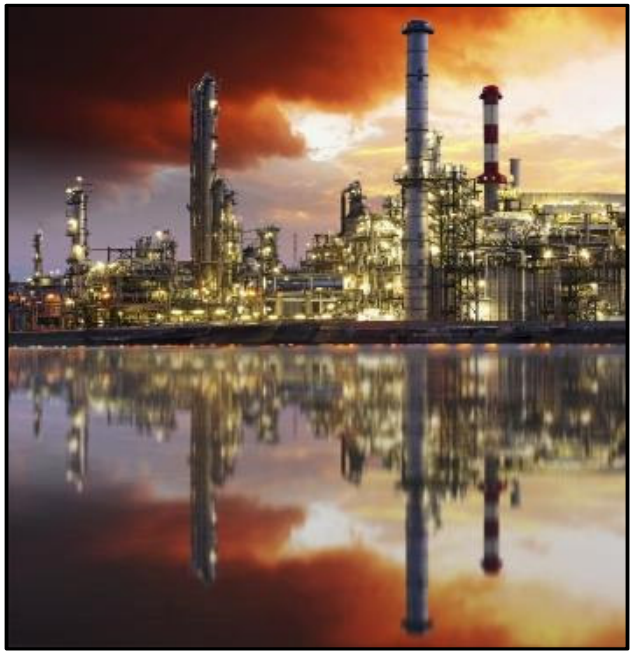
PARA-XYLENE PRODUCTION VIA BP CRYSTALLIZATION

AICHE LECTURE DINNER MEETING
SEPTEMBER 2021

LUMMUS TECHNOLOGY

Presentation Agenda

- **Lummus Technology Overview**
- PX Production by BP Crystallization
- Q&A



A Snapshot of Lummus Technology

Overview

- Founded in 1907
- The global leader in developing and implementing process technologies.
- Master Licensor of petrochemical, refining, gasification and gas processing technologies, and a supplier of catalysts, proprietary equipment and related services to customers worldwide.
- Through 50/50 JV with Chevron (Chevron Lummus Global), Lummus is the market leader in hydroprocessing and resid upgrading technology
- Acquired by The Chatterjee Group and Rhône Capital in 2020

Key Figures

Key End Markets Today:

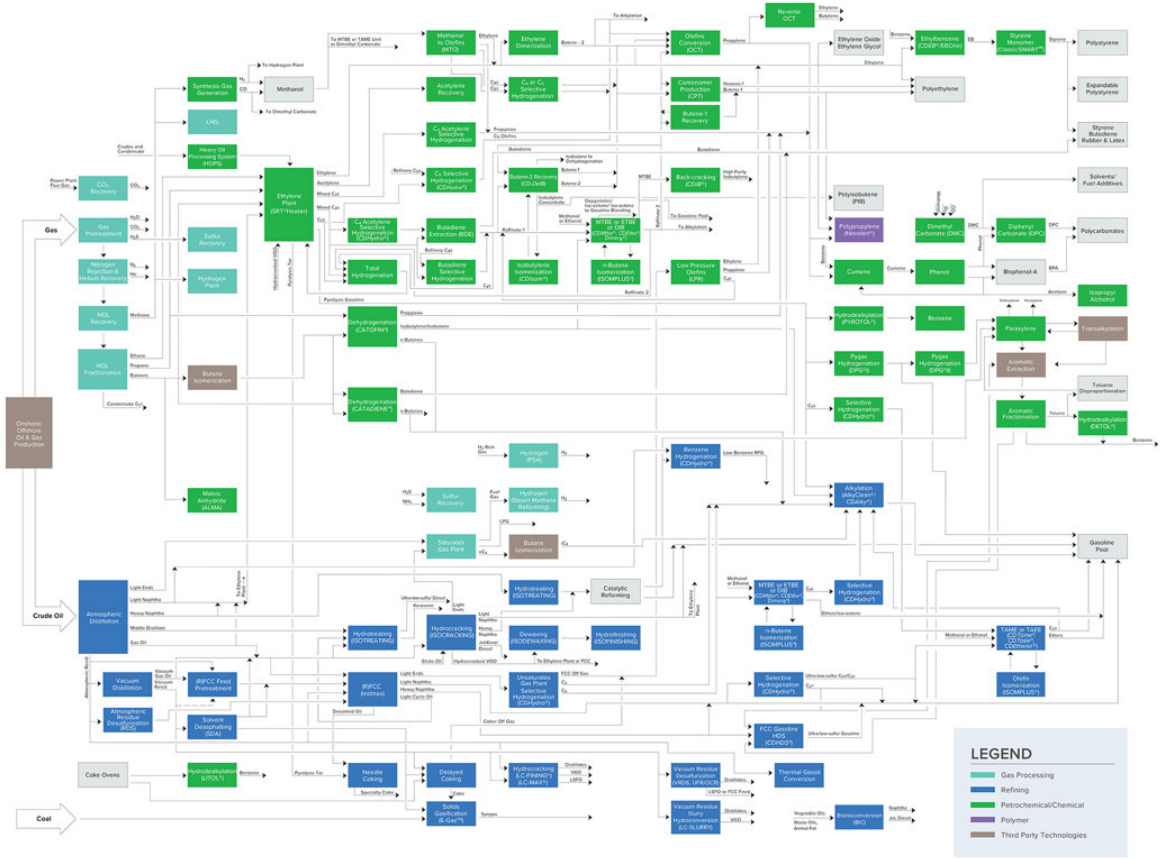
Refining

Petrochemicals

Technologies **125**	*Patents* **3,400+**
Licensed Units **2,400+**	*Years Legacy* **110+**

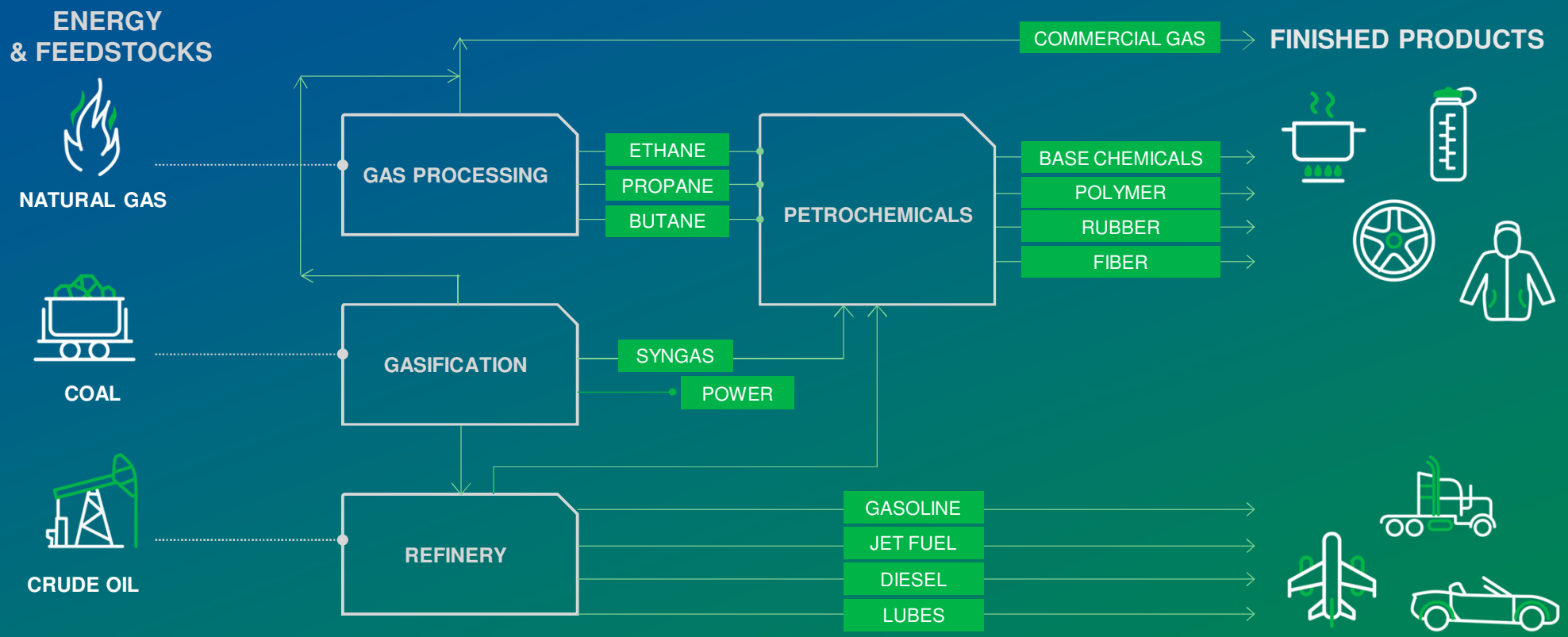
What does Lummus provide?

- World-class research & development
- Planning and consulting
- Technology license and basic engineering
- Master licensor capabilities
- Catalysts
- Proprietary equipment
- Plant start-up support
- Technical services
- Digital services



Markets Served

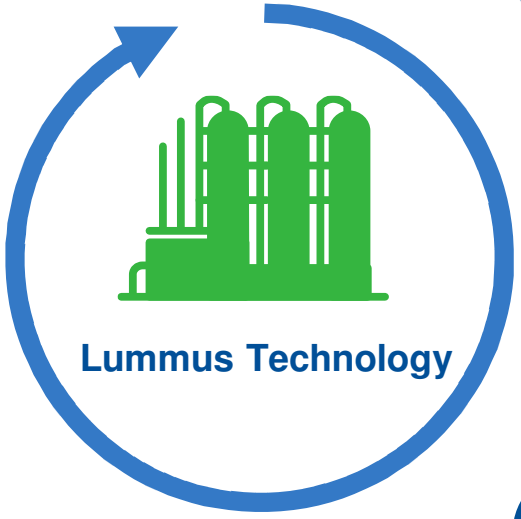
LUMMUS TECHNOLOGY



RESEARCH CATALYST PROCESS DESIGN CRITICAL EQUIPMENT TECH SERVICES

A Top Tier Global Player Across the Value Chain

Leading portfolio of customer solutions available throughout the process facility life cycle



Retrofit opportunities aligned with latest innovations and developments

Broadest and most diversified technology portfolio

Asset optimization services over the process facility life cycle

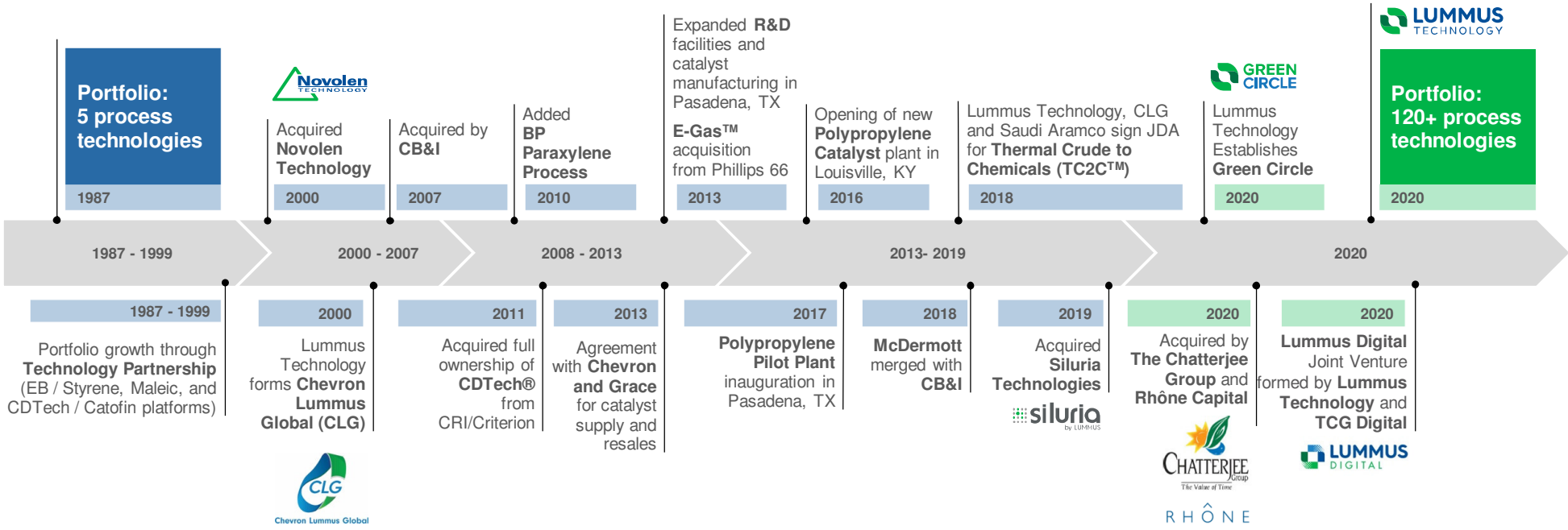
Differentiated master licensor: one-stop-shop solution

Catalyst and spare parts provide ongoing relationships

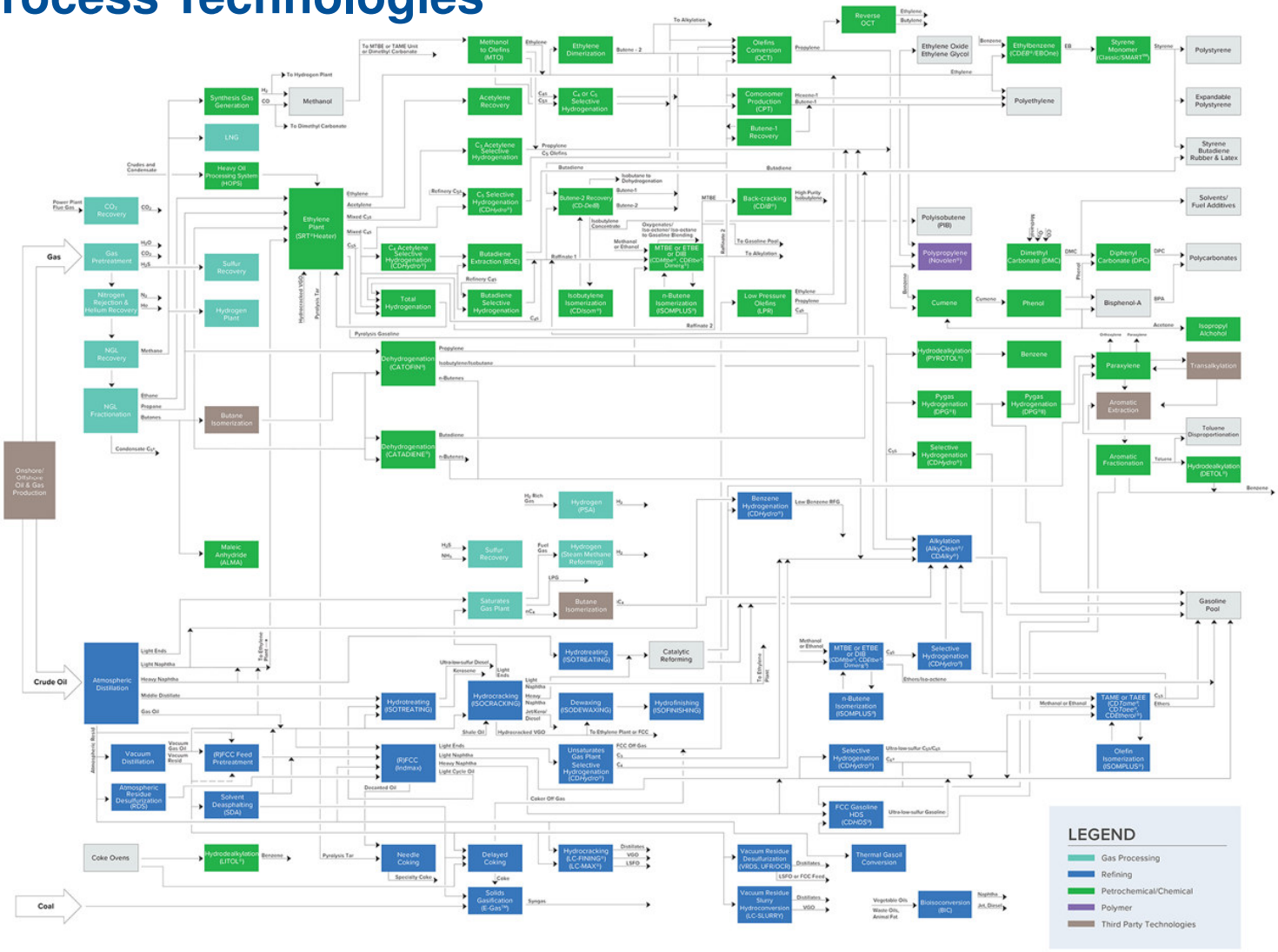
Equipment and modularized solutions

Growing and Enhancing Portfolio

Continuous innovation is the growth engine of Lummus Technology

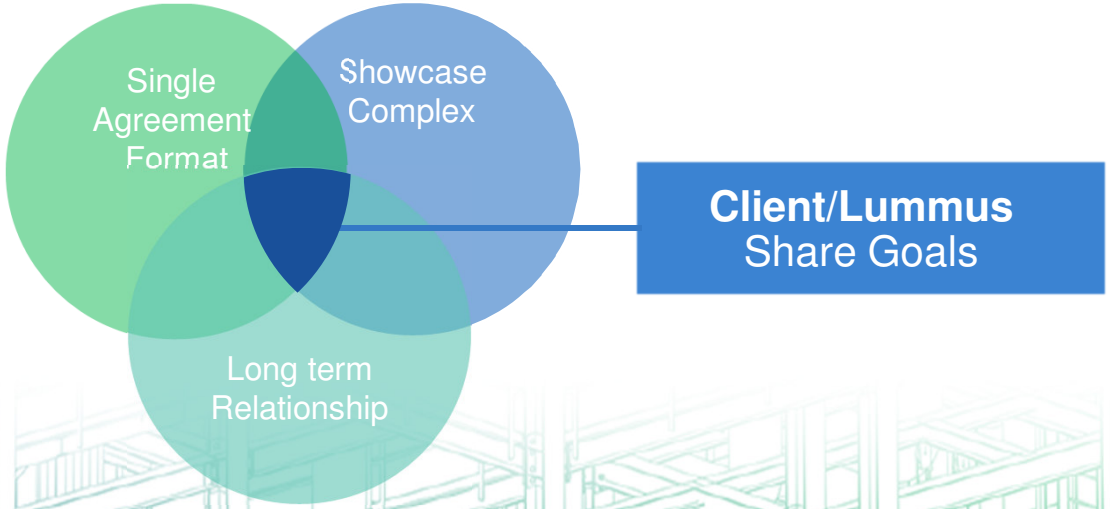


Lummus Process Technologies



Master Licensor Role

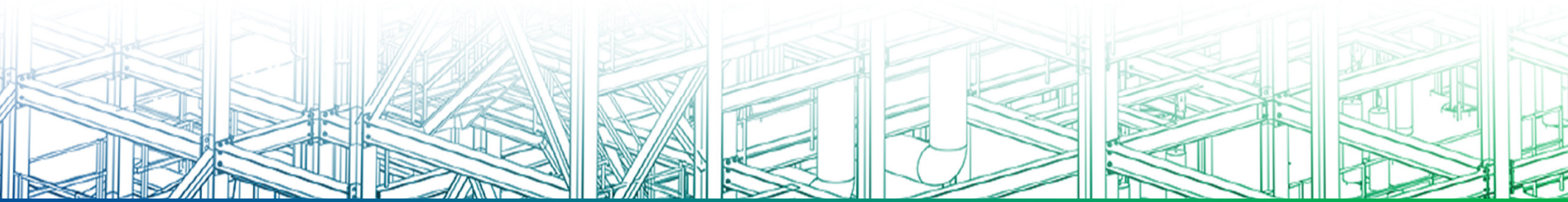
- Diversified portfolio offering, 125 best-in-class technologies
- Single point licensor contact responsibility
- Single contract format
- Master complex configuration planning and optimization
- Seamless coordination and integration of the various processes
  - Shorter project schedule
  - Optimized CAPEX/OPEX
  - Overall performance guarantee
  - Consolidated design basis
- Company wide functional expertise
- Showcase complex
- Plant life cycle support
- Executive Project Sponsor



Business Units

- **Ethylene & Petrochemicals**
  Olefins, Aromatics and Carbonates
- **Refining and Gasification**
  Refining, Gasification, Gas Processing
- **Lummus Heat Transfer**
  Specialized Heat Transfer Equipment
- **Lummus Consultants International**
  Advisory Services for financing and investment in Energy, Petrochemicals and Refining Markets

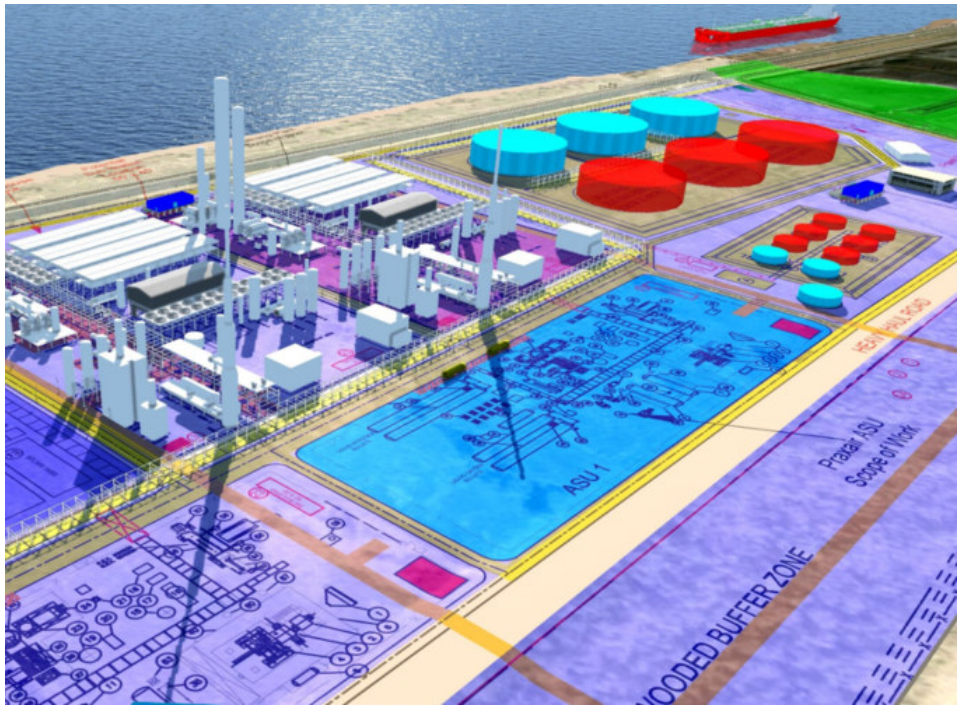
- **Chevron Lummus Global (Joint Venture)**
  Hydroprocessing including Base Oils and Heavy Oil Upgrading
- **Novolen Technology**
  Polypropylene
- **Green Circle**
  Lummus Technology's Sustainability Platform
- **Siluria**
- **Lummus Digital (Joint Venture)**
- **Process Planning Services**



Process Planning Services

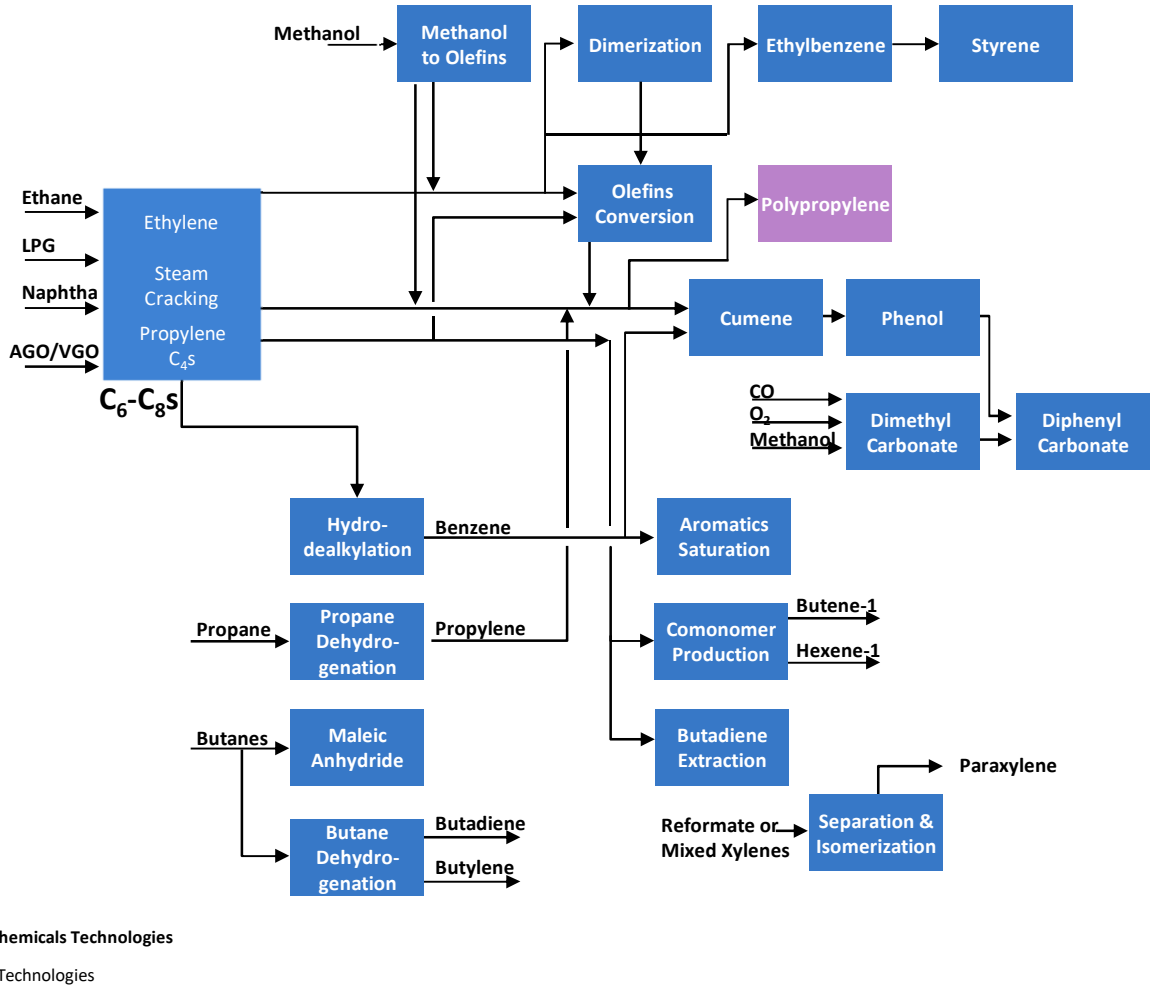
Early Customer Engagement

- Refinery/Petrochemicals complex optimization that provides our customers with up-front strategies to achieve their processing goals
  - Including greenfield, revamp, integrated, and crude to chemicals configurations
- More than 200 major planning studies since 1975
  - Evaluations range from simple, pre-feasibility work to detailed analyses
  - Wide range of industries addressed: full gamut of refining processes, basic and niche petrochemicals, gas processing, syngas and power generation
- Resources include:
  - Technology licensing
  - EPCM
  - Cost estimating
  - Project Development
  - Finance



Ethylene & Petrochemicals Technologies

- Provide integrated technology solutions for complex, differentiated projects in all regions of the petrochemicals market
- Positioned to take advantage of expected capacity additions driven by low-cost feedstocks and demand from continuing product substitution of natural fibers with synthetics
- Breadth of portfolio addresses market trend for diversification from oil to petrochemicals



Lummus Heat Transfer

Provides Critical Engineered Equipment

Enhances Technology portfolio Offering

More than 80 years of expertise designing and supplying specialized heat transfer equipment to the process industry

Heaters

Ethylene Heaters

- SRT® Pyrolysis furnaces - the reactors in ethylene plants

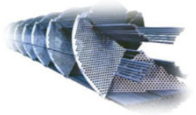
Process Heaters

- Styrene, hydrogen, coking

Heat Exchangers (5,000 units worldwide)

HELIXCHANGER®

- Offer reduced investment costs through increased heat transfer rate
- Reduced total life cycle and operating expenses



Lummus Advanced Breech-Lock Exchanger®

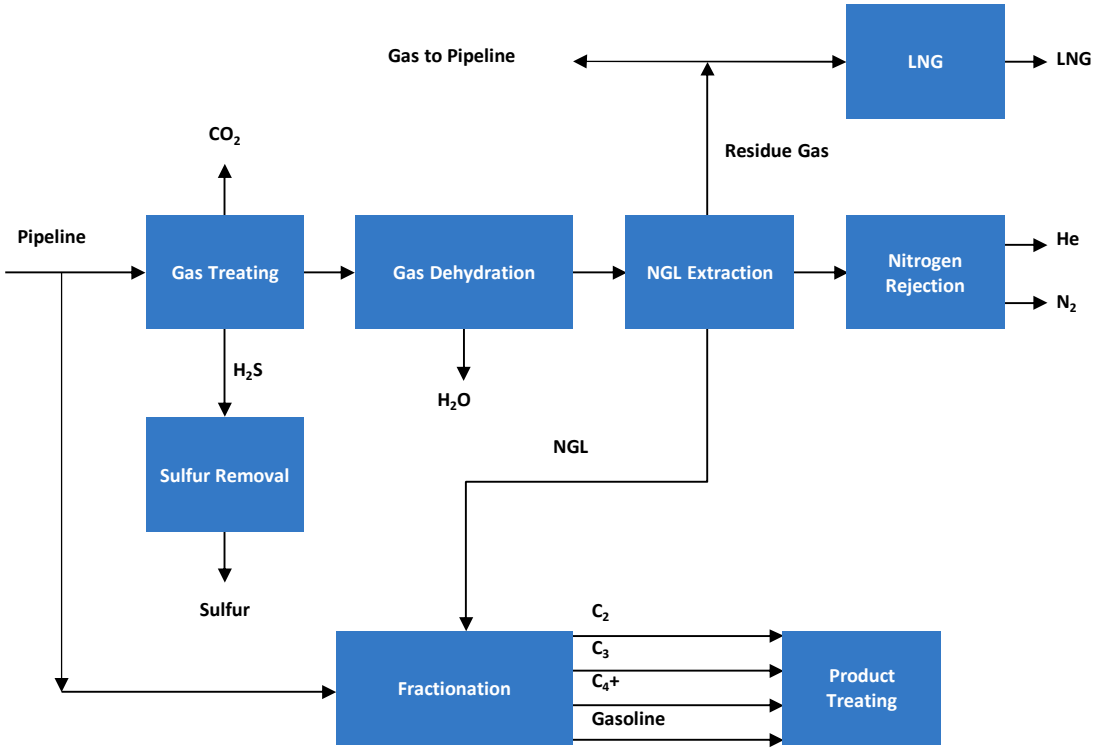
- Used in critical high pressure and high temperature service
- Safer operations and maintenance
- Sealing achieved with normal wrenches (no welding)

Gas Processing Technologies

LUMMUS TECHNOLOGY

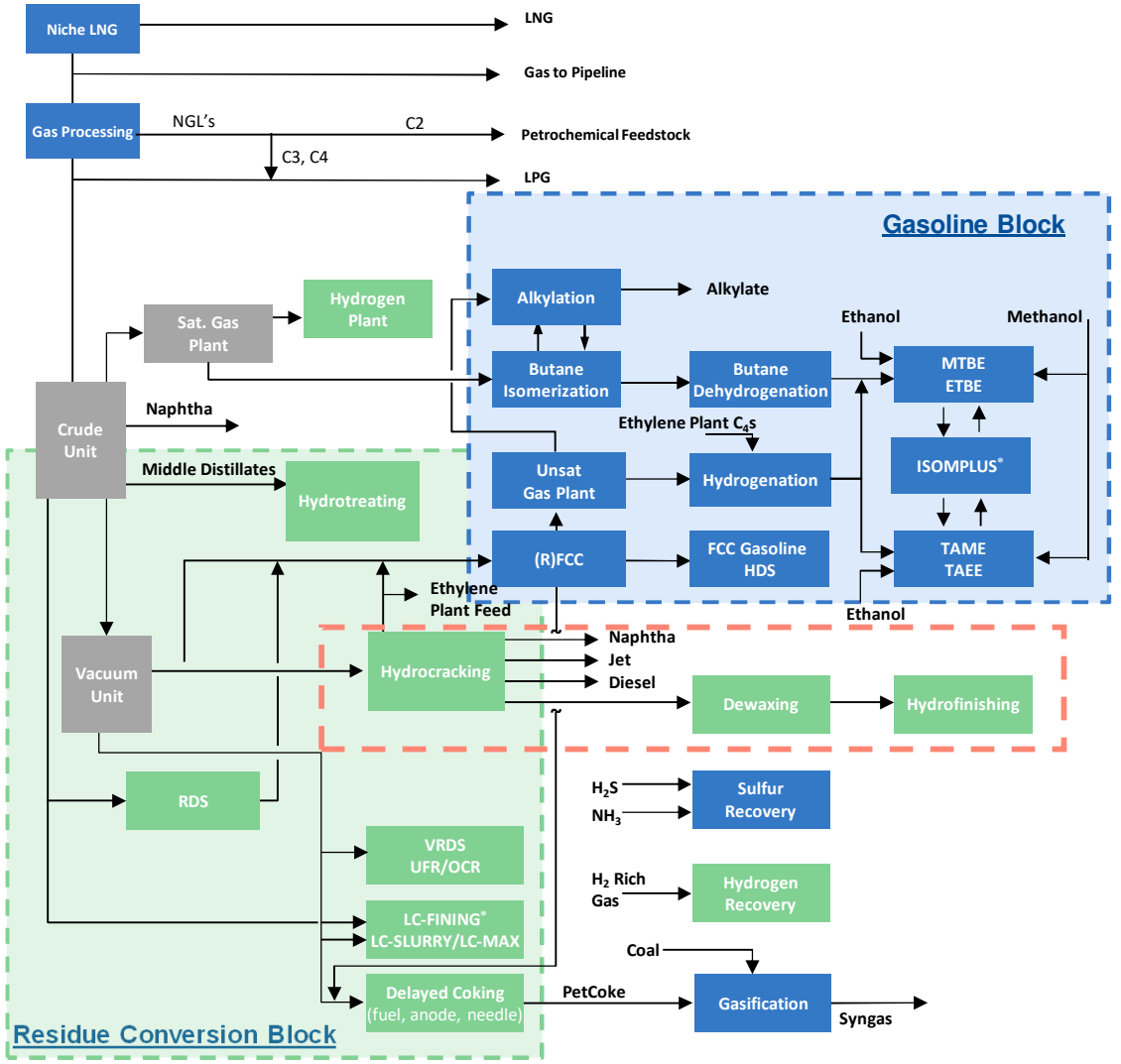
Natural Gas Processing

- Processes gas and condensate from pipeline
- Proprietary process to separate NGL with feed and product flexibility
- Can optimize design based on preferred products
- Modularized process units



Refining and Gasification Technologies

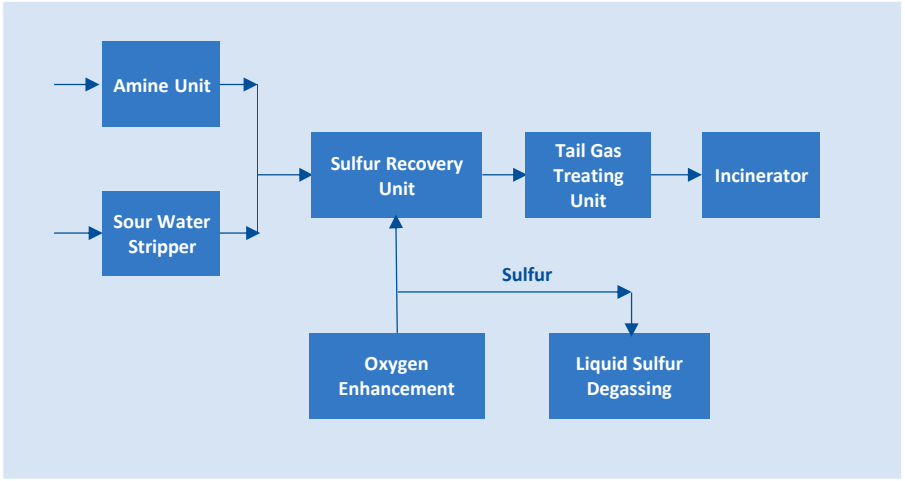
- Licensing a broad portfolio of key technologies across the value Chain
- Market address higher fuel quality standards, lower residual fuel demand, and abundance of cheap feedstock
- Extending technology platforms and integration with petrochemical processes allows manufacturing products in high demand



Sulfur Technologies

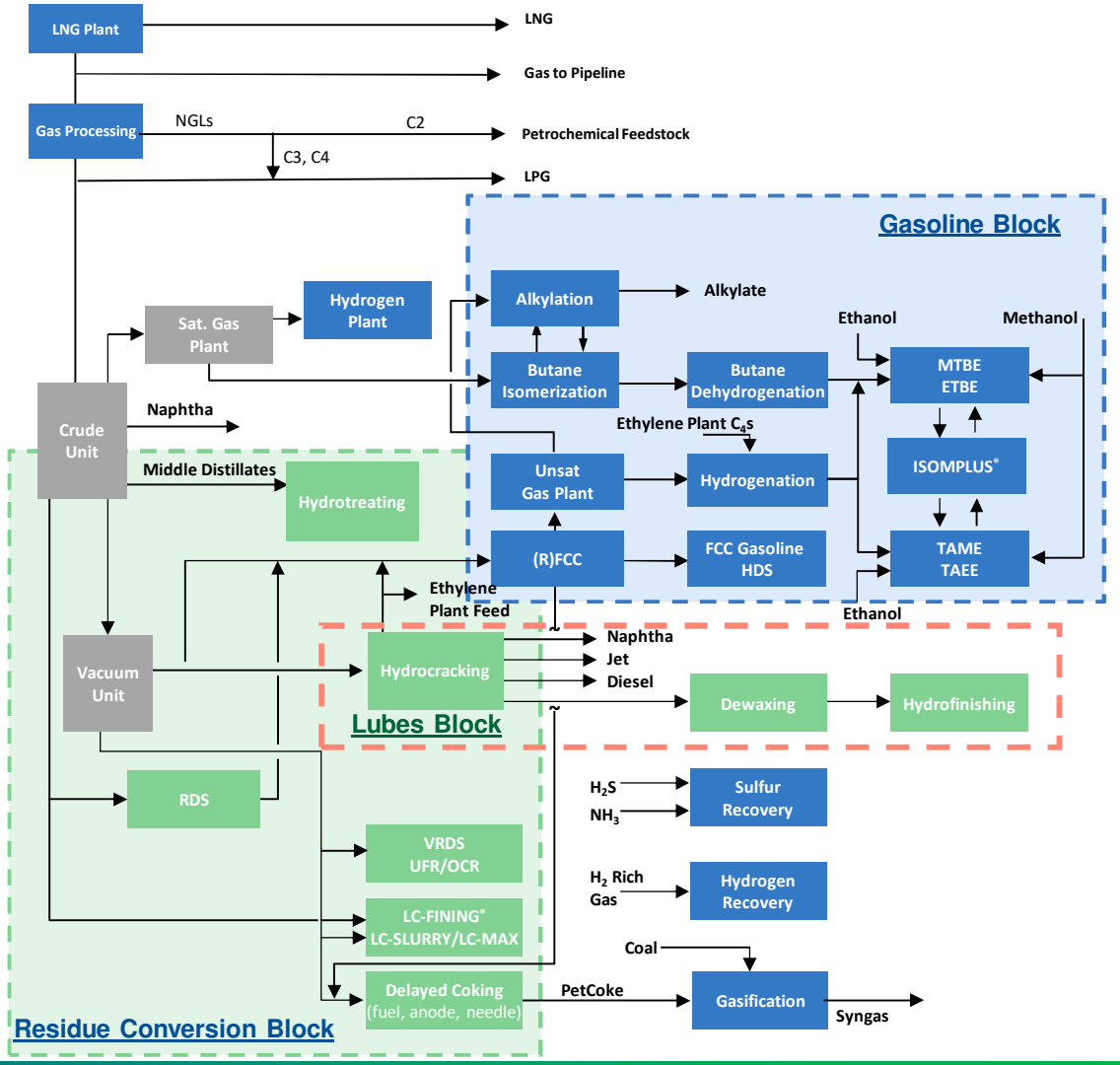
- Technologies used in over 350 units around the world
- Sulfur recovery technologies include: amine treating and regeneration, sour water stripping, sulfur recovery, tail gas treating and oxygen injection
- Sulfur recovery technology meets most stringent SO_2 emission requirements set by World bank
- Proprietary equipment supply includes: Claus Combustor™, Oxygen Injector, OxyPac, waste heat boiler tubesheet protection system, SulfSep™, and sulfur degassing assemblies
- Modular design and supply of sulfur units

Sulfur Recovery Technology Overview



Chevron Lummus Global Technologies

- Market Leader in Hydrocracking, Resid Upgrading and Lube Base Oils Technologies
- CLG licenses a wide array of innovative technologies for hydroprocessing of middle distillates and lube base oils, as well as heavy oil upgrading
- Addresses crude to chemicals objectives with a broad range of hydroprocessing options to minimize fuel oils



Novolen Business Unit

Overview

- Focuses on polypropylene technology development (catalysts, process and product application) and licensing
- Offers full range of PP products as well as catalysts for the production of high margin specialties
- Also offers services to support the operation of the licensees' plants, to secure the quality of the products produced, to launch new products in their markets and also transfers all innovation in a timely manner

Innovation Development Initiatives

- Built a pilot plant in Pasadena/Texas for the further development of product applications and the testing of new catalyst (2017)
- Invested in a Polypropylene Catalyst plant together with Clariant in Louisville/Kentucky to produce a new generation of catalysts (2016)

Polypropylene Pilot plant, Pasadena, Texas U.S.

Louisville, Kentucky

Green Circle – Lummus Technology's Sustainability Platform

Circular Economy

- **Waste recycling**, turning end-of-life plastics into valuable feedstocks
- Solutions for the **full range** municipal and industrial **solid waste streams**

NEW HOPE ENERGY

- **150 TPD plastics pyrolysis unit** in Tyler, Texas operated by New Hope Energy, our Strategic Partner

Decarbonization

- Leader in licensing, engineering/fabricating **hydrogen units**, including blue and grey
- Establish a strategic cooperation for **green hydrogen**
- **Carbon capture** for gas processing and off-gas to decarbonize clients' **existing assets**
- Energy Intensification Strategies to **lower CO2 footprint**

Biofuels and Biochemicals

- Fuels, chemicals, and ethers **production routes from bio-based feedstocks**
- Chemicals include bio-ethylene, bio-propylene, bio-butadiene

Green Circle Focus

CIRCULAR ECONOMY

Municipal Solid Waste (MSW)/ Waste Plastic Processing

SUSTAINABILITY

Green Chemicals Production

Renewable Fuels

DECARBONIZATION

Carbon Capture and Utilization
Blue Hydrogen

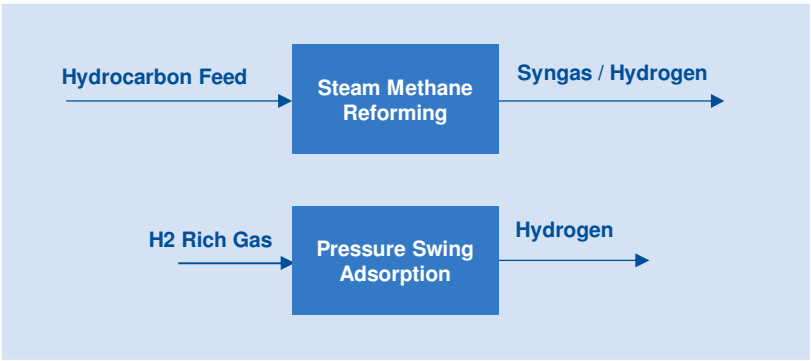
Energy Efficiency Solutions

Zero Carbon Energy Storage

Hydrogen Technologies

- Hydrogen and syngas experience includes more than 200 hydrogen and syngas plants designed and built around the world
- Proprietary equipment supply includes the steam methane reformer (SMR) furnace
- Hydrogen technology is highly complimentary to CLG hydroprocessing technologies
- Modular design & supply concepts ranging from 600,000 SCFD to 120 MM SCFD H2

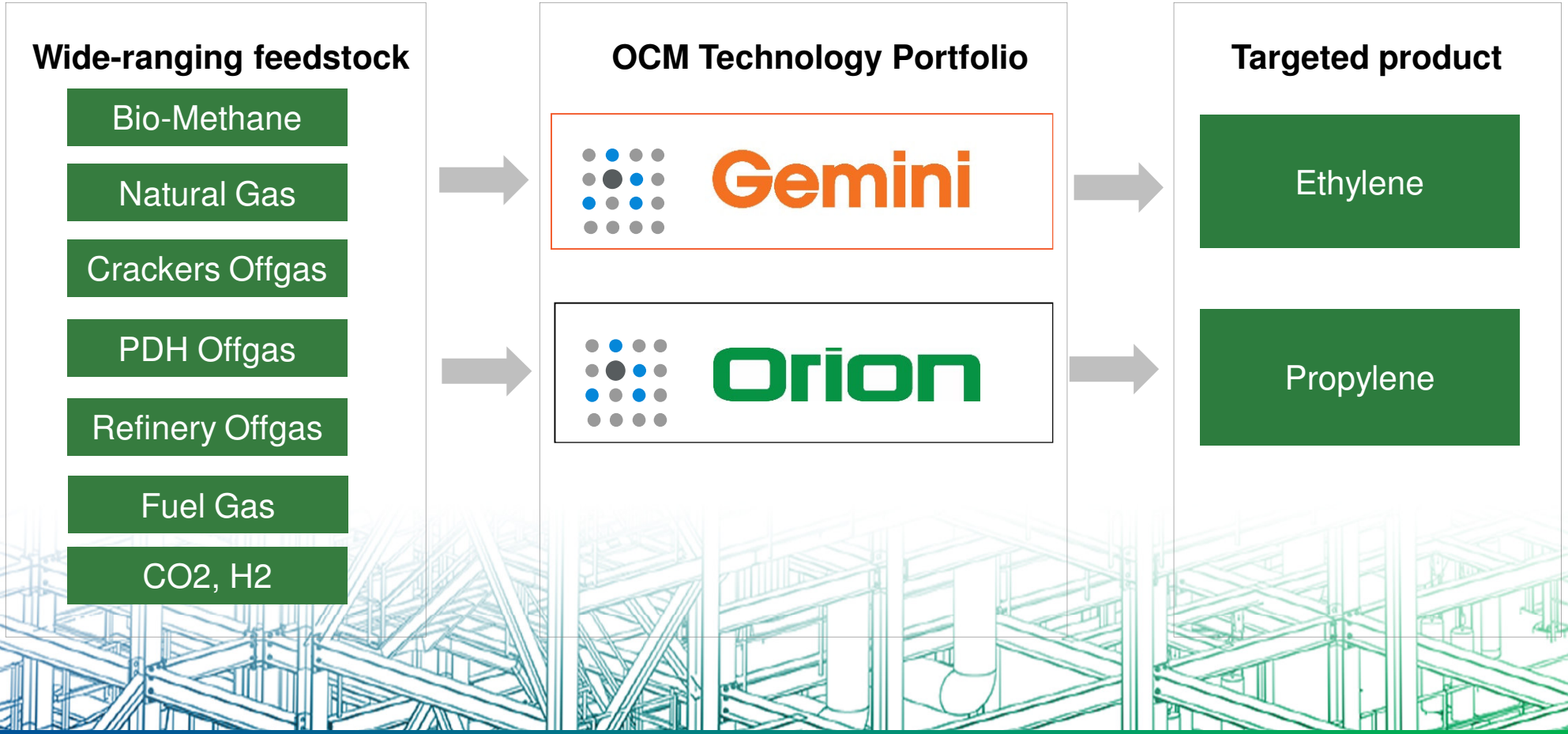
Hydrogen Technology Overview



Siluria OCM™ Technology

LUMMUS TECHNOLOGY

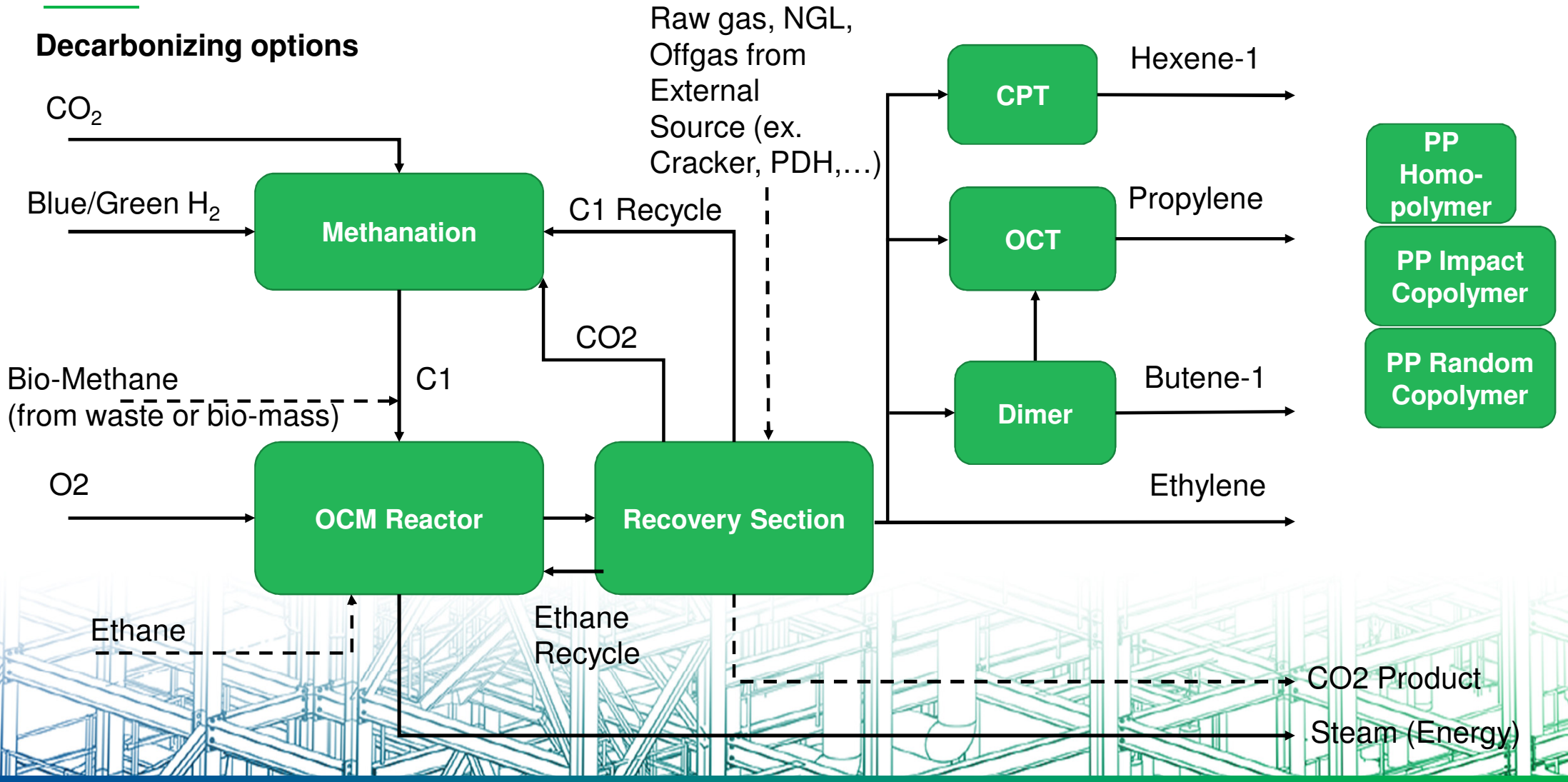
Transforming Low Value Gas Streams to Valuable Olefins, Reducing CH4 emissions



Siluria OCM™ Technology

LUMMUS TECHNOLOGY

Decarbonizing options



Lummus Digital

Joint Venture Overview

- Joint venture between Lummus Technology and TCG Digital
- Formed in 2020
- Combines Lummus' process know-how and operational excellence with TCG Digital's Big Data and AI capabilities to forecast into the future of a customer's asset lifecycle.

TCG Digital

The flagship technology consulting and solutions company of The Chatterjee Group, TCG Digital enables organizations to go digital by leveraging transformative technologies, advanced analytics, and operational expertise to accelerate value realization for our clients.

Research and Development Facilities

Technology Development & Manufacturing Center
Pasadena, TX

- R&D partner with every business line
- Exploratory through Commercial Demonstration Pilot Plants
- Full Service Analytical Laboratory
- CDModules Manufacturing Center

Novolen Technology BASF Site
Ludwigshafen, Germany

- Polypropylene Technology R&D
- Catalyst and reaction testing, process innovation, polymer science
- Close customer interactions for product applications

Chevron Lummus Global
Richmond, CA

- Access to Chevron R&D organization and its **PhDs, scientists**
- "Bottom of the barrel" Upgrading
- Hydroprocessing & Catalyst R&D
- Owned and operated by Chevron

Recognition of Innovation, Industry Leadership

LUMMUS TECHNOLOGY

Indmax FCC

CDAlky® and OCT

130 Technologies

Benz-Free®

Best Petrochemical Technology: **BP Paraxylene**

Best Gas Processing Technology: NGL-MAX

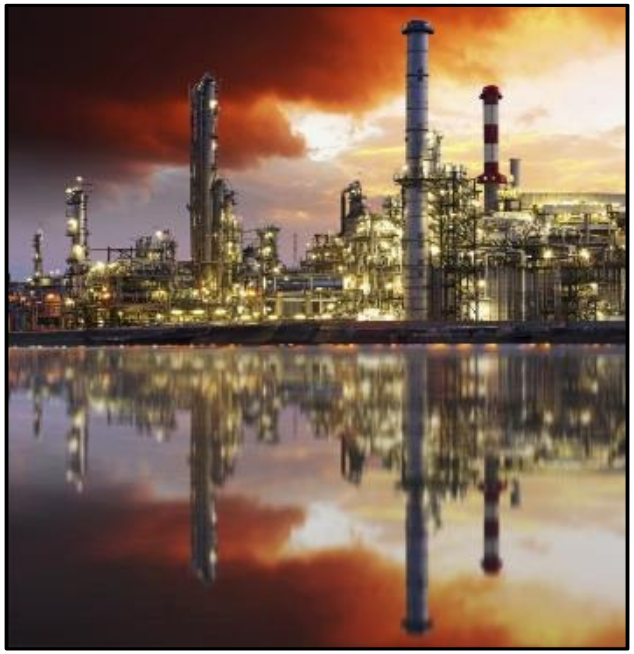
Breakthrough Technology (2016):
AlkyClean
(EPA Presidential Green Chemistry Challenge)

Nominated as finalists for **2021 Hydrocarbon Processing Awards:**

1. Executive of the Year
   Leon de Bruyn
2. Sustainability
   Green Circle
3. Best Refining Technology
   CDHydro/CDAlky®
4. Best Refining Technology
   Single Regenerator Dual Catalyst (SRDC)

Presentation Agenda

- Lummus Technology Overview
- **PX Production by BP Crystallization**
- Q&A



BP / Lummus Synergy

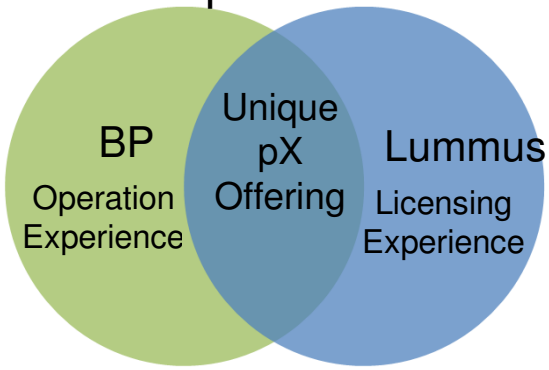
LUMMUS TECHNOLOGY

BP: Owner & Operator

11	Refineries
1.88	Million Barrels/Day
16	Petrochem sites
18.6	Mtonnes/year Petrochem capacity

Industry leaders in PX and PTA production

200+ years of combined experience



8 MM MT of licensed pX recovered via BP PX technology

Lummus: Licensor

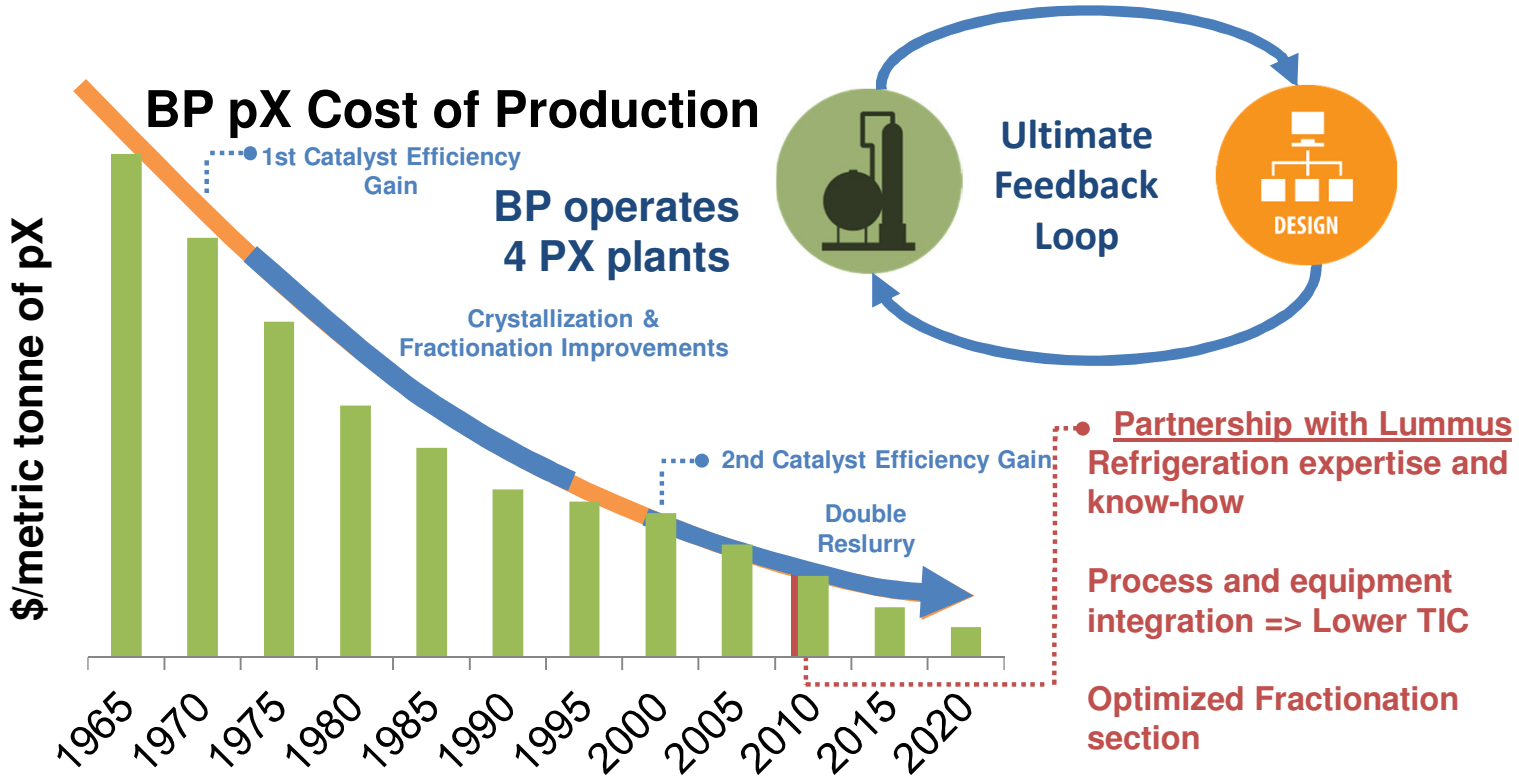
Technology Patents	3,400+
Petrochemical and Refining Processes	125
Projects licensed globally	2,400+

Technology Improvement

Dedicated to maximizing value of client's refinery & petrochemical complexes

The BP Experience Advantage

50 Years of Continuous Improvements



BP pX Technology Differentiators

- More advanced process scheme using crystallization as opposed to the conventional adsorption/desorption
  - No proprietary equipment
  - No adsorbent/desorbent or makeup chemicals
  - No Special control system required (ACCS)
  - No long turnaround due to absorbent replacement
  - No noble metal catalyst
  - No stringent C7/C9 feed specification
  - No oxygen stripping or clay treating for imported feeds
  - No single equipment risk to shutdown plant

- OPEX savings over SA
- Easily expandable – modular process
- >99 % process reliability
- Longer Equipment (Crystallizers/Centrifuges) life vs. Adsorbent life
- 10 year min. catalyst life

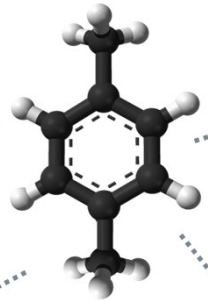
BP and Lummus – Paraxylene Experience

PX Plants	Capacity, kta	Start-up Date
BP Geel, Belgium	675	2000
BP Texas City, USA #3	390	1996
Indorama Decatur, USA #2	720	1978
BP Texas City, USA #2	530	1975
Indorama Decatur, USA #1 shutdown	380	1968
BP Texas City, USA #1	350	1967
Reliance, India	2,250	Dec. 2016 (**)
Total (operating)	**5,300**	
Hyundai Cosmo Oilbank, Korea	180	Sept 2020
STEAS, Europe	834	2024, Basic Engineering
GS Caltex	1,000	on hold
Shenghong, China	4,000	2021, Detail Engineering / Construction
Ningbo Union King, China	1,600	2022, Detail Engineering / Construction
Total Under design or Construction	7,600+	

(**) currently operate SA plants and have switched to BP PX

BP PX Recovery Process – Key Facts

- Isomer in the mixed C_8 aromatics family
  - Para, Ortho, Meta & Ethylbenzene
- Primary feedstock for PTA
- PTA feeds the polyester fiber market



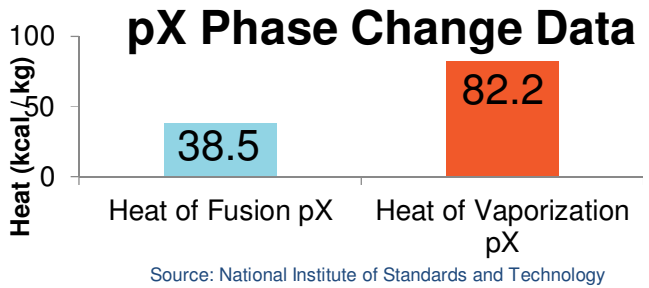
2 Primary Commercial Routes

Crystallization **Selective Adsorption**

Freezing Vaporization

Properties, ℃

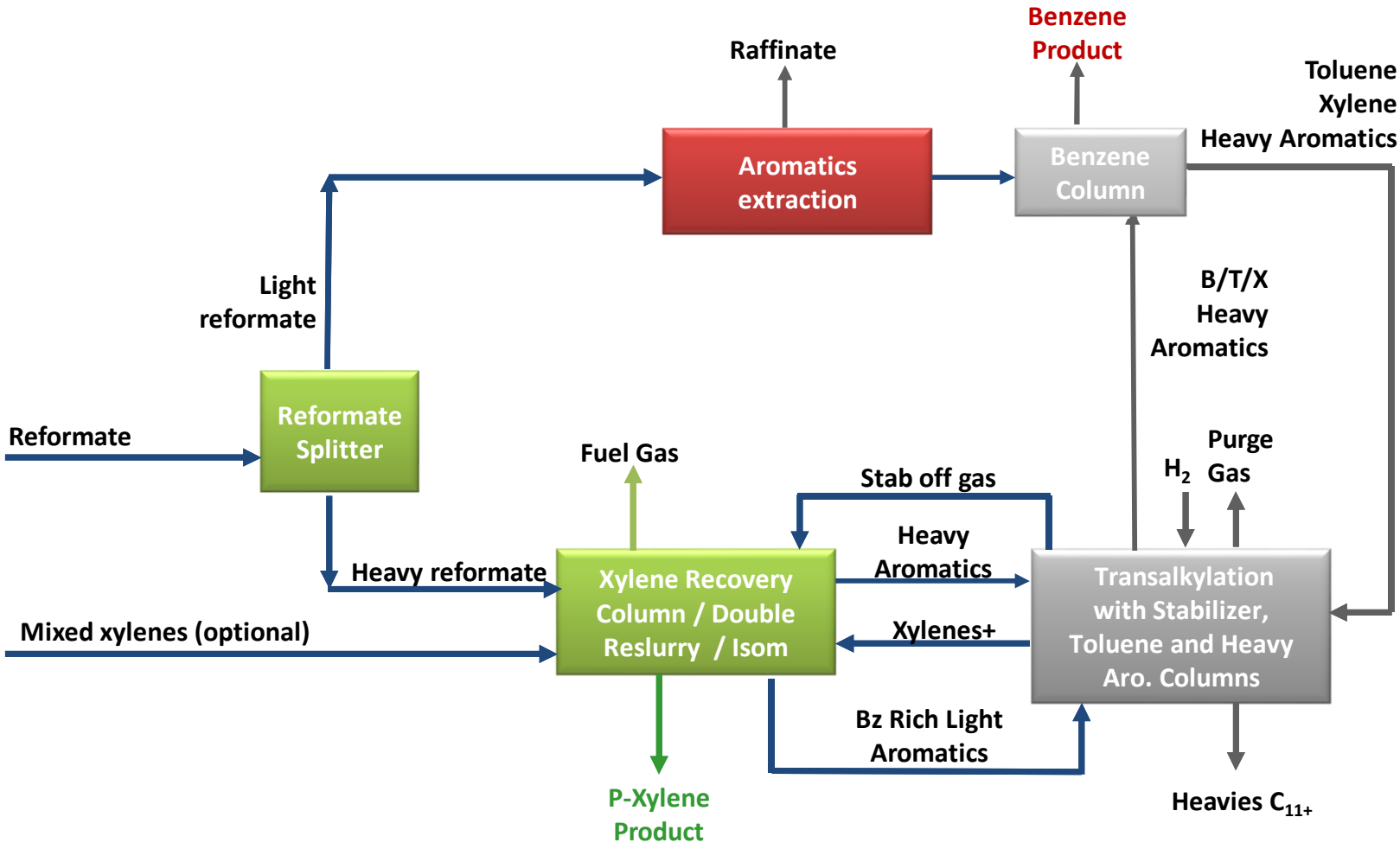
	Freezing	Boiling
pX	**+13**	**138.4**
oX	-25	144.4
mX	-48	139.1
EB	-95	136.2



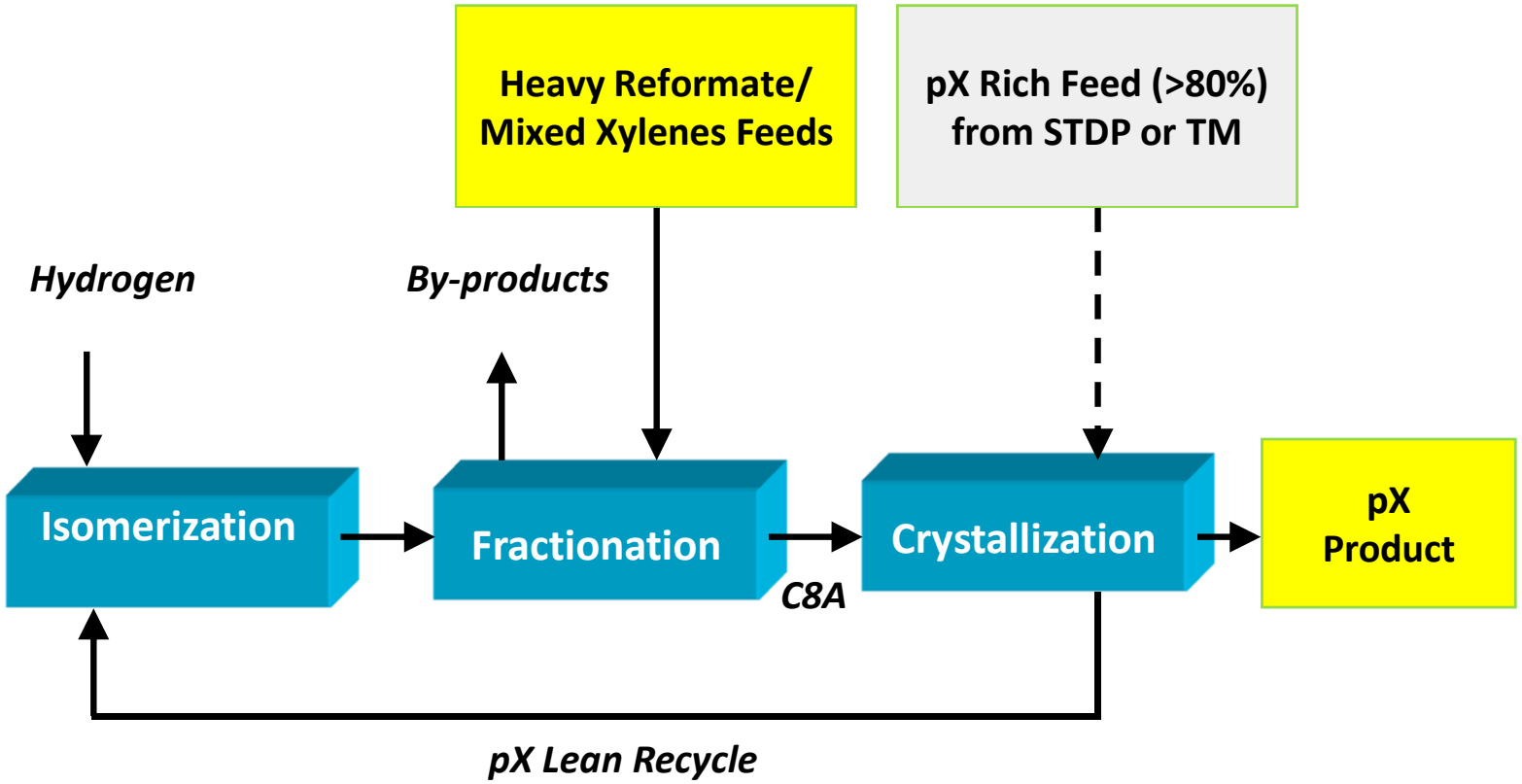
Source: National Institute of Standards and Technology

Crystallization	Selective Absorption
Most energy efficient purification of PX through freezing-point differences between PX and the other xylene isomers	Purifies PX using a solid absorbent with an affinity for PX compared with other xylenes
Crystallizers :Simple DCS (Distributed Control System)	Simulate moving Beds : Special Adsorbent Chamber Control System

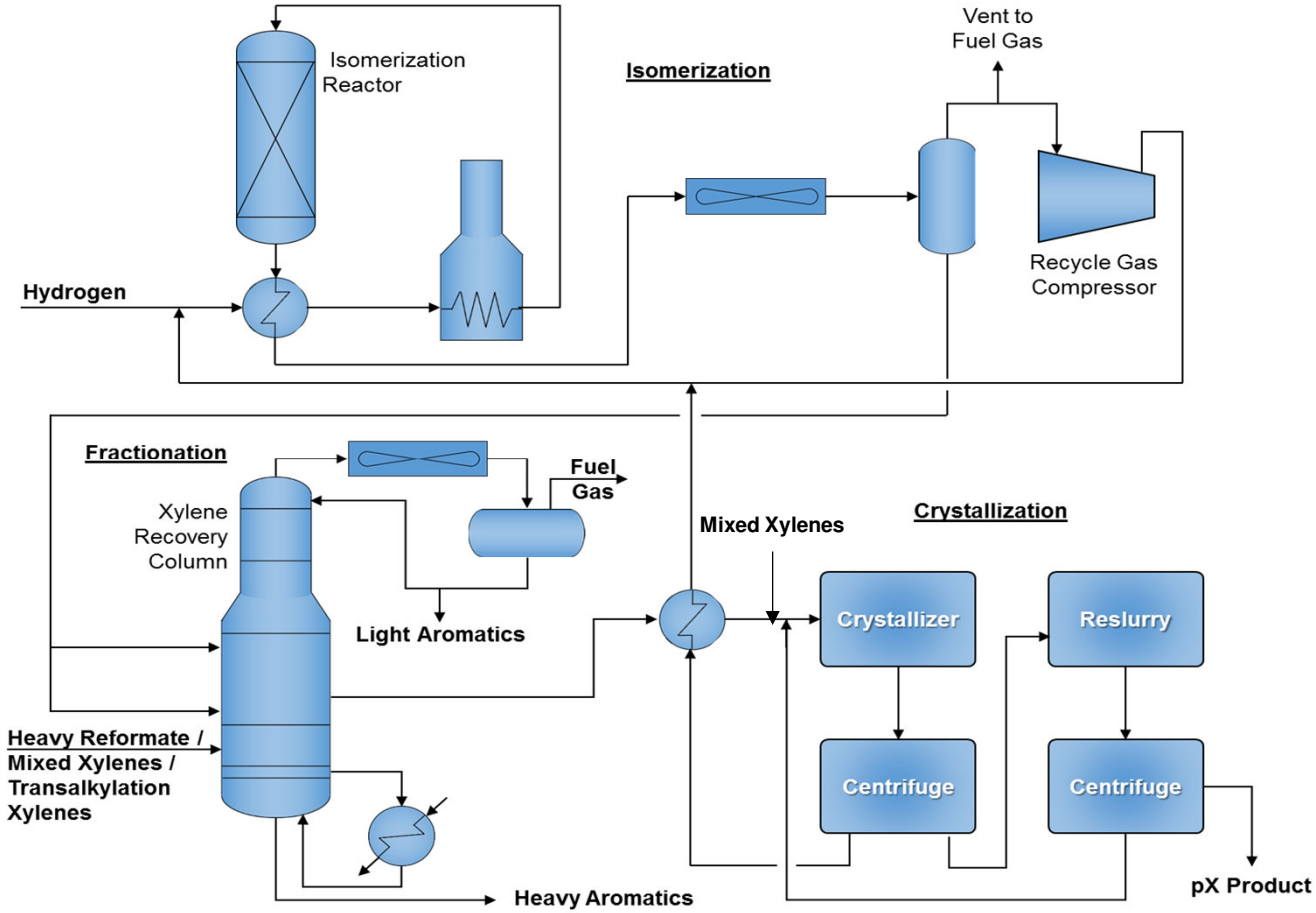
Aromatics Complex Block Flow Diagram



BP / Lummus pX Technology



Overall Process Scheme – BP pX Technology



Overall Process – BP pX Technology

- Xylenes isomerization / EB conversion
  - oX and mX isomerized to pX up to equilibrium composition
  - EB is converted to benzene (primarily), toluene, xylenes and by-products
  - Reactions consume hydrogen
- Low Pressure Fractionation
  - Separates light [C7-] and heavy [C9+] aromatics from xylenes [C8s] in mixed xylenes feed
  - C8s are fed to pX recovery section
- pX recovery via BP Double Reslurry Crystallization
  - pX is recovered as 99.8%+ product
  - Other xylene isomers (oX/mX) and EB are fed to xylenes isomerization/EB conversion section

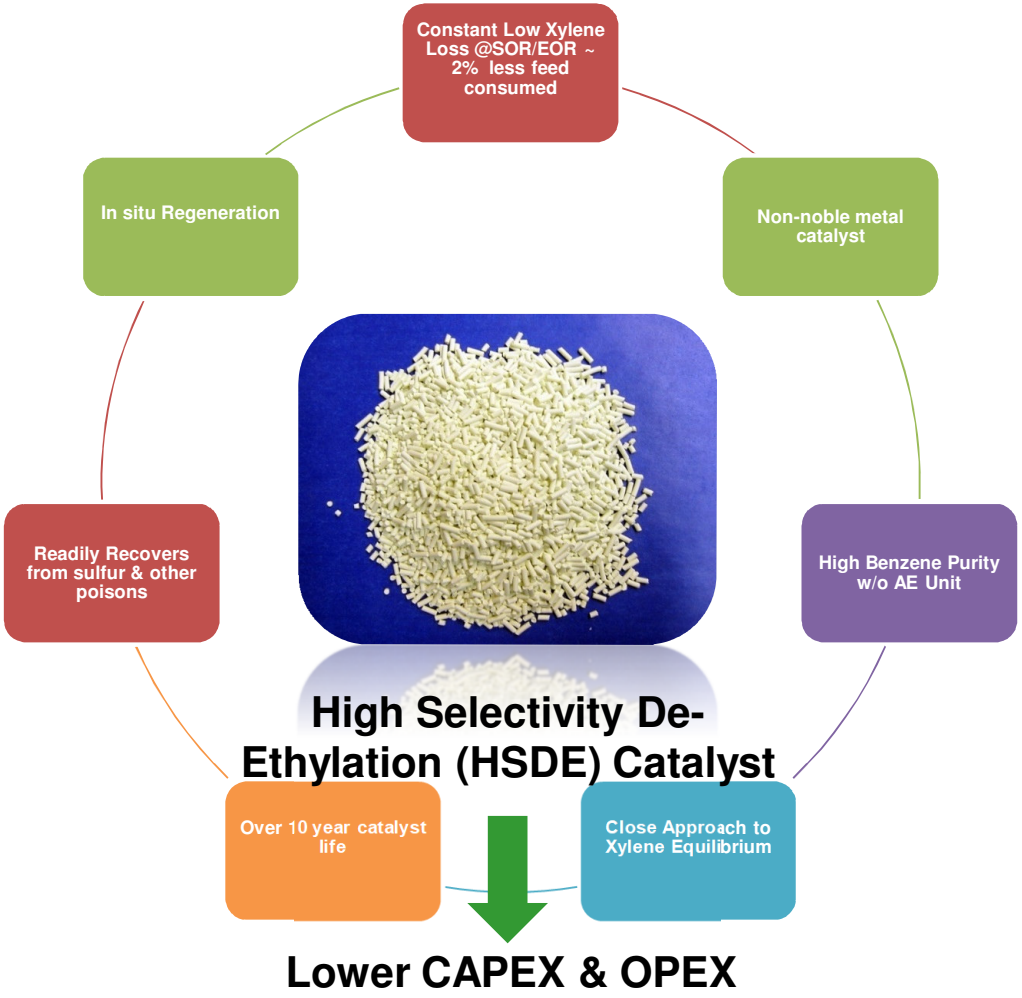
Continuous Improvement

- LP (Low Pressure) Xylene Recovery Column
  - 25% ~ 35% of additional XRC reboiling duty savings
  - Allowing Steam Reboiling to be used
- Crystallizers and Centrifuge optimization ~ TIC Savings by 10% with equipment piece count reduction
- Isomerization Catalyst Improvements
  - 20% Increase in Catalytic Activity
  - Reduction in Volume of Catalyst Used or Increased pX Production

Isomerization

Ethylbenzene + H2 → Benzene + Ethane

oX and mX → pX



Low CAPEX Drivers

Key Drivers

Low Pressure Xylene Recovery

- Reduced xylene separation equipment count
- 66% Reduction in Flare system Lower Fuel Consumption
  → Reboiling using Steam possible
- BP PX Steel Requirements 1/8 of SA

Crystallization Feed

- Less stringent spec
  → Reboiler duty ~ 10 – 20% of SA Unit
- Vapor side draw heat integration
- No oxygen stripper or Clay Towers

Selective Adsorption

Separate stabilizer / xylene splitter

SA Xylene Splitters:

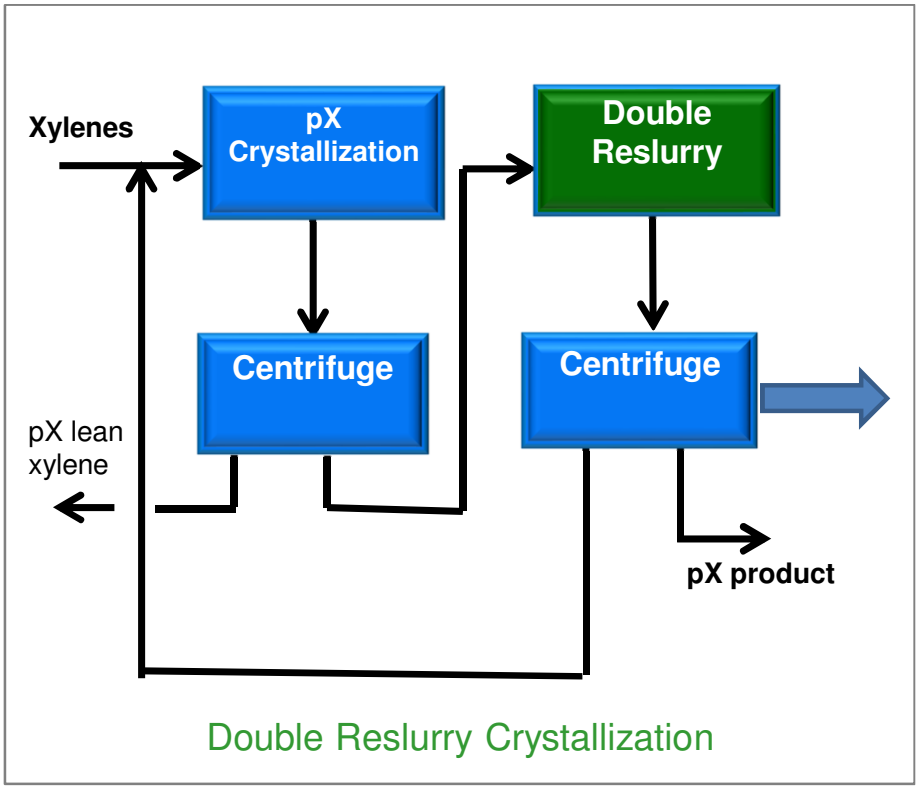
- Large steel weight
- Proprietary trays
- Limited expandability
- Logistics issues: special transport & lifting considerations

BP PX

- Combined splitter / stabilizer
- Steel weight: 1/8 of SA Unit

Double Reslurry Crystallization

Paraxylene is recovered as 99.8%+ product via *double reslurry* Crystallization and other xylene isomers (oX/mX) and ethylbenzene are fed to isomerization

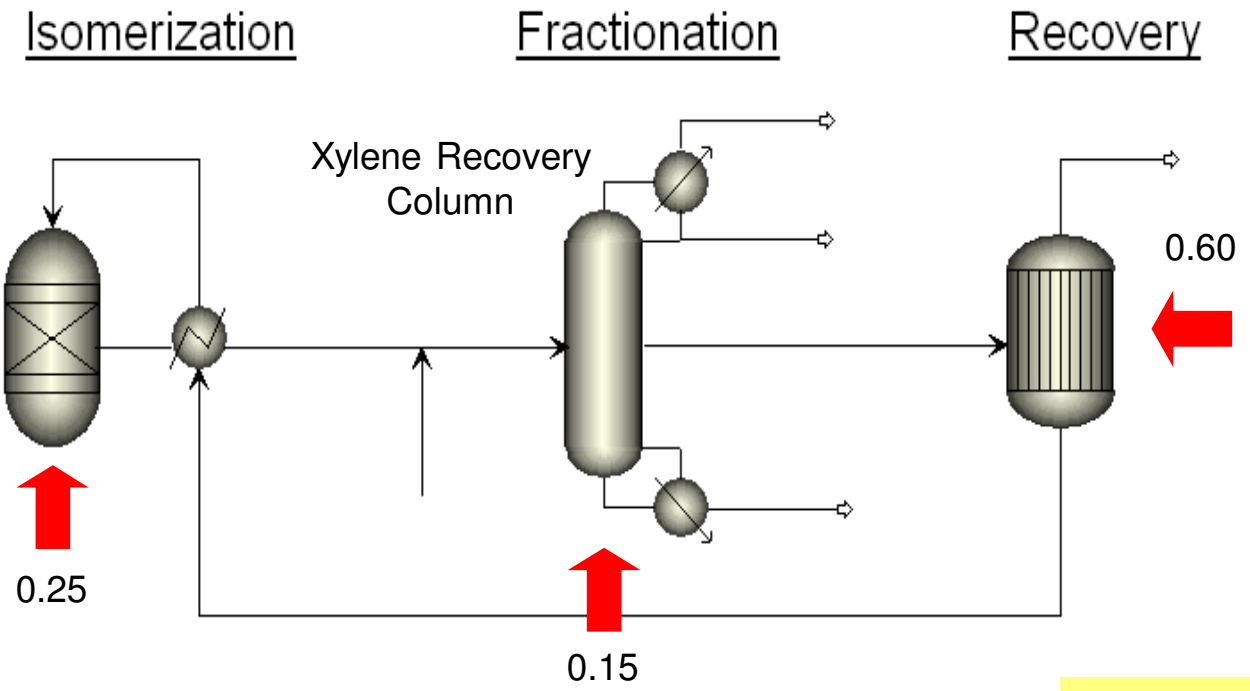


Double Reslurry Crystallization

	Refrigeration power requirement
Reslurry Crystallization with improved refrigeration (present day)	+55% Reduction
Double reslurry crystallization	+ 50% Reduction
Traditional 2 stage crystallization	Base

Overall Energy BP Double Reslurry Crystalization Process

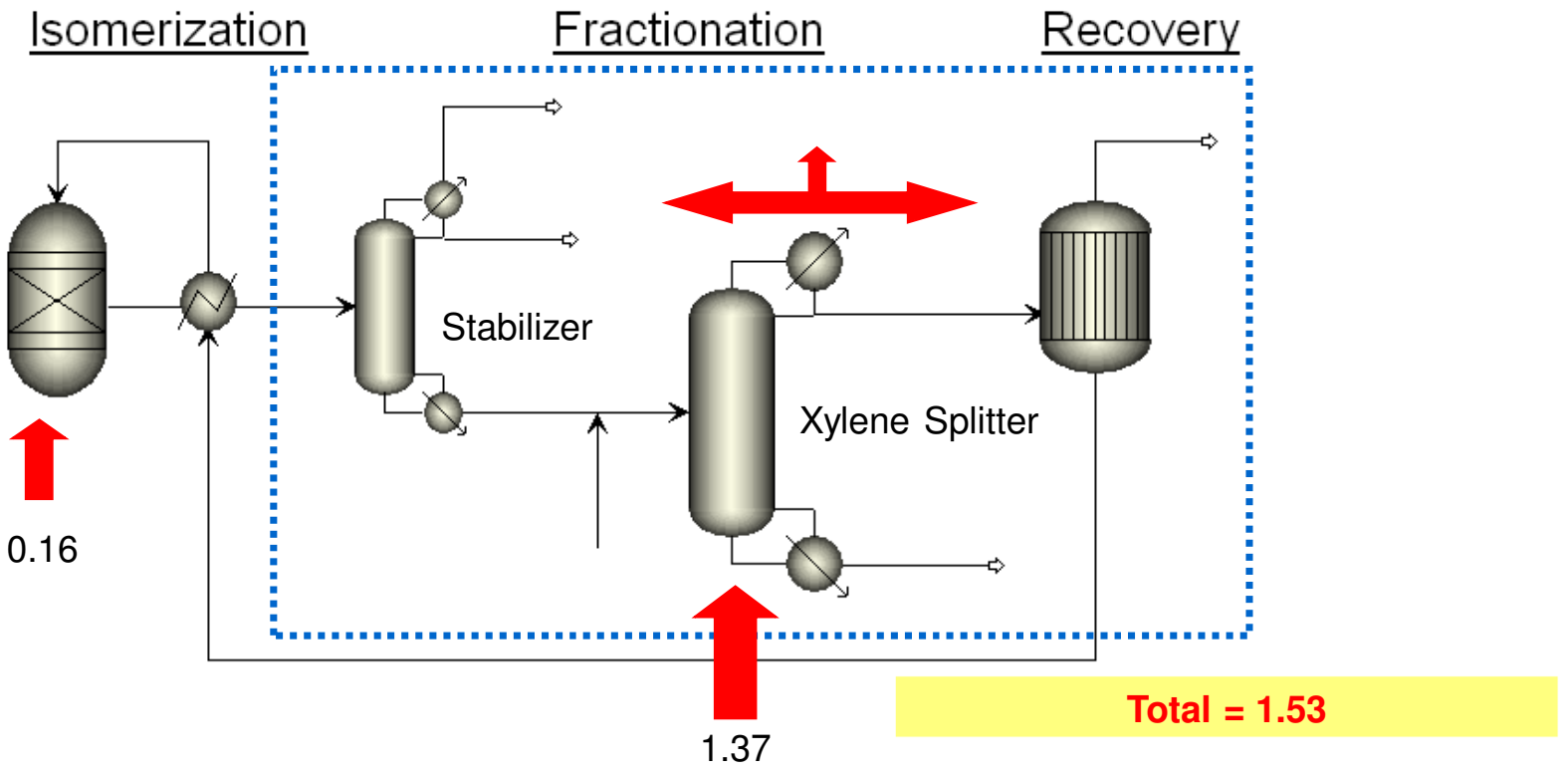
BP Double Reslurry Crystallization: Relative Energy (Standard Oil Basis) Consumption
Feed Basis : Mixed Xylene



Total = 1.0

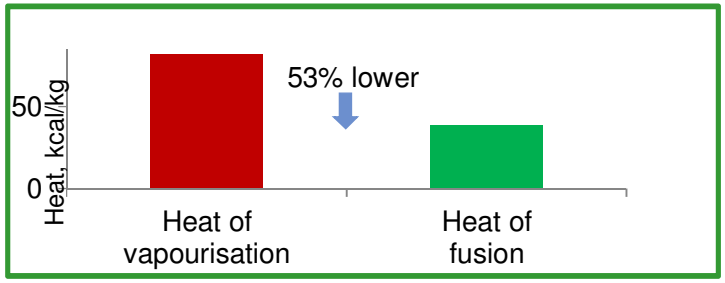
Overall Energy for Selective Adsorption

Selective Adsorption: Relative Energy Consumption



Energy Advantage with Double Reslurry Technology

Freezing is much more favourable and efficient than boiling thermodynamically



Energy reduction with *double reslurry* Crystallization and optimized Refrigeration

One low pressure xylene recovery/ stabilizer column with lower reflux due to high feed impurity (heavy aromatics) tolerance to crystallizer

As of 2017	Fuel $/MT pX	Power $/MT pX	Total $/MT pX
Crystallization	Base	Base	Base
Selective Adsorption (SA) (EEAC for HD and LD system)	Base + $20	Base - $8	Base + $12@ ME
	Base + $60	Base - $ 12	Base + $48 @ SE Asia*

	Fuel	Electricity
Middle East (ME)	$16.3/ MMKcal	$60/MWh
SE Asia, China	$48.5/MMKcal	$83/MWh

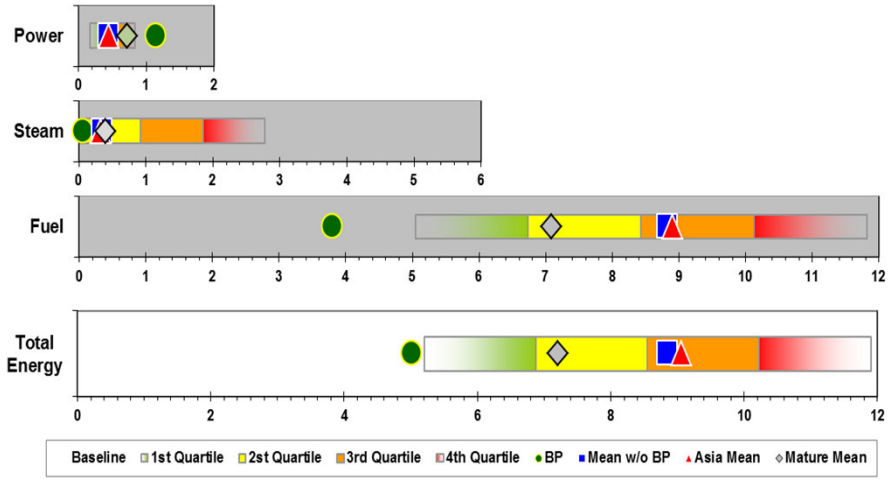
Because fuel use is much lower, environmental emissions are also much lower

*Information from Hydrocarbon Processing January 2018, Maximizing Energy Efficiency in Paraxylene Production-Part 2

BP pX Benchmarking study

Townsend Aromatics Study

BP Assets lead PX Industry in energy efficiency – **first quartile**

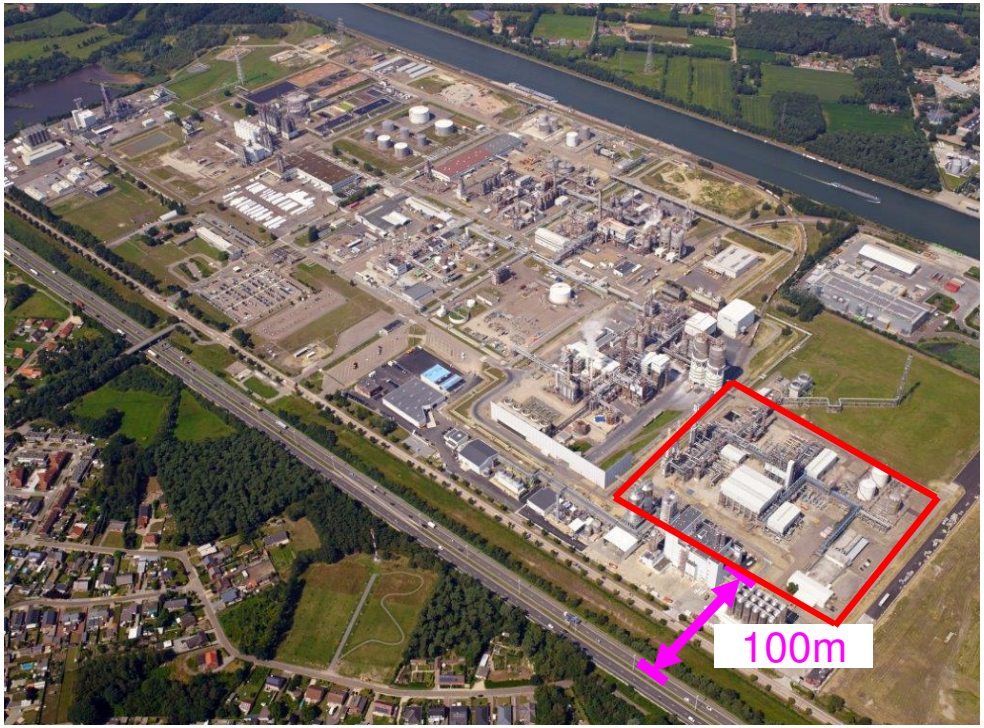


BP PX Outperforms the Industry in environmental performance – validated by an independent third party ERM in 2016

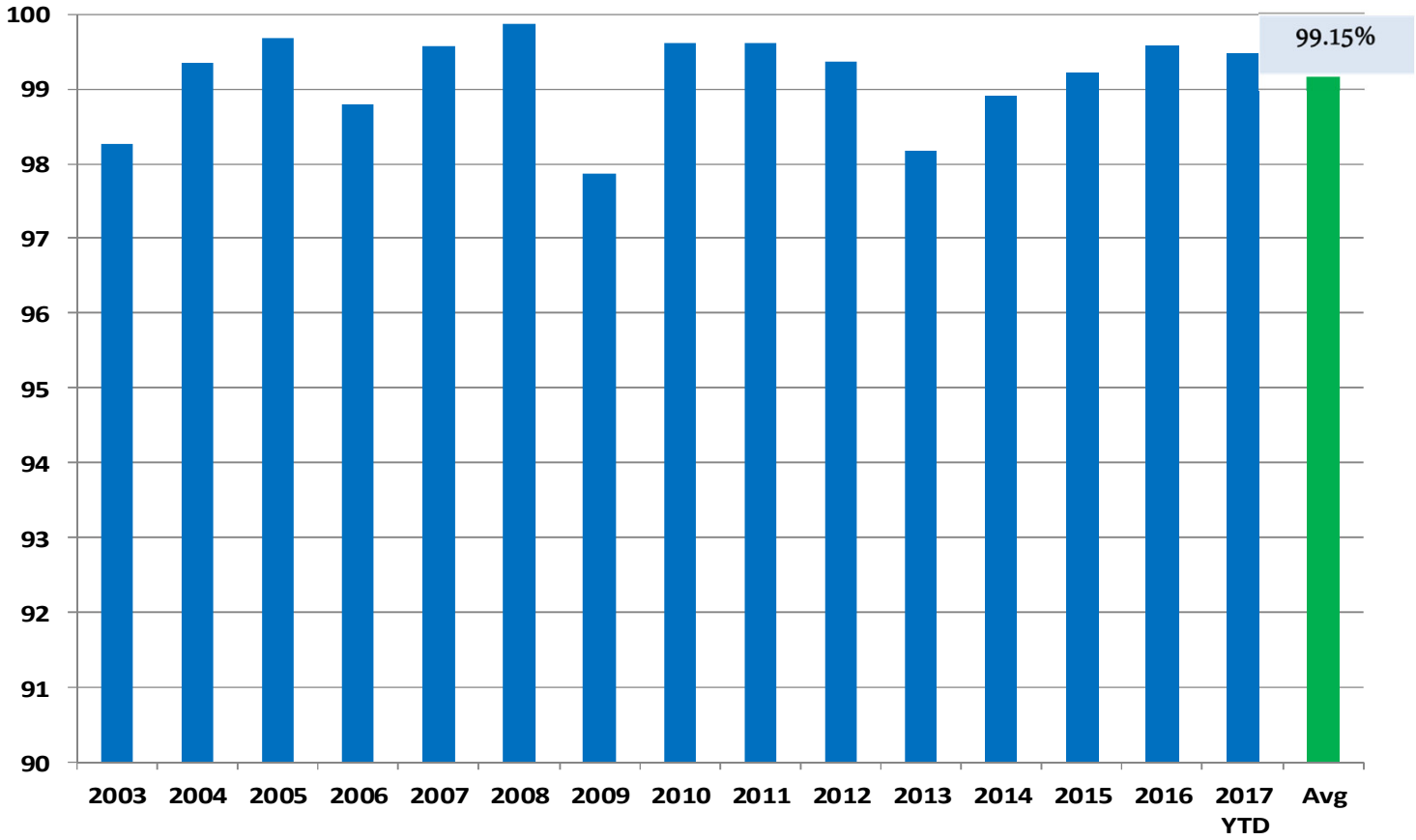
- ✓ 27% lower global warming potential
- ✓ 32% reduced acidification potential and Ozone depletion
- ✓ 10% reduction in nutrients such as phosphates released in water that stimulate the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen

Geel, Belgium Plant

- Average PX purity > 99.8%; higher product purity easily achievable
- Average reliability over last 10 years = 99%+
- Exceeds strict European emissions criteria



Double Reslurry Crystallization Reliability – GEEL (2003 -2017)



Preventive maintenance based on 50 year operation experience

Reliability = Maximum production capacity – unplanned operational and equipment losses

BEST PETROCHEMICAL TECHNOLOGY awarded by Hydrocarbon Processing in 2017

LUMMUS TECHNOLOGY

BEST PETROCHEMICAL TECHNOLOGY

This award is given to the best executed petrochemical process globally, with nominees comprising the technology team for that project.

FINALISTS: Fluidized Catalytic Dehydrogenation (FCDh) technology, **The Dow Chemical Co.;** Maximizing Catalytic Propylene (MCP) technology, **SINOPEC Research Institute of Petroleum Processing (RIPP)**

WINNER: BP Paraxylene (pX) technology, **BP Amoco Chemical Co.**

BP's pX technology consists of three main sections: isomerization, fractionation and crystallization. The low-energy usage process helps produce pX in an environmentally friendly manner. It uses crystallization to make pX, which is based on differences in freezing points rather than boiling points. The process utilizes a novel fractionation section consisting of a much smaller, single distillation column. The xylene recovery column features a vapor side draw that can be used for steam generation or as a boiling source. Another fractionation section features reduced column traffic, which decreases the overall column size, flare load, capital cost and energy consumption.

BP pX Double reslurry technology Benefits

Commercially Proven

- Improved over 50 years
- +100 years of cumulative experience

Lowest Capex

- 10% lower TIC (USGC basis)
- No Proprietary Equipment and Special Control System
- Non-noble metal Catalyst with +10 years active life
- Sharing the propylene refrigeration for CCR Reformer/ Stabilizers in Aromatics complex

Lowest Opex

- Lower energy consumption
- Lowest maintenance costs (< 0.2% of total installed costs)

Highly Flexible

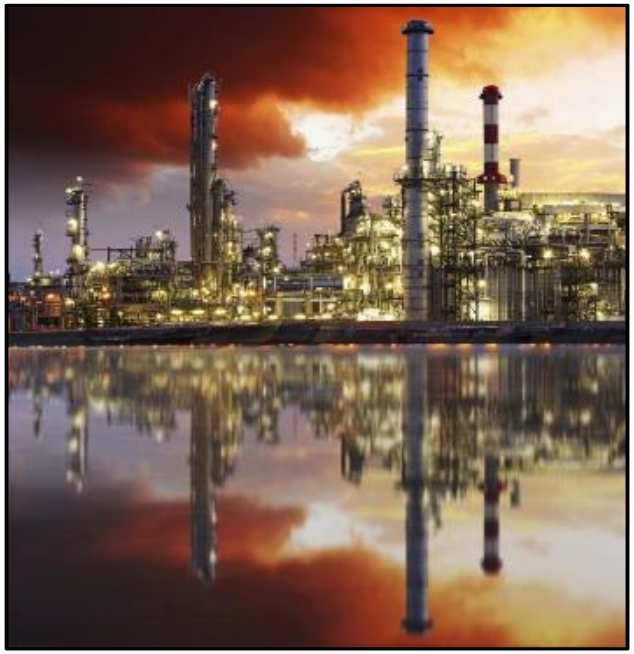
- Lowest environmental emissions
- Smaller Flare size
- Debottleneck at minimal capex
- No feedstock constraints

High Reliability

- +1% = ~ +$1-2 million income per year for a 1 mta PX unit

Presentation Agenda

- Lummus Technology Overview
- PX Production by BP Crystallization
- **Q&A**



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