Aromatics Production from Cost-Advantaged Ethane Feedstock

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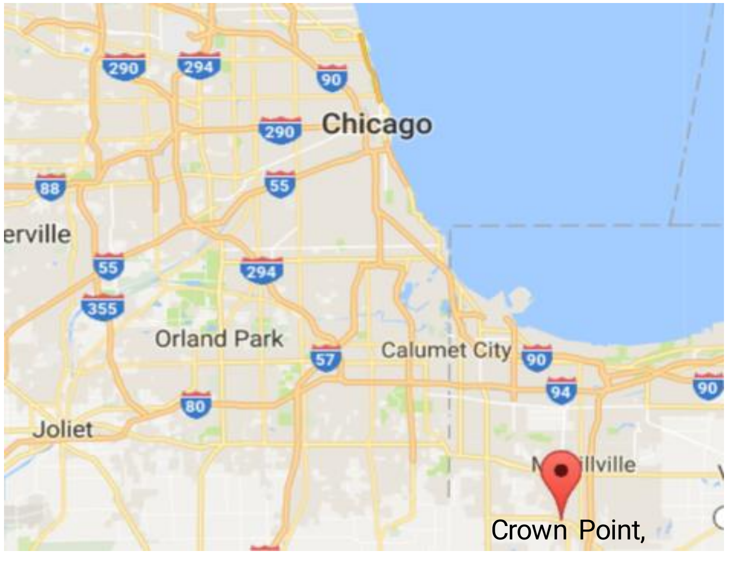
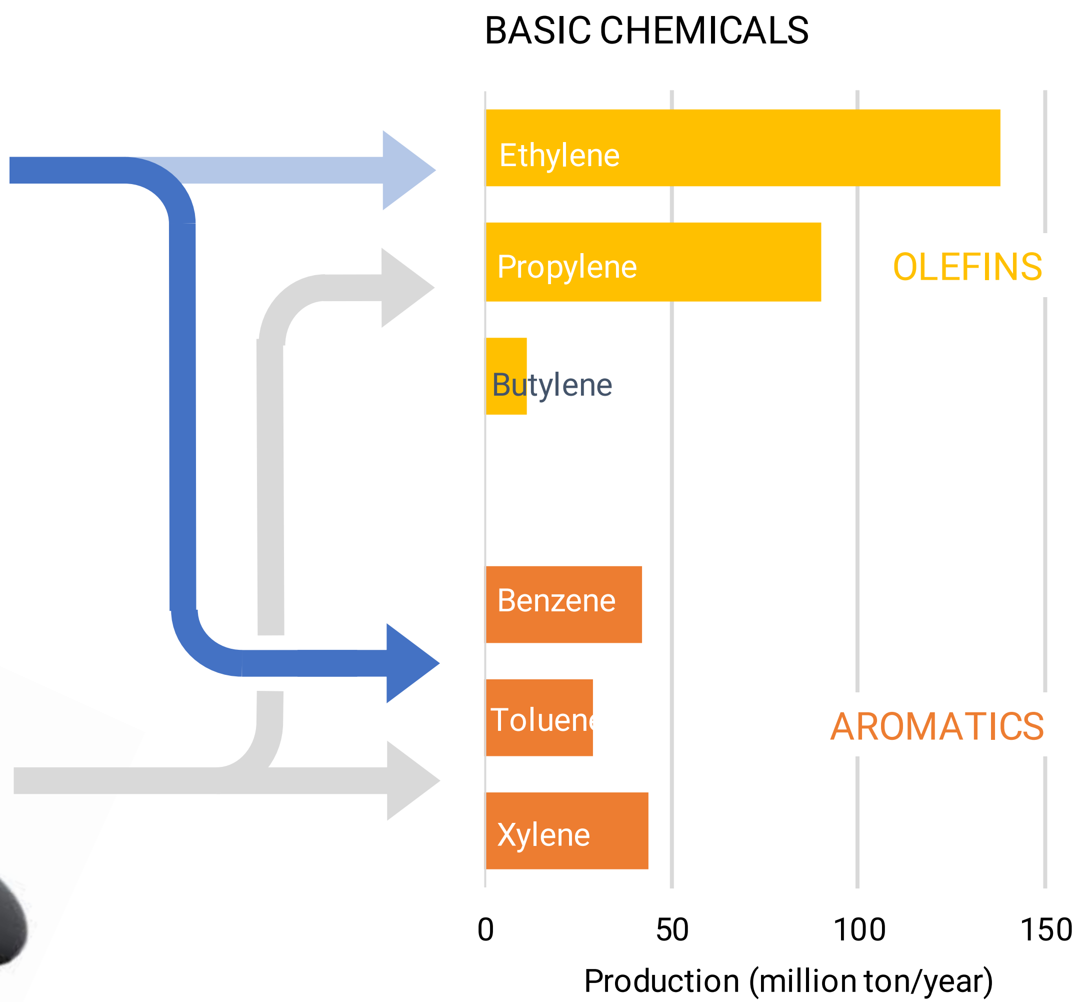
COMPANY OVERVIEW, KEY FACTS

- Start-up for commercializing "ethane-to-aromatics" process technology
- Incubated by Oh Pharmaceutical Co., Ltd.in 2015. Incorporated in 2017
- Co-Founders: Jin Ki Hong (President), Gibum Oh (CEO)
- Location: Purdue Technology Center in Crown Point, Indiana
- Lab-scale catalyst development
- Commercial-scale reactor and process development.
- 4 US patents granted



ETHANE GAS FOR AROMATICS PRODUCTION



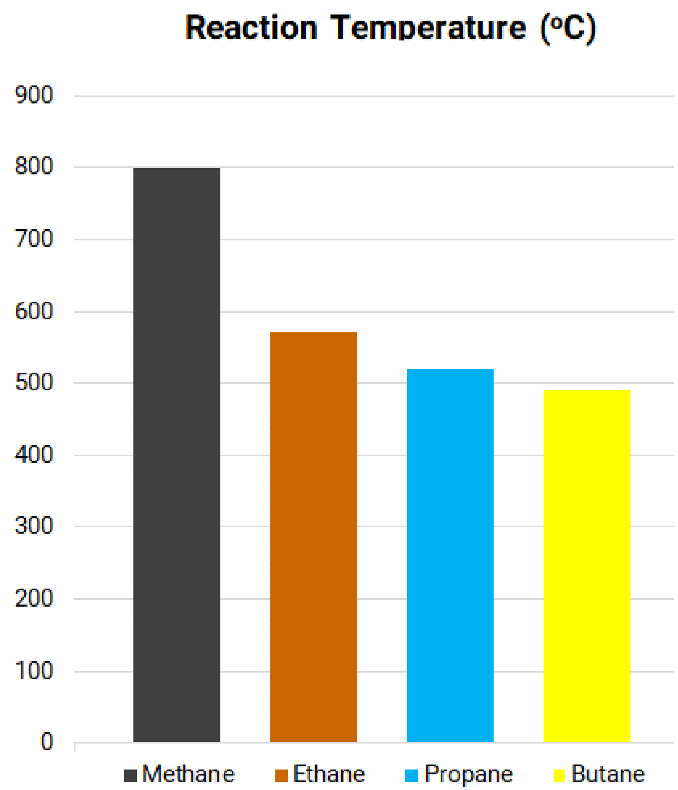
ETHANE AS A COST-ADVANTAGED FEEDSTOCK

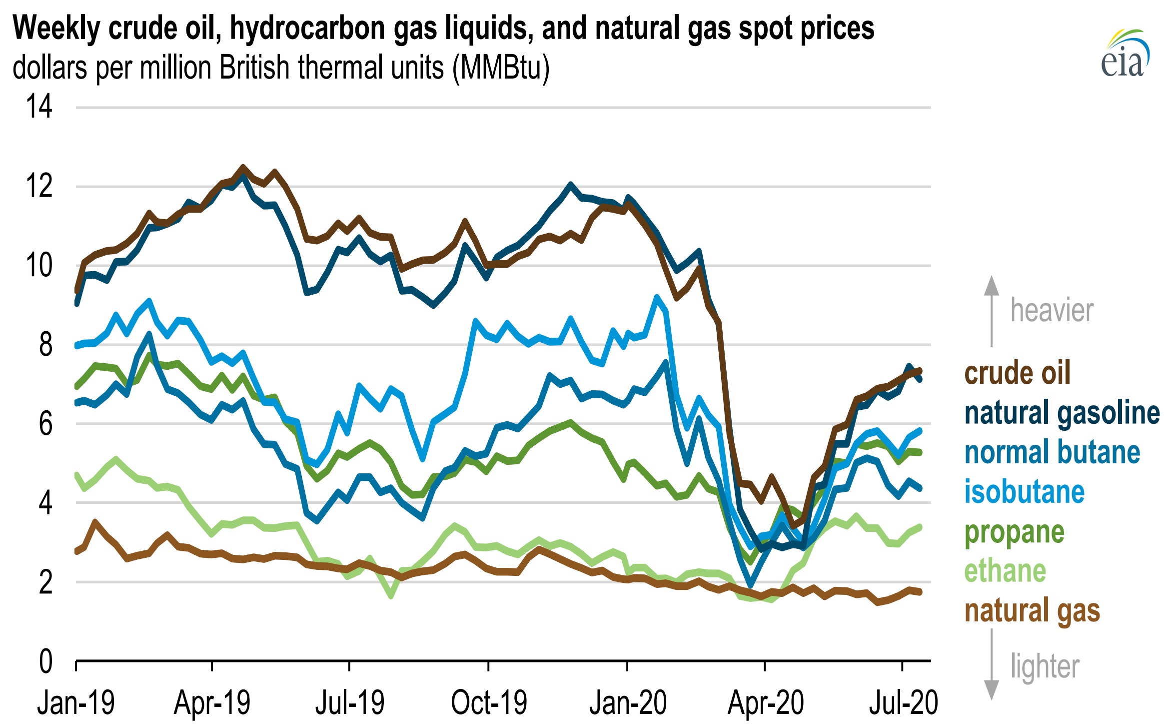
- 2nd largest component of US shale gas
- Ethylene production as the only outlet for its chemical value. Limited demand
- Low ethane price does not justify ethane recovery cost (fractionation and transportation)

- Significant amount of ethane is not recovered (simply burned along with methane for its heating value)
- Ethane's chemical value is lost in combustion process

ETHANE AS A COST-ADVANTAGED FEEDSTOCK

- Ethane is way more chemically active than methane
- Ethane is a cost-advantaged feedstock ($2-4/MMBtu Ethane vs $10-12/MMBtu Naphtha)



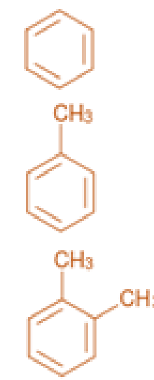


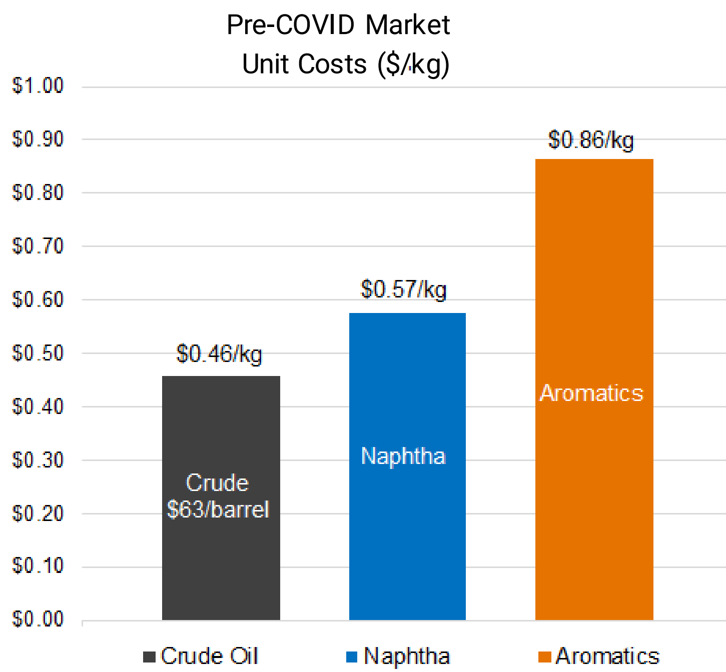
FEEDSTOCK COST FOR AROMATICS

Existing Technology

- Catalytic Reforming
- Steam Cracking

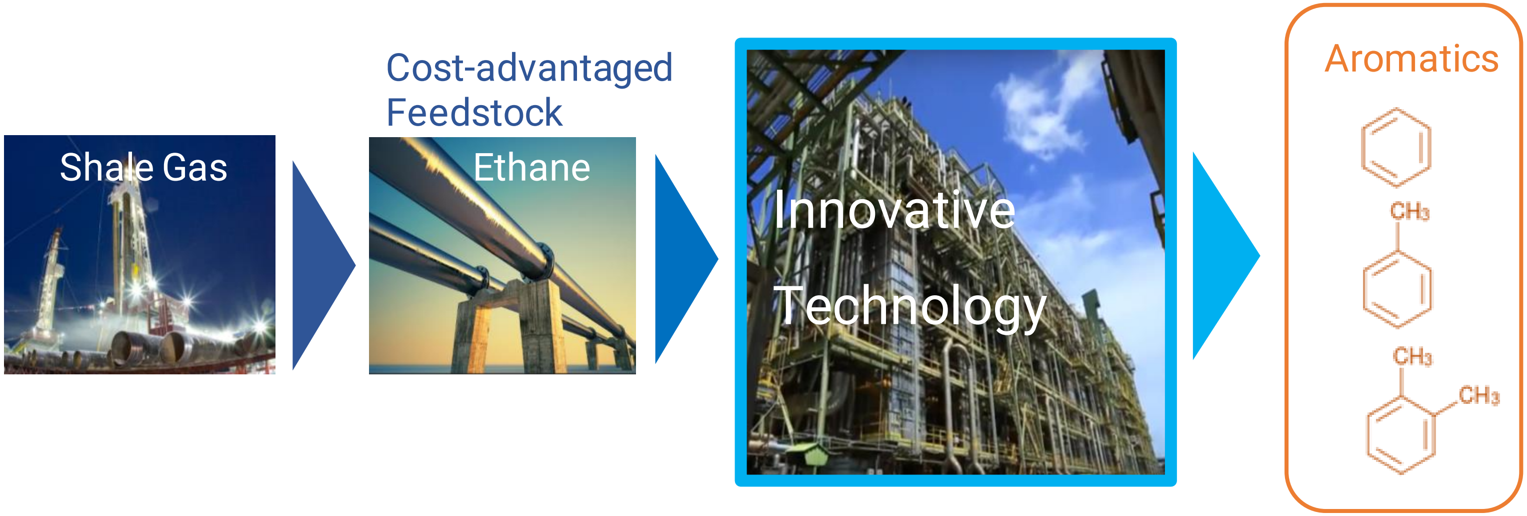
Aromatics

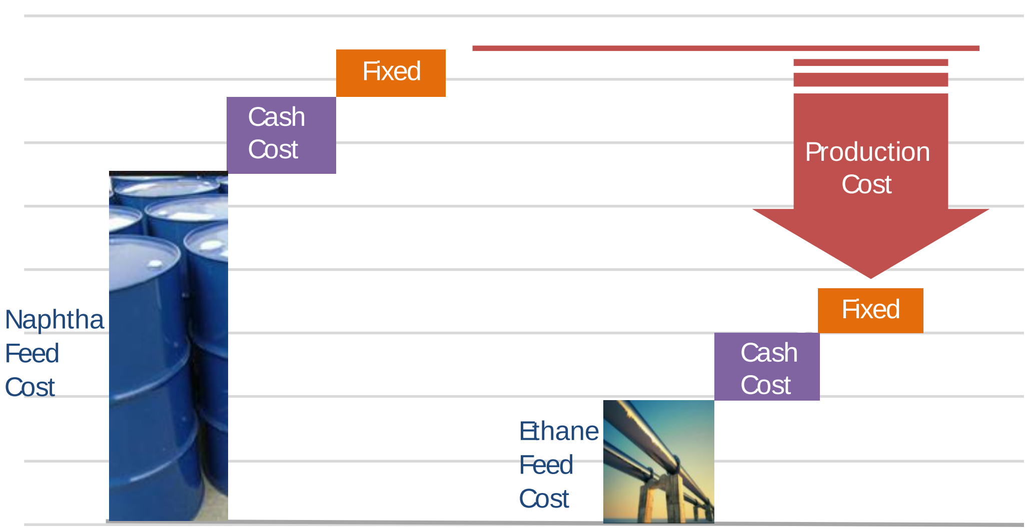




- Aromatics produced from naphtha (catalytic reforming or steam cracking)
- Naphtha feedstock cost accounts for more than 2/3 of aromatics production cost
- Slim operation margin
- Limited space for cost reduction
- New feedstock with cost-advantage is sought

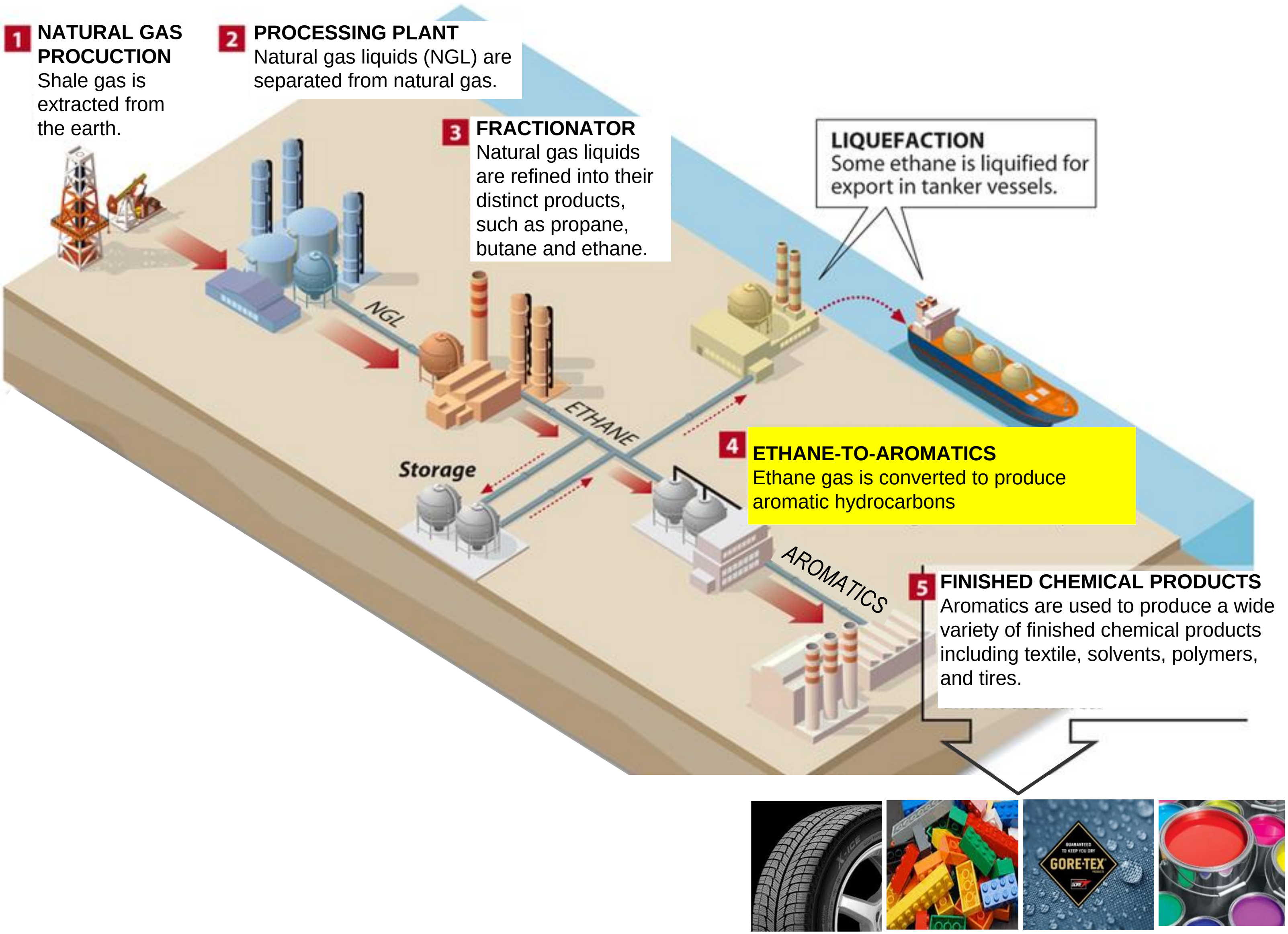
AROMATICS PRODUCTION COST REDUCTION





- Ethane from US shale gas as a new feedstock for aromatics production
- Ethane at a fraction of naphtha cost as a result of shale gas production
- Cost-advantaged ethane feedstock creates clear path for supernormal market power

THE BIG PICTURE



Credit: PAUL HORN / InsideClimate News

THE MARKET OPPORTUNITY

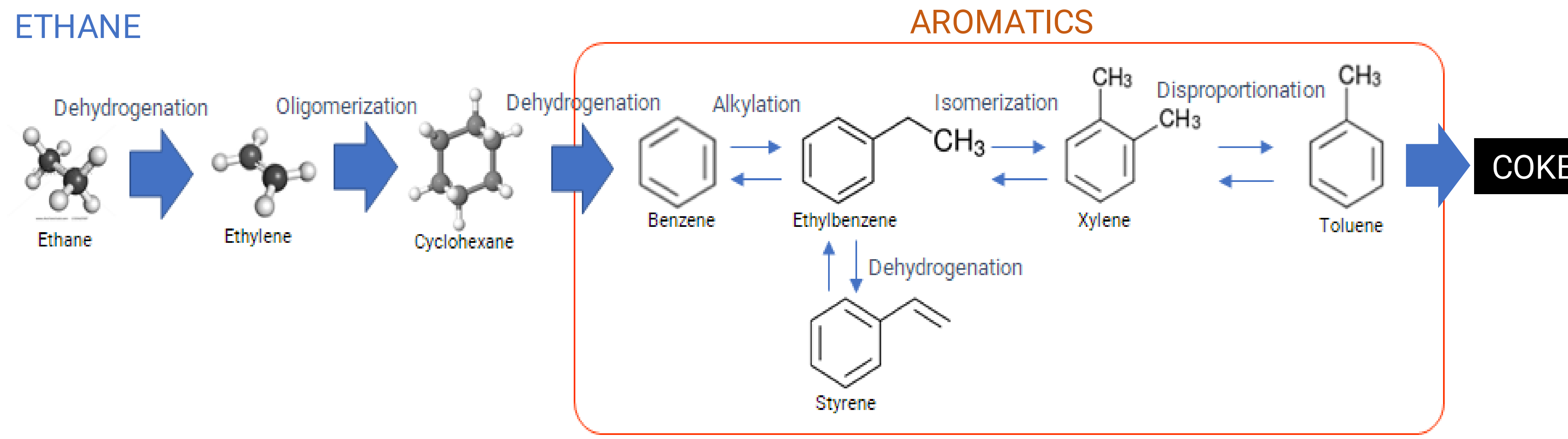
Basic Chemicals

- Aromatics
  (benzene, toluene, xylene)
- Olefins
  (ethylene, propylene, butylene)
- Methanol
- Chloro-Alkali
  (chlorine, caustic soda)
- Ammonia

Global Aromatics Market Approximately $200B/Year with 4% Annual Growth

North America Aromatics Market > $35B/Year

"ETHANE-TO-AROMATICS" CHEMISTRY



REACTION ENGINEERING FOR AROMATICS YIELD

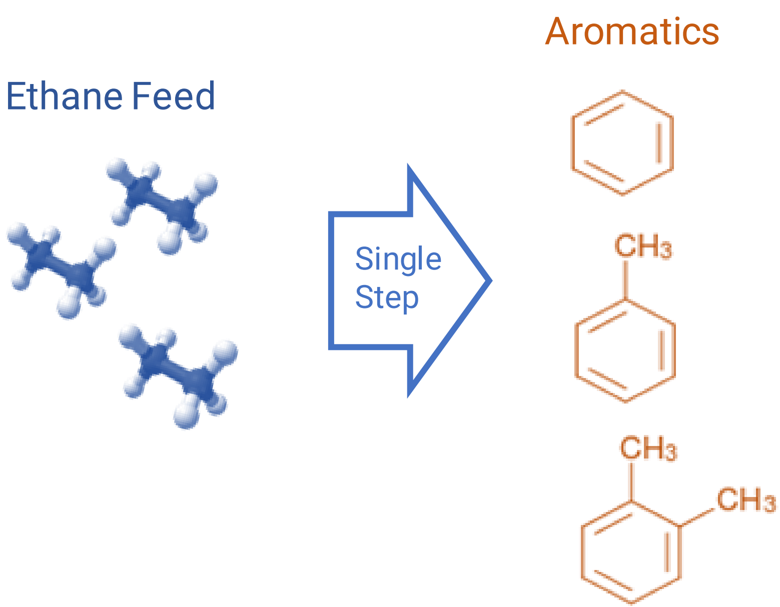
- Maximize ethane feed conversion (minimize separation load and recycle load)
- Minimize coke production (minimize catalyst regenerations and maximize production cycle time)

STRONG ENDOTHERMIC REACTION

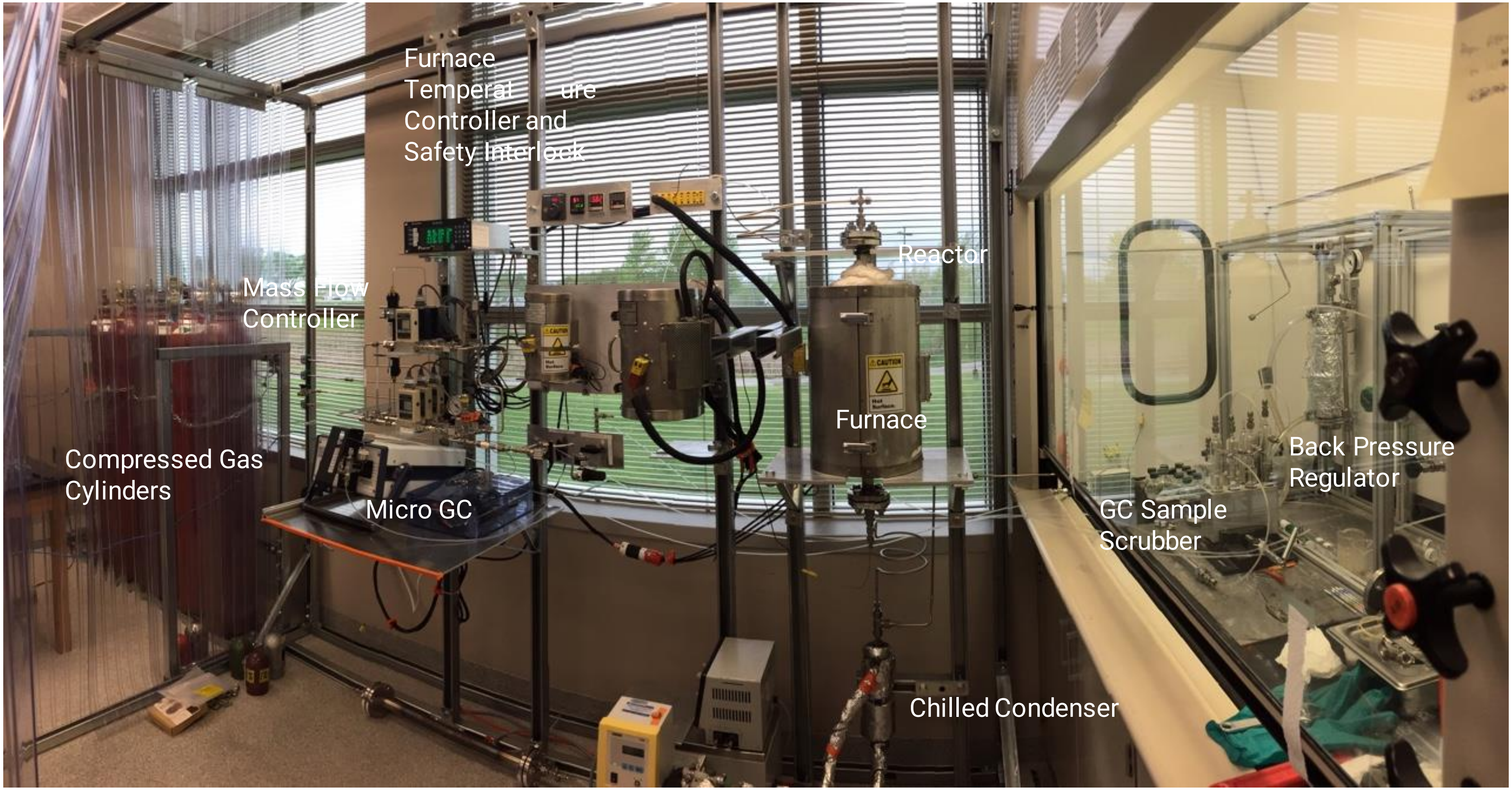
- Endothermic requirement as strong as ethane cracking
- $65MW_{th}$ for commercial-scale plant (500 kilo-ton aromatics production per year)

TECHNICAL HURDLES

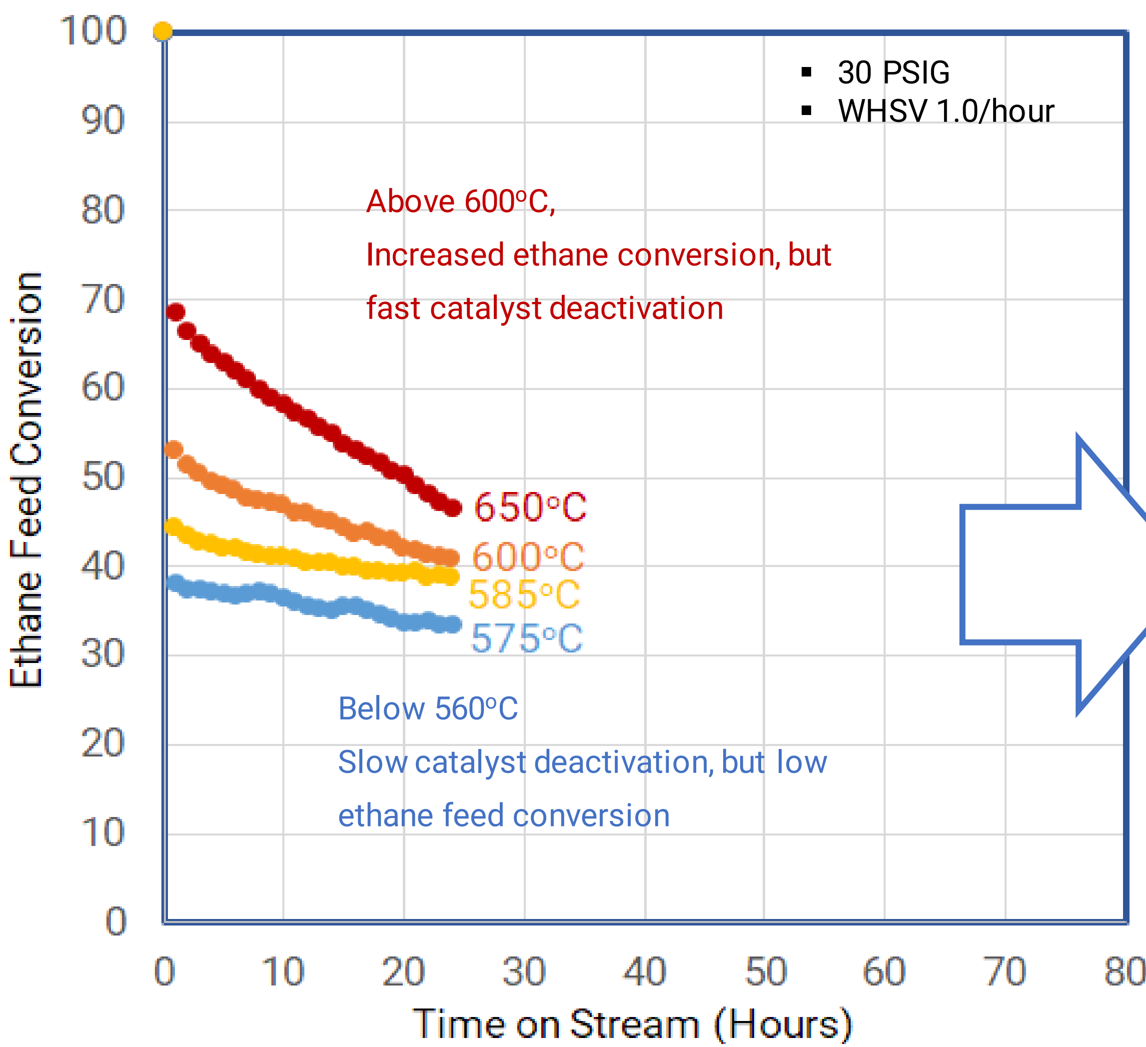
- Two step conversion (through ethylene intermediate) is inefficient, complex, and costly
- Huge reaction heat requirement (as huge as ethane cracking) at commercial-scale production
- Stringent reaction temperature window (560°C – 600°C) for commercially attractive feed conversion, product selectivity, and catalyst cycle-time
- Continuous aromatic hydrocarbons production with catalyst regeneration
- No reactor/process design available that addresses the three technical hurdles described above



KAINOS TECH LAB-SCALE TEST SYSTEM



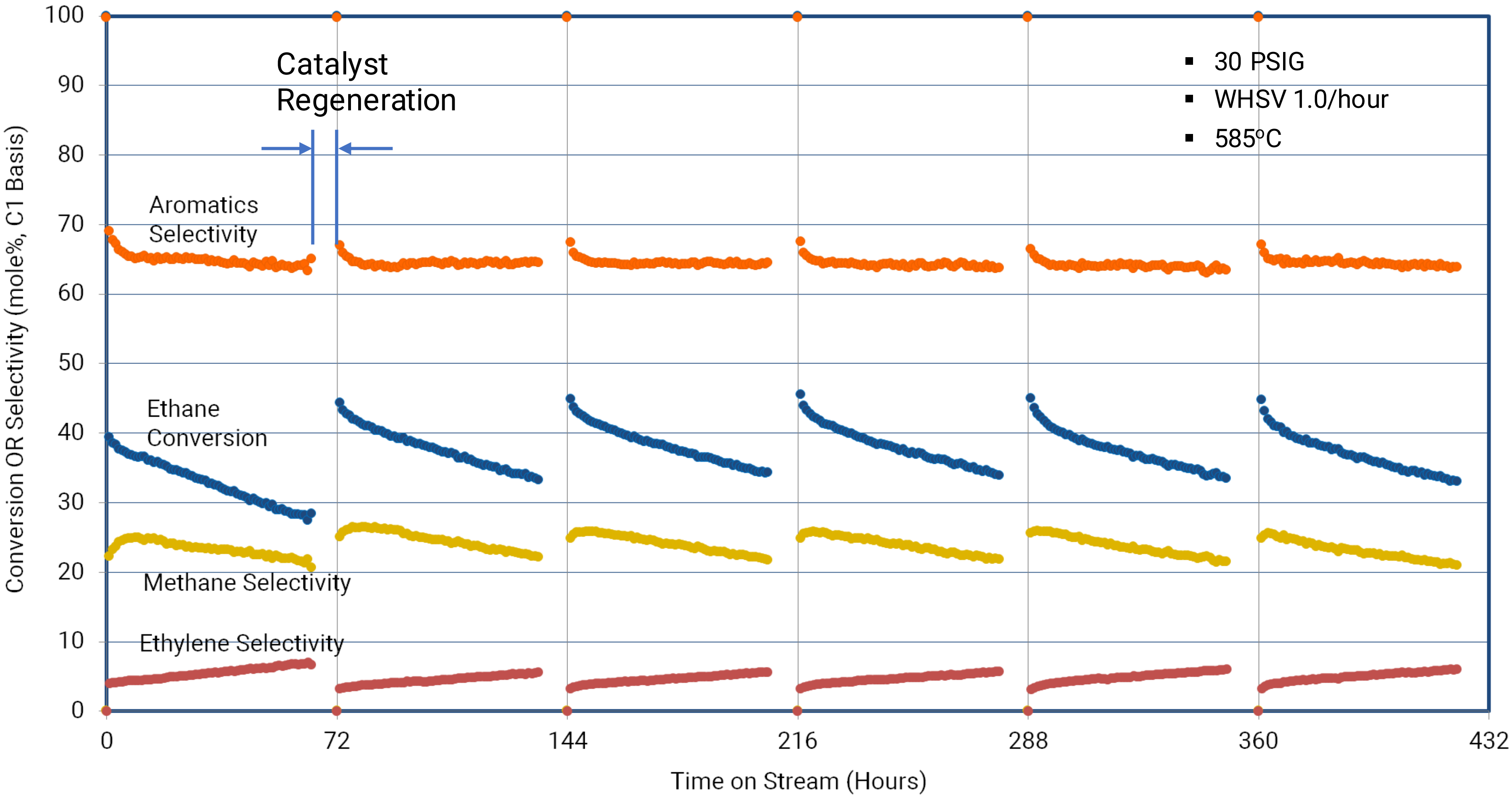
REACTION TEMPERATURE REQUIREMENT



Very narrow temperature window (560°C – 600°C) for ethane feed conversion and catalyst deactivation rate

CATALYST REGENERATION, 6 REPEAT CYCLES

- Lab-scale (10gram catalyst loading) fixed bed reactor. Single pass run (no recycle stream)
- Highly regenerable catalyst performance
- No sign of catalyst performance loss through repeat cycles



DIFFERENTIATED SOLUTION AND IP

- Single-step aromatics production from ethane
- Differentiated reactor/process design for scalability, development cost/schedule, and process economics
- Lab-scale catalyst performance demonstrated for commercial viability (over 150 catalyst samples prepared and over 20,000 hours of catalyst performance evaluated)
  - Catalyst productivity – more than 6 kg aromatics production per kg catalyst per day
  - Continuous aromatics production for 3 days or longer before catalyst regenerations
  - No sign of catalyst performance loss during 6 repeated cycles (totally 18 days). One cycle (3 days) include 65 hours of continuous aromatics production and 7 hours of catalyst regeneration
- 4 patents for radically differentiated and scalable reactor and process design
  - US 10,934,230
  - US 10,640,436
  - US 10,640,434
  - US10,087,124

REACTOR/PROCESS DESIGN

CATALYST PERFORMANCE DEMONSTRATED

1. Small scale (or, ideal condition)
2. Small reaction heat requirement
3. Uniform temperature profile

Scale Up

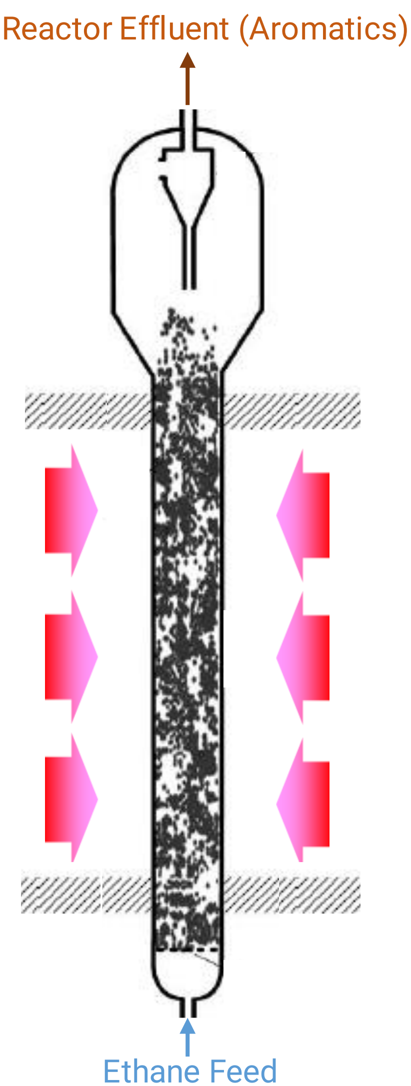
REACTOR/PROCESS (SCALE-UP) REQUIREMENTS

1. Heat supply mechanism at scale (Strong endothermic)
2. Uniform (narrow) temperature (Unreactive feed & reactive product)
3. Elevated pressure for conversion & cycle time
4. Continuous production with catalyst regenerations

REACTOR/PROCESS (SCALE-UP) DESIGN

1. Internally circulating fluidized bed reactor for catalyst bed temperature
2. Fired furnace for heat supply
3. Multiple reactors (500 barrels/day or higher) arranged as a group in a furnace
4. Multiple furnaces (modular) for swing mode operation

FLUIDIZED BED REACTOR INTEGRATED WITH FIRED FURNACE



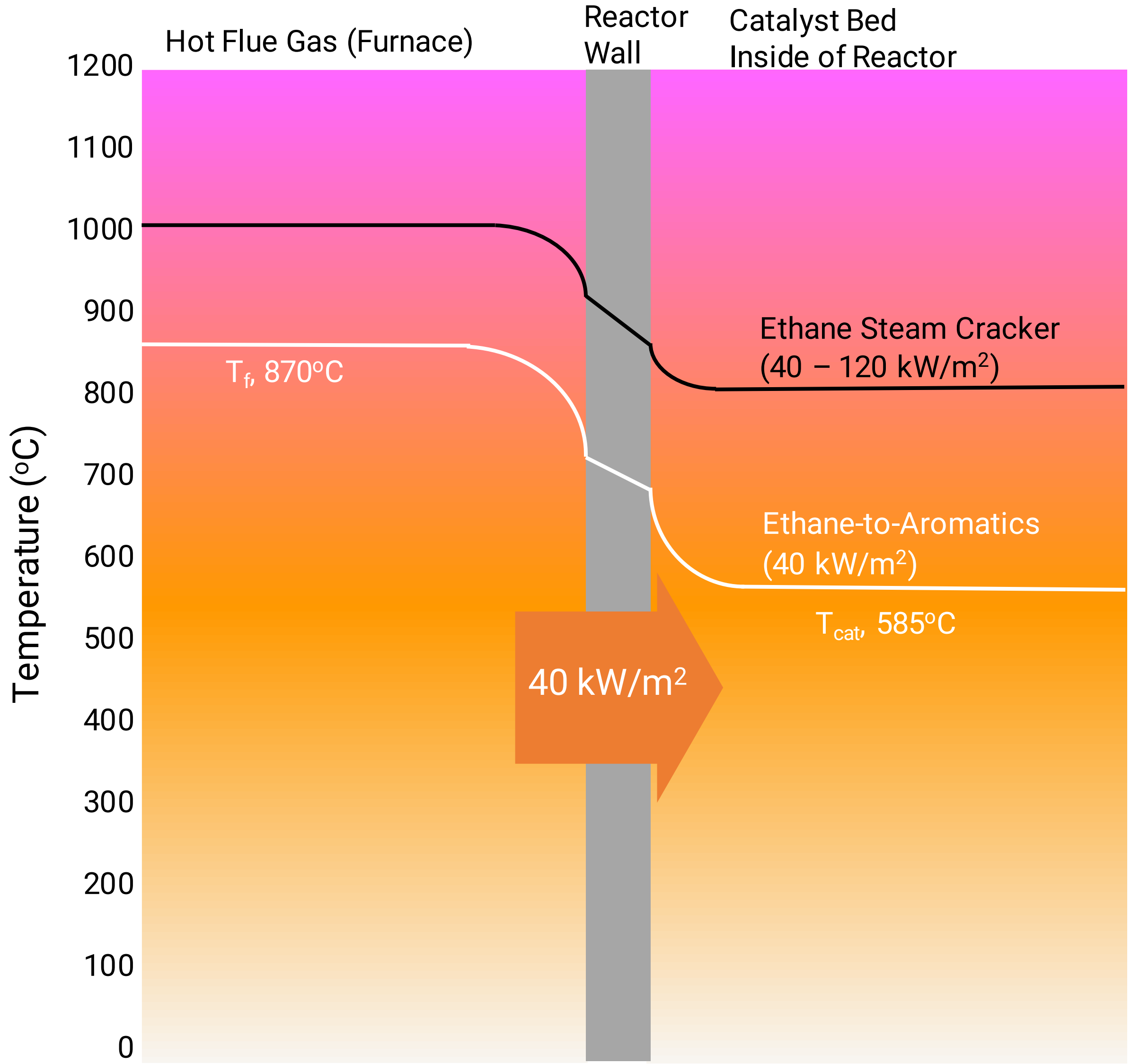
THERMAL ENERGY BALANCE AROUND THE REACTOR

- Ethane feed rate and preheating temperature
- Catalyst bed (or reaction) temperature
- Ethane feed conversion and product selectivity
- Catalyst bed volume
- Reactor wall area, wall thickness, and wall thermal conductivity
- Flue gas temperature
- Convectional heat transfer (inside and outside the reactor)
- Radiant heat transfer (outside the reactor)

LIMITATION IN REACTOR SCALE-UP

- Reactor model predicts reactor scale-up is limited by reactor wall area
- Reactor wall area does not grow as much as reactor volume with scale-up (wall area-to-volume relationship).
- Maximum production rate of 1,000 barrels/day aromatics per reactor

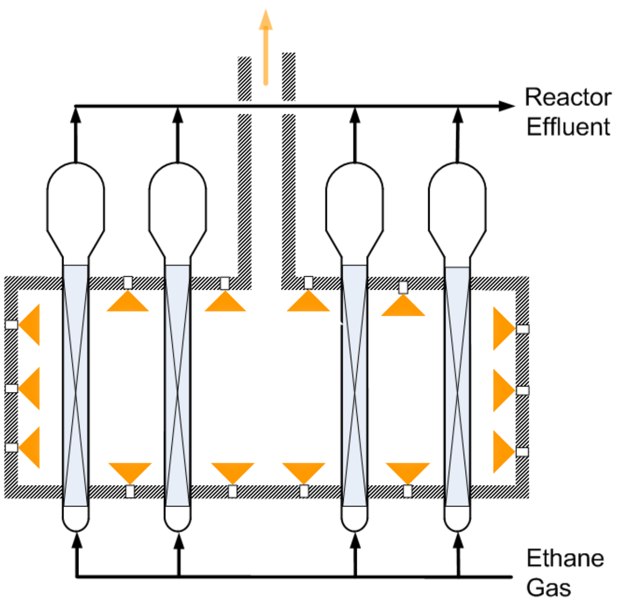
500 BARREL/DAY REACTOR - RADIAL TEMPERATURE PROFILE



PROCESS DESIGN

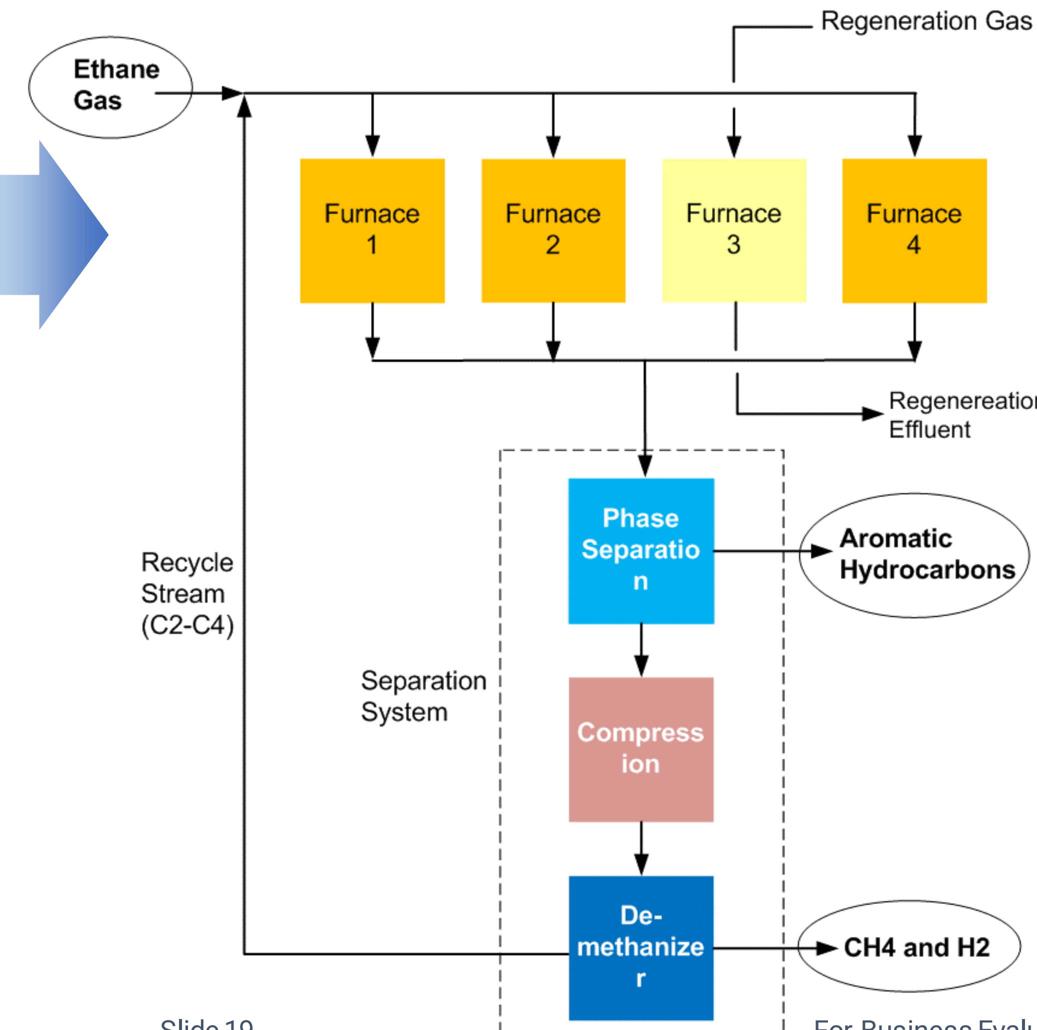
MULTIPLE REACTORS IN A FURNACE

- Multiple reactors arranged as a group in the furnace (scalable production)



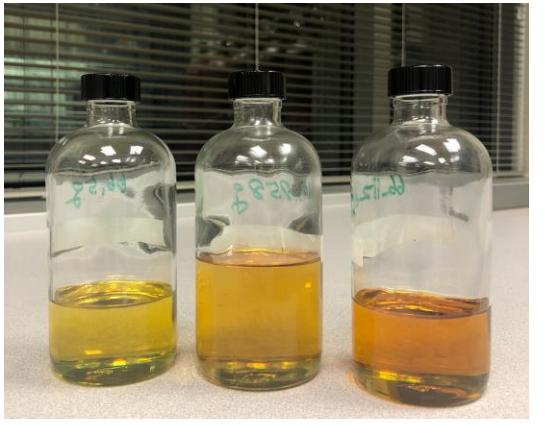
MULTIPLE FURNACES FOR SWING MODE OPERATION

- Multiple furnaces for swing mode operation (continuous production with catalyst regenerations)



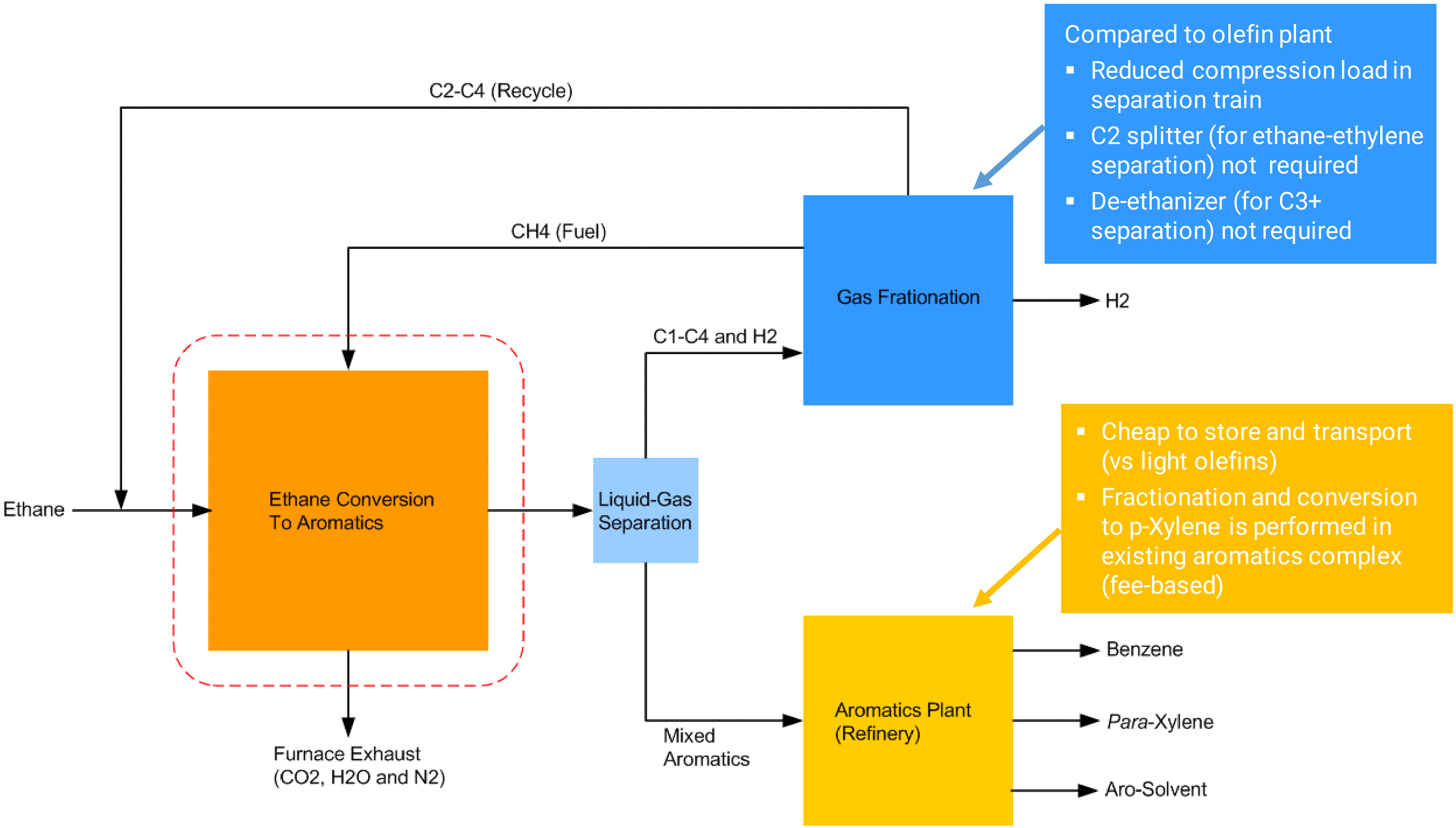
AROMATICS PRODUCT

- 100% Aromatics. Extractive distillation for aromatics recovery from paraffins/olefins is NOT required
- No Impurities (S, Cl, O, N and Metals) : No need for hydrotreating
- Benzene 30-32 wt%, Toluene 34-39 wt%, Xylene 8-12 wt%, Balance C9+
- C6-C8 aromatics approximately 80 wt%

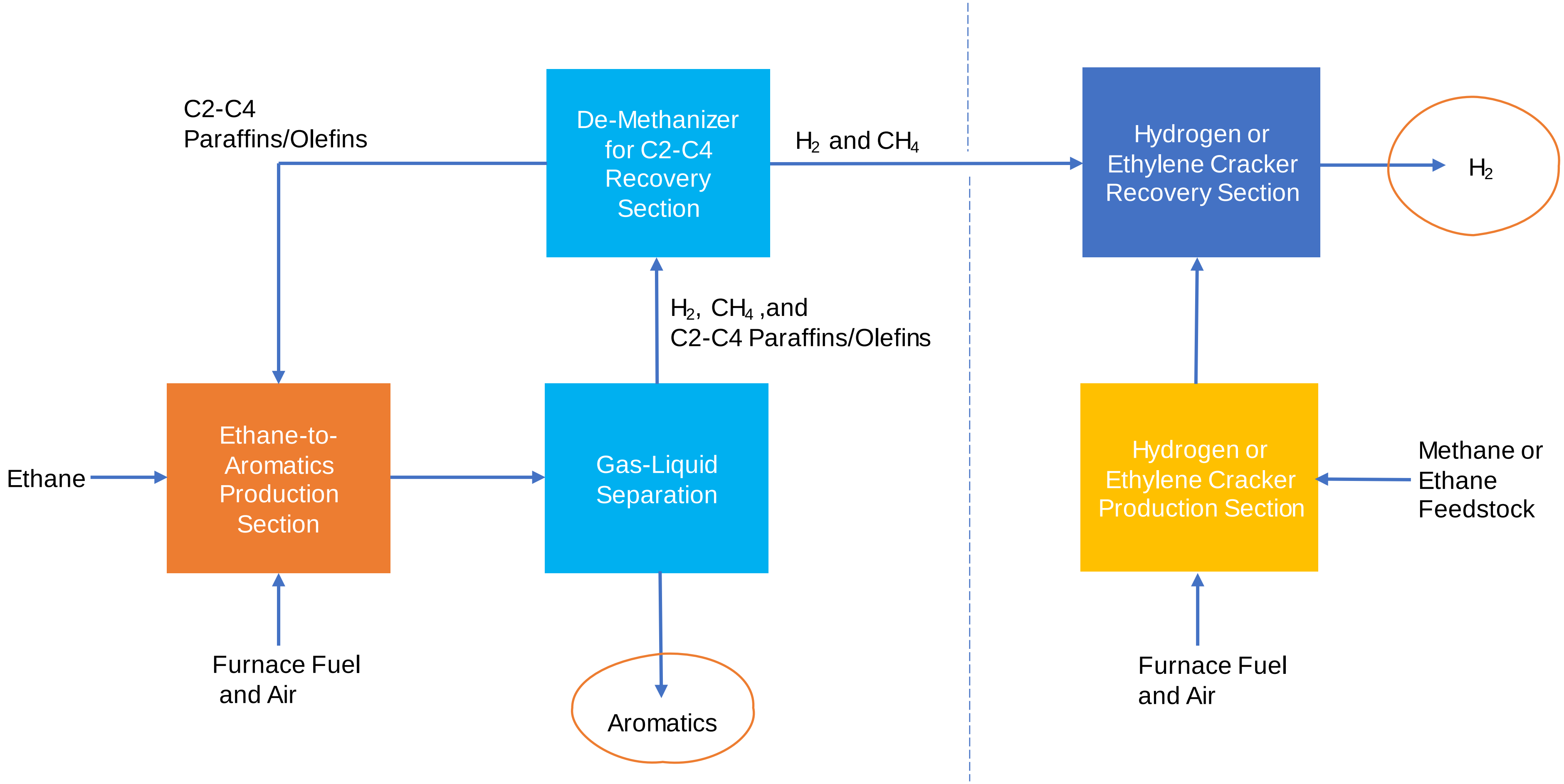


Component	Pyrolysis Gasoline	Reformate	Kainos Tech
Total Aromatics	60	54	100
Naphthenes	High	Low	0
Olefins	High	High	0
Paraffins	Low	High	0
Sulfur	Up to 1,000 ppm	< 1 ppm	0

HIGH-LEVEL BLOCK FLOW DIAGRAM



INTEGRATION WITH HYDROGEN OR ETHYLENE (OR OTHER PETROCHEMICAL/REFINERY) PLANT



500 KILOTONS/YEAR PLANT ECONOMICS

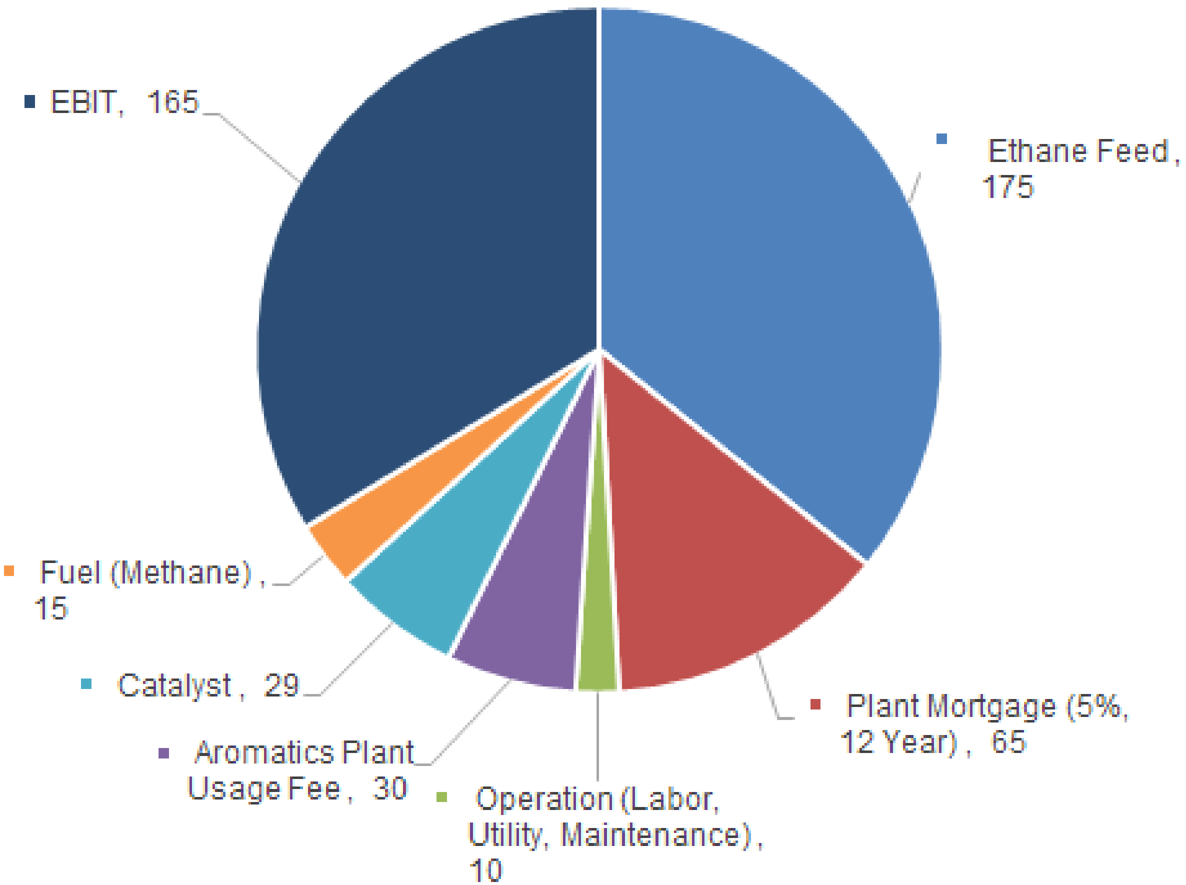
- Preliminary Estimation
- Plant cost at $576MM (stand-alone plant, green field project)
- EBIT at $165MM/year

Mass Balance, kg/hour

Feed	Ethane	90,763
Product	H2	6,792
	Methane	26,893
	Benzene	18,179
	Toluene	22,400
	Xylene	6,948
	EB	1,100
	Styrene	227
	C9+	8,223

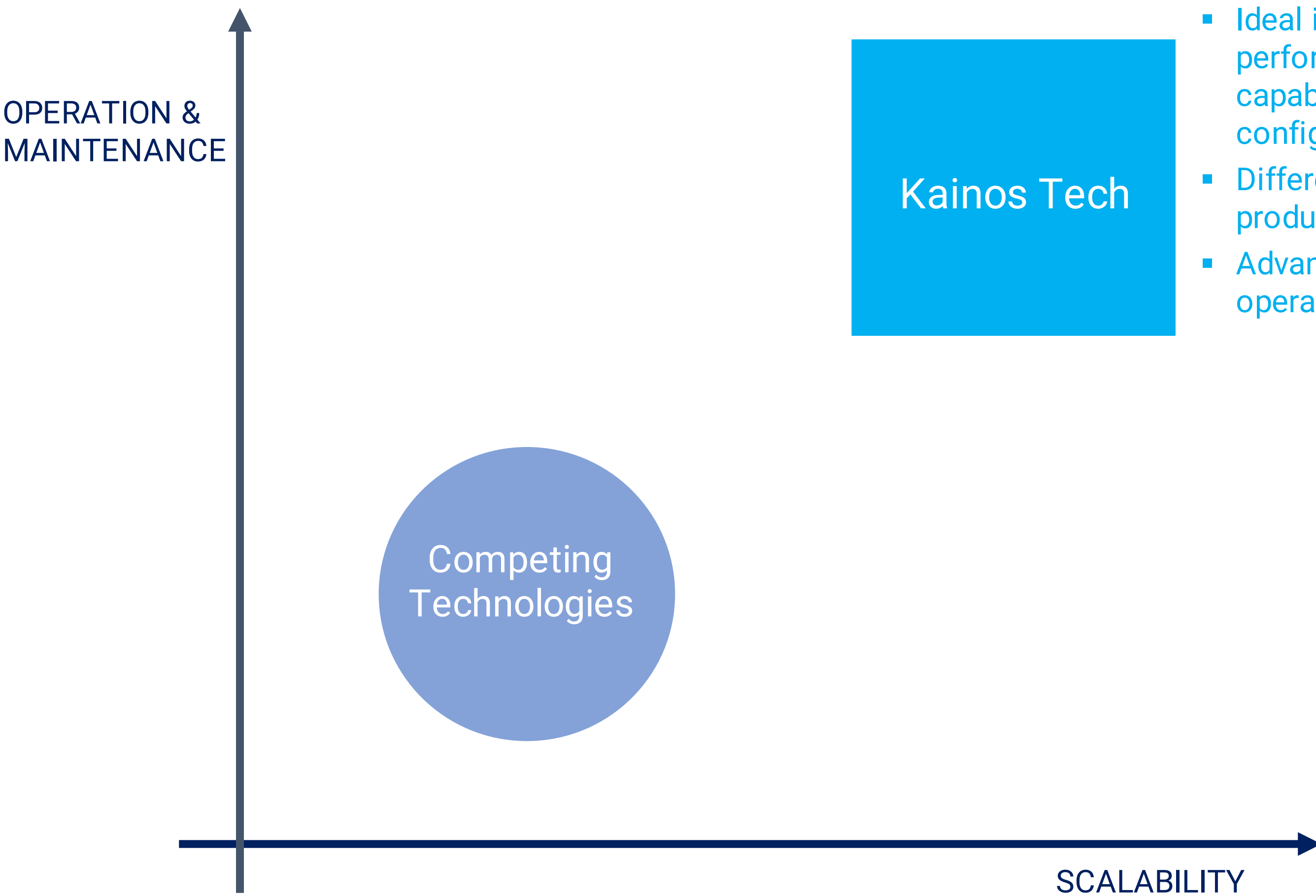
Pre COVDID-19 Market Data

Benzene, $/kg	0.75
p-Xylene, $/kg	0.90
Arosolvent, $/kg	0.75
H2, $/kg	1.00
Fuel (CH4), $/kg	0.13
Ethane Feed, $/kg	0.22
Plant Cost, $MM	576
Aromatics Plant Usage Fee, $/kg	0.075



THE COMPETITION

- Competitors are chemical/petrochemical R&D organizations
- Competitors are in laboratory-scale R&D stage
- No pilot-, demo- or commercial-scale development announced
- Kainos Tech established strong IP position



- Ideal integration of catalyst performance, reactor capability and process configuration
- Differentiated scalable production technology
- Advantaged in terms of operation & maintenance

SUMMARY

TECHNOLOGY

1. Commercially attractive catalyst performance and lifetime
2. Radically differentiated reactor design (endothermic and ideal temperature profile requirements) for commercial-scale reactor (1,000 barrels aromatics/day)
3. Scalable process design

ECONOMICS

1. Compelling economics and due to cheap feedstock and aromatics yield
2. Ideal for integration with hydrogen (SMR) or olefin plant
3. Reduced development cost, schedule, and risk. Scale-up to 500–1,000 barrels/day reactor and multiply for commercial deployment