Phoenix from the Flames: Can Technology Drive Asia's Petrochemical Recovery?

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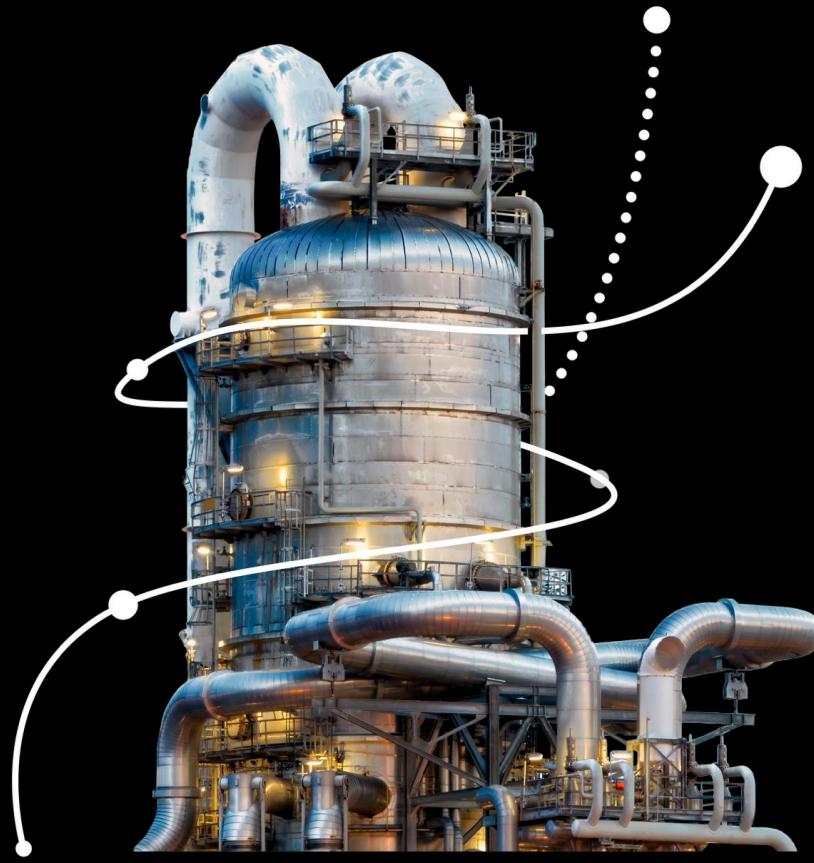

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Agenda

- An industry in decline
- Technology developments
- Technologies to drive recovery?
- Process economics
- Key takeaways

An industry in decline

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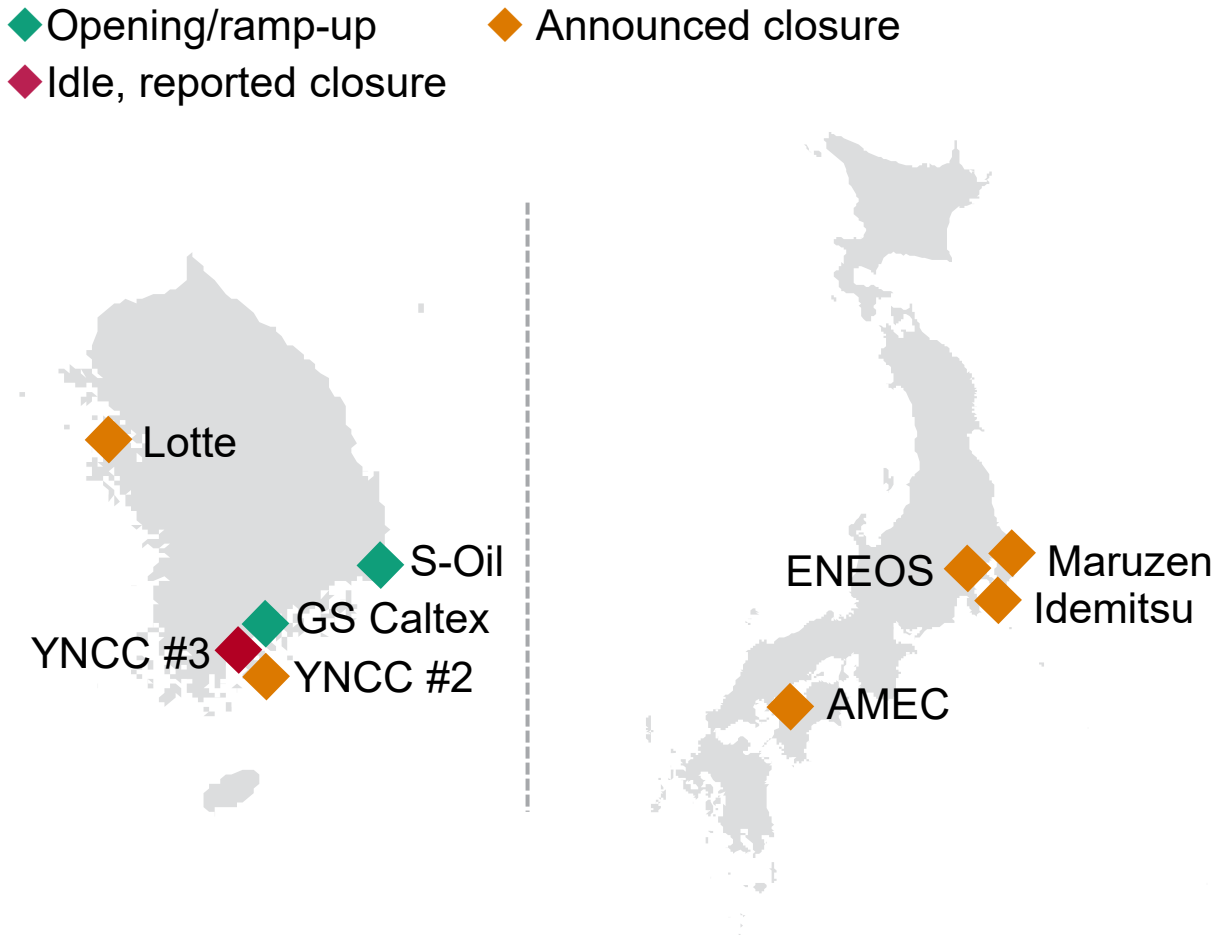
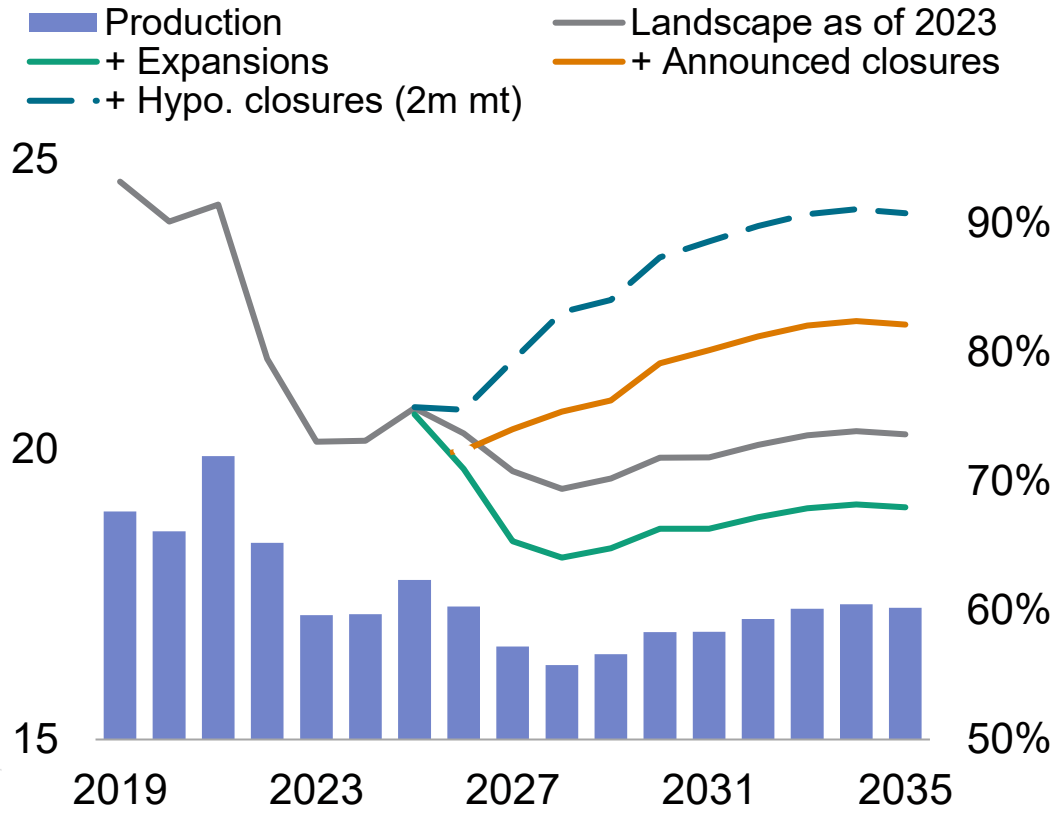
4.3 million mt of closures are announced or reported in Japan & S.Korea - 3-4 additional closures needed to meet +6.5 million mt closure target including Taiwan



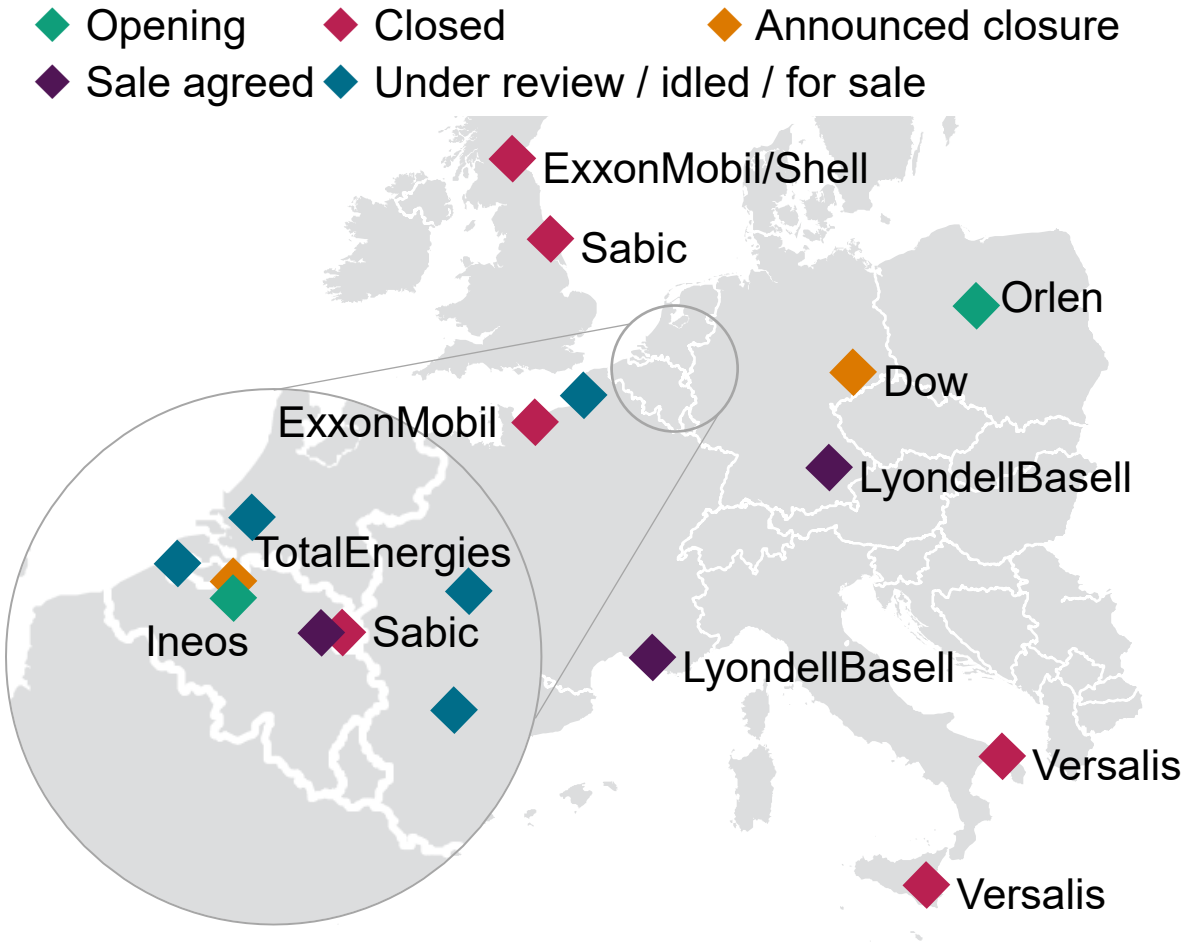
Source: S&P Global Energy

NE. Asia ethylene production (million tons) & operating rate scenarios



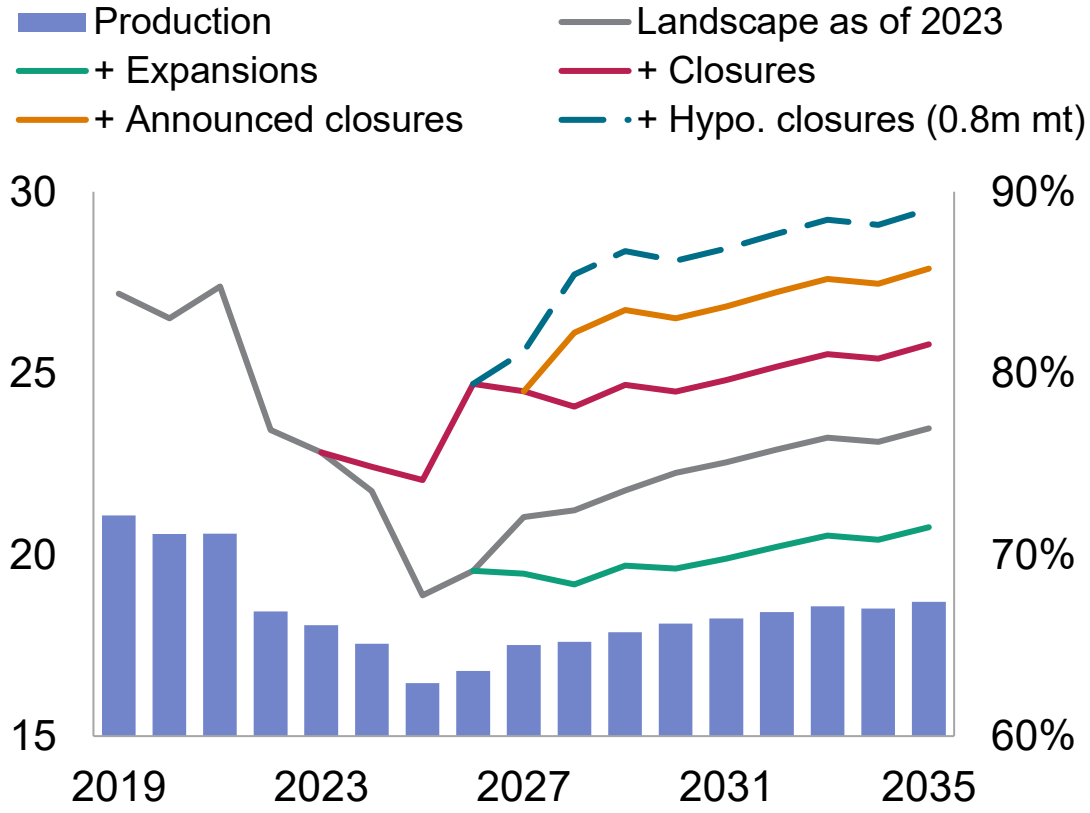
Source: S&P Global Energy

In Europe it is just as bad with 3.3 million mt of ethylene capacity closed across six European crackers with another 1.2 million mt announced



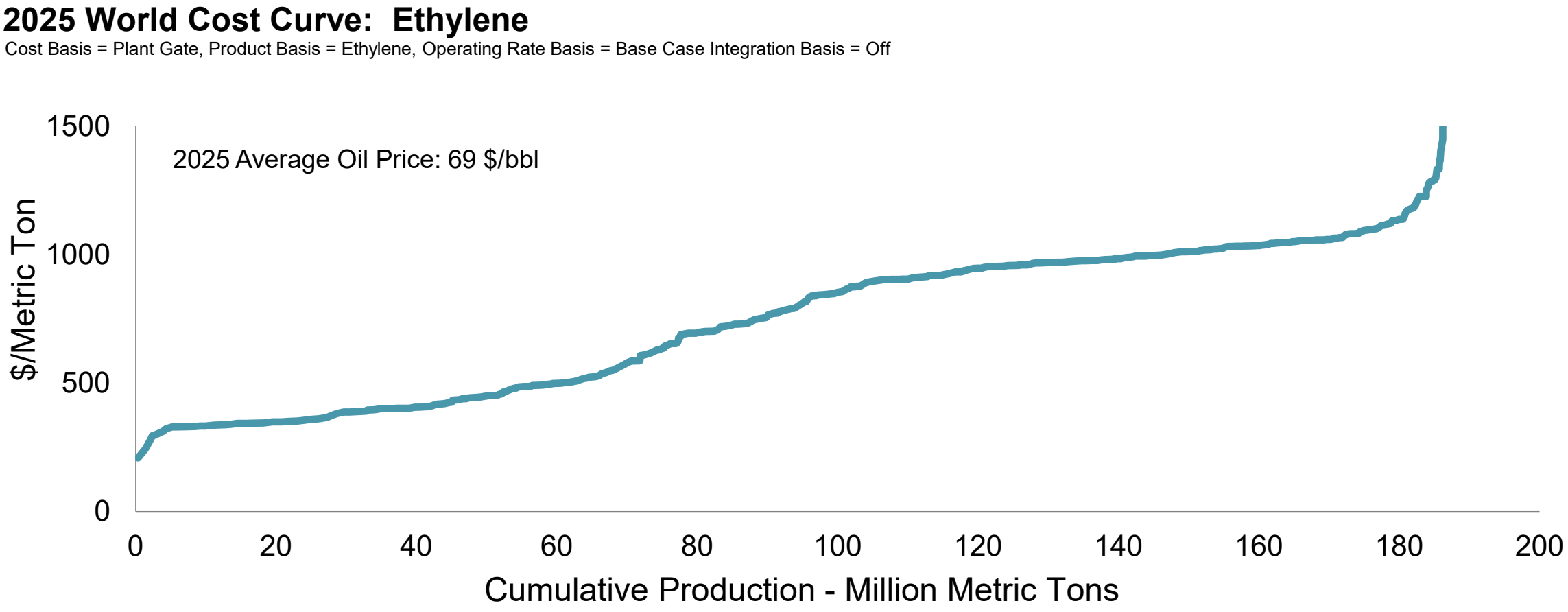
Source: S&P Global Energy

European ethylene production (million mt) & operating rate scenarios



Source: S&P Global Energy

Cash cost curve for ethylene is steep due to different feedstocks, technologies, regional feed prices and other regional cost differences

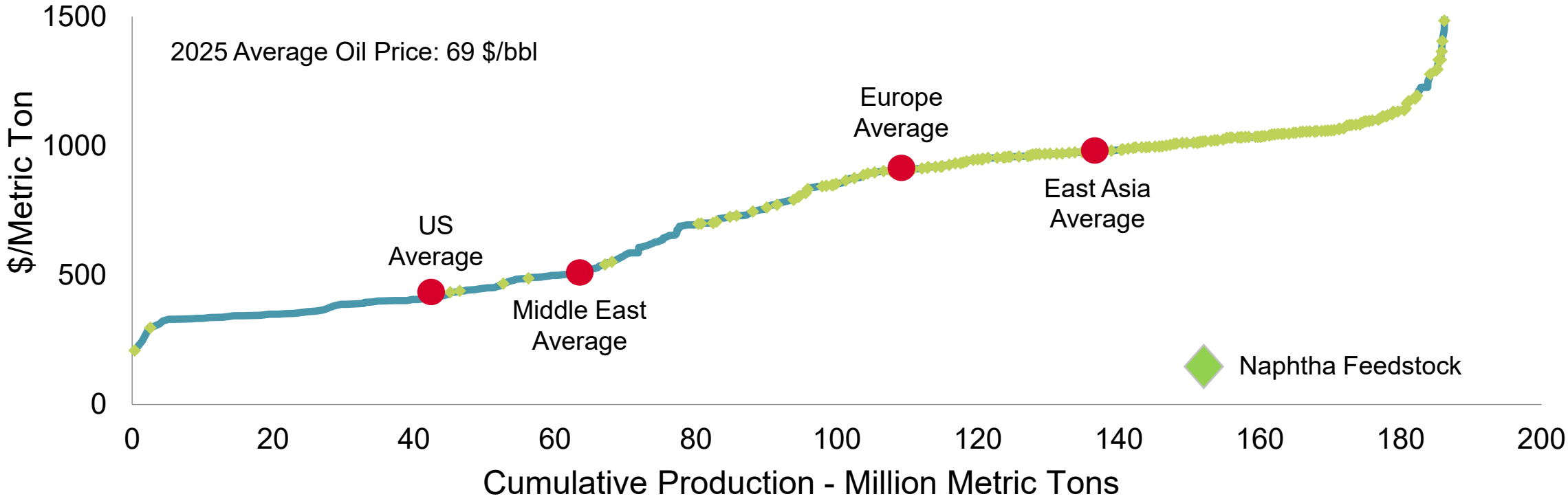


Source: S&P Global Energy Competitive Cost & Margin Analytics

The economics don’t lie - US and Middle East NGLs continue to be advantaged versus expensive naphtha feedstock in Europe and East Asia

2025 World Cost Curve: Ethylene

Cost Basis = Plant Gate, Product Basis = Ethylene, Operating Rate Basis = Base Case Integration Basis = Off



Source: S&P Global Energy Competitive Cost & Margin Analytics

Technology developments

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In 50+ years, **real** innovation in the olefins industry has been sadly lacking….

ICI Olefins Plant at Wilton, UK, 1968

S-Oil Olefins at Ulsan, Korea, 2025

Nevertheless, many developments have been commercialized; but many still in pilot/demonstration stage. Can any make a step change in competitiveness?

Furnace Technologies

- Ultra-Selective Cracking Coils (USC®)
- Enhanced Heat Transfer & Materials
- Low-Emission Burners
- SPYRO® and Digitalization

Feedstock

- Ethane Cracking through access to associated gas and shale gas
- Feedstock Flexibility for gas, liquids & residues
- Methanol-to-Olefins (MTO)
- Coal-to-Olefins (CTO)
- Crude Oil to Chemicals (COTC)
- Bio-based Ethylene (Ethanol Dehydration)
- Naphtha-to-Ethane/Propane
- Oxidative Dehydrogenation of Ethane (ODHE)

Sustainable Pathways

- Dow Net-Zero
- Electrified Steam Cracking (eFurnace)
- Electric cracking: RotoDynamic Reactor
- Circular Feedstock (Plastic Waste)
- Bio-based Ethylene (Ethanol Dehydration)

Technologies to drive recovery?

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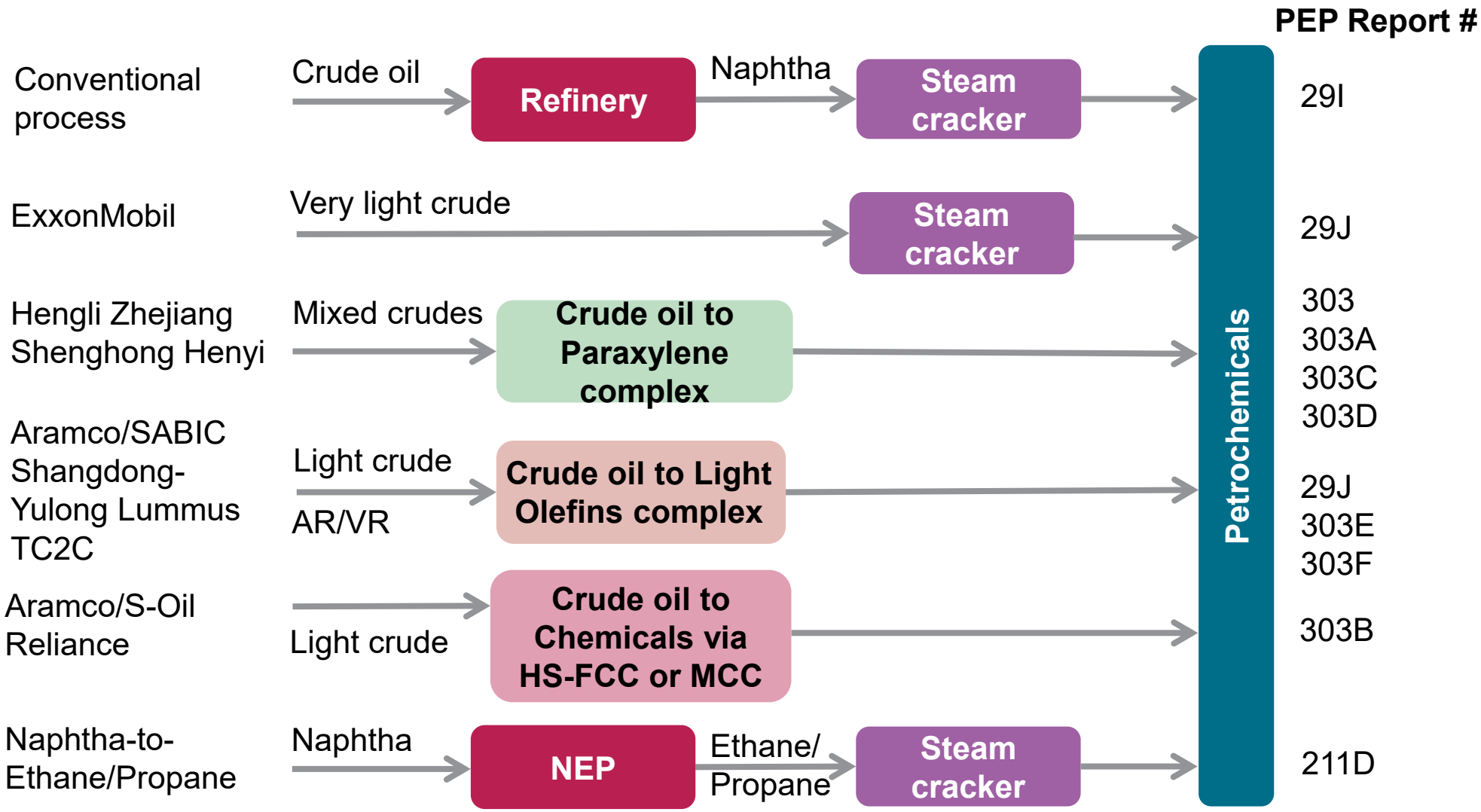
COTC has been commercialized in Asia, but COTC plants are not created equal



Note: TC2C = Thermal Crude to Chemical, AR = atmospheric residue; VR = vacuum residue; HS-FCC = High severity fluidized catalytic cracking; MCC = Multi-zone Catalytic Cracking
Source: S&P Global's Process Economics Program (PEP)

ExxonMobil's approach to steam cracking crude oil has been in operation in Singapore for over 10 years

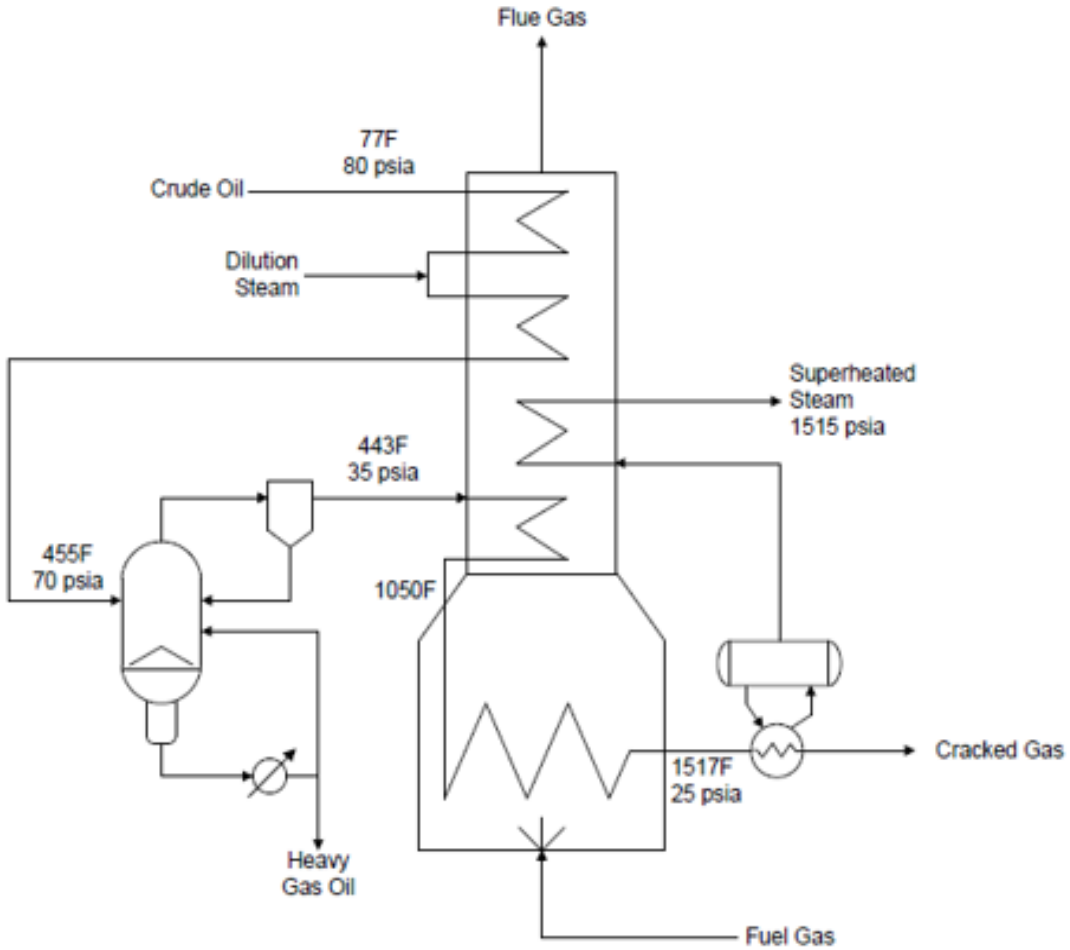
Preheat crude oil in cracker furnace convection section

Partially vaporize heated crude in flash pot outside furnace

- Flash pot overhead vapor to cracker furnace radiant coils
- Dispose of flash pot bottoms liquid (resid) in refinery

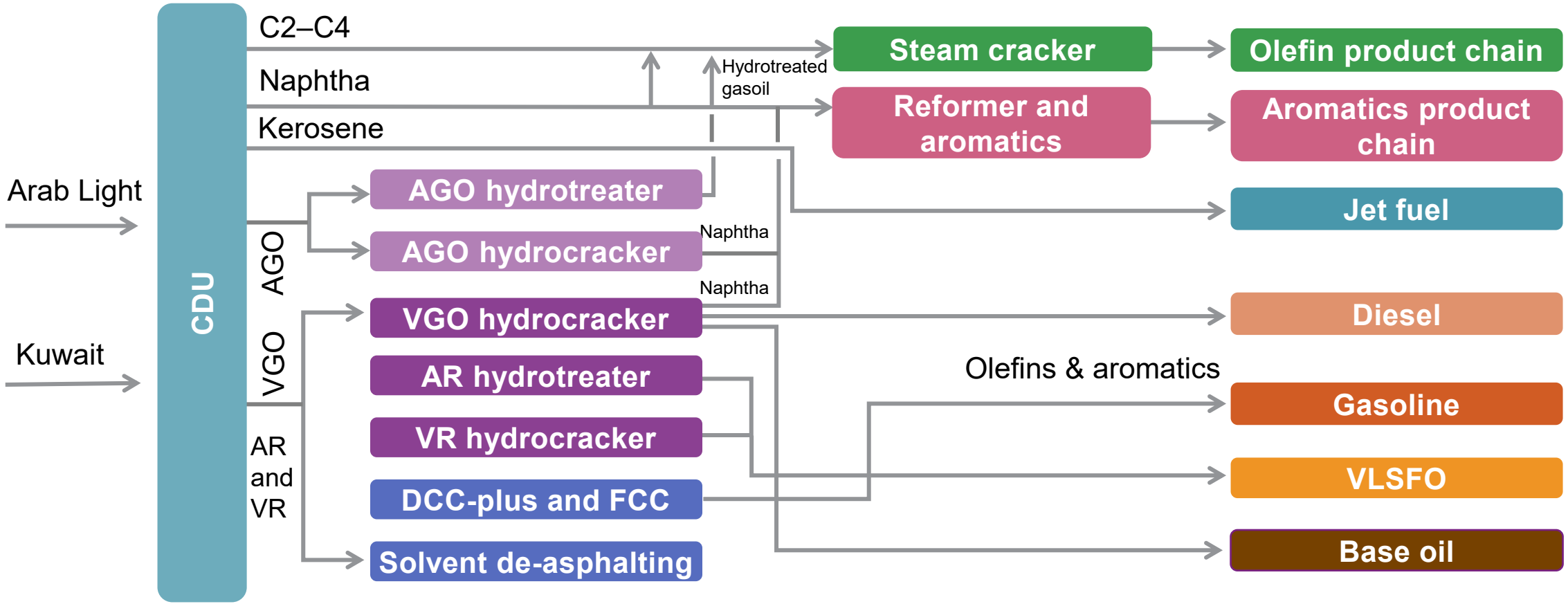
Implementation of this technology depends on very light sweet oil such as Malaysian Tapis

Scale is limited by steam cracker



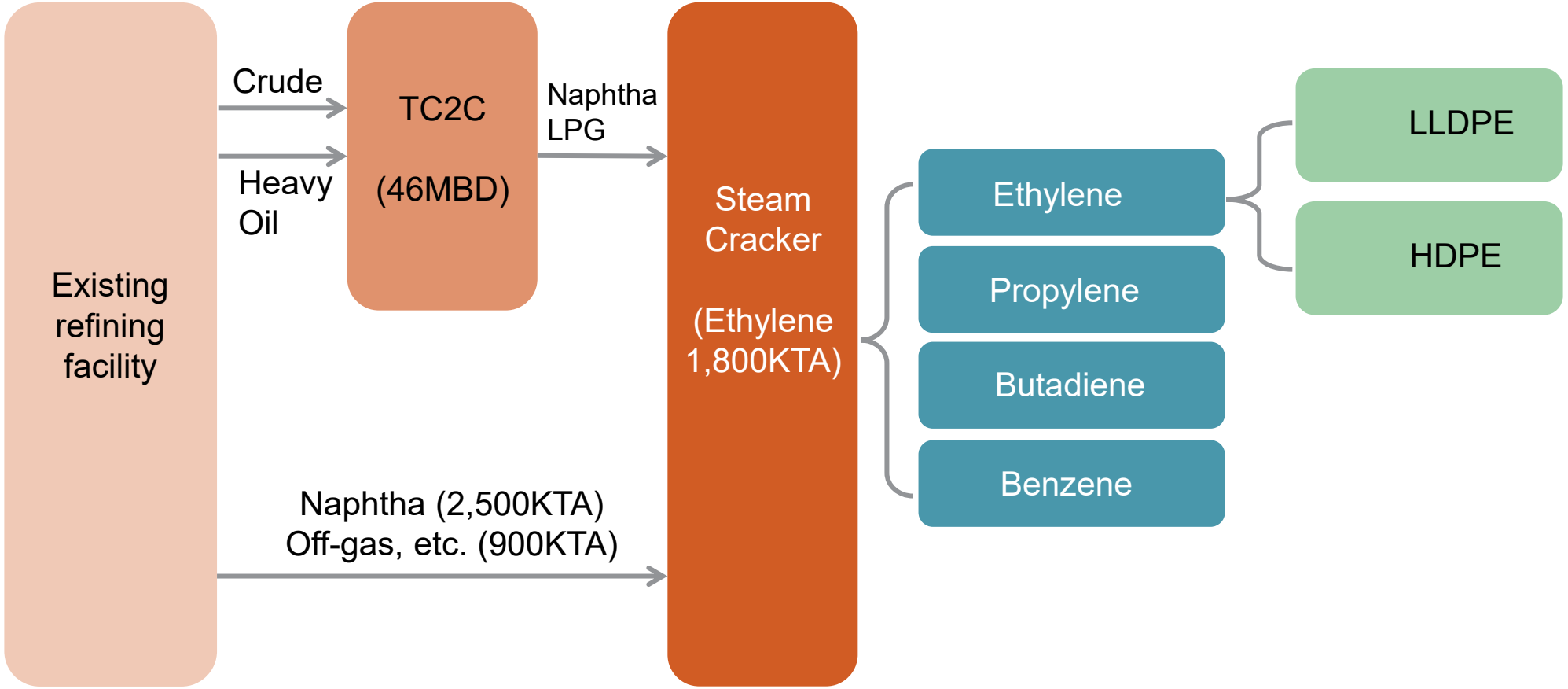
Source: S&P Global's PEP Report 29J Steam Cracking of Crude Oil

Shangdong Yulong Integrated Petrochemicals Phase-1 is both aromatics and light olefins focused with two trains of world-scale mixed feed steam crackers



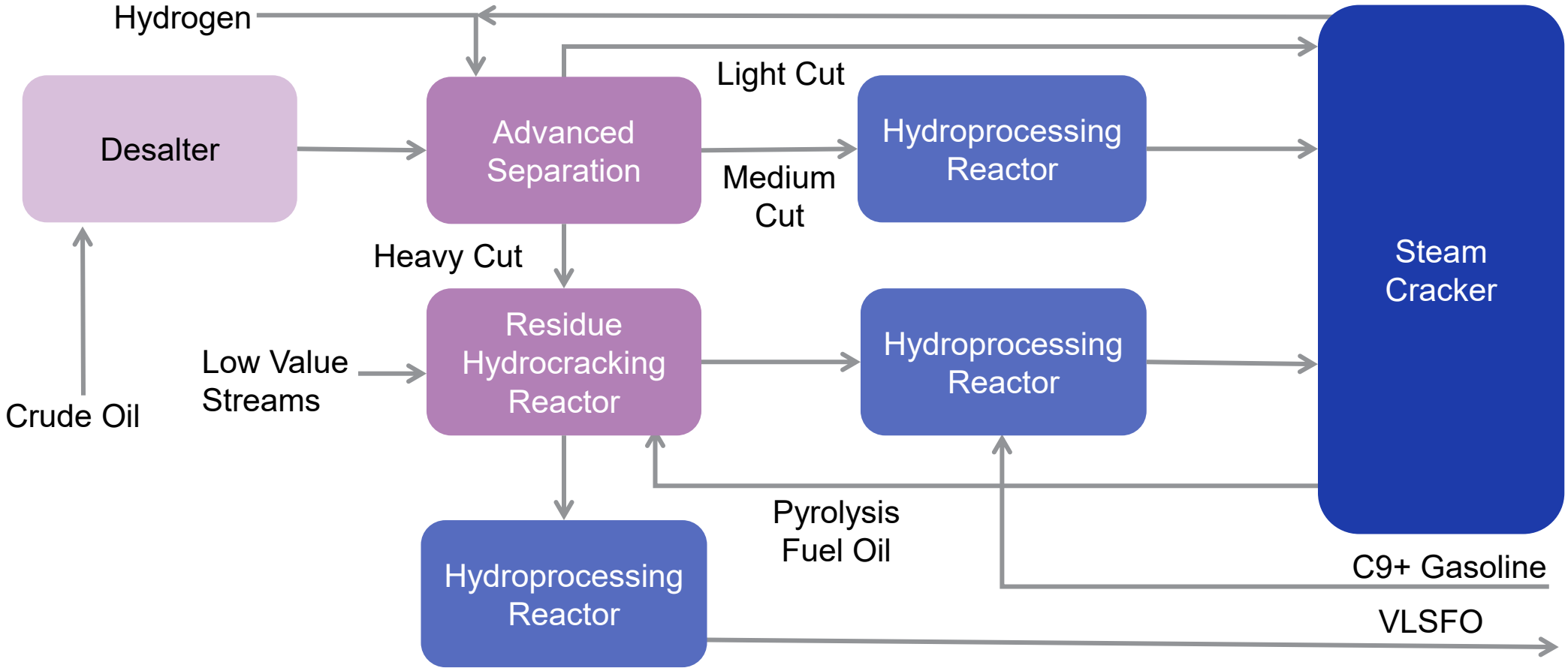
Note: AGO=atmospheric gas oil; AR=atmospheric residue; VR=vacuum residue ; DCC=deep catalytic cracking; FCC=fluid catalytic cracking; VLSFO=very-low sulfur fuel oil.
Source: S&P Global's PEP Report 303E Light Olefins Focused Crude Oil to Chemicals Complex & S&P Report on Yulong Petrochemical

Saudi Aramco's approach to COTC is olefins focused using Thermal Crude to Chemical (TC2C) technology located at S-Oil's Shaheen complex in South Korea



Source: Shaheen Project Investor Briefing

Thermal Crude to Chemical (TC2C) technology involves several unit operations



Source: Aramco MEPEC 2024 Presentation, TC2C™ More Carbon Effective Conversion of Crude into Chemicals & S&P Global's PEP Report 303F TC2C™ Thermal Crude to Chemicals Technology

There has been limited development of light olefins focused COTC projects compared with aromatics projects

Project	Refinery Capacity (MMt/y)	P-Xylene Capacity (MMt/y)	Ethylene Capacity (MMt/y)	Propylene Capacity (MMt/y)	Est. Chemical conversion/ bbl. of oil (%)	Investment ($bn)	Full line Operation
Shandong Yulong (Phase 1)	20	3.5 (Mx & Ox)	3.0	1.2			
Shaheen[b], S. Korea	5.8	--	1.8	0.8			
Haldia Petrochemical, India	6.2	--	1.8	1.7			
Reliance, India[c]	--	4.0 (Px+Ox)	5.4	7.1			
Aramco/SABIC[b], Saudi Arabia	20	--[e]	--[e]	--[e]			

a. Use downflow HS-FCC (High severity Fluid Catalytic Cracking) technology
b. Use Aramco TC2C (thermal crude to chemical) technology for the hydrocarbons used from the refinery (5.8 MMt/y of the capacity of 33 MMt/y)
c. Use Reliance MCC (Multi-zone FCC) Technology
d. Revamp from current refinery
e. No specific details in public domain

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Shandong Yulong (Phase 1)	20	3.5 (Mx & Ox)	3.0	1.2	>50	20 (1st phase)	2024 (1st phase)
Shaheen[b], S. Korea	5.8	--	1.8	0.8	>65	7	2026
Haldia Petrochemical, India	6.2	--	1.8	1.7	>55	10	2030
Reliance, India[c]	--	4.0 (Px+Ox)	5.4	7.1	>70[d]	10	On-hold
Aramco/SABIC[b], Saudi Arabia	20	--[e]	--[e]	--[e]	70-80	--[e]	On-hold

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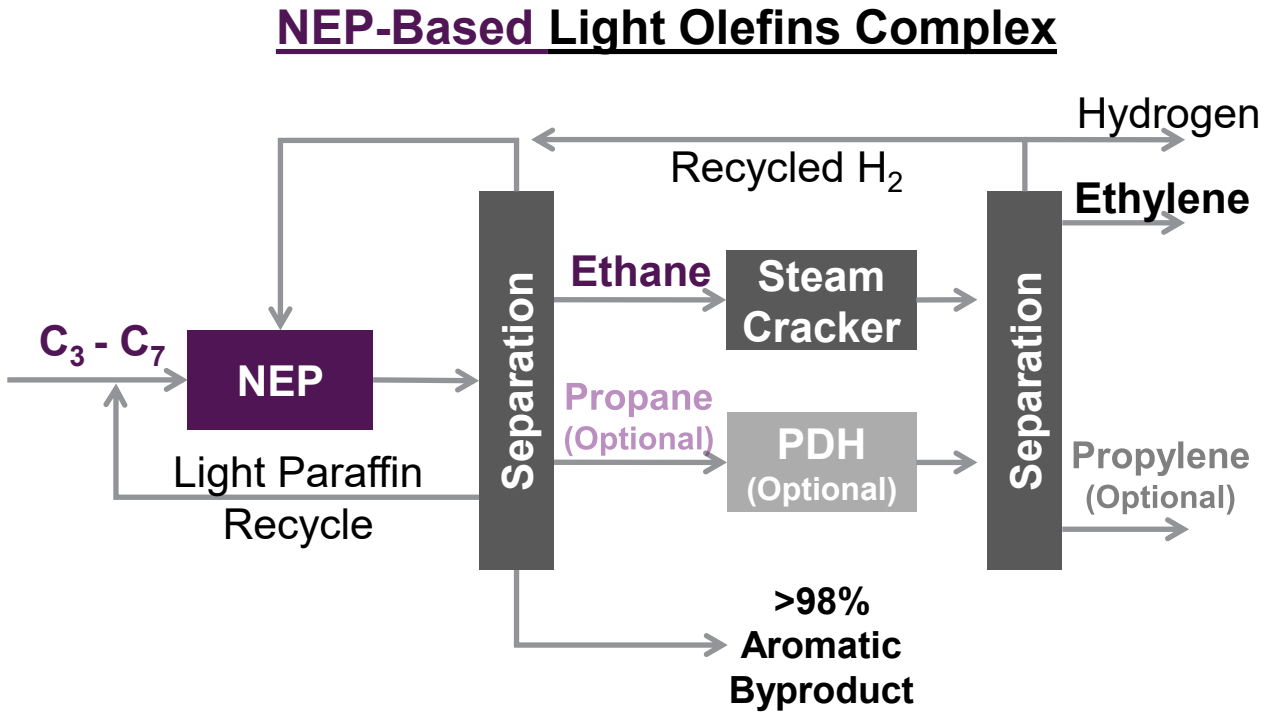
Honeywell has developed naphtha to ethane & propane (NEP) as a step-change in olefins production

~ 79% conversion of crude to chemicals
> 35% Net Cash Margin per bbl of crude
> 25% improved capital efficiency/ton

40% reduced CO2/ton of light olefin
40% crude reduction for same LO
Eliminate fuels export; minimize scope 3

Wide range of E/P design flexibility
Zero net propane / propylene option
MOU signed with Petro Rabigh



Source: Honeywell WPC 2025 Presentation
Economic results shown for 2,260 kMTA Light olefins investment relative to base

Process economics

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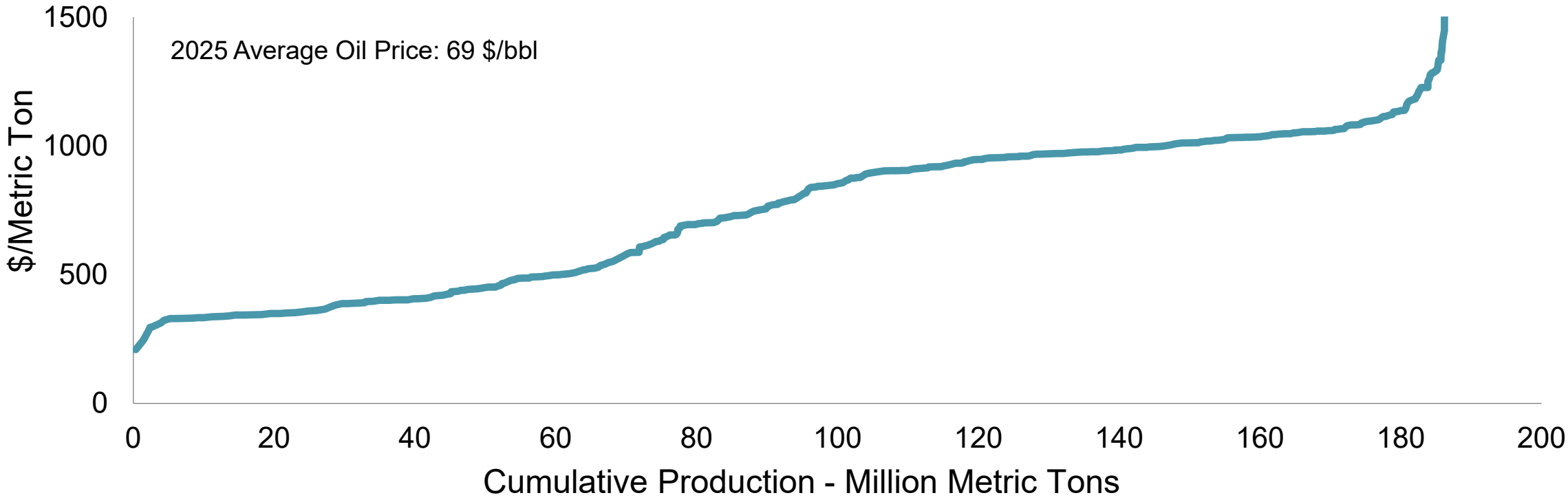
Back to the ethylene cash cost curve…..

2025 World Cost Curve: Ethylene

Cost Basis = Plant Gate, Product Basis = Ethylene, Operating Rate Basis = Base Case Integration Basis = Off



Source: S&P Global Energy Competitive Cost & Margin Analytics

Existing ethylene COTC projects are high 2nd quartile and into the 3rd quartile on the 2025 cash cost curve

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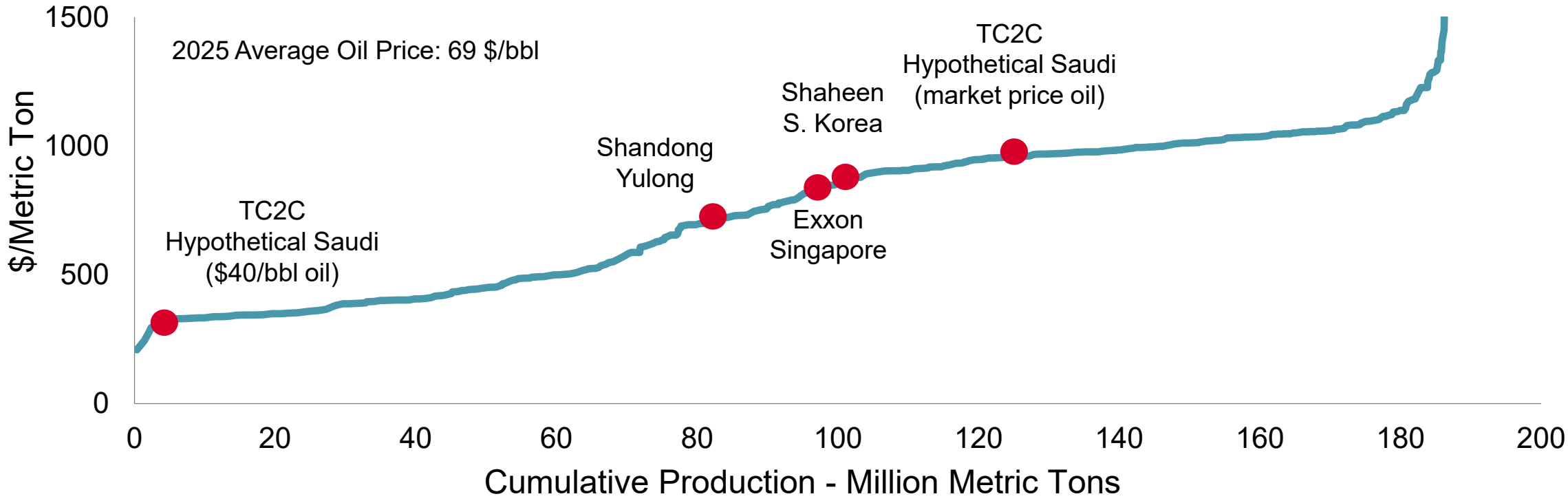
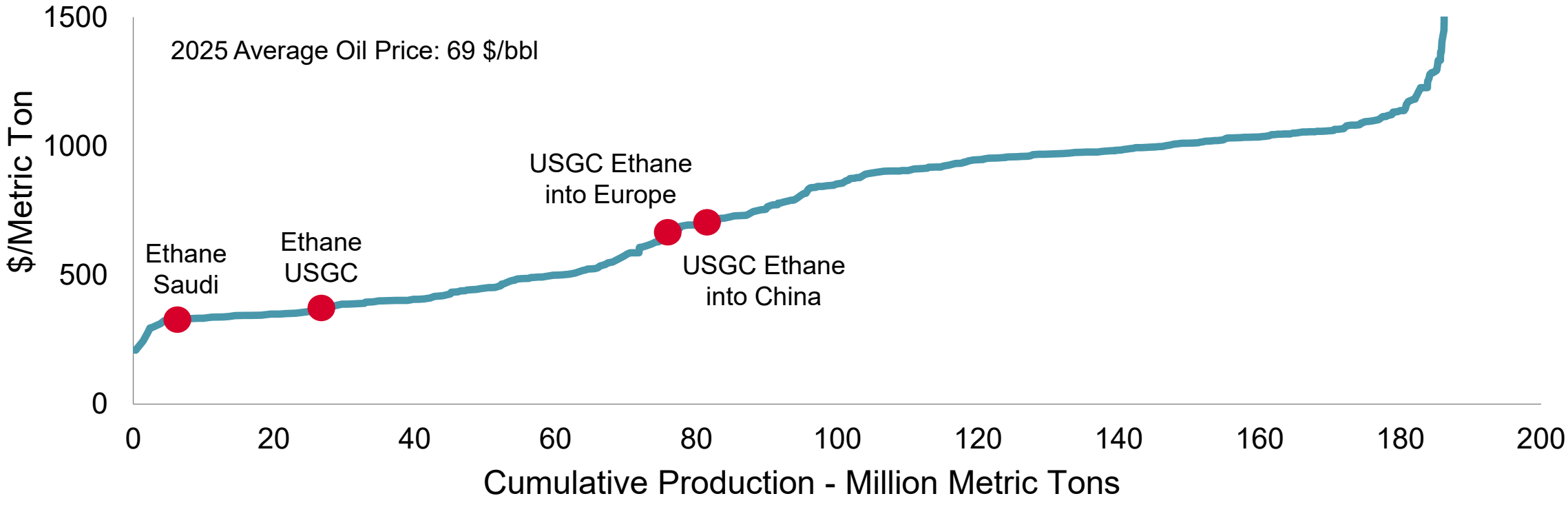


Source: S&P Global Energy Competitive Cost & Margin Analytics

However ethylene from market priced ethane is lower cost even if imported into China and Europe.

2025 World Cost Curve: Ethylene

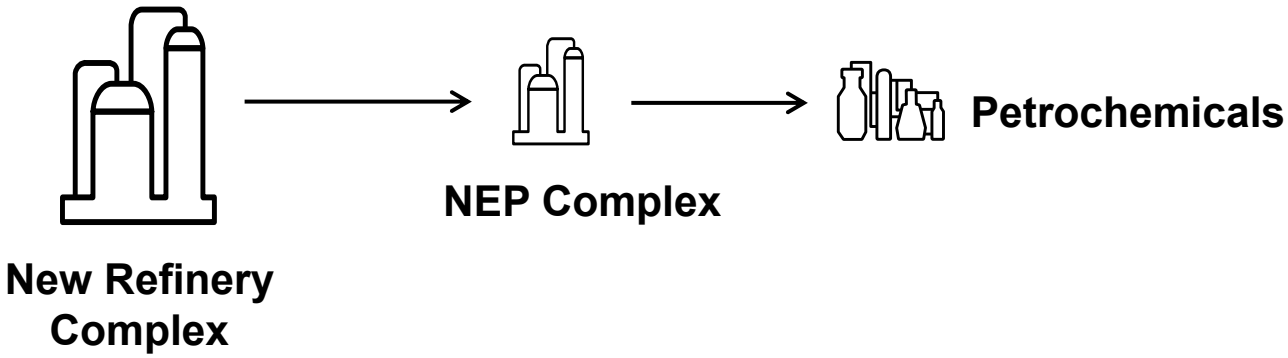
Cost Basis = Plant Gate, Product Basis = Ethylene, Operating Rate Basis = Base Case Integration Basis = Off



Source: S&P Global Energy Competitive Cost & Margin Analytics

NEP is suitable for refinery projects to move downstream and reduce emissions

Case Study: New hydrocracking refinery with NEP in China (CAPEX location factor of 0.55 vs. USGC)



Source: S&P Global's Refinery & Petrochemical Integrator & Decarbonizer (RAPID), PEP Report 211D Hydrocracking Naphtha to Ethane and Propane (NEP) & PEP Review 2025-12 Dynamic Construction Location Factors Update

Key takeaways

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Current developments in olefins technology are not mature enough to drive Asia's petrochemical recovery in the short term. Ethane feedstock for revamps is vital

Asian Olefins capacity is inherently uncompetitive due to naphtha feedstock dominance	Light crude cracking & COTC projects marginally more viable in China due to lower CAPEX	COTC projects in Saudi Arabia will require crude discounts to be financially attractive	NEP more likely to be used for integrated refinery/ petrochemical revamps to increase olefins	Importing ethane to existing /revamped cracker complexes is more attractive