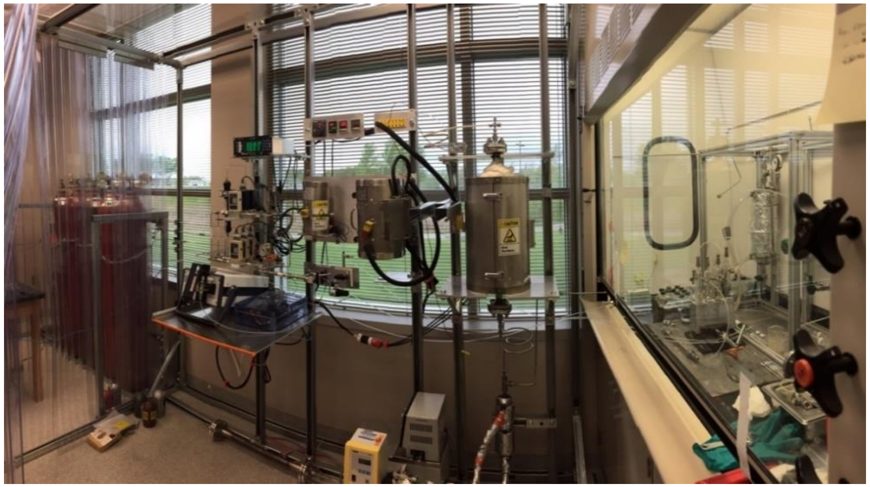
Aromatics Production from Cost-Advantaged Ethane Feedstock

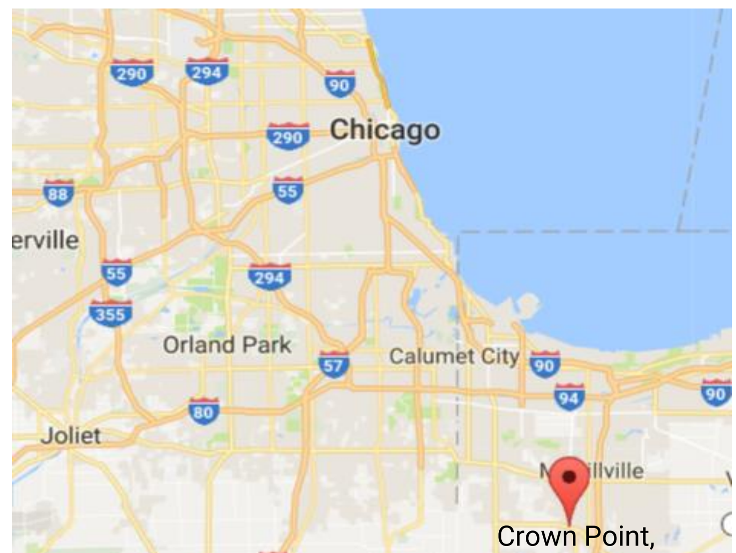
Jin Ki Hong, PhD
Kainos Tech Incorporated
9800 Connecticut Dr.,
Crown Point, INDIANA 46307
USA

http://www.kainostechinc.com
jkhong@kainostechinc.com
+1 (720) 341-8633

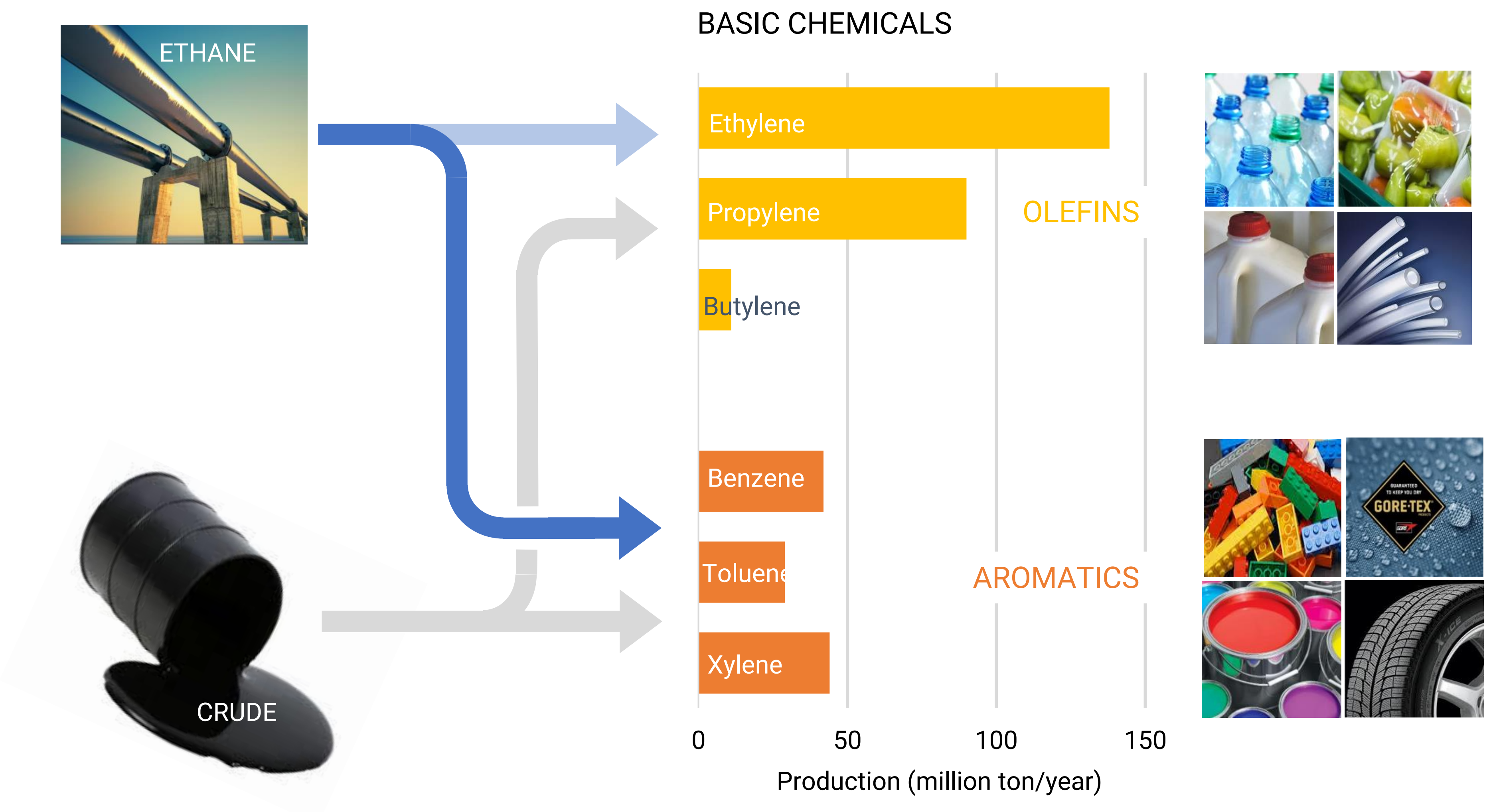
COMPANY OVERVIEW, KEY FACTS



- 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

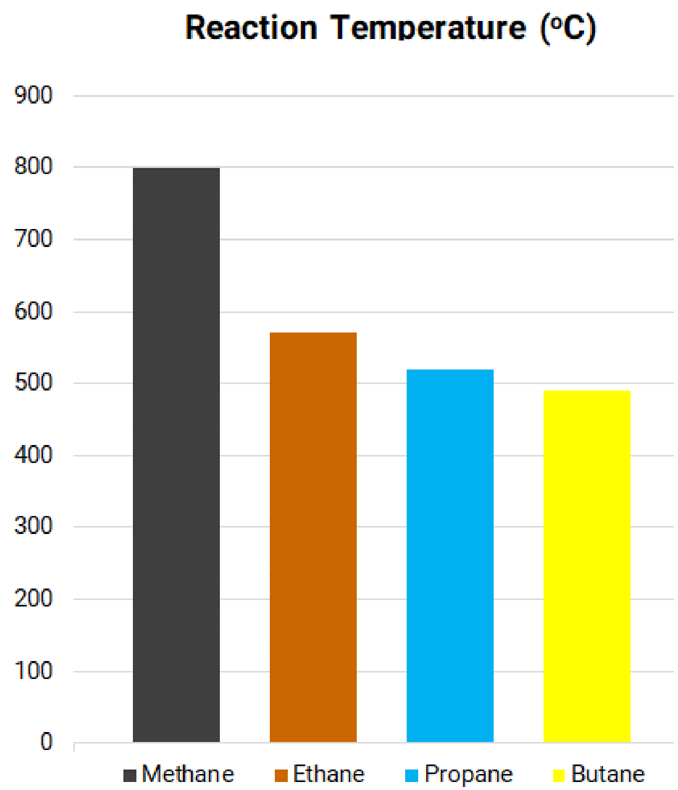


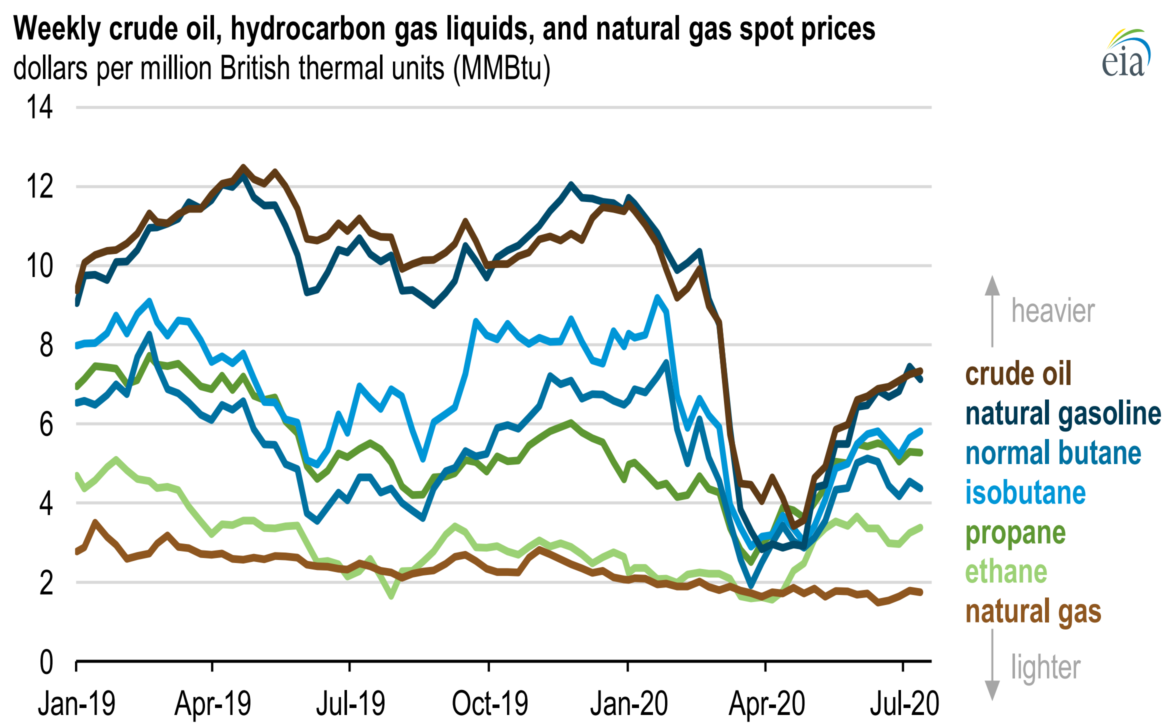
ETHANE AS A COST-ADVANTAGED FEEDSTOCK

- 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)



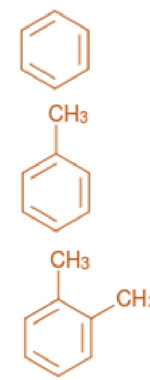


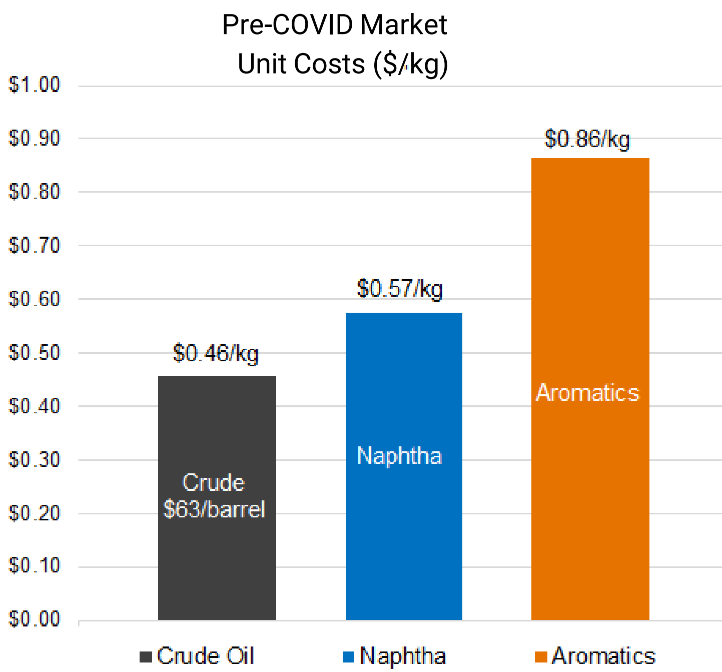
FEEDSTOCK COST FOR AROMATICS

Existing Technology

- Catalytic Reforming
- Steam Cracking

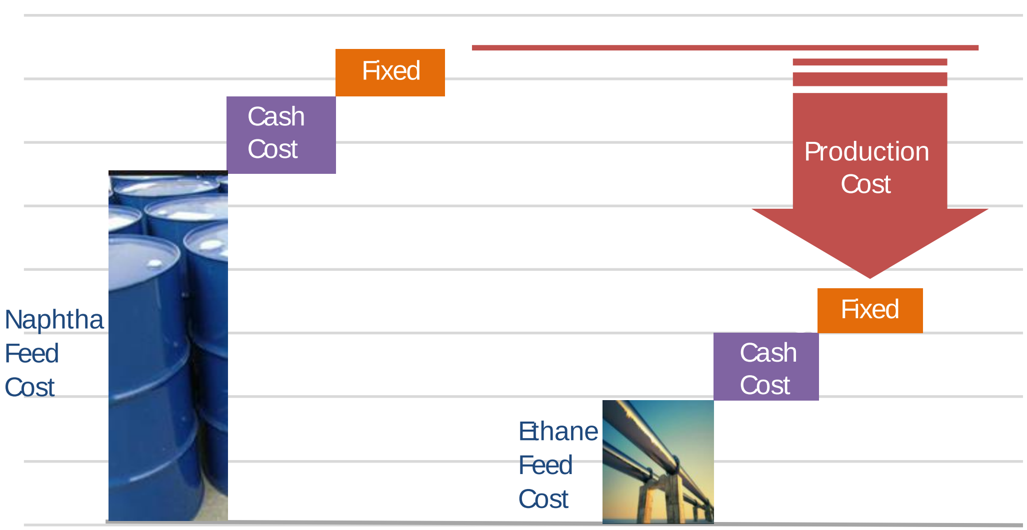
Aromatics





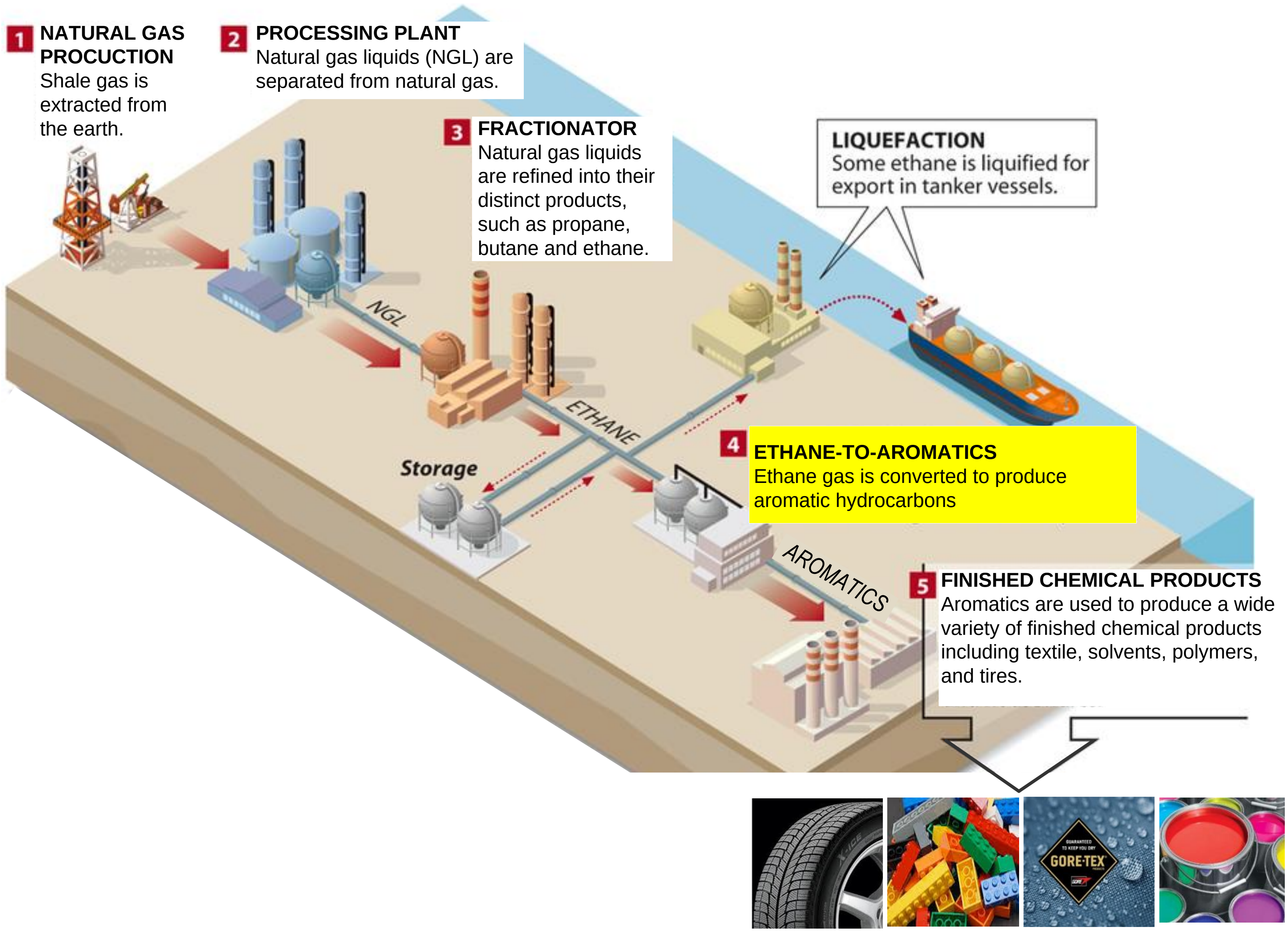
- Aromatics produced from naphtha (catalytic reforming or steam cracking)
- Naphtha feedstock cost accounts for more than 2/3 of aromatics production cost
- Slim operation margin
- Limited space for cost reduction
- New feedstock with cost-advantage is sought

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

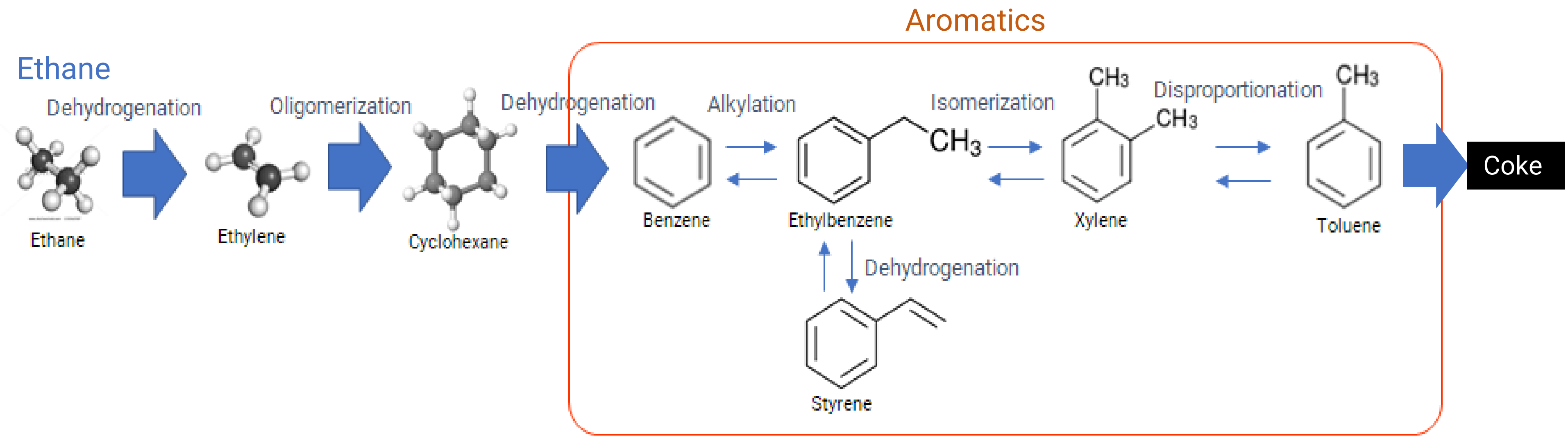
Basic Chemicals

- **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

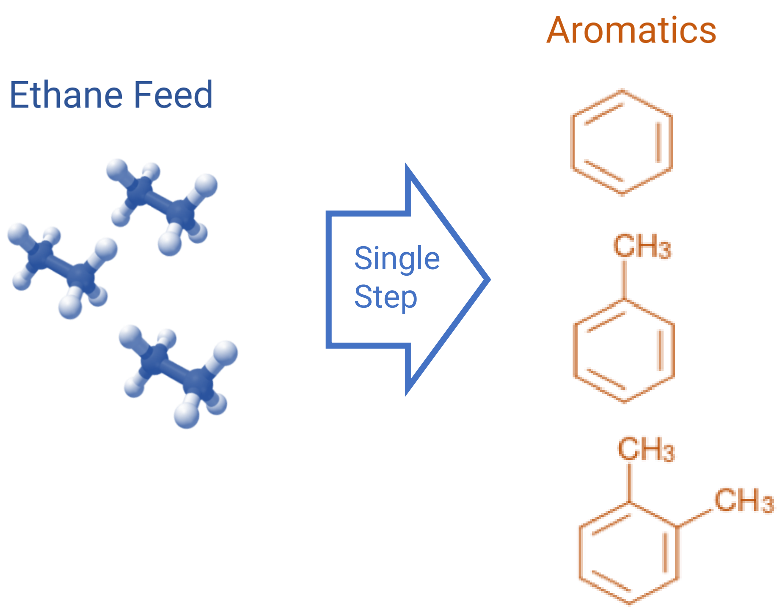
- Maximize ethane feed conversion (minimize separation load and recycle load)
- Minimize coke production (minimize catalyst regenerations and maximize production cycle time)

STRONG ENDOTHERMIC REACTION

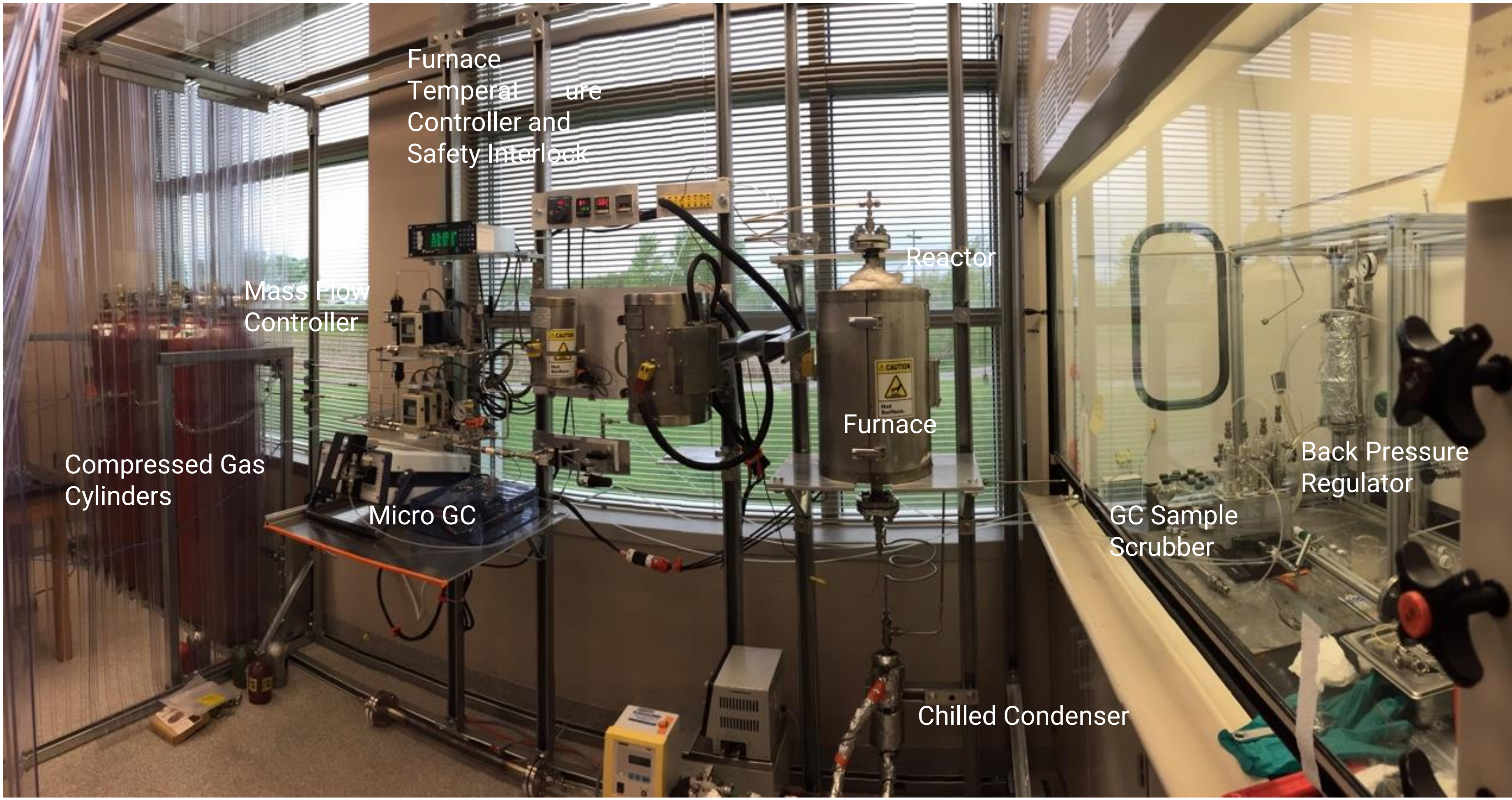
- Endothermic requirement as strong as ethane cracking
- $65MW_{th}$ for commercial-scale plant (500 kilo-ton aromatics production per year)

TECHNICAL HURDLES

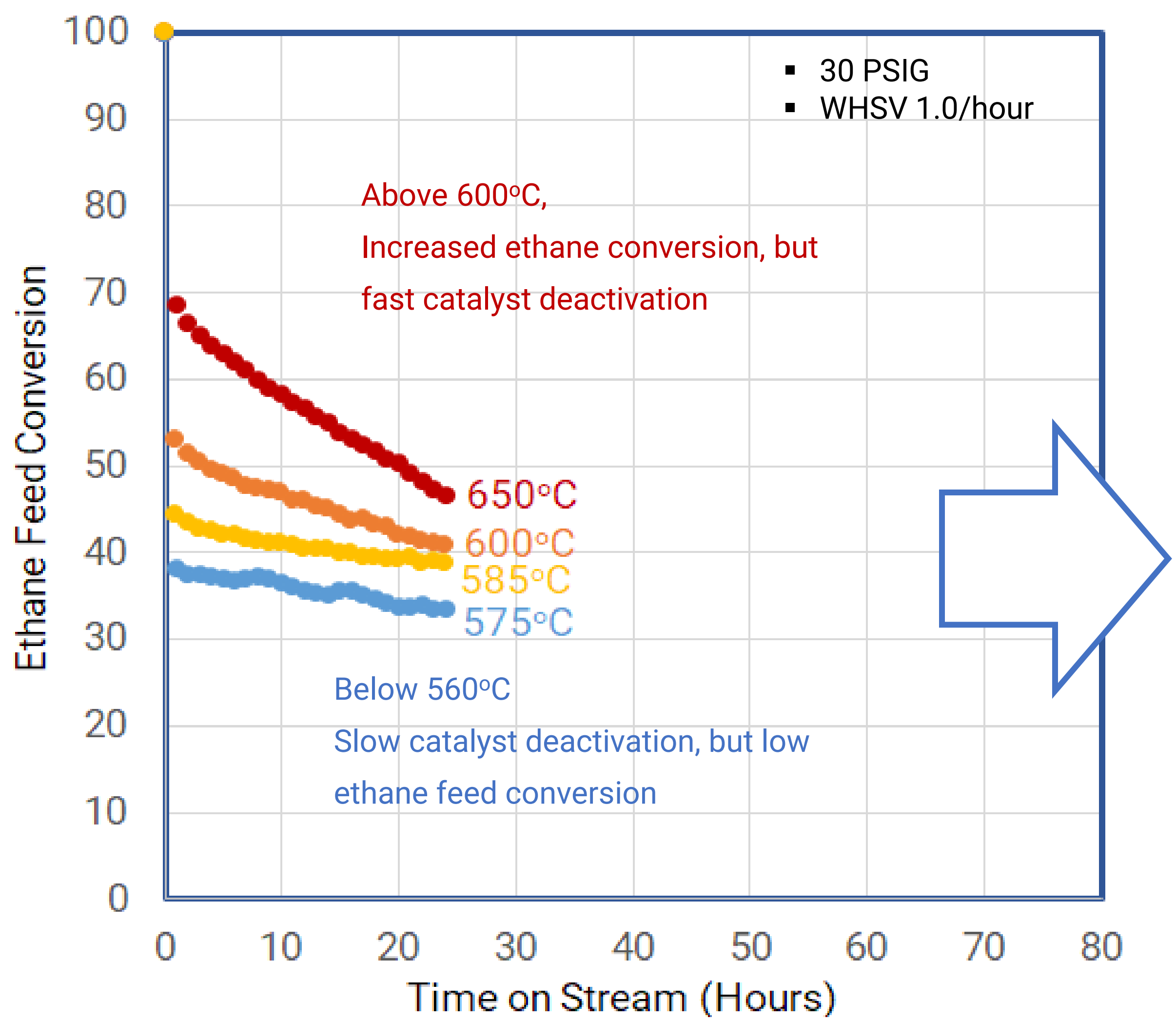
- Two step conversion (through ethylene intermediate) is inefficient, complex, and costly
- Huge reaction heat requirement (as huge as ethane cracking) at commercial-scale production
- Stringent reaction temperature window (560°C – 600°C) for commercially attractive feed conversion, product selectivity, 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



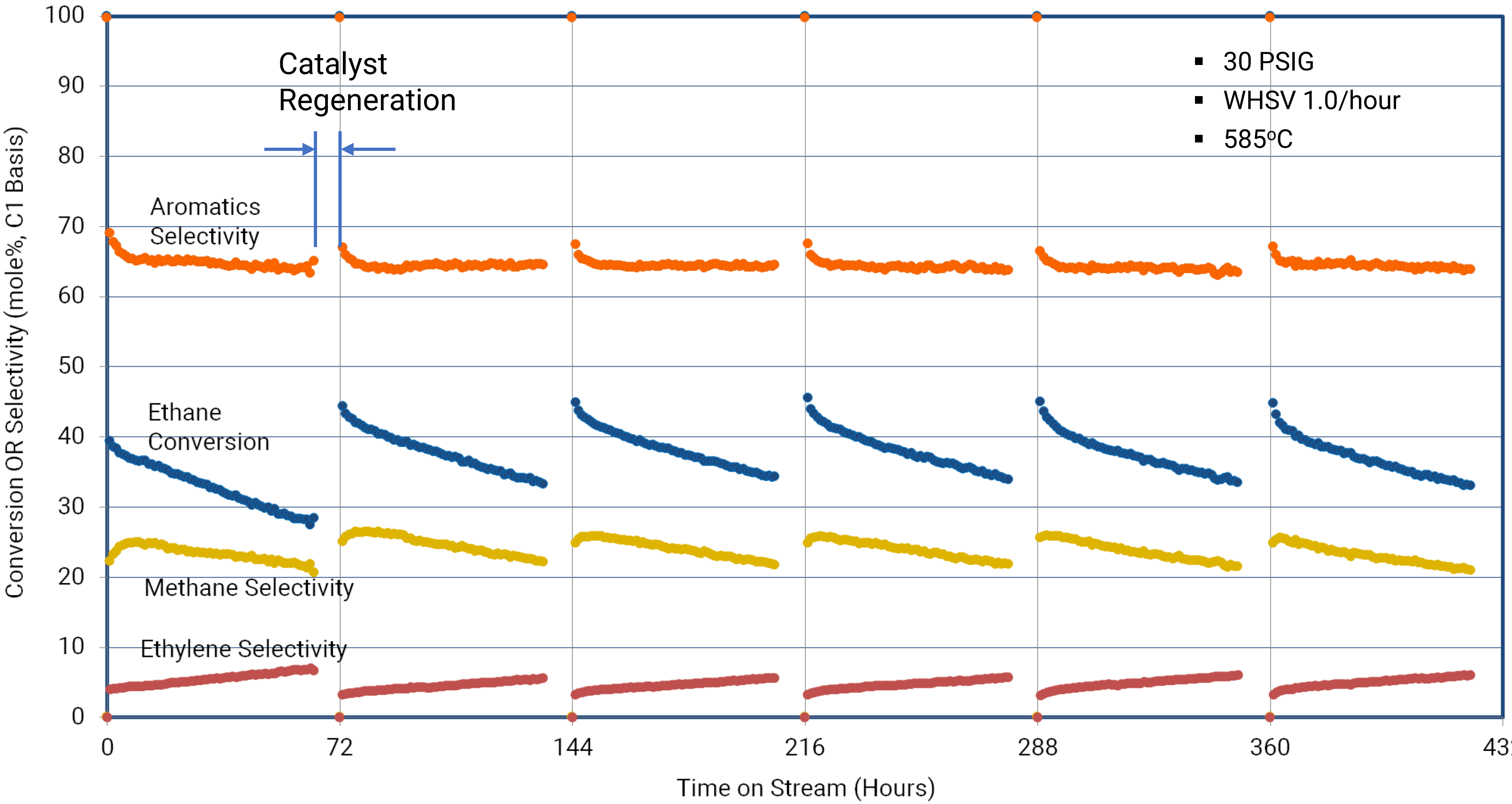
REACTION TEMPERATURE REQUIREMENT



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

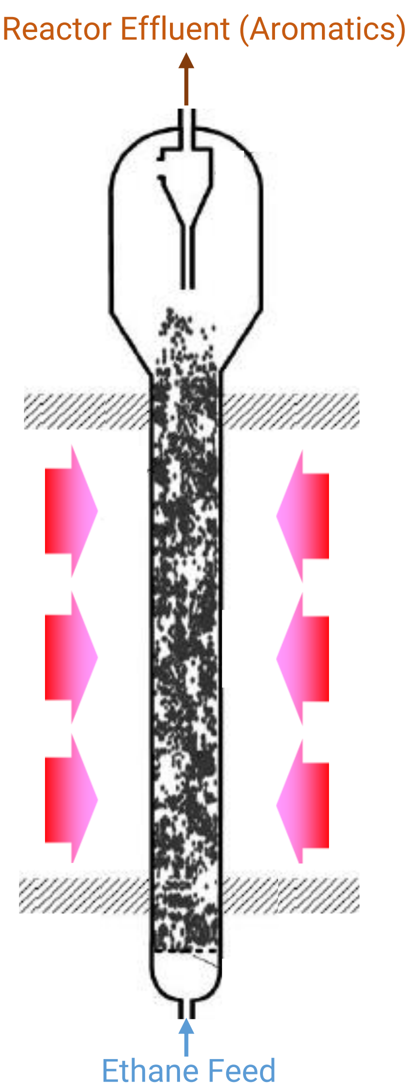
REACTOR/PROCESS (SCALE-UP) REQUIREMENTS

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



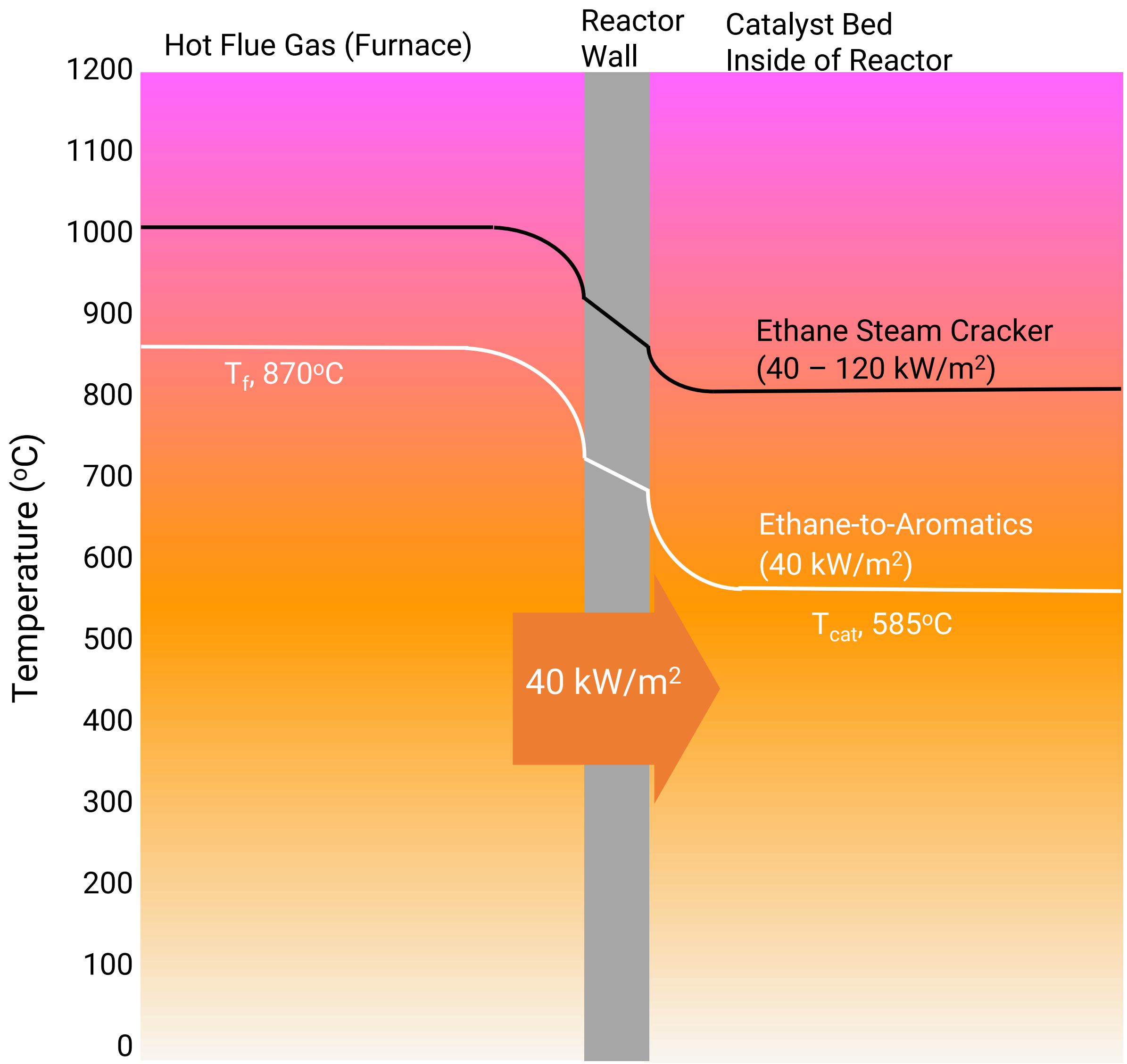
THERMAL ENERGY BALANCE AROUND THE REACTOR

- 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

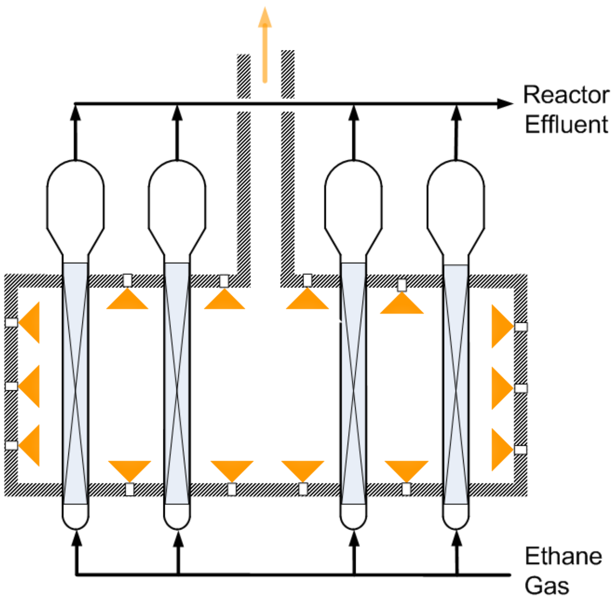
500 BARREL/DAY REACTOR
- RADIAL TEMPERATURE PROFILE



PROCESS DESIGN

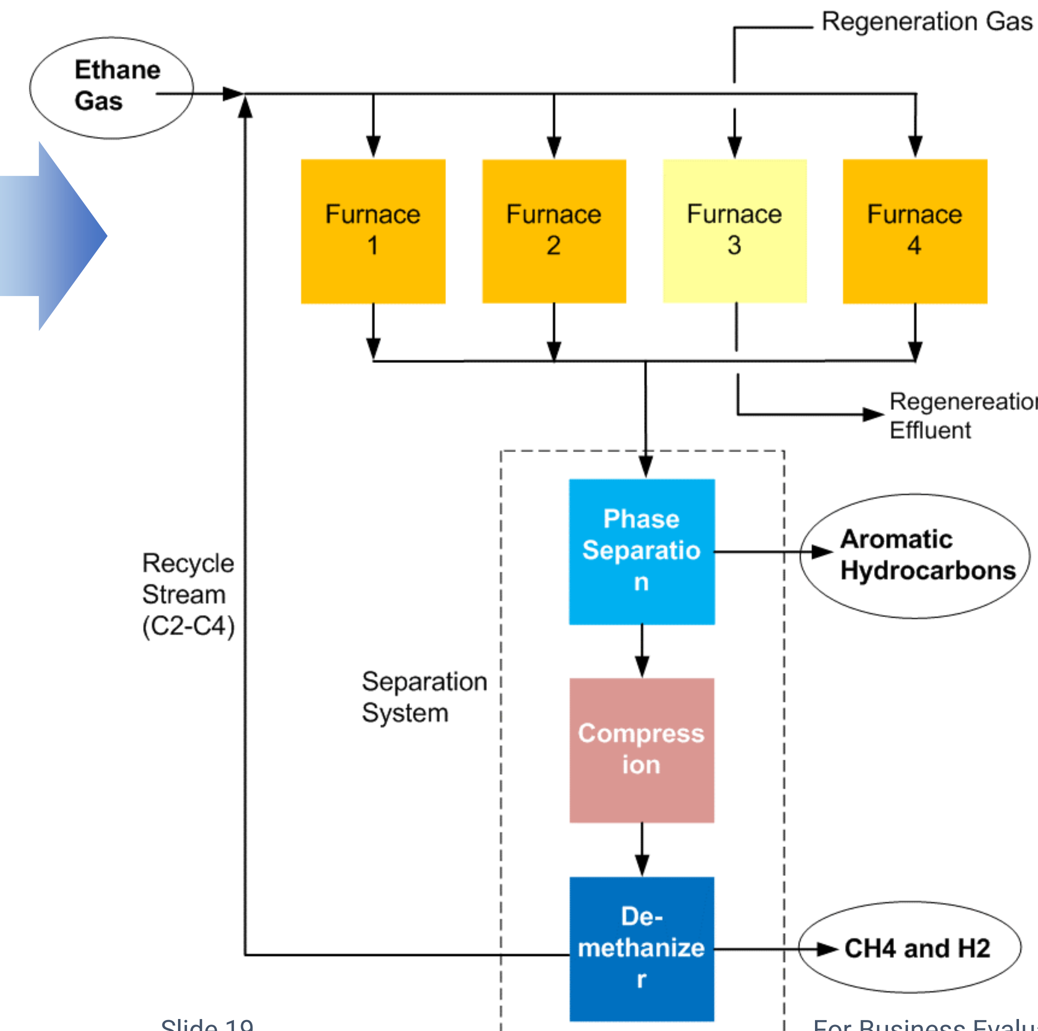
MULTIPLE REACTORS IN A FURNACE

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



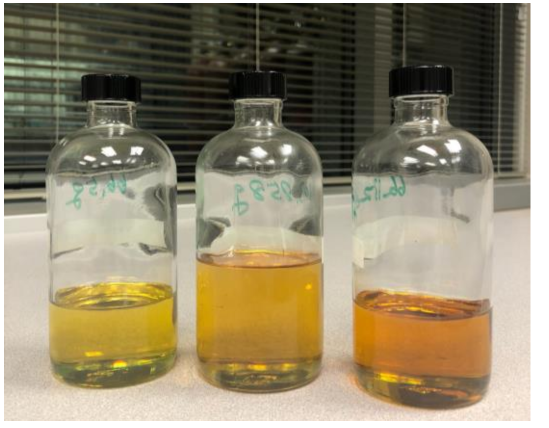
MULTIPLE FURNACES FOR SWING MODE OPERATION

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



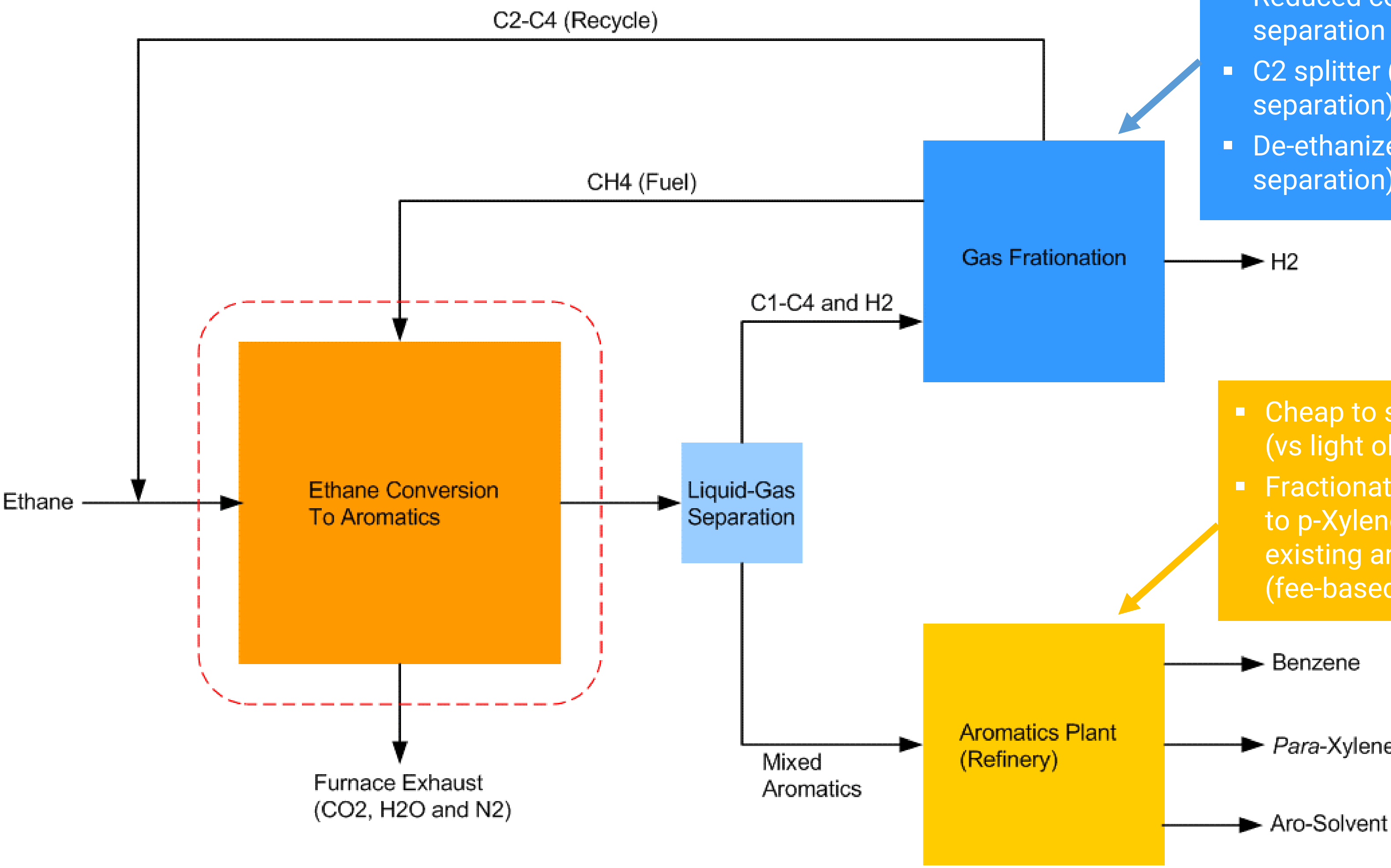
AROMATICS PRODUCT

- 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

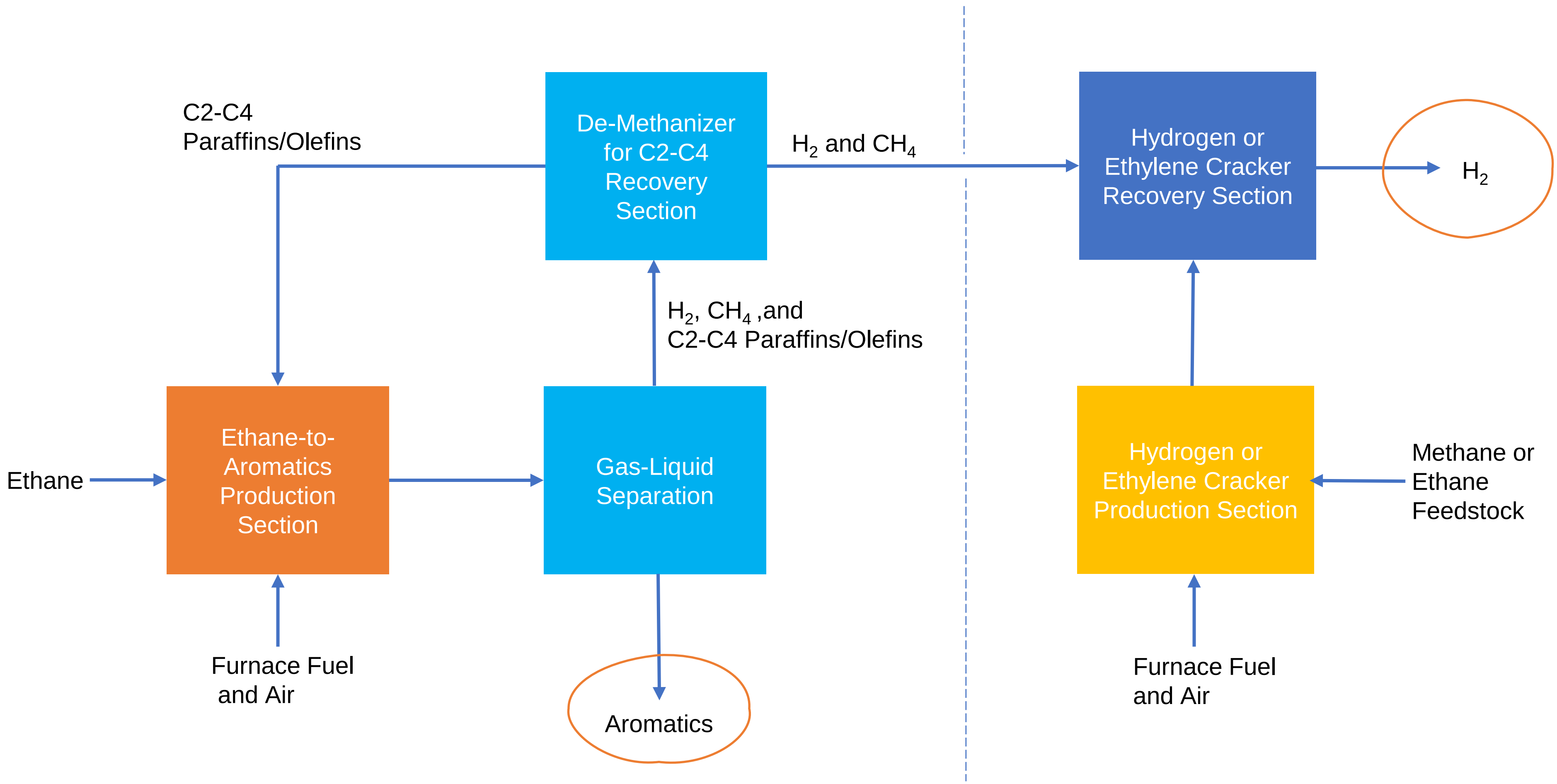


Compared to olefin plant

- Reduced compression load in separation train
- C2 splitter (for ethane-ethylene separation) not required
- De-ethanizer (for C3+ separation) not required

- Cheap to store and transport (vs light olefins)
- Fractionation and conversion to p-Xylene is performed in existing aromatics complex (fee-based)

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



500 KILOTONS/YEAR PLANT ECONOMICS

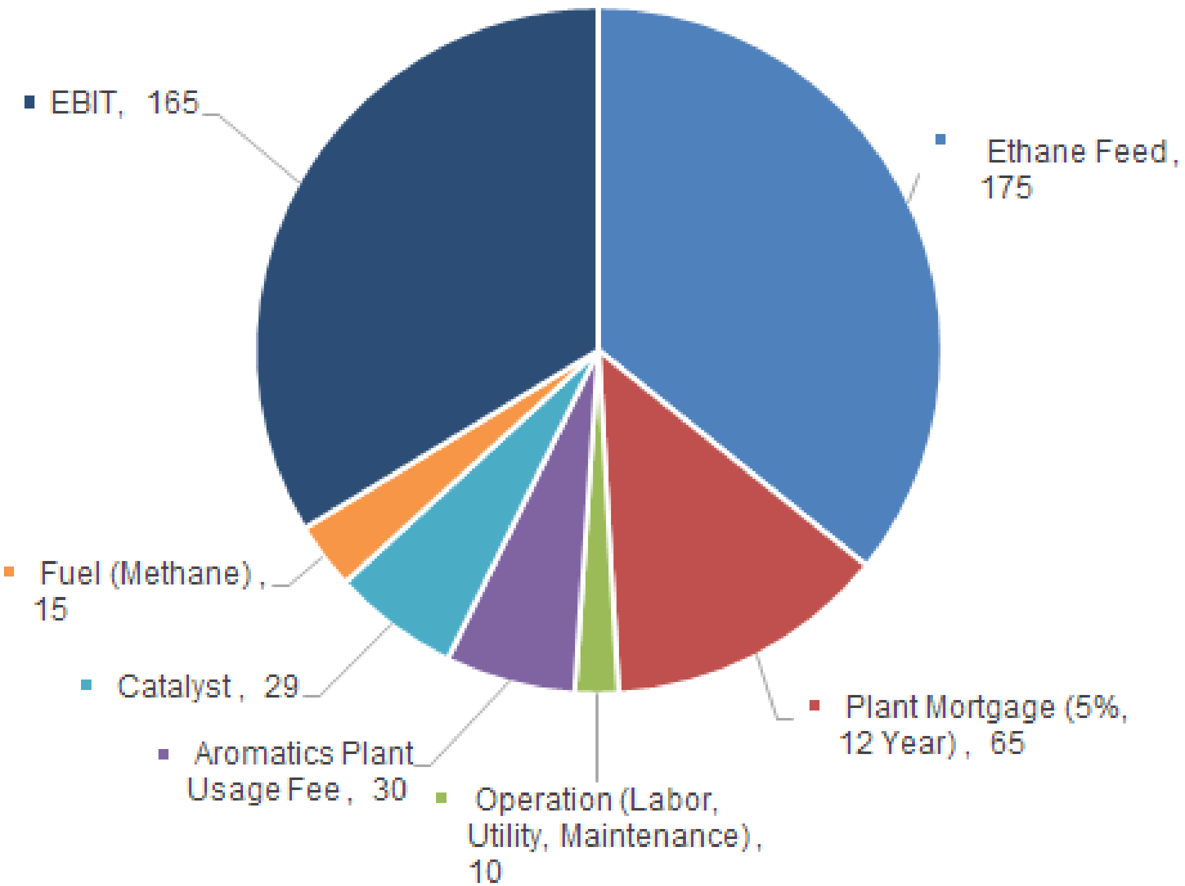
- Preliminary Estimation
- Plant cost at $576MM (stand-alone plant, green field project)
- EBIT at $165MM/year

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

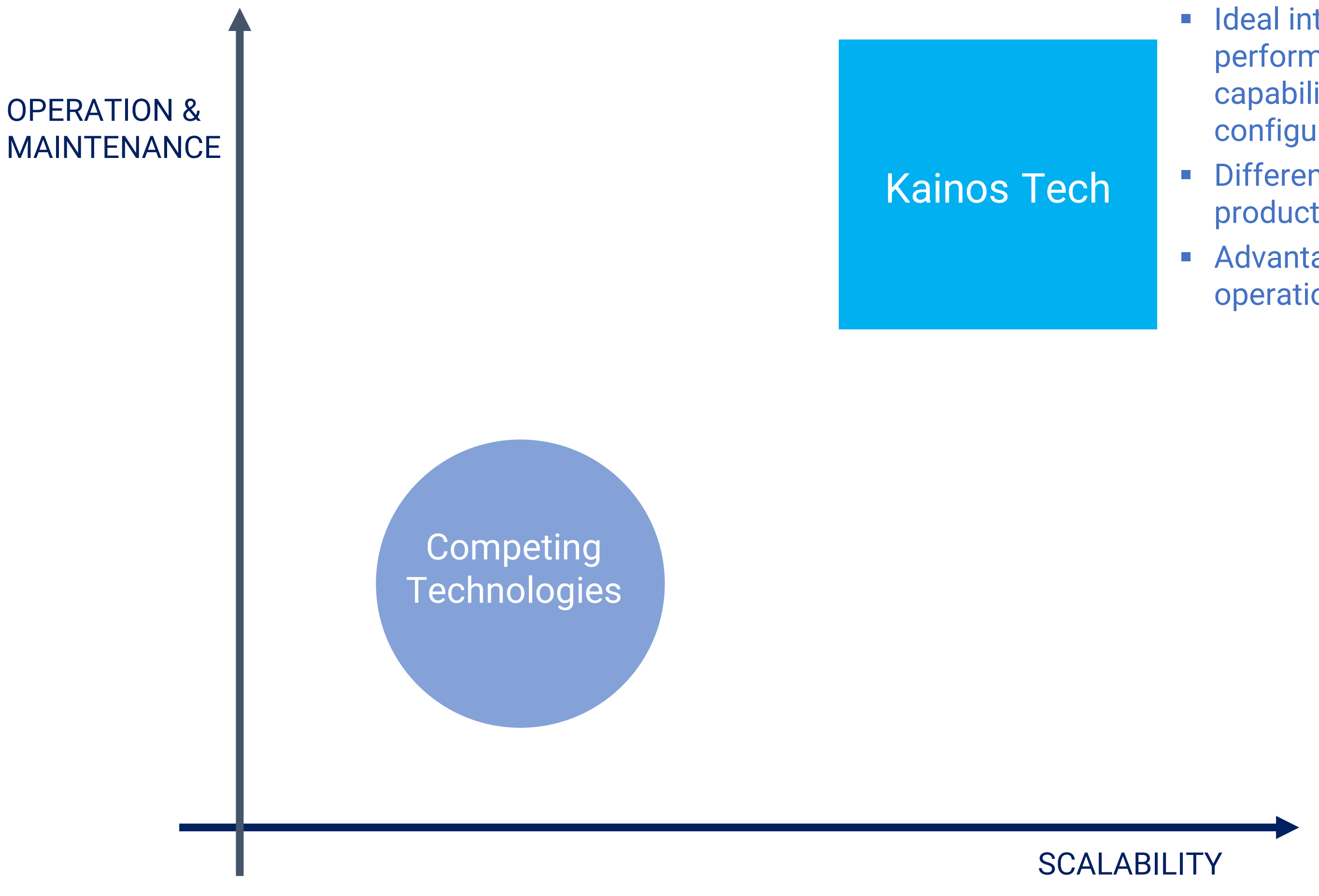
Pre COVDID-19 Market Data

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 due to cost-advantaged feedstock and commercially attractive aromatics yield
2. Ideal for integration with hydrogen or olefin plants
3. Reduced development cost, schedule, and risk. Scale-up to 500–1,000 barrels/day reactor and multiply for commercial deployment