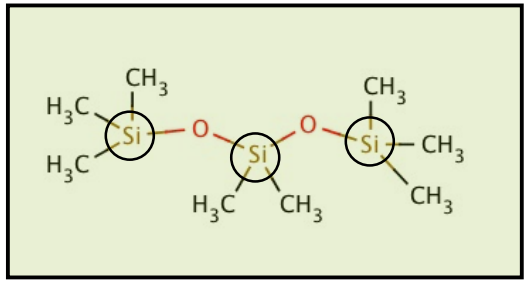


Heptane (C_7H_{16})

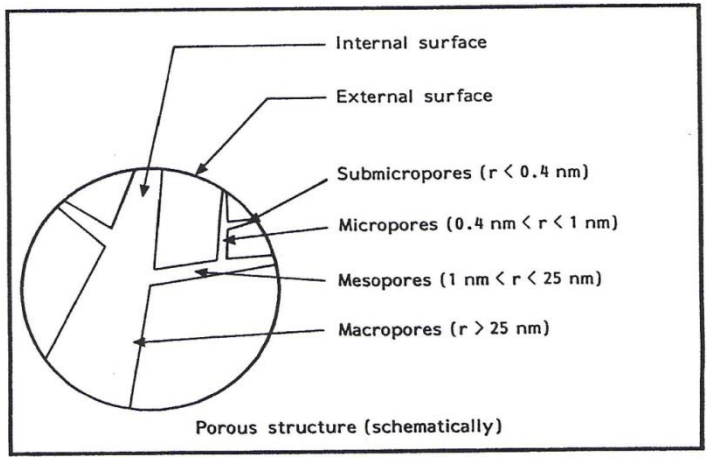




Hexamethylcyclotrisiloxane (D3)



Octamethyltrisiloxane (L3)



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Biogas Testing

Before starting a project, we recommend the following biogas tests be performed:

- **Major Components**
  - Methane
  - Nitrogen
  - Oxygen
  - Carbon dioxide
  - BTU calculation
- **Siloxanes**, by speciation
  - Up to 8 compounds common to biogas
- **Sulfur Compounds**, by speciation
  - **Hydrogen sulfide**
  - Mercaptans
  - Other sulfide compounds
- **Volatile Organic Compounds (VOCs)**, by speciation
  - Follows EPA TO-15 protocol

These compounds will also need to be tested on a regular basis to determine media change out intervals

Equipment Needed

Digester or Landfill

Biogas Conditioning System

H_2S Removal

Gas Compression/ Moisture Removal

Siloxane/VOC Removal

CO_2 Removal

CNG Vehicle Fueling Station

IC Engines

MicroTurbines

Boilers

Vehicle Fuel/Pipelines

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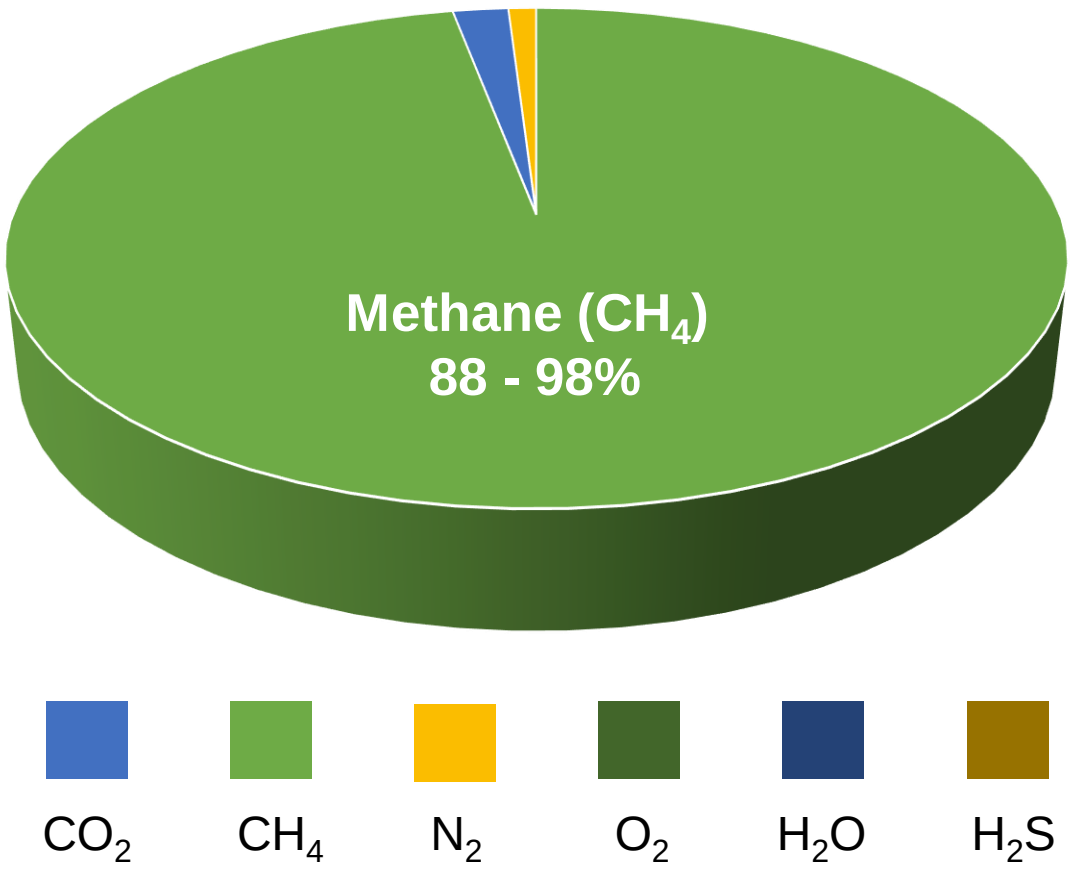
Biogas to RNG

bi·o·gas, ˈbīōˌgas/, *noun,* gaseous fuel, especially methane, produced by the fermentation of organic matter.

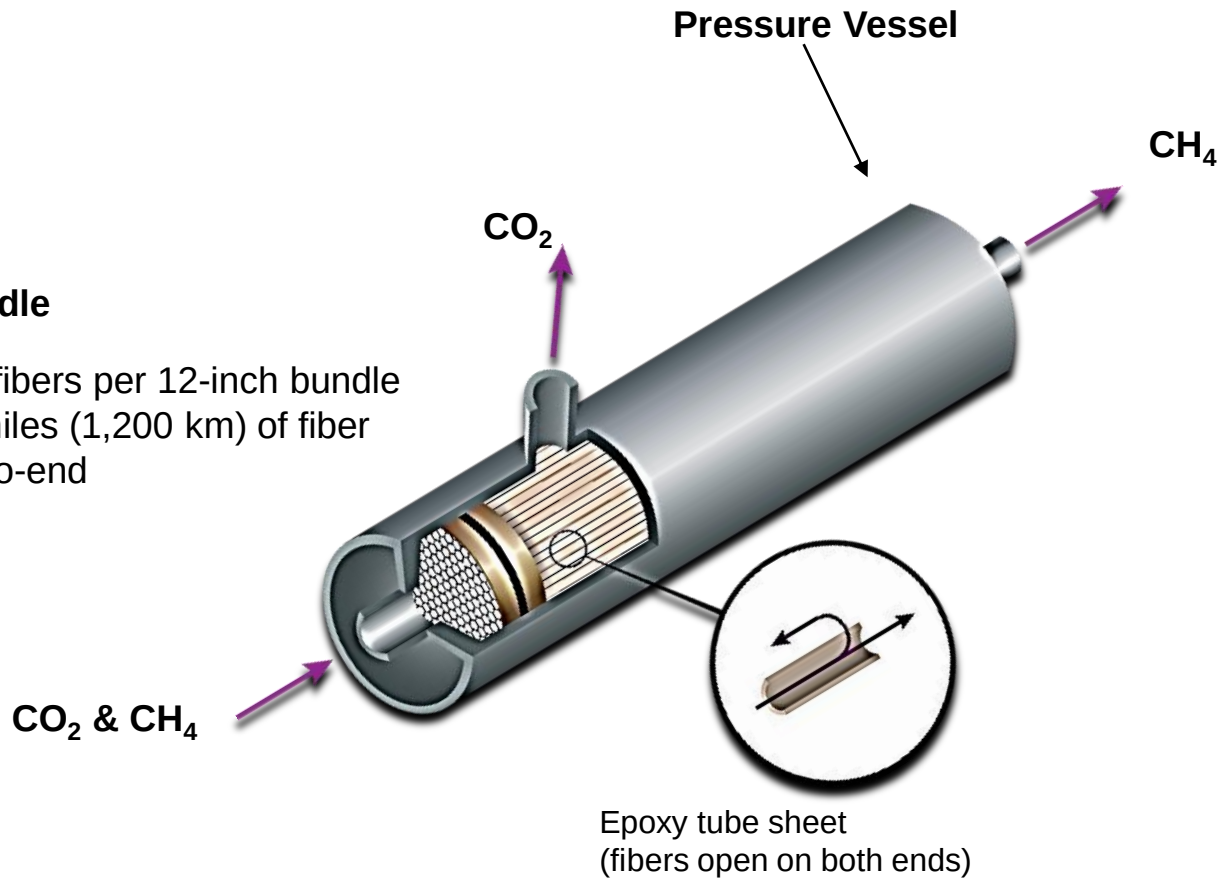
- Methane (CH_4)
- Carbon dioxide (CO_2)
- Nitrogen (N_2)
- Oxygen (O_2)
- Hydrogen sulfide (H_2S)
- Moisture
- Particulates
- Siloxanes
- Volatile organic compounds (VOCs)



Membrane Separation Schematic

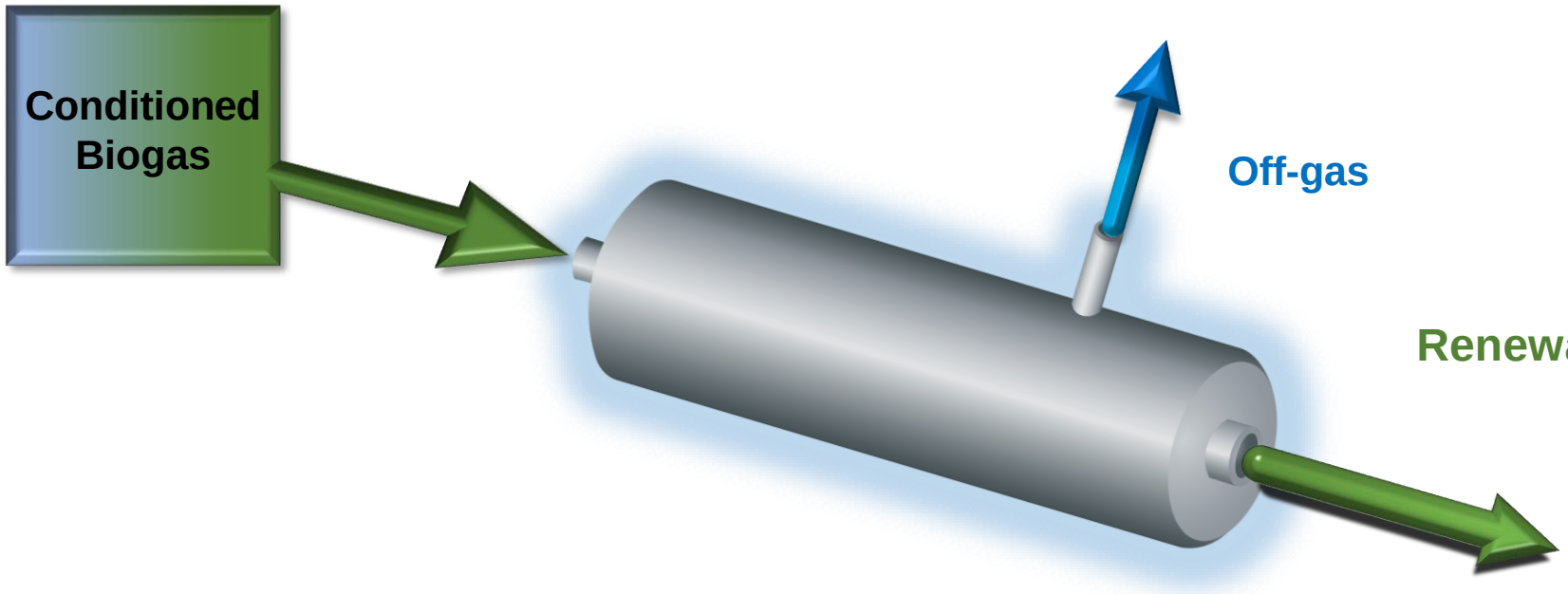
Hollow Fiber Bundle

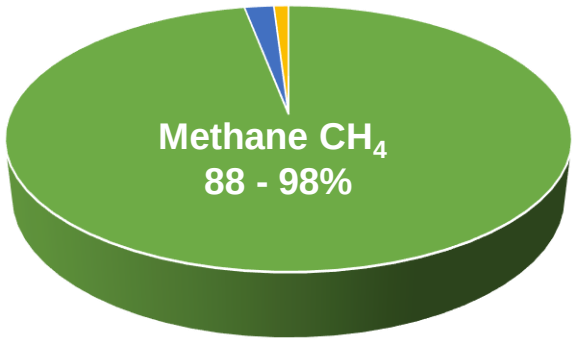
- 0.5–1.2 million fibers per 12-inch bundle
- Contains 750 miles (1,200 km) of fiber when laid end-to-end



Single-Stage Membrane Process

SAE J1616 Vehicle Fuel Specifications





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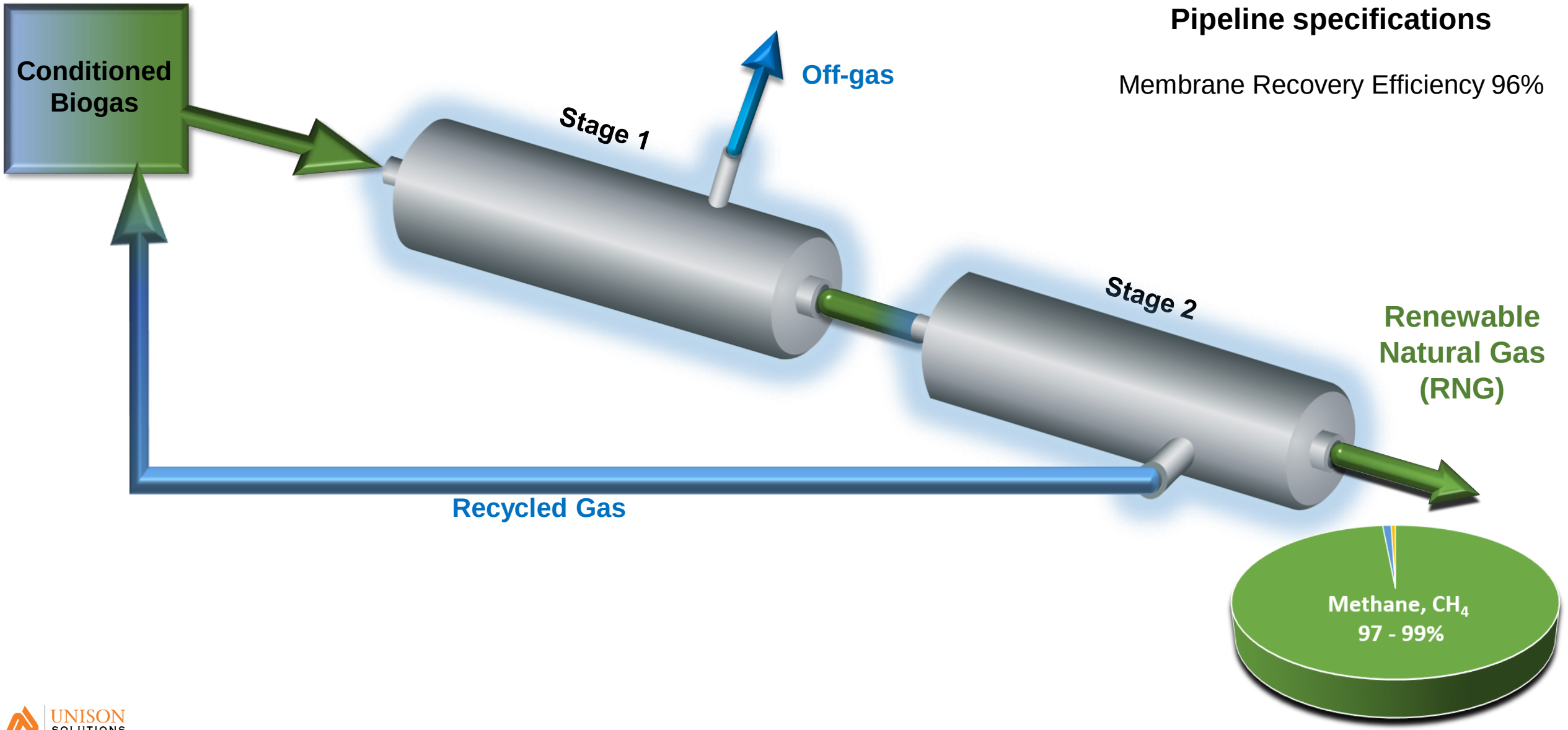
Dual/Two-Stage Membrane Process



Pipeline specifications

Membrane Recovery Efficiency 96%

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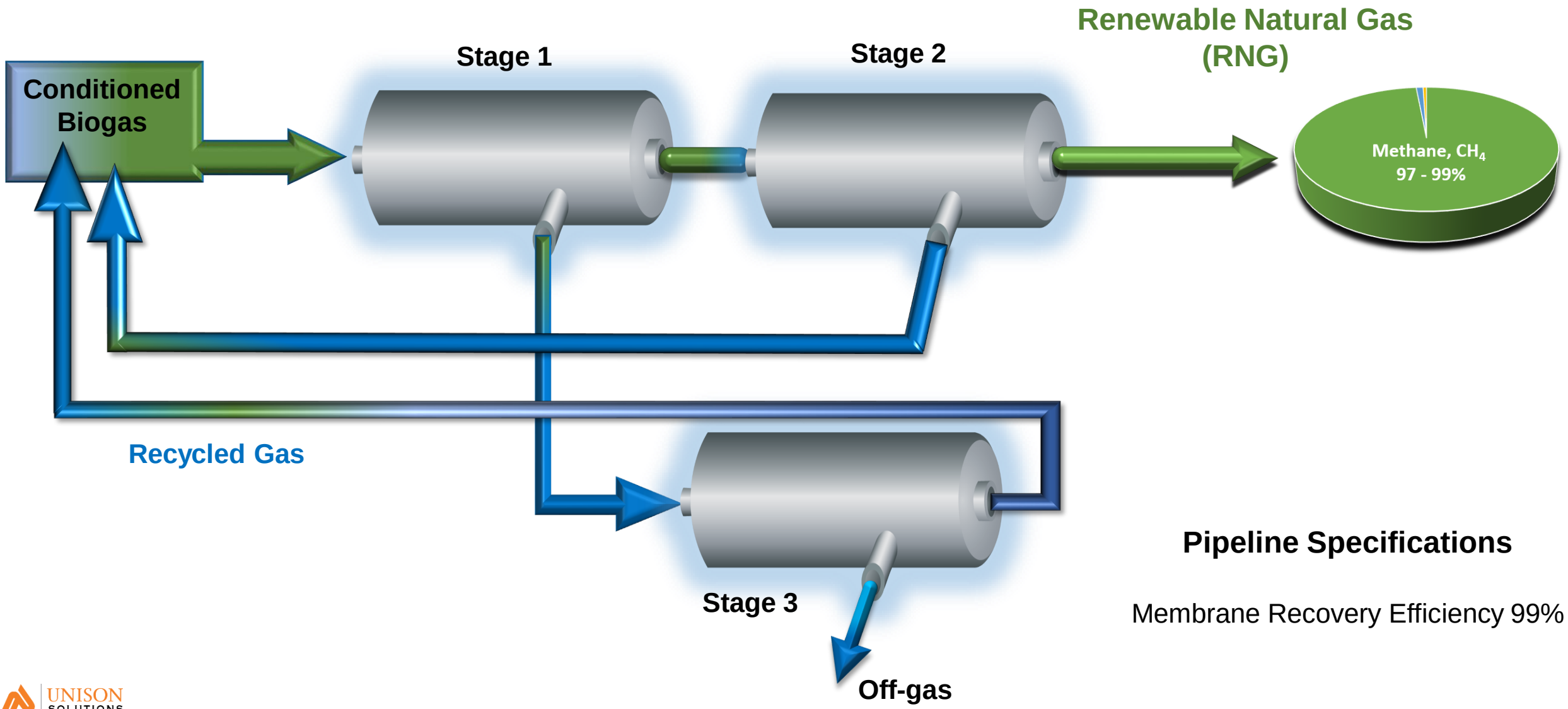
Three-Stage Membrane Process



Pipeline Specifications

Membrane Recovery Efficiency 99%

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Pipeline Injection Project Highlights

South Platte WRP, Colorado

- Plant capacity: 24 MGD
- Upgrading to pipeline injection
- 400 scfm
- H_2S, moisture, siloxanes, CO_2 and bacteria removal
- Dual-stage membrane technology

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Pipeline Injection Highlights

Major Gases by EPA Method 3C	Raw Gas	RNG	Pipeline Specs
Carbon Dioxide %	36.5	0.8	3
Carbon Monoxide %	ND	ND	
Methane %	61.9	98.4	
Nitrogen %	0.943	0.62	
Oxygen %	0.591	0.1	2
BTU (BTU/ft^3) HHV	626	1000	956–1100

Siloxanes by EPA Method TO-15	Raw Gas	RNG	Pipeline Specs
Decamethylcyclopentasiloxane (D5)	0.0844	ND	
Decamethyltetrasiloxane-L4 (MD2M)	0.0436	ND	
Hexamethylcyclotrisiloxane (D3)	0.0265	ND	
Hexamethyldisiloxane-L2 (MM)	ND	ND	
Octamethylcyclotetrasiloxane (D4)	1.8244	ND	
Octamethyltrisiloxane-L3 (MDM)	0.0222	0.062	
Pentamethyldisiloxane	ND	ND	
Trimethyl silanol	ND	0.0115	
Total (mg Si/m3)	**2.001**	**0.074**	**0.2**

Pipeline Injection Highlights

Sulfur Compounds by EPA Method TO-15 (ppmv)	Raw Gas	RNG	Pipeline Specs
Carbon Disulfide	ND	ND	
Carbonyl Sulfide	0.011	ND	
Dimethyl Sulfide	ND	ND	
Ethyl Mercaptan	0.091	ND	
Hydrogen Sulfide	279	ND	4
Isobutyl Mercaptan	0.011	ND	
Isopropyl Mercaptan	0.093	ND	
Methyl Mercaptan	0.516	ND	
Total Sulfur (ppmv)	**279.7**	**ND**	**85**

Volatile Organic Compounds by EPA Method TO-15 (ppmv)	Raw Gas	RNG	Pipeline Specs
BTEX Compounds Total	1.057	0.029	50
Other VOC Total	6.43	ND	0.1
Chlorinated/Halogenated Total	0.039	ND	0.1
Hexanes & Alkanes Total	0.037	0.004	100
Semi-Volatile Total	0.001	ND	0.1
Formaldehydes/Aldehydes & Ketones	0.106	ND	0.1
Vinyl Chloride	0.005	ND	1.17

Pipeline specifications were met at commissioning of the system

Theresa Street WRRF, Nebraska

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Theresa Street WRRF, Nebraska

- Plant capacity: 27 MGD
- Upgrading to pipeline injection
- 400 scfm
- H_2S, moisture, siloxanes, CO_2, and bacteria removal
- Dual-stage membrane technology

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Methods to Deliver RNG: On-site Fueling and Storage

Fast-fill

- Final product gas is stored on-site in storage spheres
- Dispensing is done at high pressure, one vehicle at a time

Time-fill

- Vehicle fuel tanks act as storage
- Hose post assemblies for multiple vehicles to fill slowly

Manteca WWTP, California

- Plant capacity: 7 MGD
- 100 scfm
- Fast-fill vehicle fueling
- H_2S removal
- Gas compression/moisture removal
- Siloxane & VOC removal
- CO_2 removal

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Manteca WWTP, California

UNISON SOLUTIONS

https://www.ci.manteca.ca.us/PublicWorks/Pages/Waste-to-Fuel-Program.aspx

Randolph Farms Landfill, Indiana

- Startup: spring 2018
- 200 scfm
- Fast-fill: vehicle fueling
- H_2S removal
- Gas compression/moisture removal
- Siloxane & VOC removal
- Carbon dioxide removal

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Janesville WWTP, Wisconsin

- Gas flow: 140 scfm
  - BioCNG 50
- Fast-fill: vehicle fueling
- Four 65 kW Capstone turbines
- One 200 kW Capstone turbine

Methods to Deliver RNG: Dedicated Pipeline

Treatment Plant

- Startup: April 2015
- H_2S, gas compression/moisture, siloxane and carbon dioxide removal
- Dedicated 5.8-mile pipeline
- Located on the Colorado River
- Extends from WWTP to existing filling stations

Filling Station

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Time-Fill and Fast-Fill Fueling Stations

- Time-fill for CNG-fueled waste haulers and city buses
- Dedicated 5.8-mile pipeline
- 142,000 gallons of gasoline diverted
- CO_2 reduction of 3 million pounds/year

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Longmont WWTP, Colorado

- Startup: February 2020
- Plant capacity: 13 MGD
- 100 scfm
- H_2S removal
- Gas compression/moisture removal
- Siloxane removal
- Carbon dioxide removal

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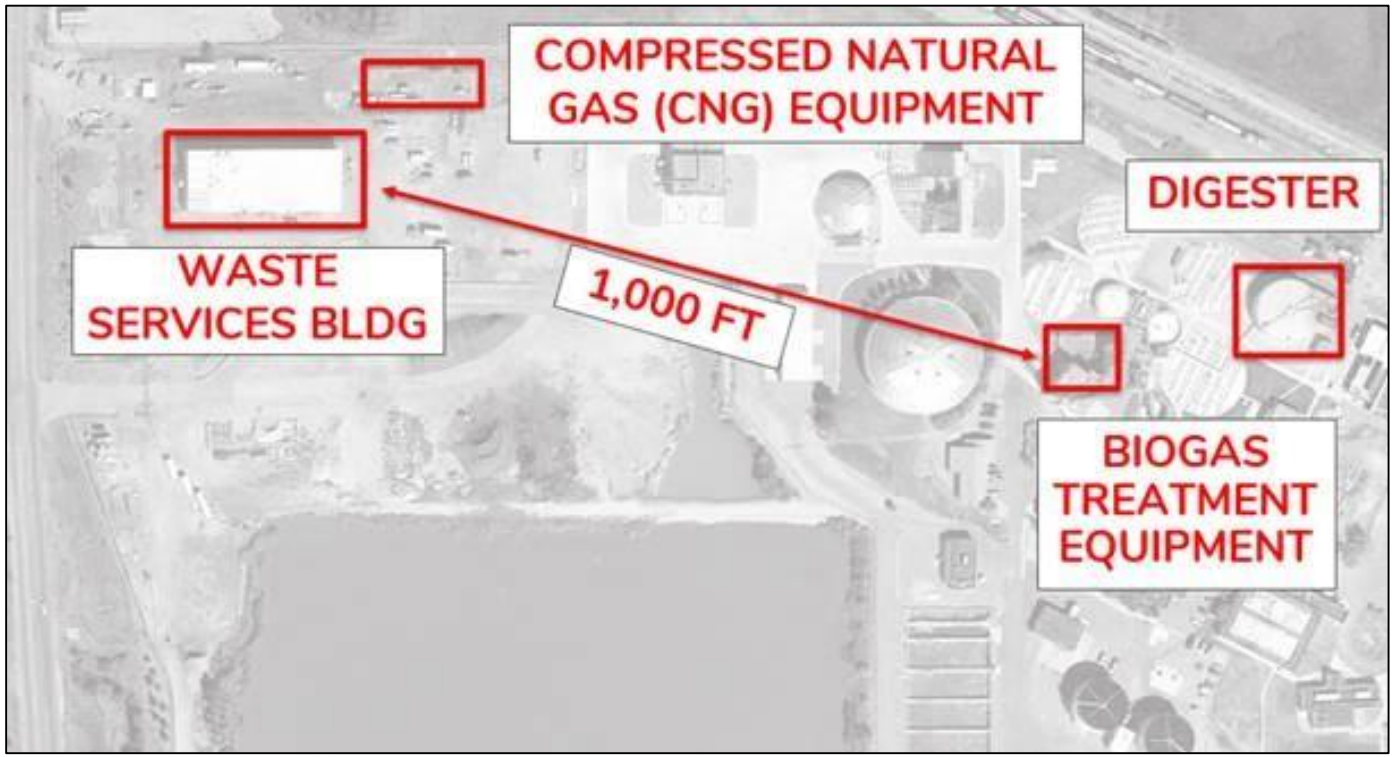
Longmont WWTP, Colorado

- ≈1,000 ft dedicated pipeline on plant property
- On-site fueling building
- Time-fill and one fast-fill dispenser for daytime fueling
- City waste haulers
  - Offsetting 100,000 gallons diesel fuel/year
  - Reducing 1000 metric tons CO_2



BioCNG™

UNISON SOLUTIONS

https://www.longmontcolorado.gov/departments/departments-n-z/water/wastewater-treatment/biogas-renewable-natural-gas

Longmont WWTP, Colorado

UNISON SOLUTIONS

https://www.longmontcolorado.gov/departments/departments-n-z/water/wastewater-treatment/biogas-renewable-natural-gas

St. Landry Parish Landfill, Louisiana—Virtual Pipeline

- Startup: March 2012
- Gas flow: 150 scfm
- BioCNG 50 & 100
- Low-pressure fuel storage vessel (120 psi)
- Fast-fill: vehicle fueling

BioCNG™

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St. Landry Parish, Louisiana

- Virtual pipeline
- Trailer with nine low-pressure storage tubes (2,580 psi)
- Fast-fill: vehicle fueling

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Manure → Biogas → Energy

- Biogas upgraded to RNG or electricity production
- Estimated opportunities of 8,100 farms (dairy & swine) suitable for a renewable energy project
- Potential of over 171 million MMBTU/year

https://www.epa.gov/agstar/agstar-market-opportunities-report

Loyd Ray Farms, North Carolina

- Swine-to-waste energy system
- 8,600 head, feeder-to-finish operation
- 50 scfm compressor system feeds a 65 kW Capstone turbine for electricity production

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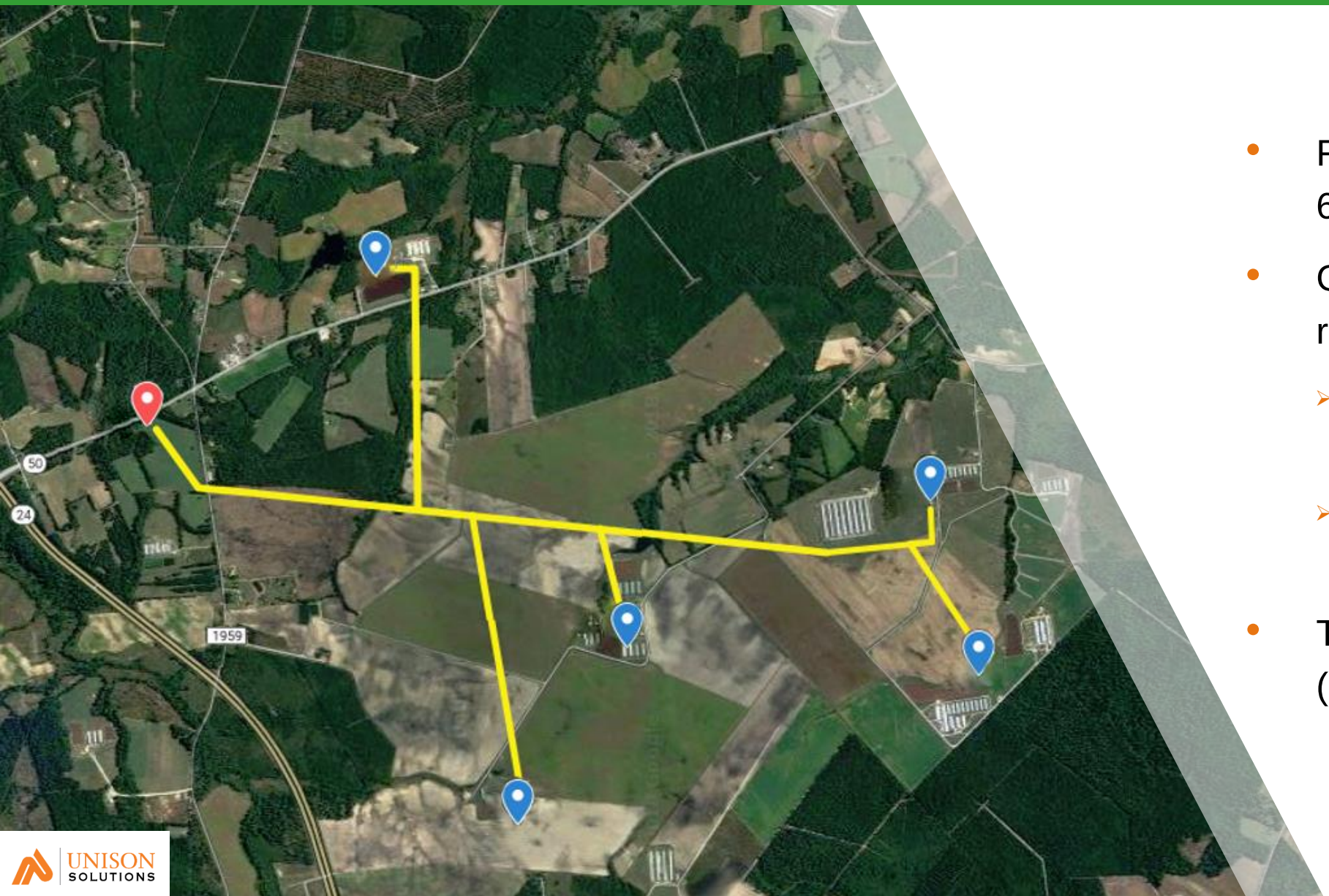
Optima KV—Key Points

- 80,000 MMBTU/year (11,000 MWh)
- 15-year agreement with Duke Energy
- Biogas upgraded to natural gas
- Injected into Piedmont Gas pipeline
- Supplies fuel to:
  - H.F. Lee Power Plant near Goldsboro
  - Sutton Power Plant in Wilmington
    - <1% of total fuel

Hog Facility at Circle K II Farms
Part of the Optima KV Project in Kenansville, NC

Dedicated Pipeline to Central Processing



- Five in-ground digesters ≈ 60,000 hogs
- Gas compression/moisture removal
  - Four 60 scfm compressor systems
  - One 140 scfm compressor system
- Two injection compressors (1,050 psig)

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Biogas Testing

Before starting a project, we recommend the following biogas tests be performed:

- **Major Components**
  - Methane
  - Nitrogen
  - Oxygen
  - Carbon dioxide
  - BTU calculation
- **Siloxanes**, by speciation
  - Up to 8 compounds common to biogas
- **Sulfur Compounds**, by speciation
  - **Hydrogen sulfide**
  - Mercaptans
  - Other sulfide compounds
- **Volatile Organic Compounds (VOCs)**, by speciation
  - Follows EPA TO-15 protocol

These compounds will also need to be tested on a regular basis to determine media change out intervals

Biogas Upgrading Summary

BIOGAS

PIPELINE INJECTION

- Equipment to meet pipeline spec/tariff
- Interconnect fees for utility
- Fuel testing to pipeline requirements

VEHICLE FUELING

- Less stringent fuel specification
- Fueling infrastructure on site
- Vehicles committed to using fuel

Thank You!

Please contact us directly to discuss your biogas upgrading requirements.

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