Applying Crude to Chemicals Technologies for Effective Petrochemicals Production

February 2023

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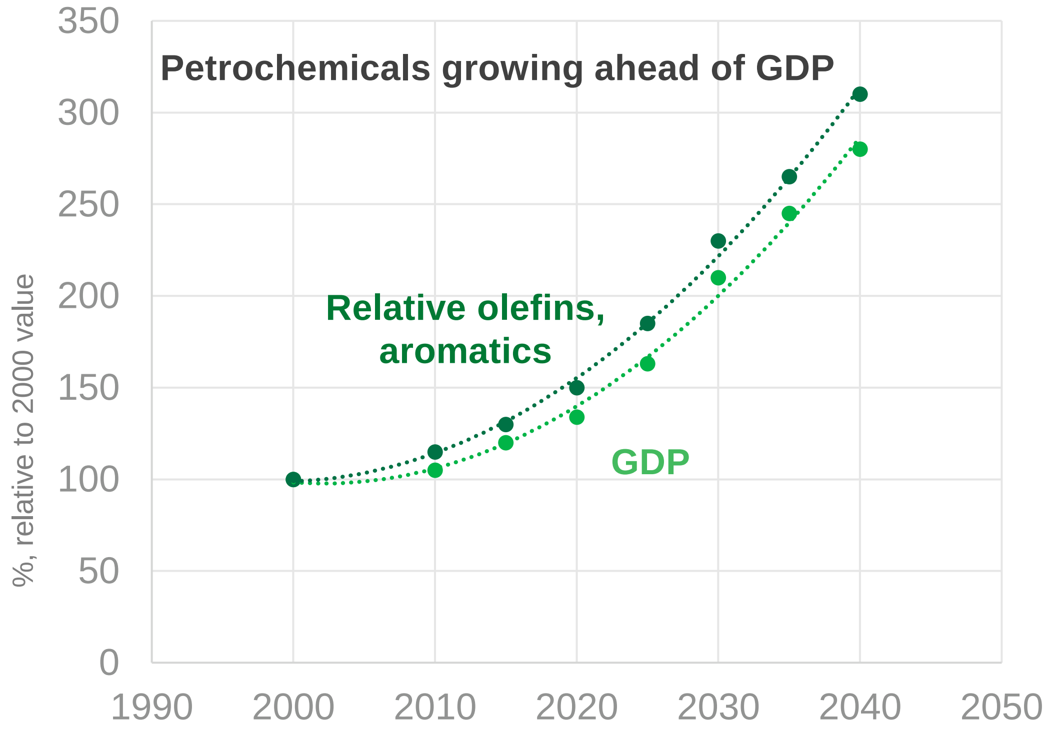
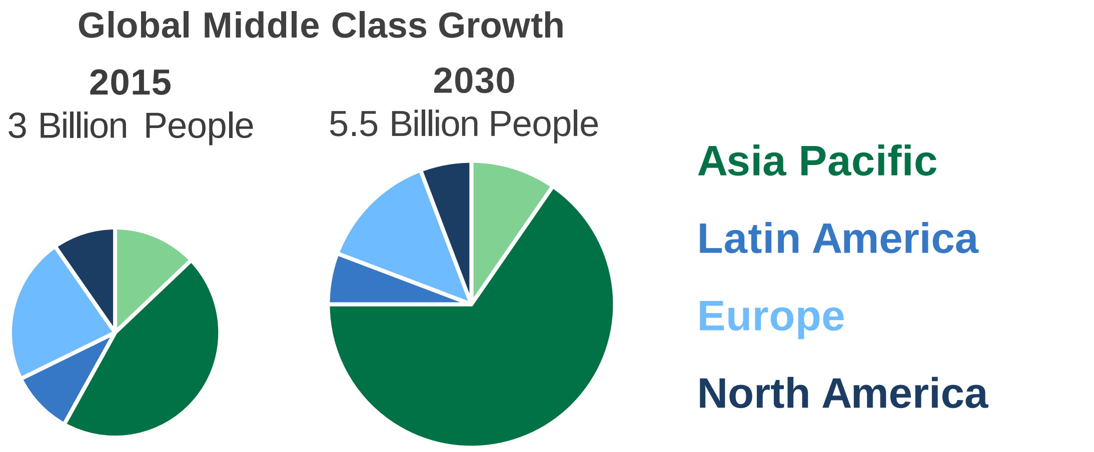
Drivers for Investments in Petrochemicals



Source: IMF, IHS Markit, 2019

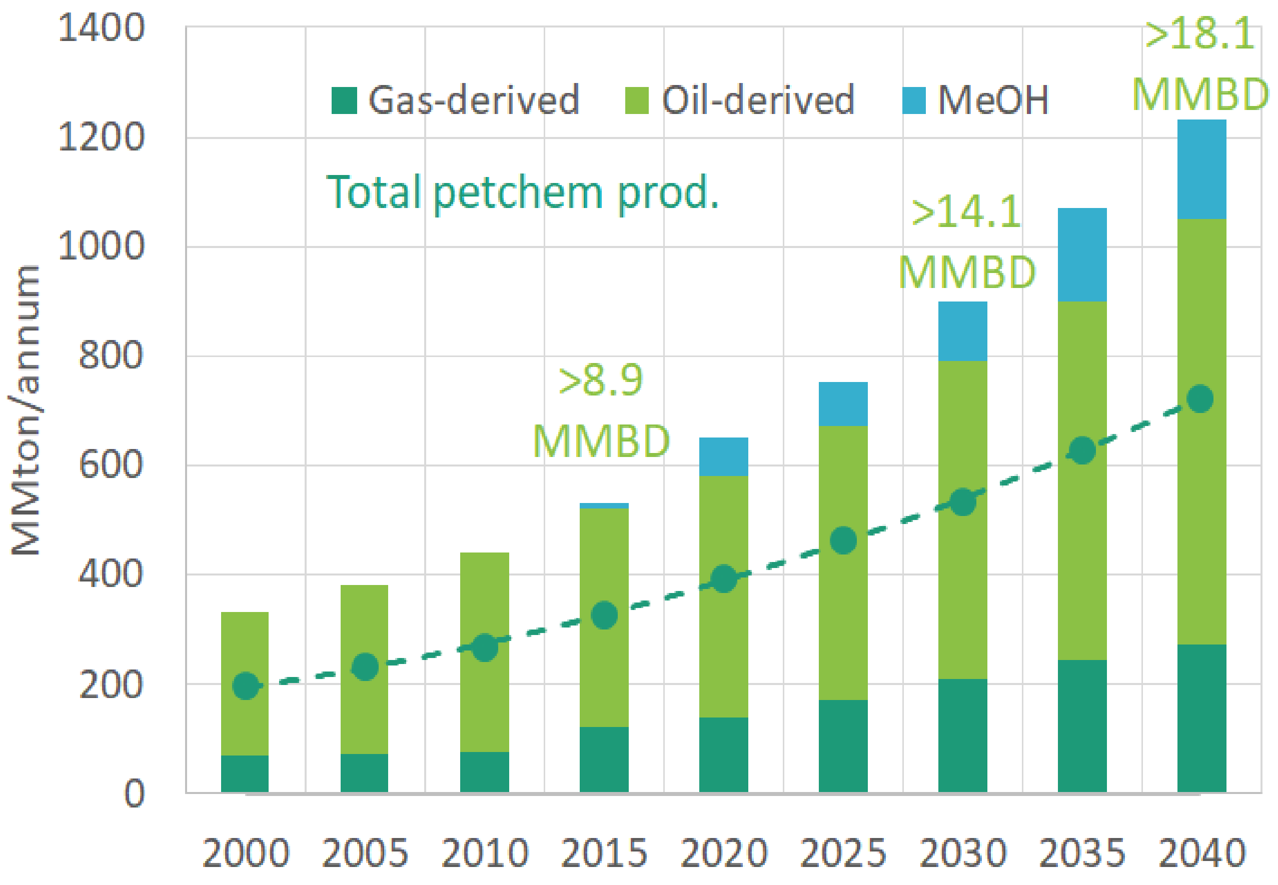


Source: The Brookings Institute
Homi Kharas, 2017

- Anticipated chemicals growth of > 40% due to:
  - Unprecedented growth in Asia Pacific
  - Petrochemical Growth > GDP Growth
  - Rising GDP
  - Rising middle class

Product Flexibility Secures Future of Crude-Derived Liquids

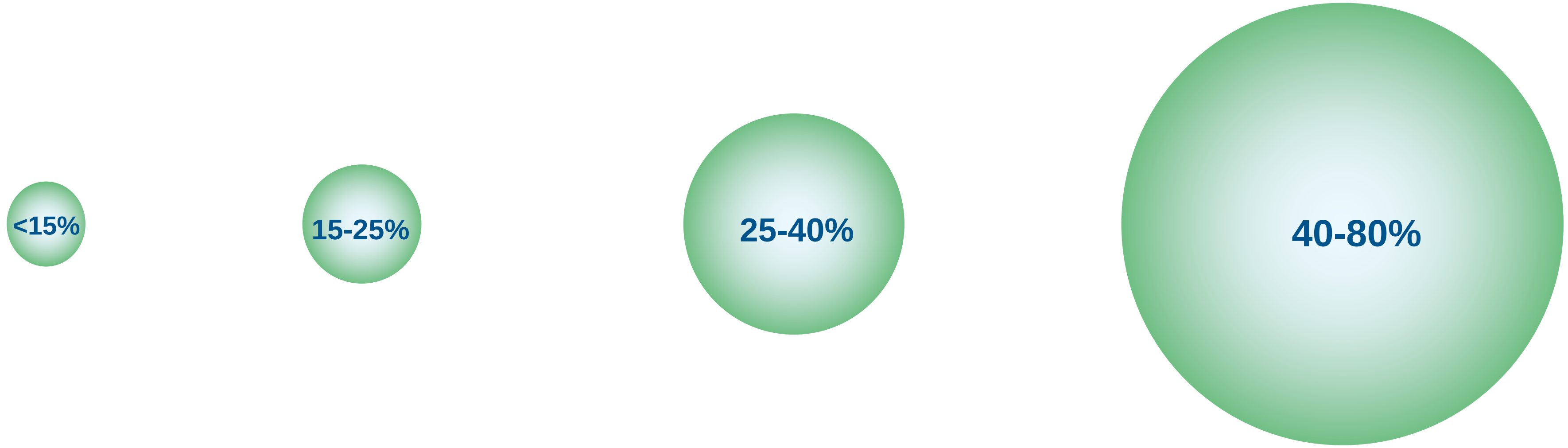
Despite other than the availability of other sources, in 2040 > 60% of petrochemical feedstock will be derived from crude derived liquids or > 18 million bpd of naphtha and heavier liquids.



Source: Woodmac, IHS Markit, 2019

Increasing Crude to Chemicals Capability to Meet Demand

Potential percentage of chemicals that can be produced per ton of crude processed in an integrated refinery



Pre 1990	1990-2000	2010-2020	2020 & Beyond
Recovery of byproduct aromatics, olefins	Forward integration; commodity derivates	Backward & forward integration; increased scale; higher derivatives complexity, flexibility	Maximum integration; refinery-scale chemicals production; fuel as byproduct

ESG Considerations

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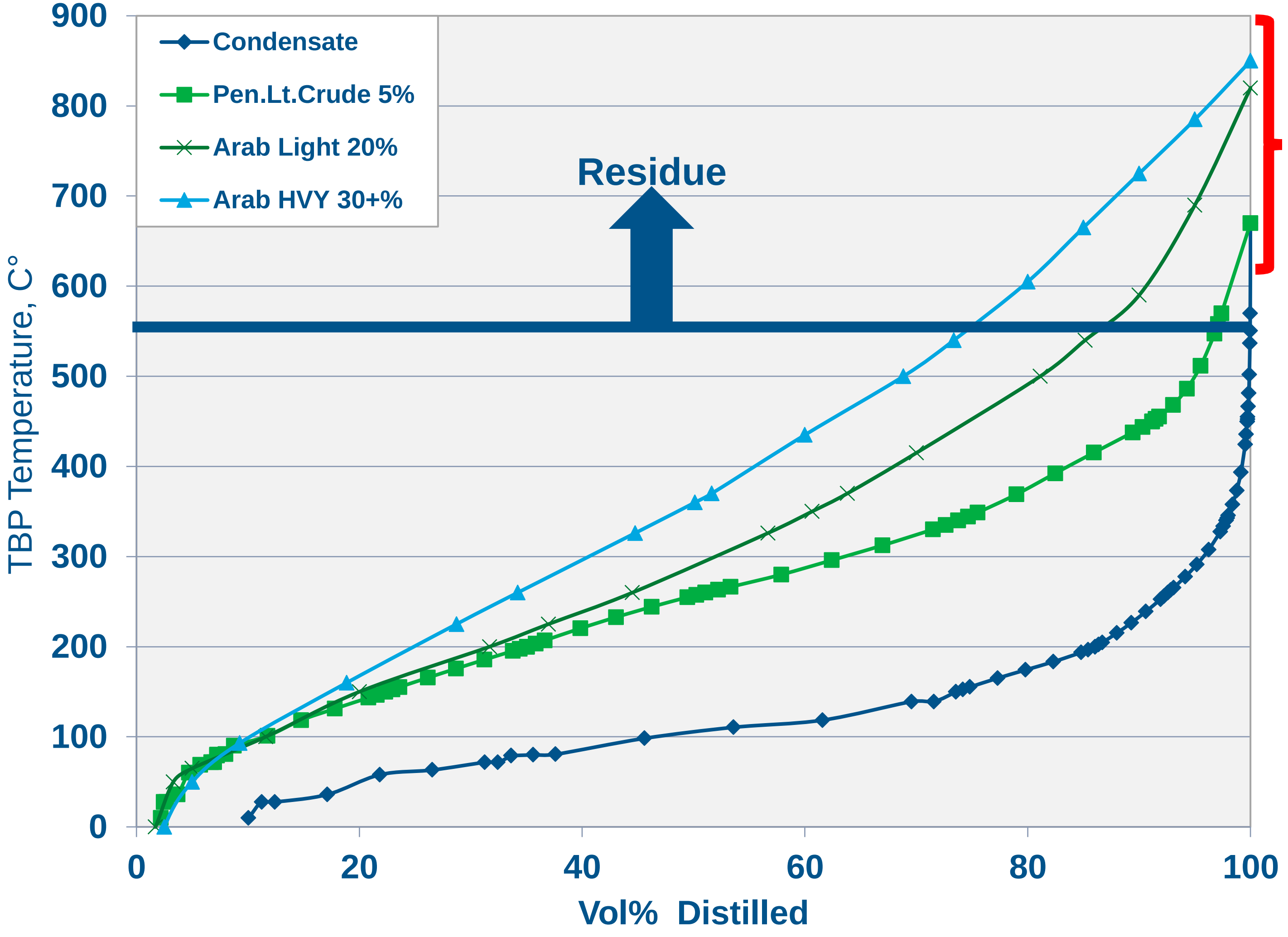
- Decarbonization
- Energy Transition
- Greenhouse Gas Emissions
- Energy Efficiency
- Energy Related Policies
- Environmental Impact

Direct Crude Cracking in an Ethylene Plant

What are the challenges?

Typically the heaviest material (residue) must be removed before cracking



Crude residue fraction much larger

Deeper into the Crude, the Non-Crackable Components Increase

Normal Paraffins

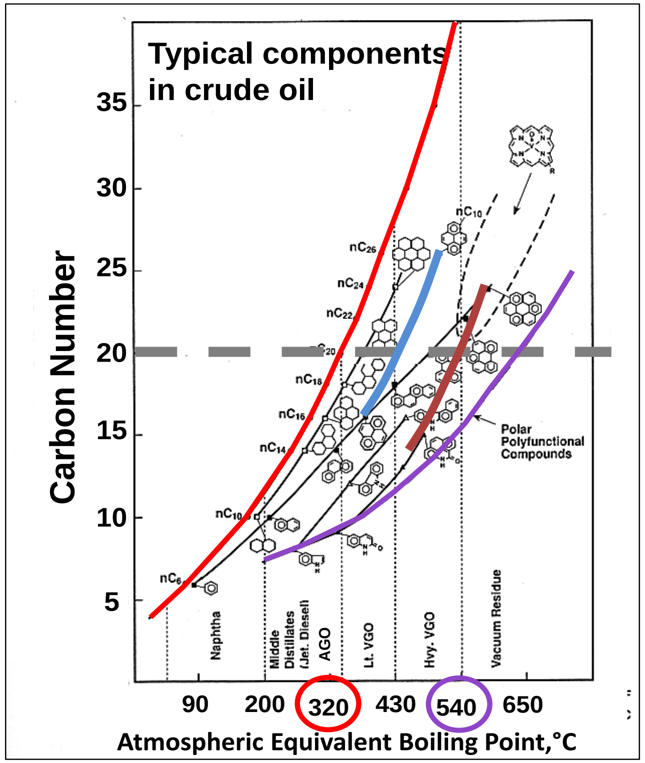
- Best olefin yield
- Very low coking rate

Polynuclear Aromatics

- Lowest olefin yields
- High coking rate

Residue

- High in MCR and Asphaltenes
- Extreme coking rate
- Asphaltenes are very difficult to vaporize
- Solids (asphaltenes and coke) will form during vaporization and cracking
- Asphaltenes are soluble in aromatics and insoluble in paraffins
- Coke is insoluble in both

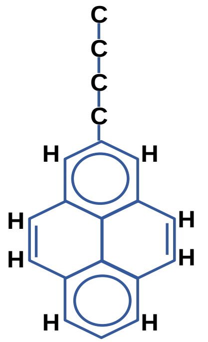


Carbon Number = 20

VGO

$nC_{20}H_{42}$

or



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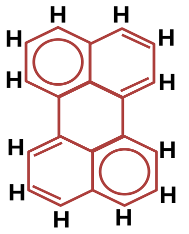
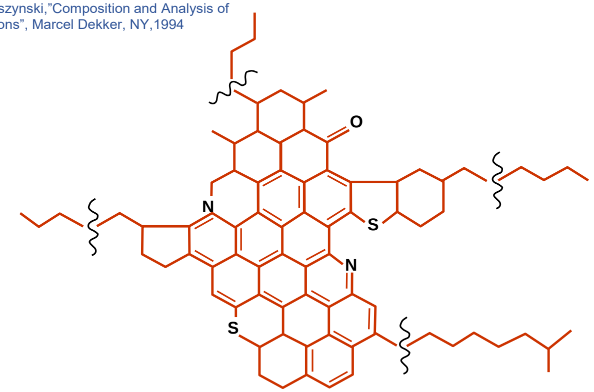
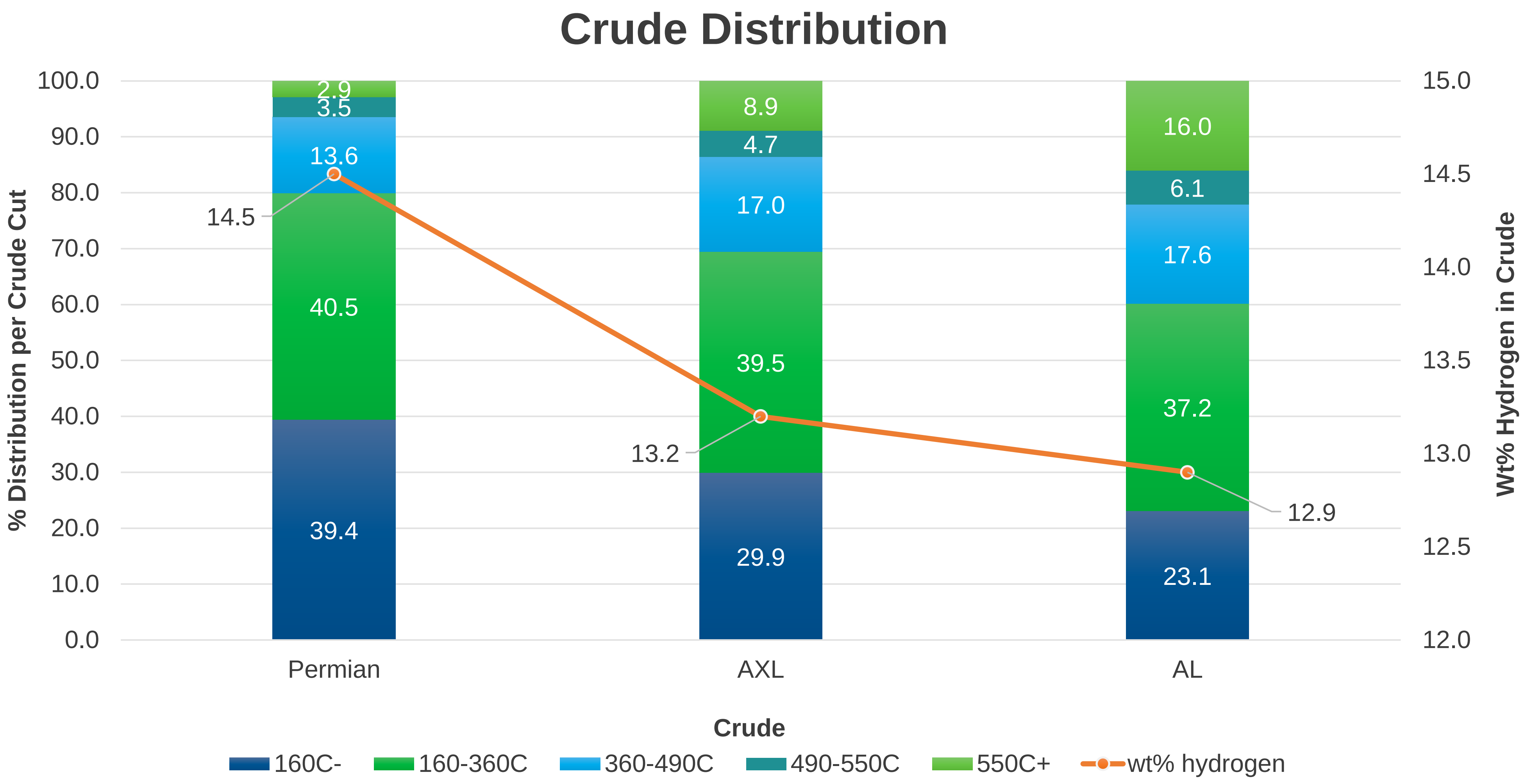


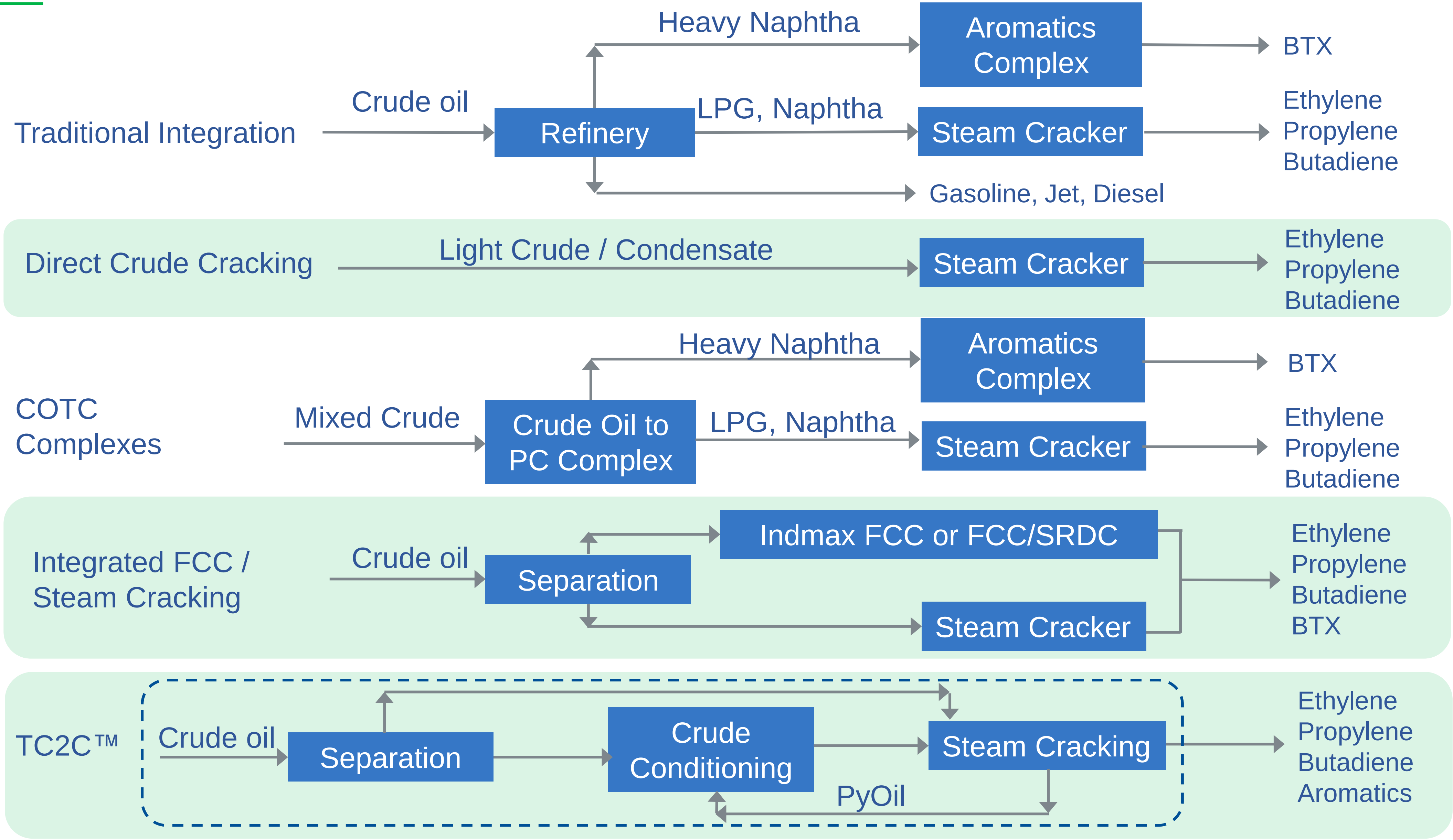
K.H.Altgelt & M.M.Boduszynski,"Composition and Analysis of Heavy Petroleum Fractions", Marcel Dekker, NY,1994



CAPEX/OPEX/CO2 Emissions all Dependent on Crude Source



Crude to Chemicals – Different Pathways



TC2C™ Set to Deploy in First Commercial Development

One of the world's largest petrochemical crackers in South Korea

First commercial deployment of our thermal crude-to-chemicals technology developed in collaboration with Lummus Technology

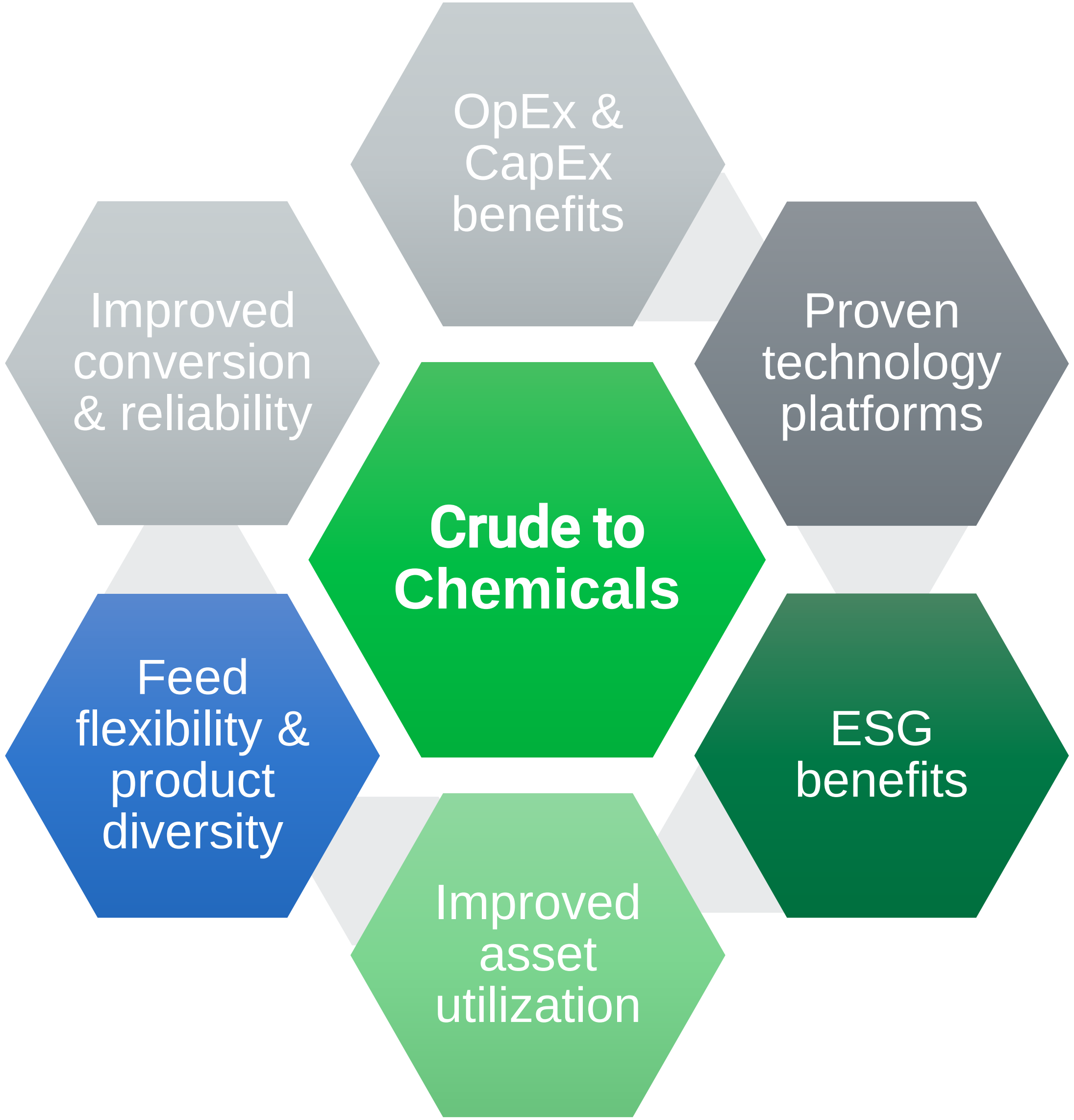
Planned to produce up to 3.2 million tons of petrochemicals annually

3.2
million tons

"TC2C increases chemical yield more than any other crude-to-chemicals technology currently under development, while also enhancing energy efficiency, reducing carbon intensity and lowering operating costs."

Leon de Bruyn President & CEO, Lummus Technology

Advanced Crude to Chemicals Solutions

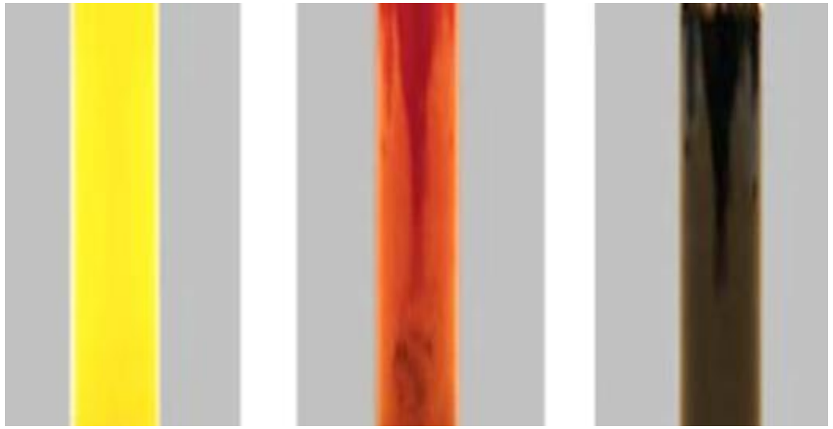


Direct Crude Cracking

Feed Selection for Chemical Production with Direct Cracking

All crude oils cannot be cracked economically

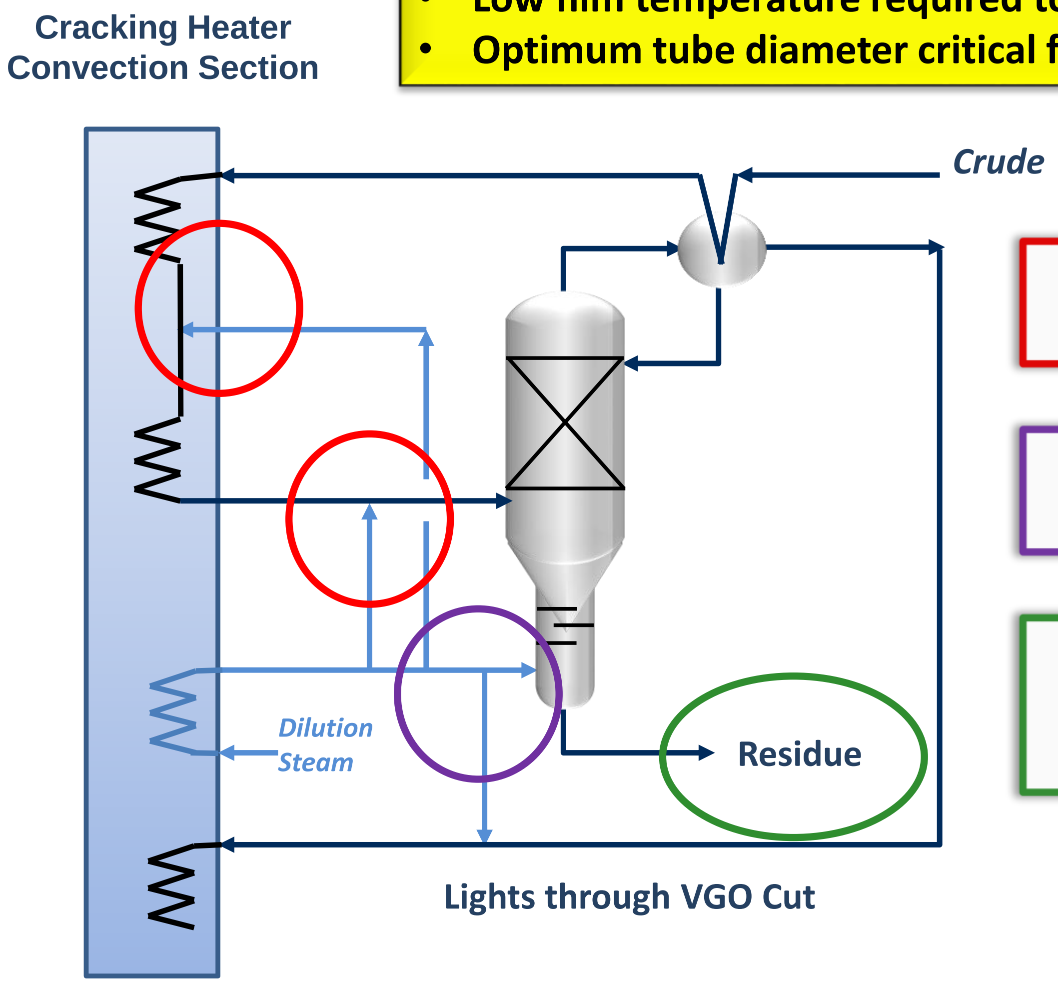
- For olefins production:
  - Light crudes (API >35; ideally > 40)
  - Boiling curve: At least 90% material boils below 575°C
  - Low sulfur, preferably <0.2 wt% (polar compounds)
  - Low metal (mainly in polar compounds)
  - Low MCR/CCR (highly condensed molecules)



Very Light Crude API>42	Light Crude	Heavy Crude API<32

Heavy Oil Processing Scheme (HOPS)

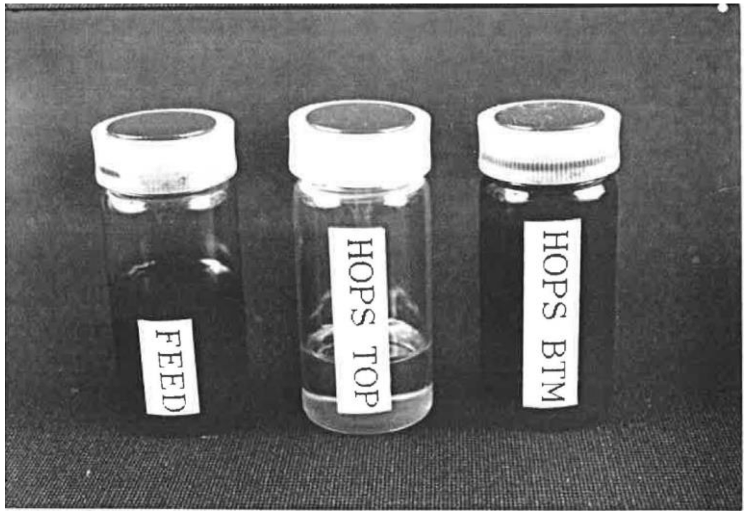
- Crude contains material that can foul convection section
- Low film temperature required to minimize coking
- Optimum tube diameter critical for design



Crude preheated and flash vaporized

High steam-to-oil ratio needed to lower dry point

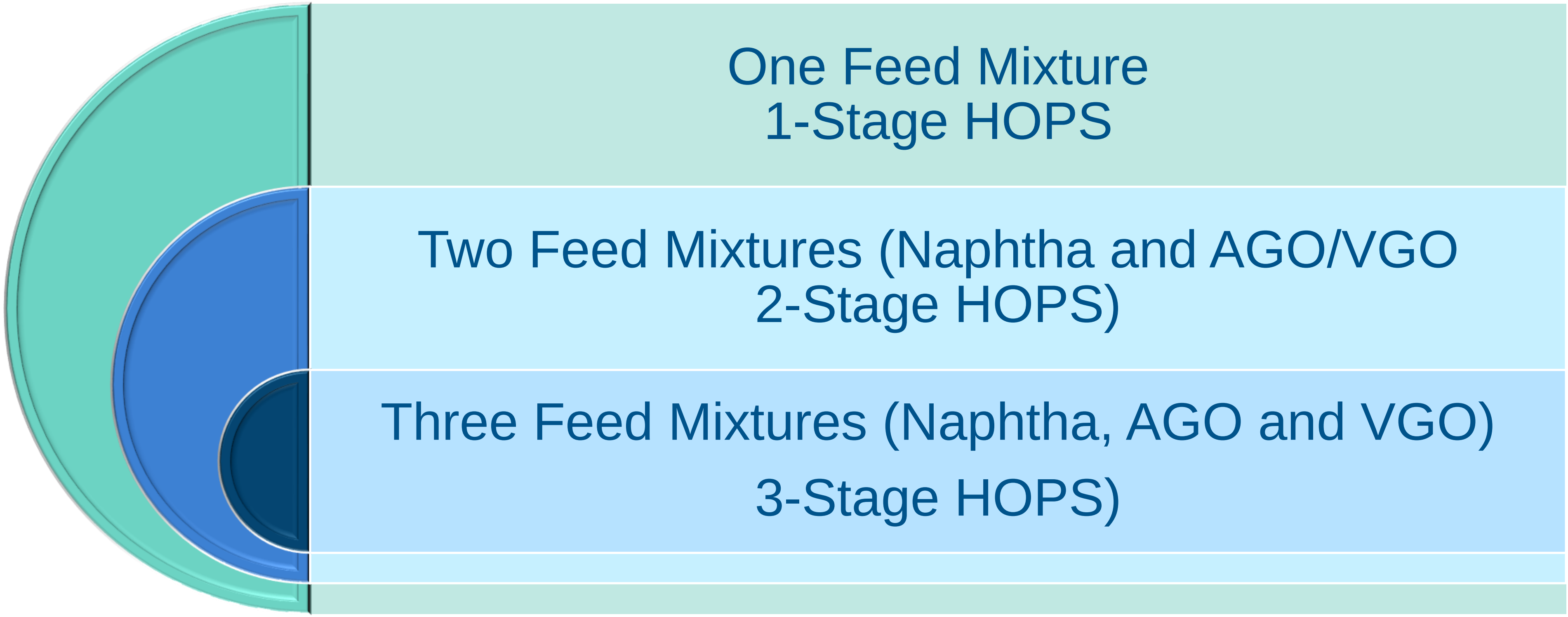
Residue rejected before entering high temperature zone of convection section



HOPS Case Study

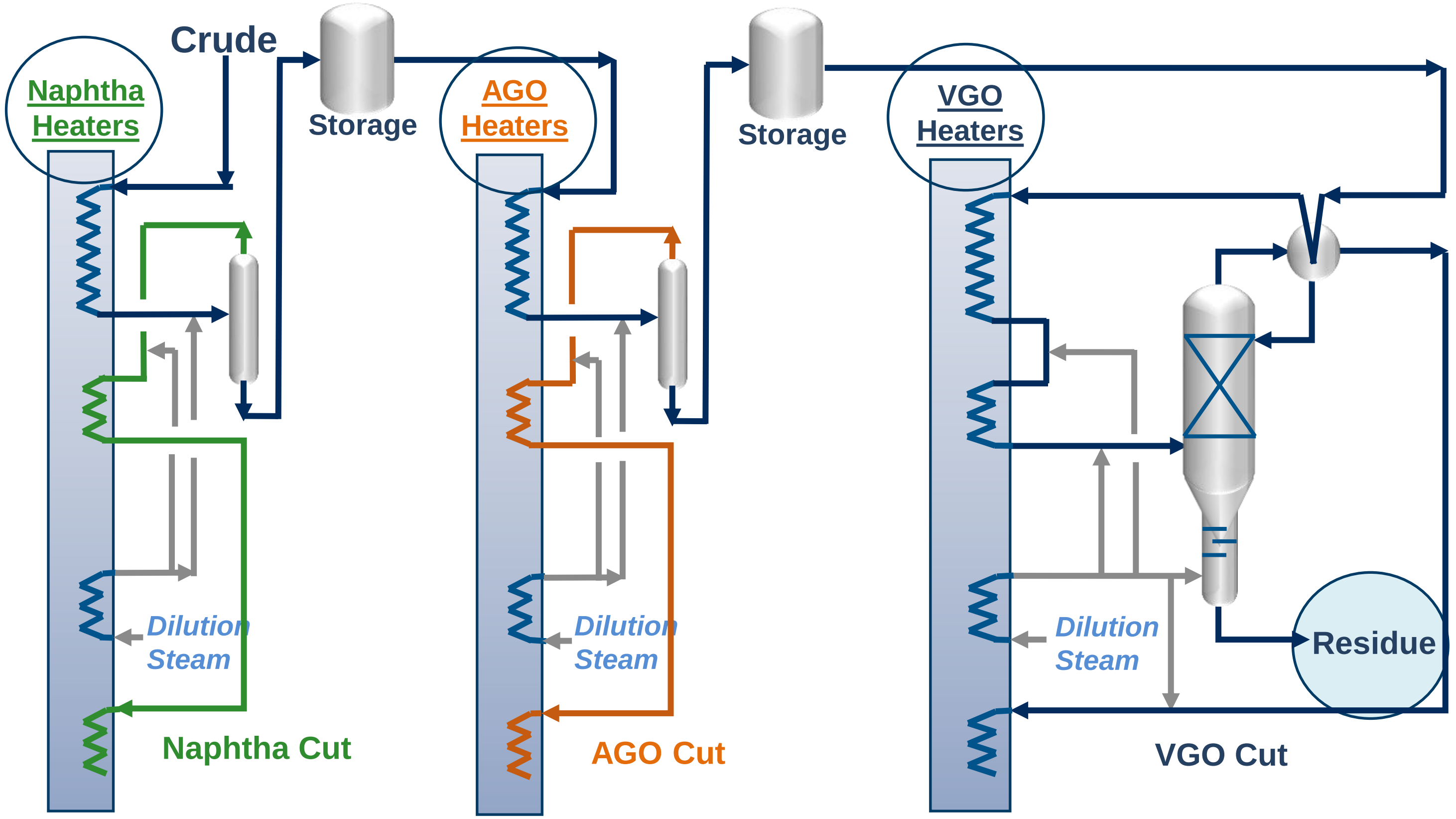
Crude is a Wide Boiling Mixture

- Challenge: If Vacuum Gas Oil (VGO) is cracked at maximum severity, the lightest cuts will be severely under cracked (below maximum propylene)
- Crude can be separated into cuts using simple HOPS combined with the heater convection section



Crude Cracking via HOPS

- Direct crude cracking can be achieved using Heavy Oil Processing Scheme (HOPS)
- Lummus patented the HOPS
  - 4 units were designed and commissioned
  - Elimination of CDU and/or VDU with multi-stage HOPS
  - Lowest investment solution
  - Careful adjustment of temperature profile and steam addition to minimize fouling



Number of HOPS Stages Dependent on Crude Gravity

Experience in Heavy Feed Cracking

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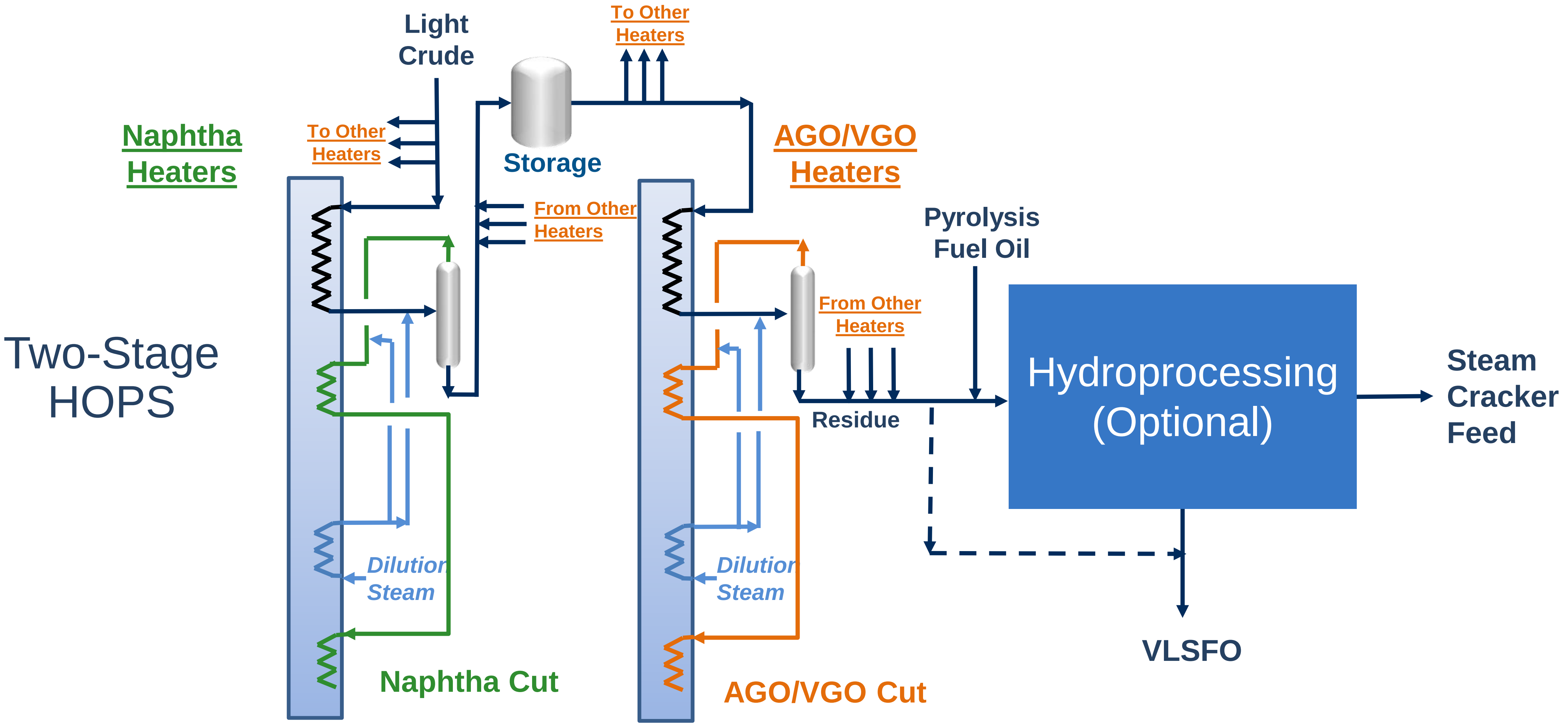
More than 100 SRT® (Short Residence Time) heaters have used heavy feeds (condensate, AGO, VGO, and Hydrocracked Vacuum Gas Oil)

BMCI	2 - 42
Specific Gravity	0.78 - 0.97
IBP, °C	56 - 366
50 vol% , °C	225 - 445
EBP, °C	312 - 585
Naphthenes, wt%	25 - 45
Aromatics, wt%	5 - 35
CA, wt% (aromatic carbon)	0.4 - 15.9
CN, wt% (naphthenic carbon)	9.5 - 33.1
CP, wt% (paraffinic carbon)	55.2 - 80.5

Direct Crude Cracking Example

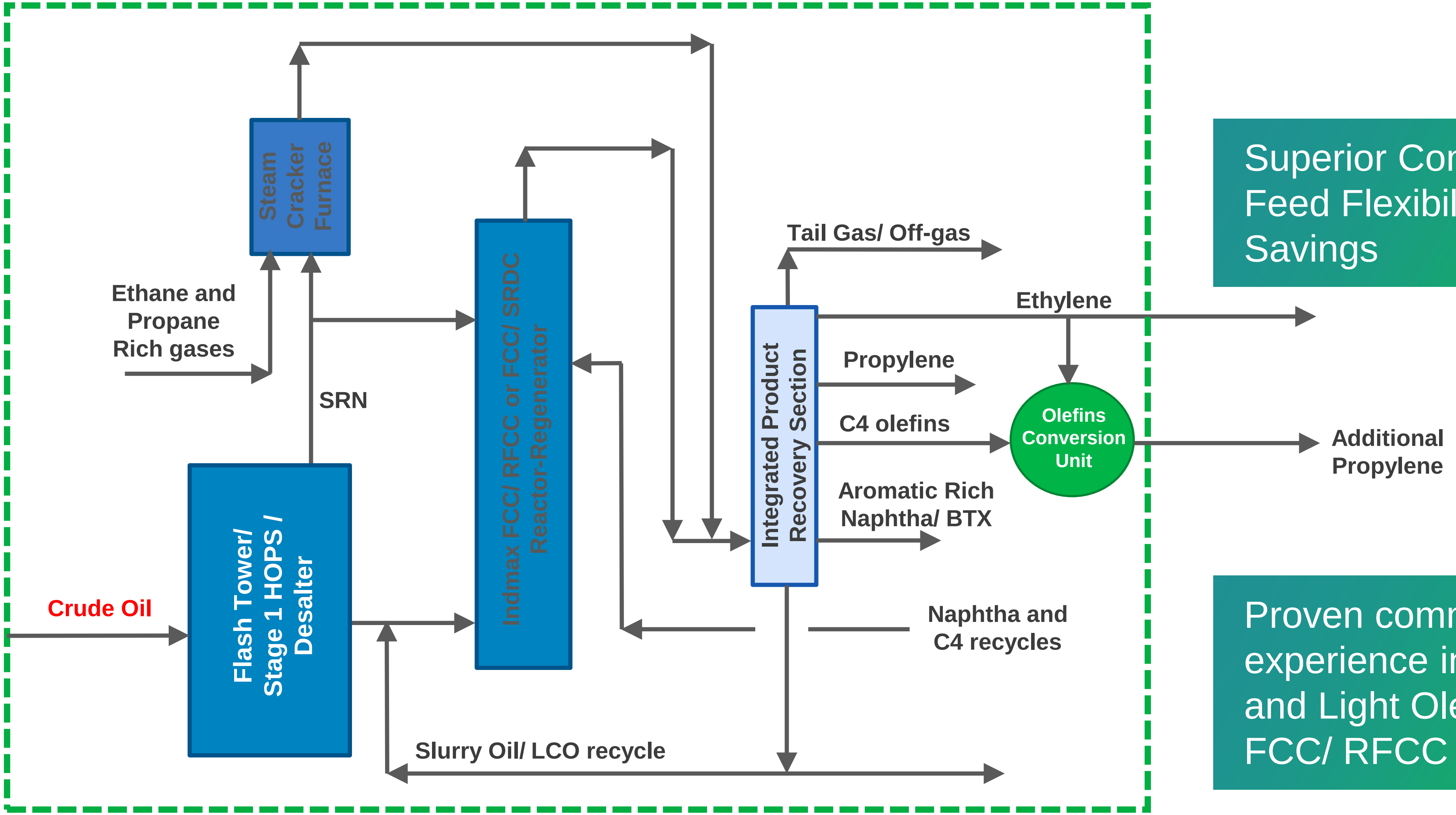


Summary of Direct Cracking of Light Crudes

- Lummus HOPS technology can be successfully applied to directly crack light crude to chemicals.
- Petrochemicals provide a direct outlet for placing light crudes.
- Economics compare favorably against naphtha cracking.
- Lower Cost of producing Ethylene on the Ethylene Cost Curve.
- Significant CAPEX and OPEX reduction.
- For light crudes - residual product can be sold as Very Low Sulfur Fuel Oil (VLSFO)
- For heavier crudes - large volume of residue needs an outlet. Difficult with IMO Regulations
- For most crudes an intermediate step is essential with **molecular management** to maximize production of desired petrochemicals

FCC & Steam Cracking Integration

Indmax FCC/ RFCC or FCC/SRDC and Steam Cracking for Chemicals



Superior Combination for Feed Flexibility, CAPEX Savings

Proven commercial experience in Steam Cracking and Light Olefins / Indmax FCC/ RFCC Technologies

FCC/ RFCC with SRDC and Steam Cracking for Chemicals

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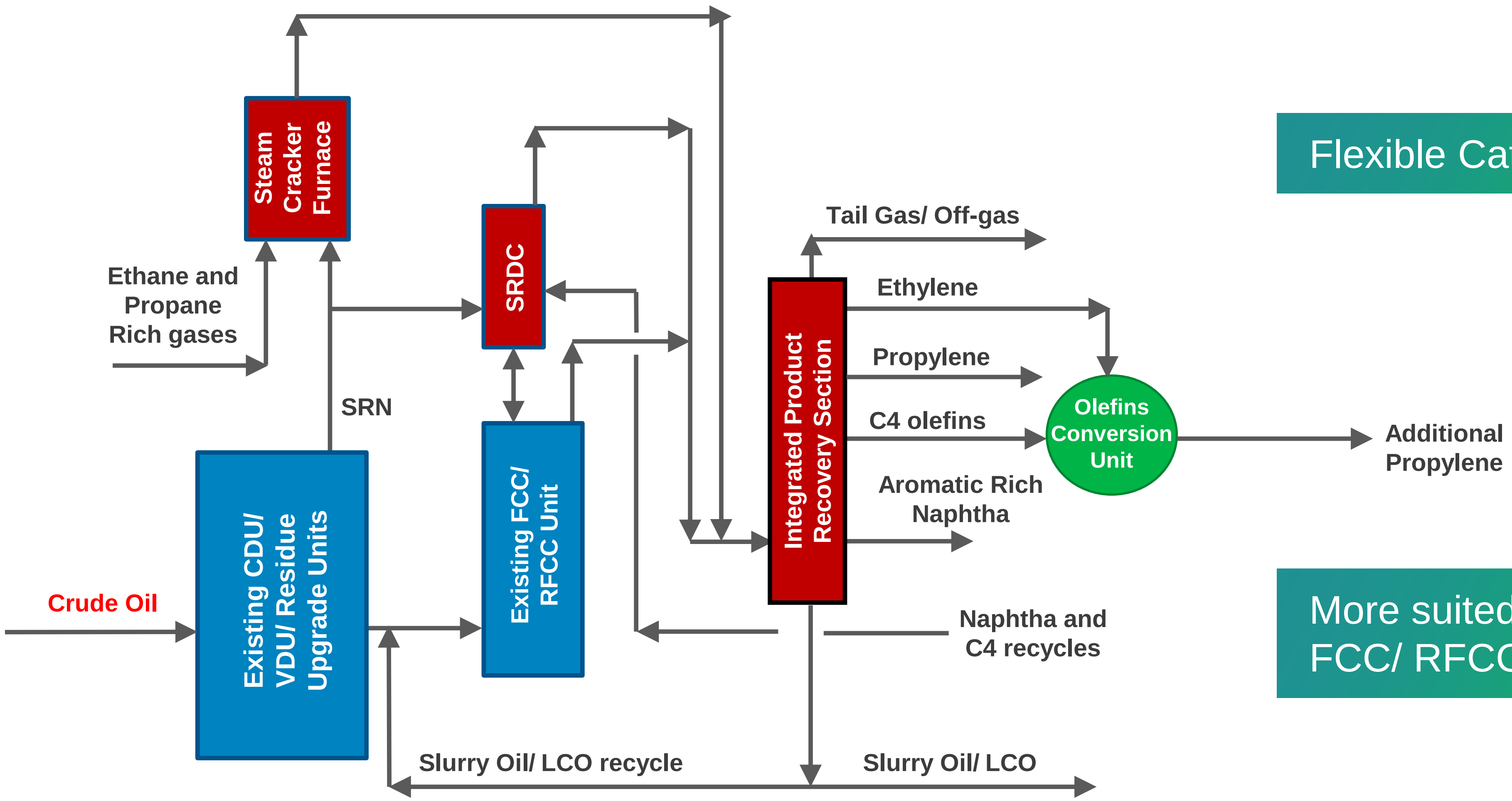


Flexible Catalyst Options

More suited for Refinery and FCC/ RFCC upgrades

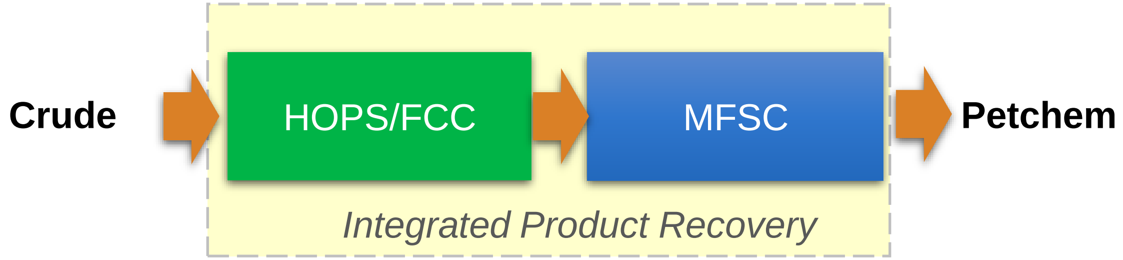
Adding FCC to HOPS Steam Cracker

2 stage HOPS + SC

- ✓ SC process entire crude fraction (VGO minus)
- ✓ Residue reject need to be sold
- ✓ Only SC recovery section

1 Stage HOPS, Integrated SC+FCC

- ✓ SC process crude fraction - (Naphtha minus)
- ✓ FCC process crude fraction - AGO+
- ✓ Combined product recovery section



- **Low Technology Risk:** Integrated C2C scheme derived from commercially proven processes and treatment methods
- Integrated SC/FCC Complex produces Light Olefins + BTX rich naphtha yield is **~ 73 wt % of the Crude**
- Robust integrated scheme that provides feed (crude) and operational flexibility
- Potential benefits on CAPEX, OPEX and Plot area savings

Profit Pivot Points for an Integrated Complex

Hydroprocessing

- Optimize cracker feeds
- Balance hydrogen consumption to optimize production of chemicals
- HVGO excellent lubes or cracker feedstock

Mixed Feed Steam Cracker

- Feed flexibility
- Cracking severity determined by propylene to ethylene (P/E) ratio

Co-Product Selectivity

- Monetize valuable co-products such as butadiene, paraxylene, BTX
- Olefins Conversion Technology maximizes C_2-C_3-C_4 product flexibility

The Miracle of Hydrogen Addition on Steam Cracker Yields

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Typical Cracker Yield Comparison

Typical Cracker Yields	Straight-run Feeds			HVGO from Hydrocracking
	Full Range Naphtha	AGO	VGO	
CH_4	15.40	10.90	9.20	12.60
C_2H_4	29.00	24.50	13.50	30.00
C_3H_6	13.50	13.30	12.00	13.30
C_4's	8.70	8.85	7.85	8.60
C_5-204°C (1)	21.20	19.05	16.60	19.00
PFO	5.60	18.16	37.45	10.10

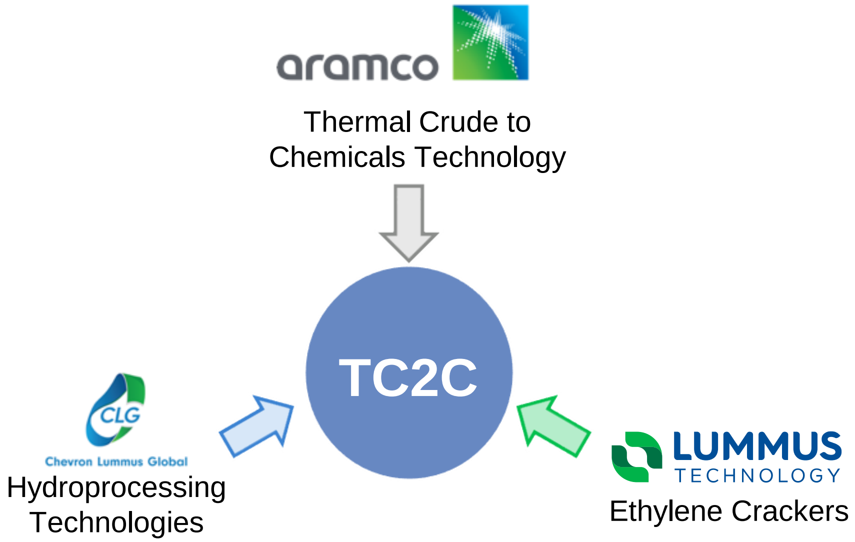
Note 1: Pyrolysis Gasoline for Benzene, Toluene, and Mixed Xylenes

TC2C™

Thermal Crude to Chemicals

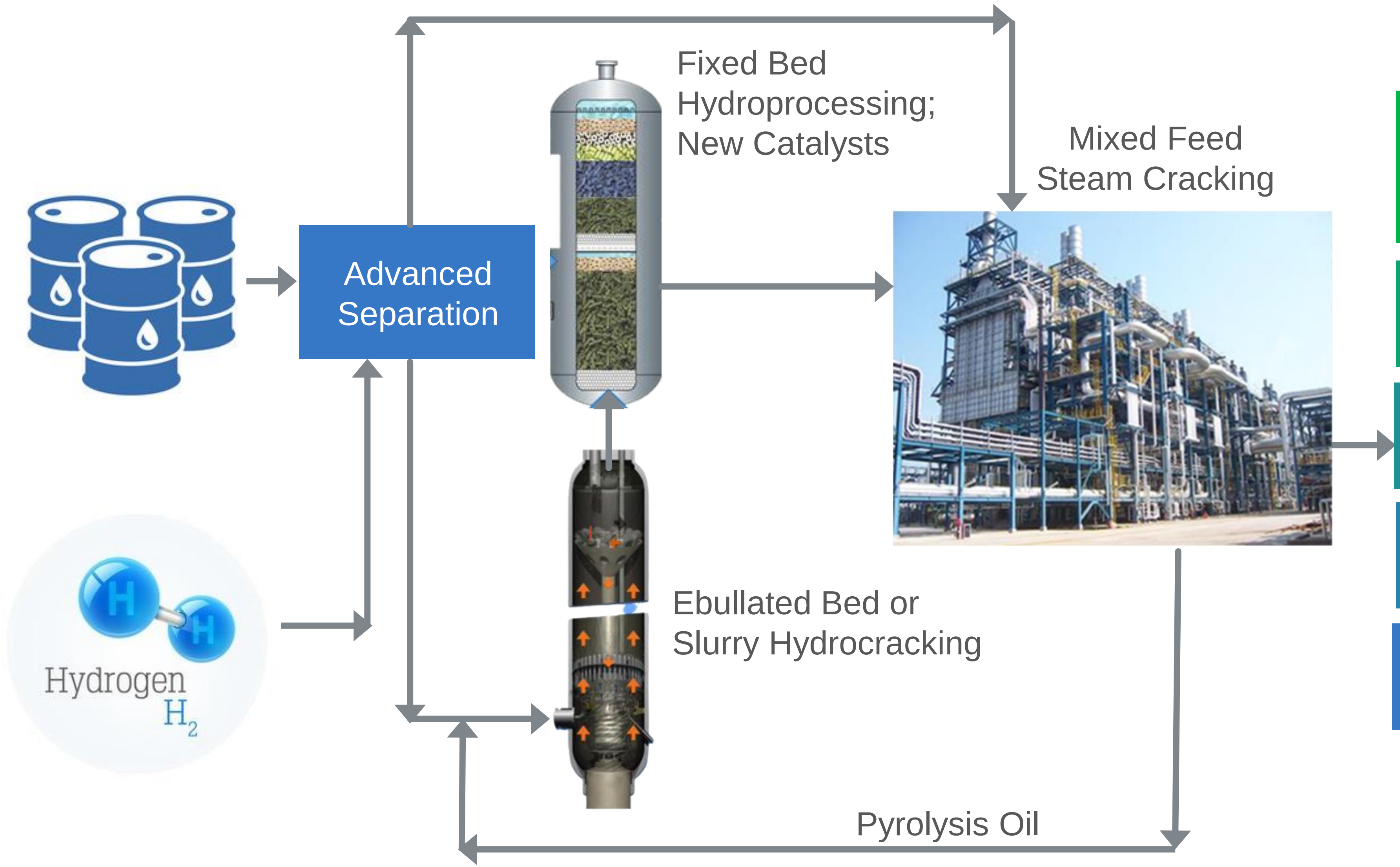
Thermal Crude to Chemicals (TC2C™) Technology

A Joint Development Agreement (JDA) signed in January 2018 between:



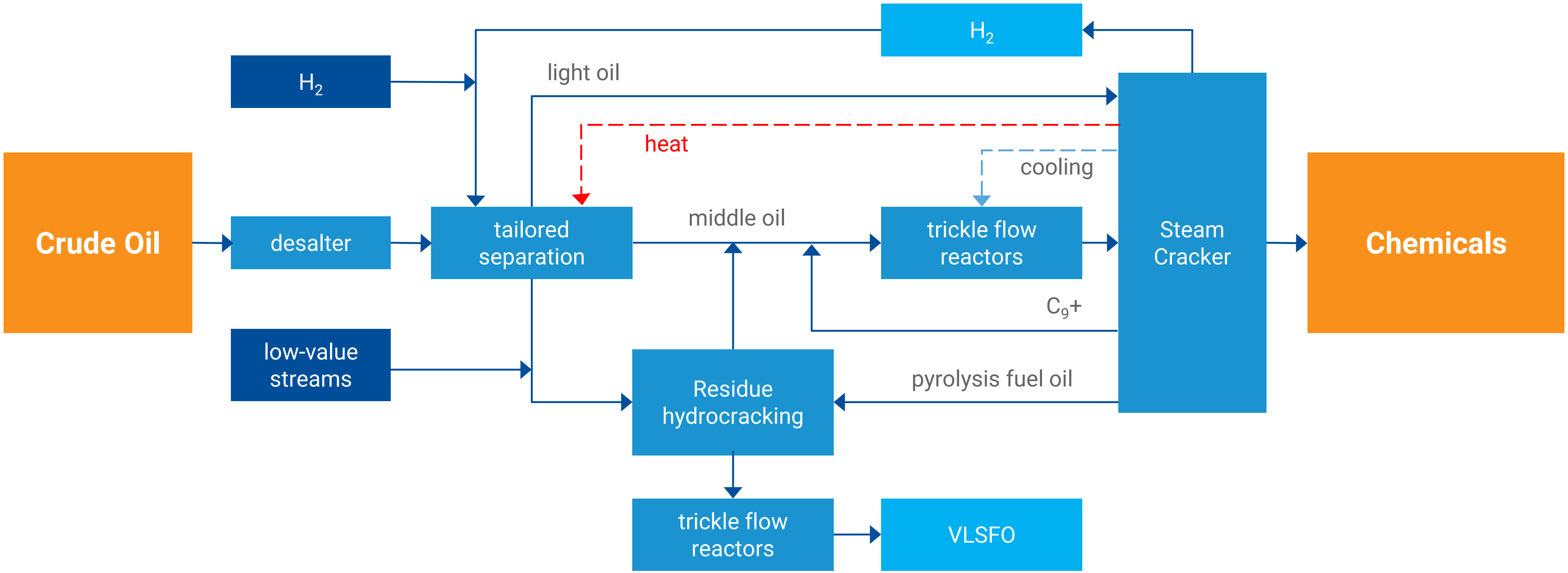
- Replaces Conventional Refinery/Ethylene Plant Integration
- ***Highest chemicals yield from crude oil, > 70%***
- ***Process integration results ~30-40% CAPEX and energy savings compared to conventional OTC***
- Flexibility to process wide range of feedstock including low value refinery streams into high value chemicals
- Configurations can produce olefins, aromatics or both, with flexibility to produce diesel based on market demand
- Grassroots applications and brownfield bolt-on options
- ***Multiple commercial license awards***

TC2C™ - Concept to Reality



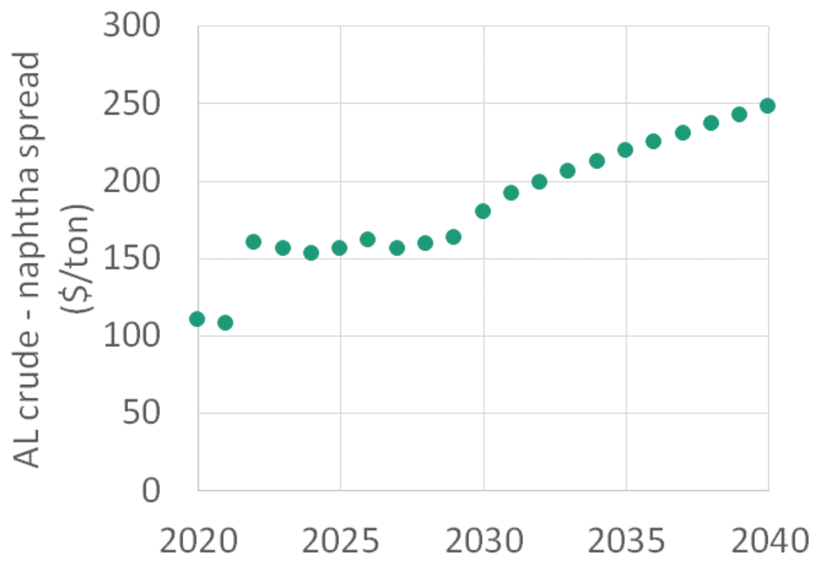
- A Disruptive Chemicals Production Pathway
- Novel Processing & Catalyst Schemes
- >70% Chemicals Yield
- Lower CAPEX & OPEX Investment
- Reduced Carbon Footprint

TC2C™: A Disruptive Chemicals Production Pathway



Advantages of TC2C™ Over Naphtha Cracker

- Healthy spread between Crudes and Naphtha
- Can process wide ranging crude oils
- Can process low-value streams e.g., slurry oil, light cycle oil, pyrolysis fuel oil, SDA pitch
- Flexible to produce fuels on-demand
- Can alter $C_3^=/C_2^=$ ratio based on market conditions



Source: IHS Markit, 2019

Advantages of Adding TC2C™ to Existing Refinery

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- Dramatic Increase in Chemicals, Decrease in Fuels Production
- Debottlenecks Refinery, Optimizes Unit Operations
- Upgrades low-value orphan streams into petrochemicals
- Can be bolted on during regular turnaround, minimum disruption
- Reduces refinery’s carbon footprint

TC2C™

TC2C™ – Why the interest?

COTC → **Plastics (Carbon is Captured)**
Transportation Fuels
(CO2 from Internal Combustion Engine)

TC2C™ → **Plastics (Carbon is Captured)**

Conversion of crude oil into chemicals places carbon into plastics and other products as opposed to burning the crude oil for energy.

TC2C: Major ESG Advantages

- Carbon from Crude captured in plastics
- 15-20% direct reduction in energy consumption
  - Reduced Fuel Firing; elimination of Crude and Vacuum Distillations.
  - Integration eliminates unnecessary cooling and reheating between units..
  - Lower piece count equals less energy expended to make those pieces of equipment.
- Emissions are reduced due to fewer point sources of emissions.
- CO2 reduced compared to processing naphtha alone. To produce naphtha feedstock, higher crude intake is required with the remainder of the crude going to units producing a lot of CO2.
- Continuous 5-year operation means cooling and reheating from storage is reduced.
- Plot area reduction; especially important for sensitive areas where there is impact on forests.
- Further ESG-oriented enhancements such as low CO2 Steam Cracking, utilizing blue hydrogen, Co-processing Waste Plastics-derived Pyrolysis Oil and/or Biofeeds

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