

Setting up a Petrochemical Industry for the Future: A Technology Journey

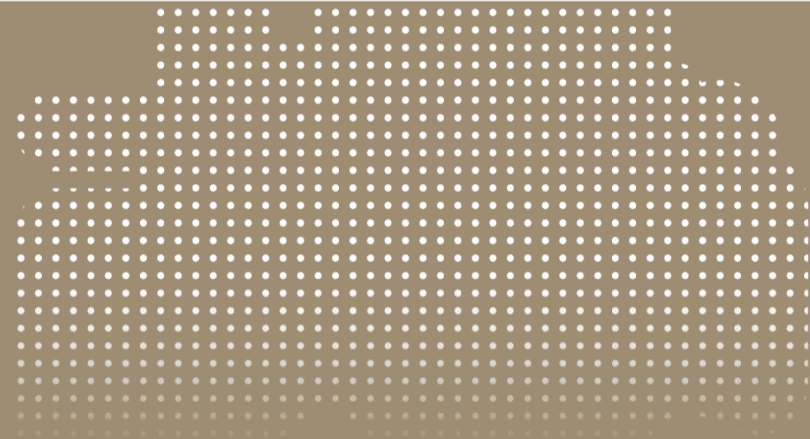
Dr Richard Charlesworth

Executive Director, Industry Processes & Cost Analytics

APIC 2025, Bangkok, Thailand

S&P Global

Commodity Insights



Agenda

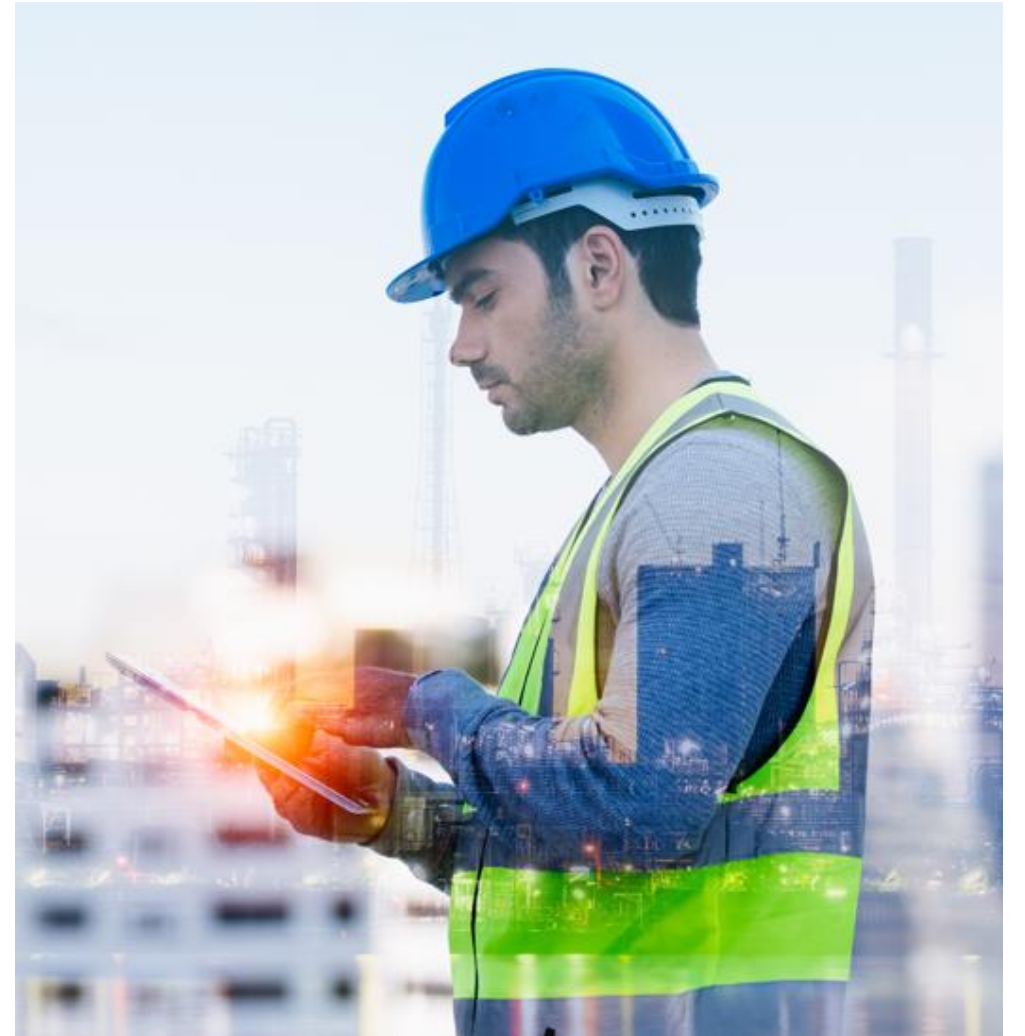
A future certainty

A smorgasbord of options

The devil is in the detail

Another future certainty

Key takeaways



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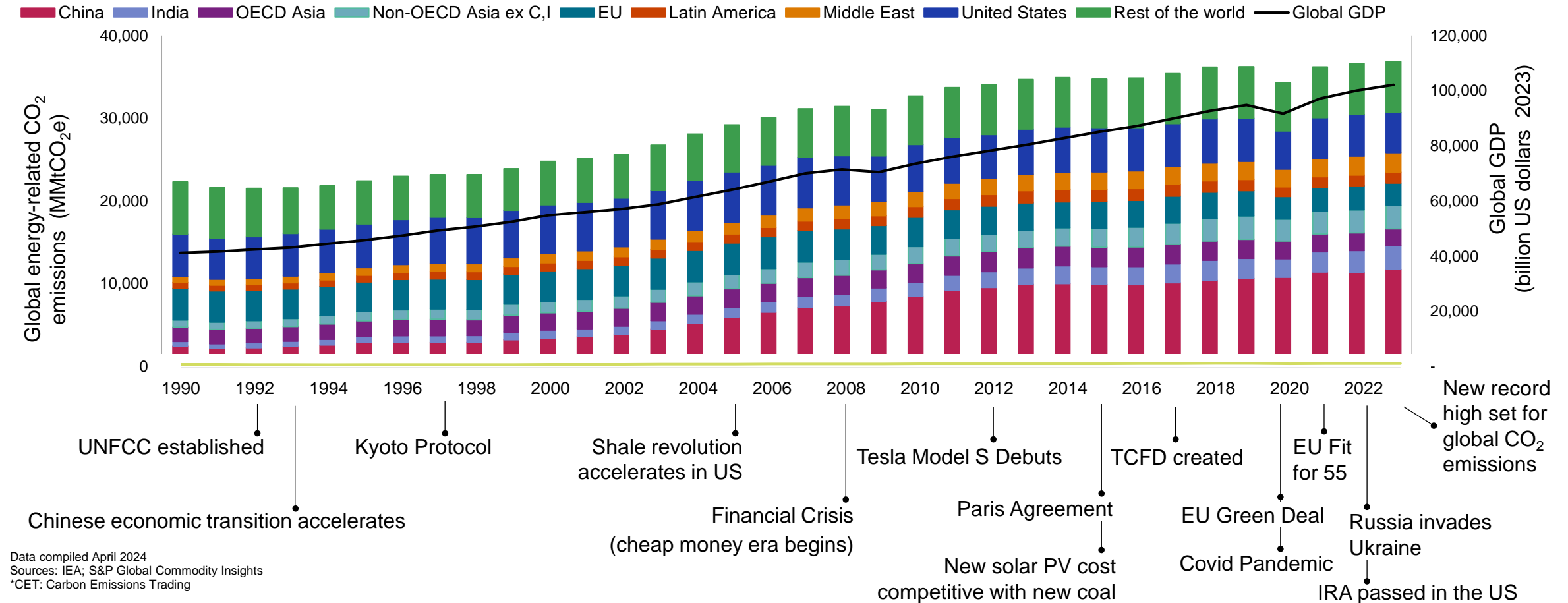
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Key takeaways



Global emissions have risen with GDP despite climate policies and CET advances

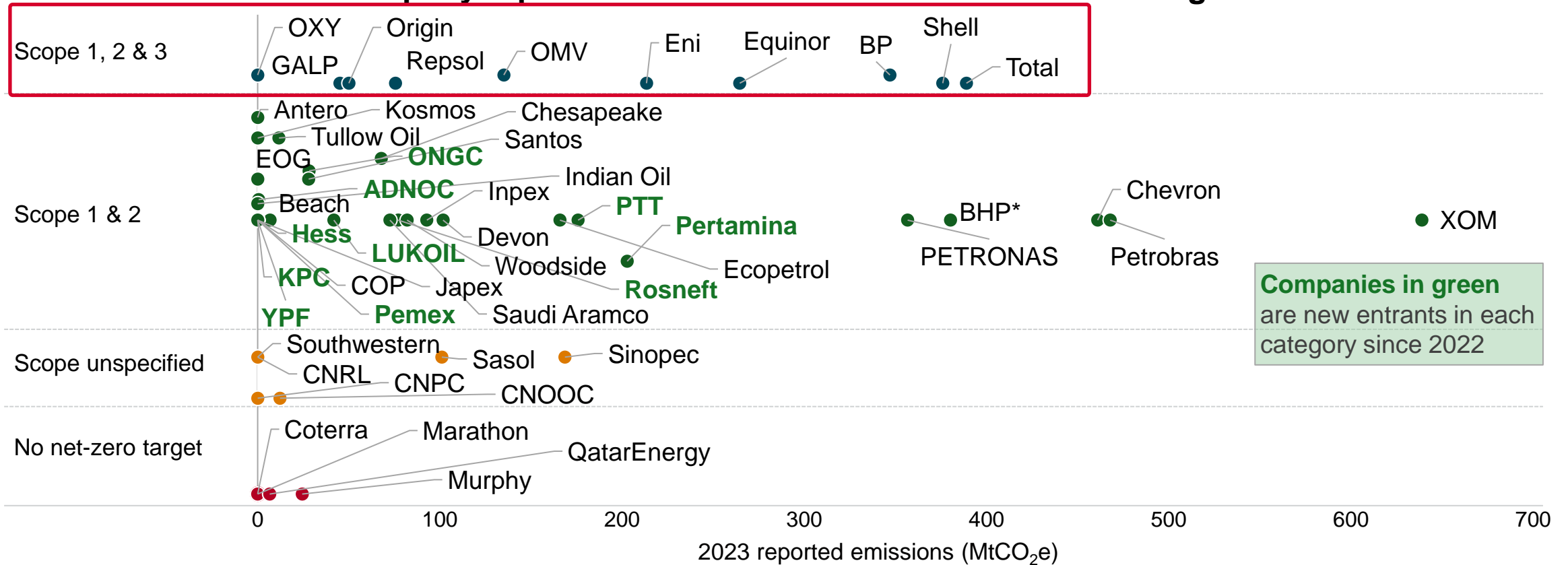
Global energy-related CO₂ emissions vs. global GDP



Data compiled April 2024
Sources: IEA; S&P Global Commodity Insights
*CET: Carbon Emissions Trading

One certainty is that the future energy and petrochemical industry will be a decarbonized one, albeit the pace is slowing

Company reported GHG emissions 2023 vs. net-zero targets



Companies in green are new entrants in each category since 2022

Note: 2023 GHG emissions are reported and may cover Scope 1, Scope 1 and 2, or Scope 1, 2, and 3, depending on company
 *BHP has a Scope 3 target, but for shipping only
 Source: S&P Global Commodity Insights

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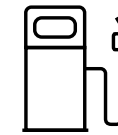
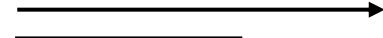
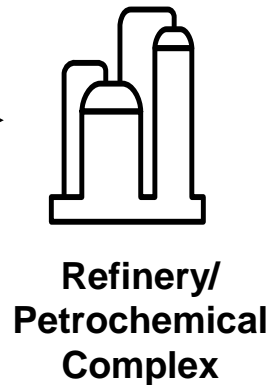
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Key takeaways



Technology developments are driven largely by decarbonization targets. There are multiple opportunities to manage emissions along the value chain

Crude oil/
natural gas

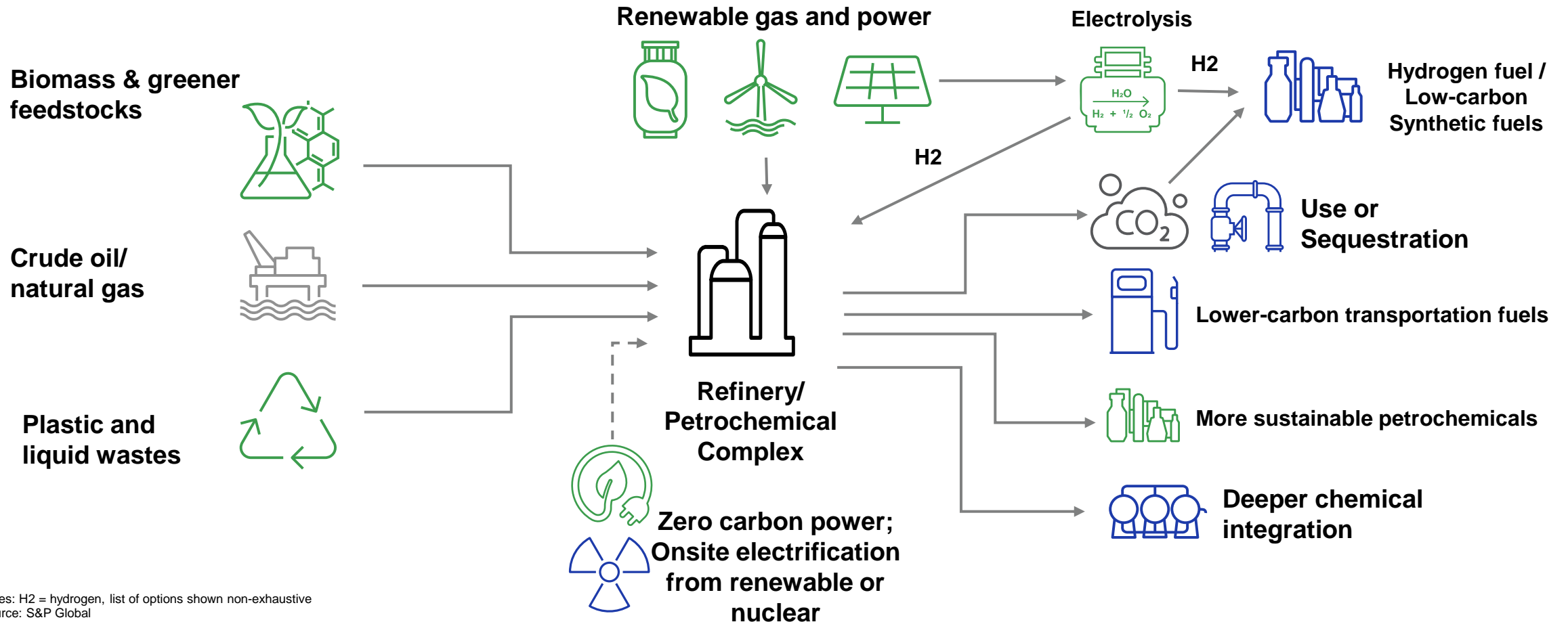


Transportation fuels



Petrochemicals

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Notes: H₂ = hydrogen, list of options shown non-exhaustive
Source: S&P Global

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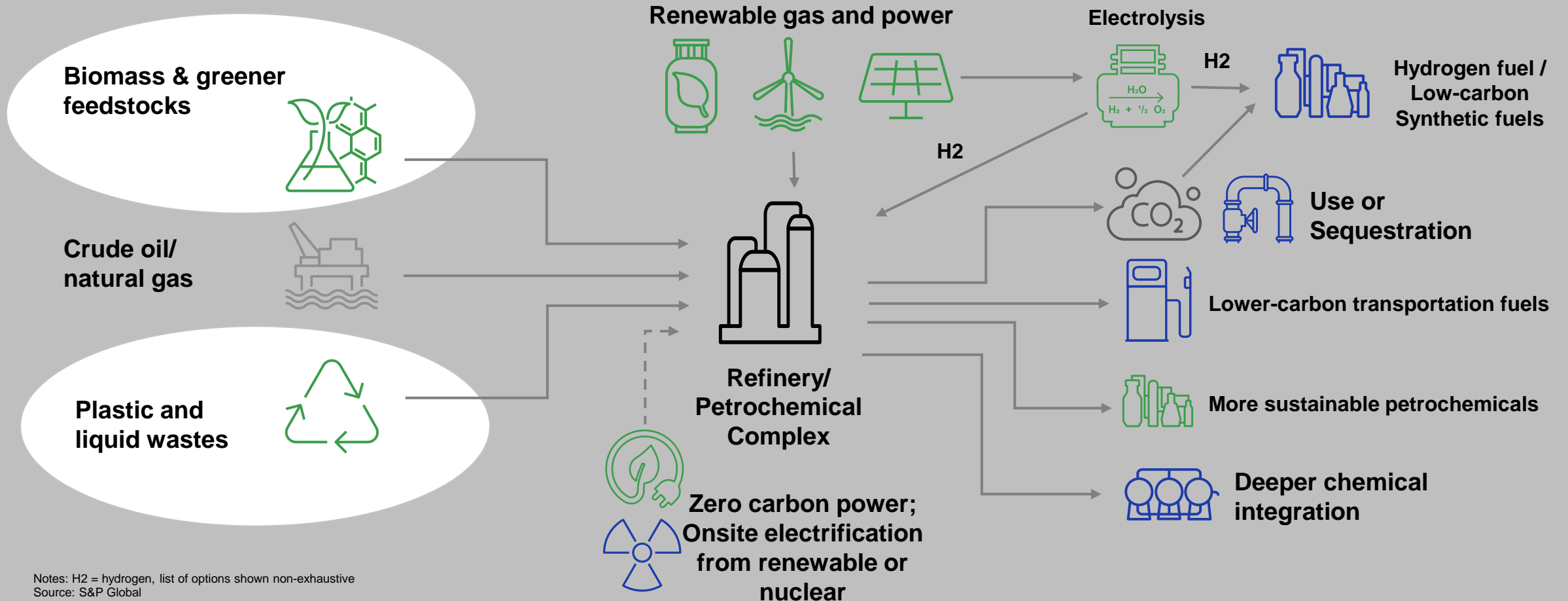
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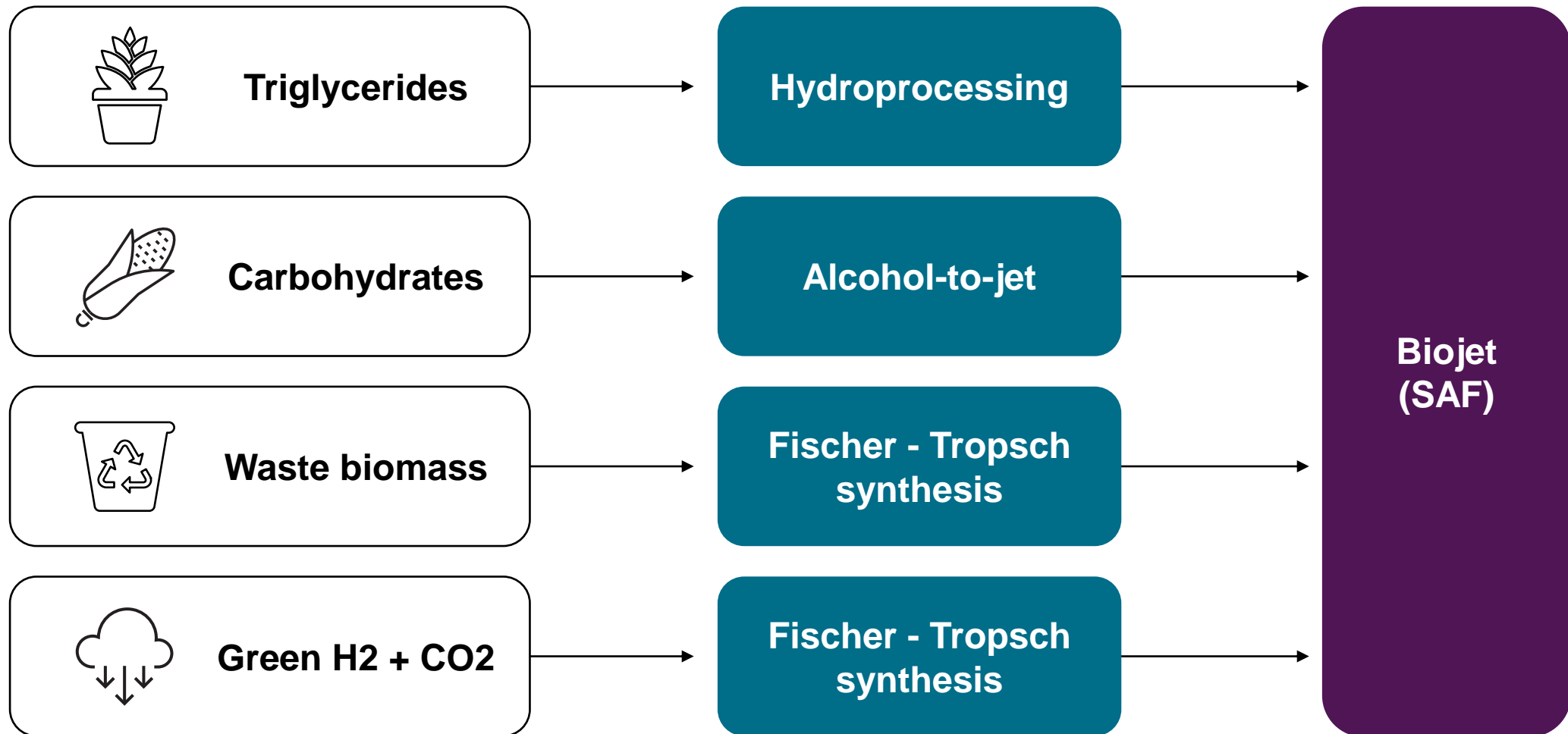


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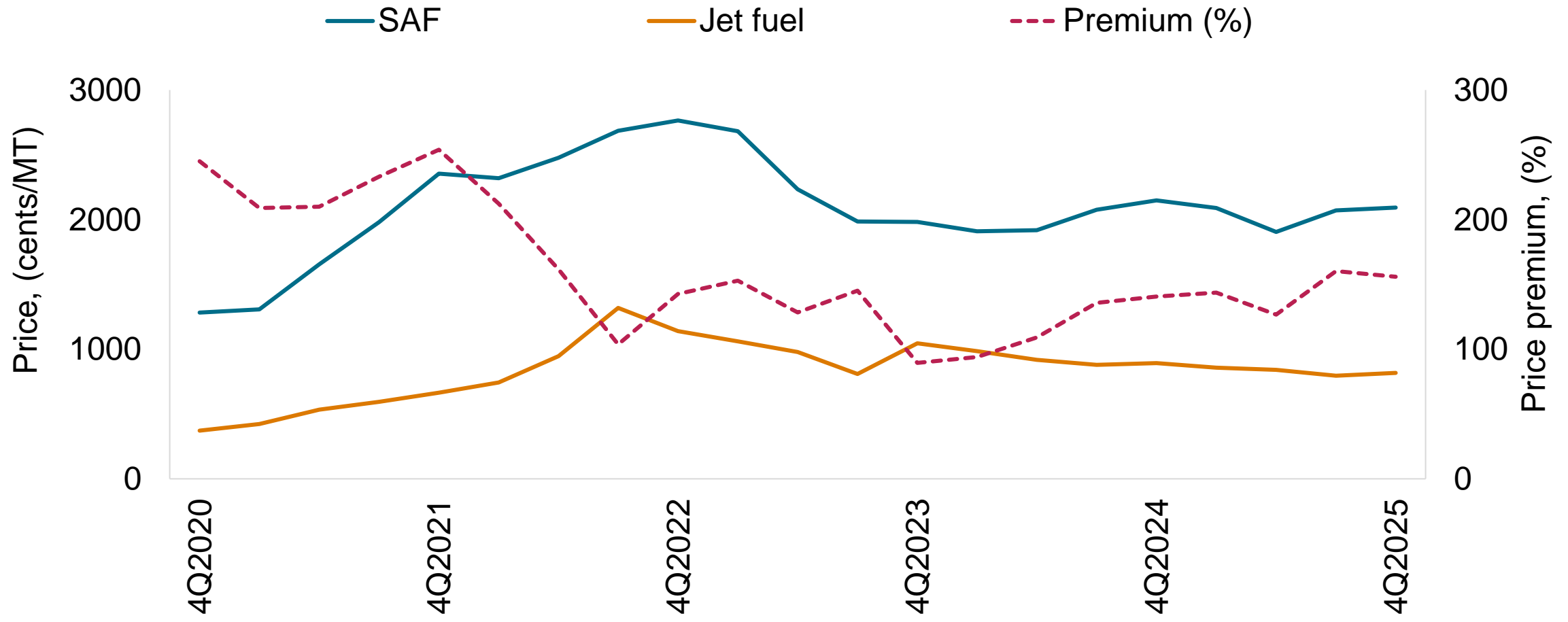


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Source: S&P Global

SAF production pathways



SAF provides price premium

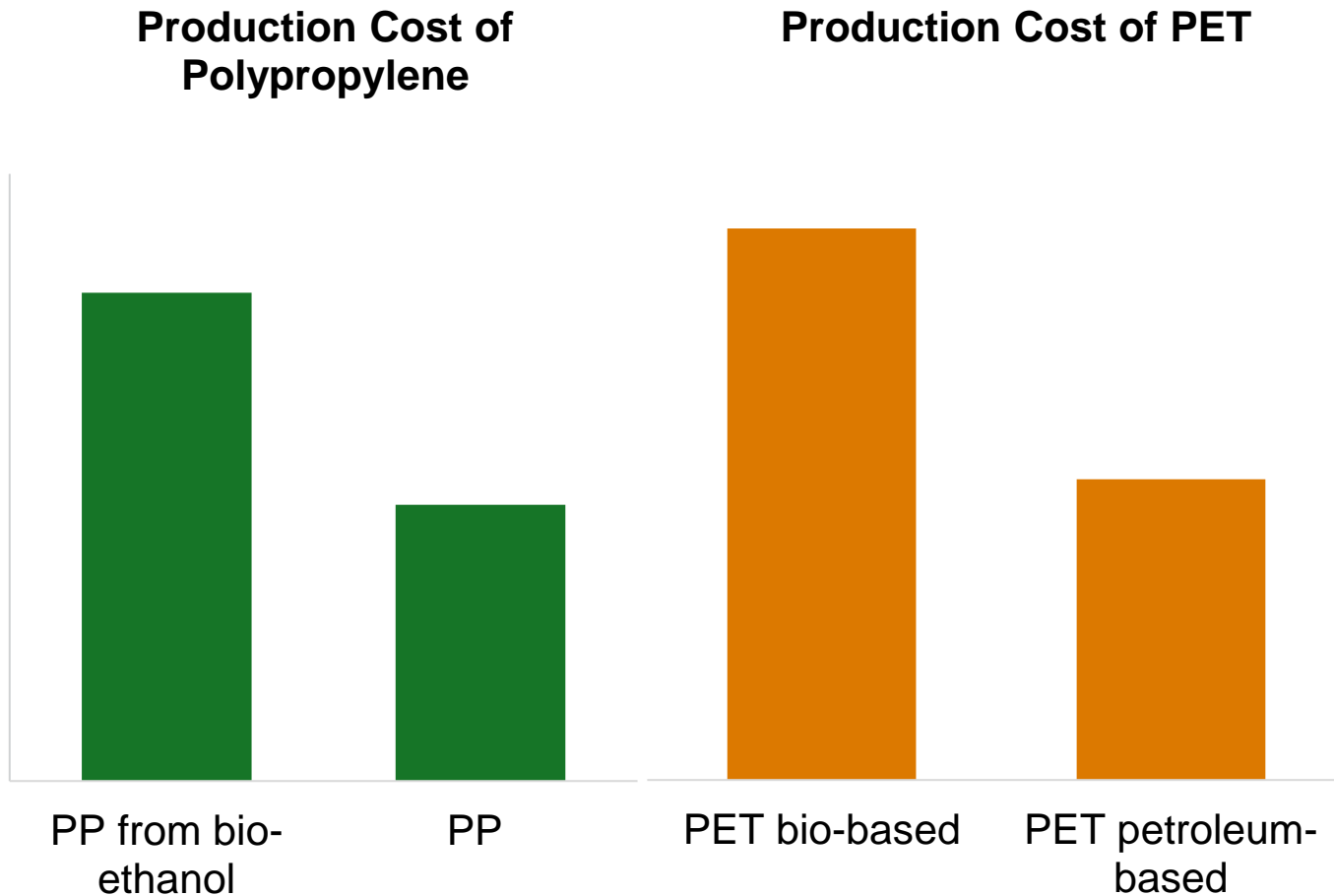


Bio-feedstocks can replicate a variety of petrochemical-based chemicals

Value Chain	Bio-Based Derivatives	Producers
C2	<ul style="list-style-type: none"> Ethylene/Green Polyethylene Ethylene Oxide/ PEGs Ethylene Glycol 	<ul style="list-style-type: none"> Braskem, SABIC, Sustainea, Lyondell-Basell Croda Chemical, Jilin Bohai Biochem India Glycols, Anhui Guozhen
C3	<ul style="list-style-type: none"> Propylene Glycol 1,3-Propanediol Green Polypropylene 	<ul style="list-style-type: none"> Archer Daniels Midland, Oleon DuPont/Tate & Lyle, Zhanjiagang Glory Borealis, SABIC, Lyondell-Basell
C4	<ul style="list-style-type: none"> 1,4-Butanediol Succinic Acid 2,3-Butylene Glycol 	<ul style="list-style-type: none"> Genomatica, Matrica Roquette, Succinium, LCY BioSciences Genomatica, Zhanjiagang Glory
C5	<ul style="list-style-type: none"> Xylose/Xylitol Furfural Levullinic Acid 	<ul style="list-style-type: none"> Danisco, Roquette, COFCO BioChem Aurus Specialties, Hongye BioChemical GBF BioChemicals
C6+	<ul style="list-style-type: none"> Adipic Acid 2,5-Furandicarboxylic Acid Sorbitol, Isosorbide 	<ul style="list-style-type: none"> Genomatica Avantium, DuPont/Archer Daniels Midland Roquette, Samyang



However, the production cost of bio-based PET and bio-based PP versus fossil-based polymers is around double (Q4 2024)



Source: S&P Global Markit Process Economics Program (PEP) Reports

Bio-based polymers command a premium to enter the market

Recycled PET follows a similar trend due to added costs of collection, sorting, upgrading, etc.

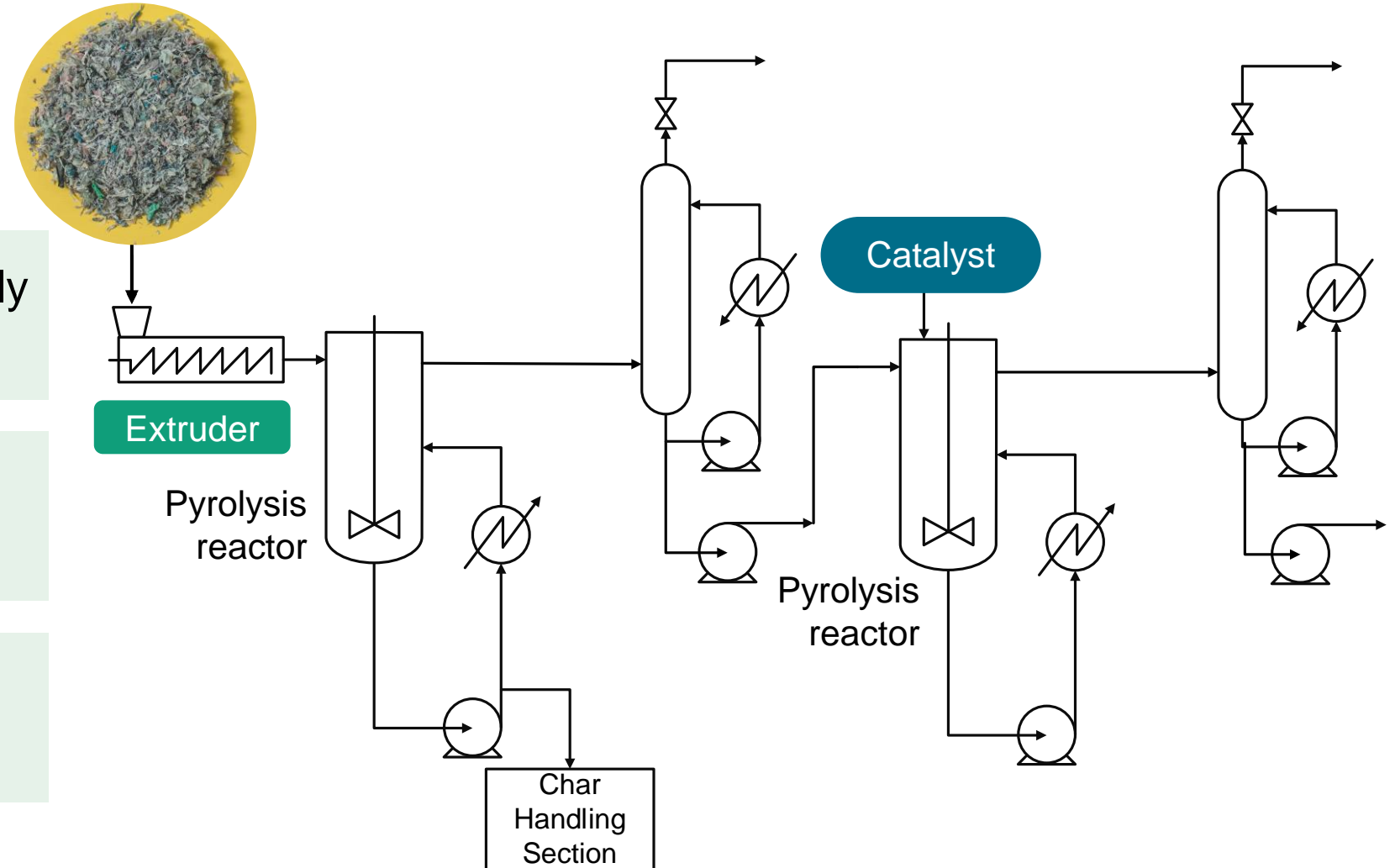
China's capacity expansions will further challenge bio-based PET's market position

Beyond mechanical and existing chemical recycling technology, the next generation is catalytic pyrolysis

Feedstock requirement: mainly PE/PP, clean, homogeneous

Products: Mainly oil, smaller amount of gas

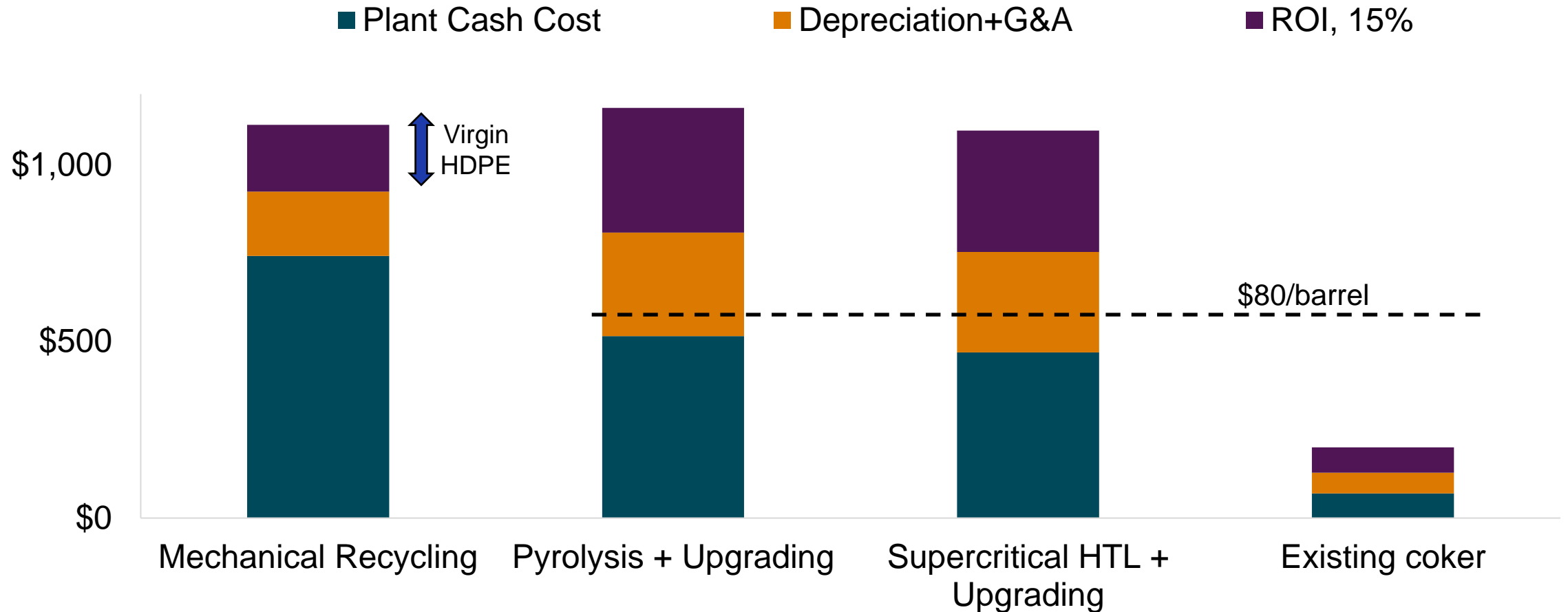
Company: LyondellBasell 50 kta plant 2025/2026



Source: US20240059974A1

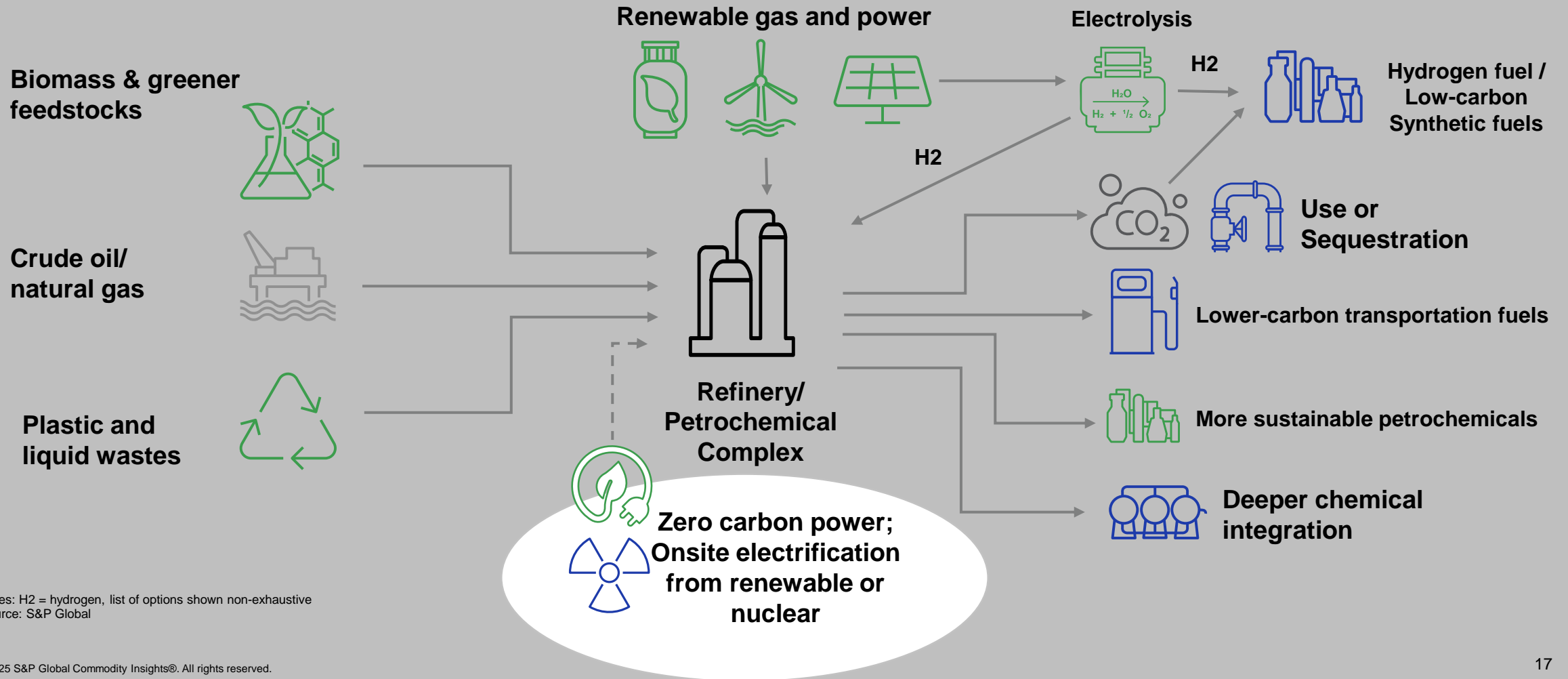
However, the production cost of recycling and upgrading is substantial (\$/ton)

Basis: USGC, 3Q 2024, 100kta plastic waste (5 cent/lb mixed polyolefin bale, 10 cent/lb HDPE bale grade C)

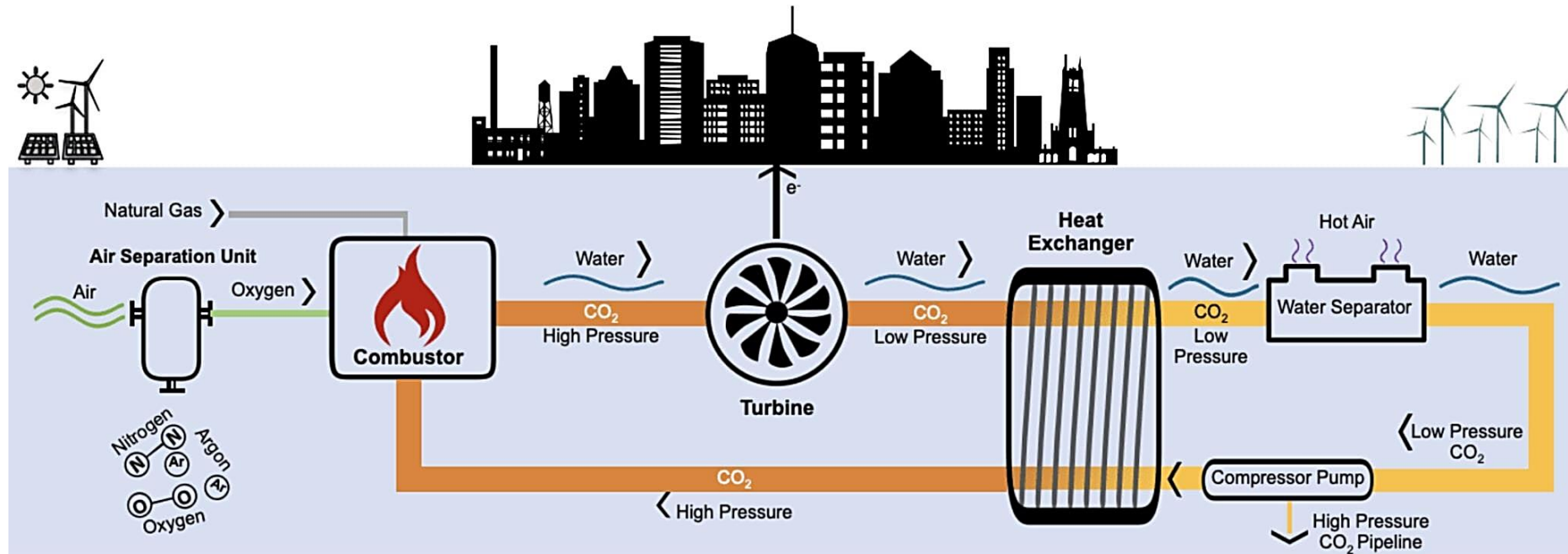


Source: S&P Global Markit Process Economics Program (PEP) Reports

Technology developments are driven largely by decarbonization targets. There are multiple opportunities to manage emissions along the value chain



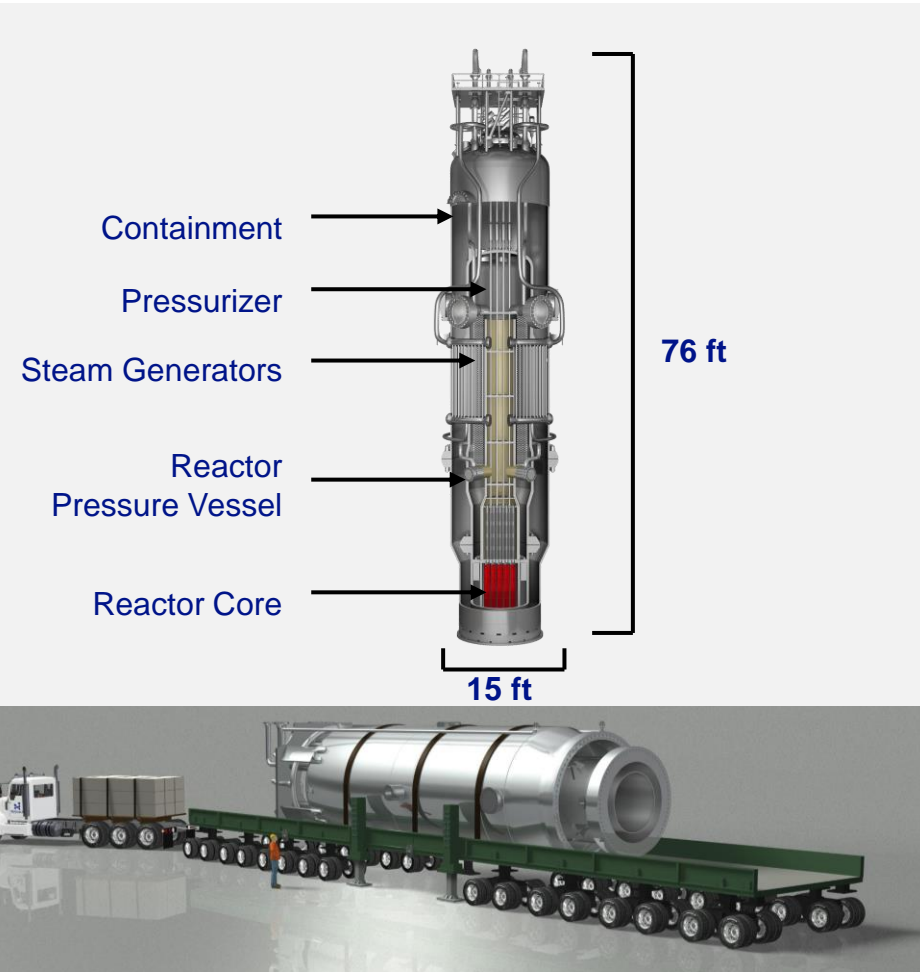
Low carbon power - NET Power has developed a process using supercritical CO₂ as operating medium for natural gas oxycombustion



325 MW Plant	Natural Gas Combined Cycle	NET Power
Relative Capital Intensity, per KW	1.00	1.60
LCOE with CO ₂ Credit, \$/MWh	--	~\$10-15 per MWh lower

Source: Powermag.com & : PEP Review 2021-02, Electric Power via the Allam Cycle

NuScale Power Module™ (NPM) is the first small modular reactor (SMR) to receive design approval from the U.S. Nuclear Regulatory Commission



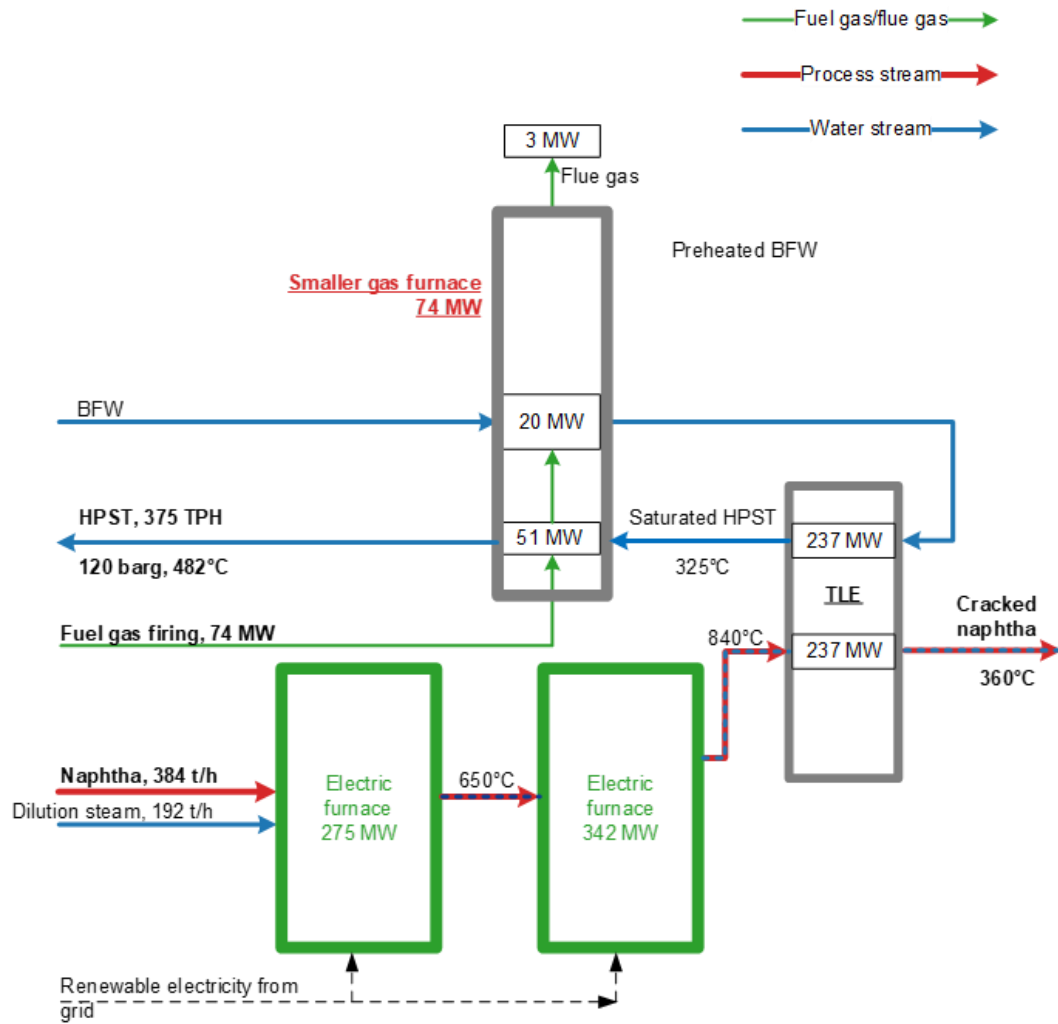
- Groundbreaking technology features a **fully factory fabricated** SMR referred to as a NuScale Power Module™ consisting of an **integral nuclear steam supply system** in which the reactor core, steam generators and pressurizer are all contained in a single vessel
- **Simple design** eliminates reactor coolant pumps, large bore piping and other systems and components found in conventional reactors
- Simplicity results in an extremely **strong safety case** and **reduced capital and operational costs**
- Modules can be incrementally added to match load growth

NuScale Power Module™ Specifications

Electrical Capacity	77 MWe
Modules per Plant	Up to 12 (924 MWe)
Design Life	60 years
Fuel Supply	Existing light water reactor nuclear fuel
Safety	Walk-away safe
Emergency Planning Zone (EPZ)	Supports site boundary EPZ

Source: NuScale WPC 2025 Presentation

Electrification of crackers is still under development



BFW = Boiler feed water; HPST = High-pressure steam; MMt/y = Million metric tons per year; MW = Megawatt; t/h = Metric tons per hour; TLE = Transfer line exchanger.
 Source: S&P Global Markit Process Economics Program (PEP) Report 290 Ethylene e-Cracker: Comparative Analysis of Electricity Sources

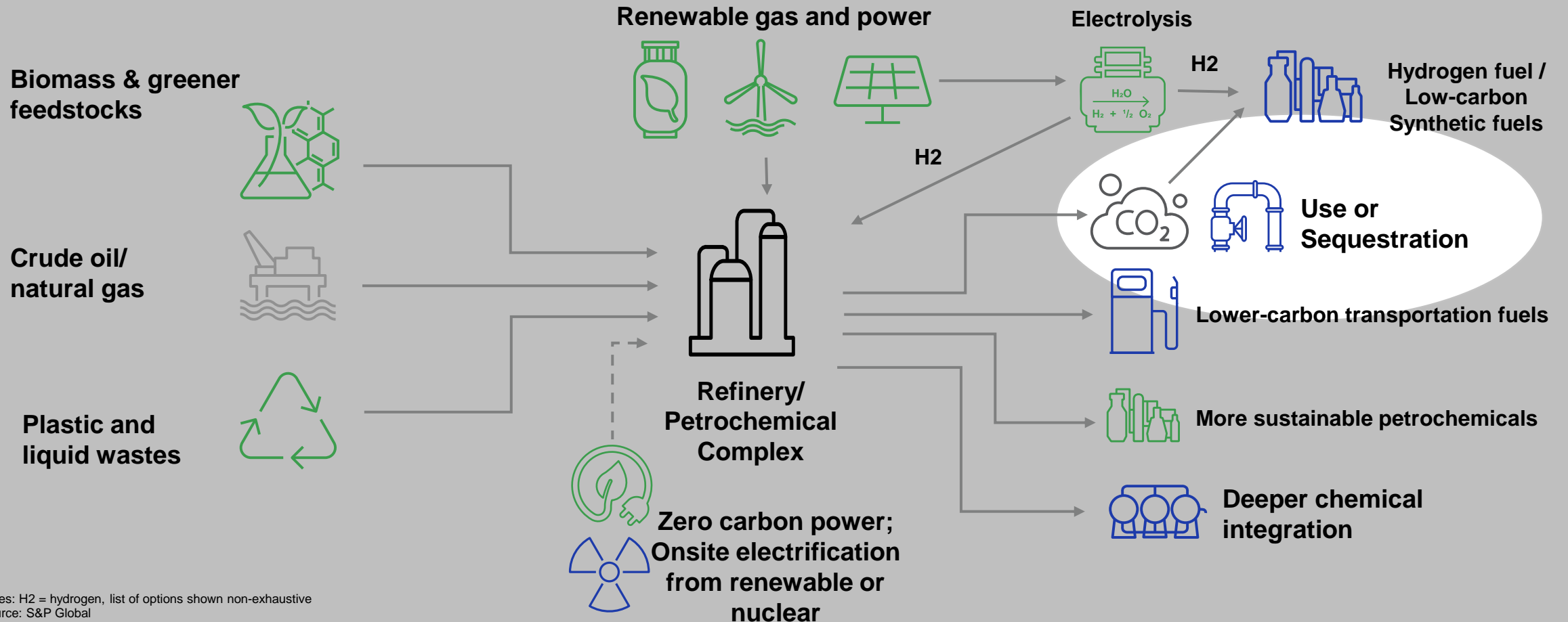
Linde/ BASF/ SABIC consortium at BASF Germany with separate direct and indirect heating concepts

Shell/Dow, Netherlands, experimental unit going into pilot plant

Technip, LyondellBasell and Chevron Phillips Chemical MOU to design, construct, and operate demonstration unit using Technip technology to produce olefins in Texas

Coolbrook/ ABB/ Linde: MOU to commercialize Coolbrook's Roto Dynamic Reactor technology currently in pilot scale in Netherlands

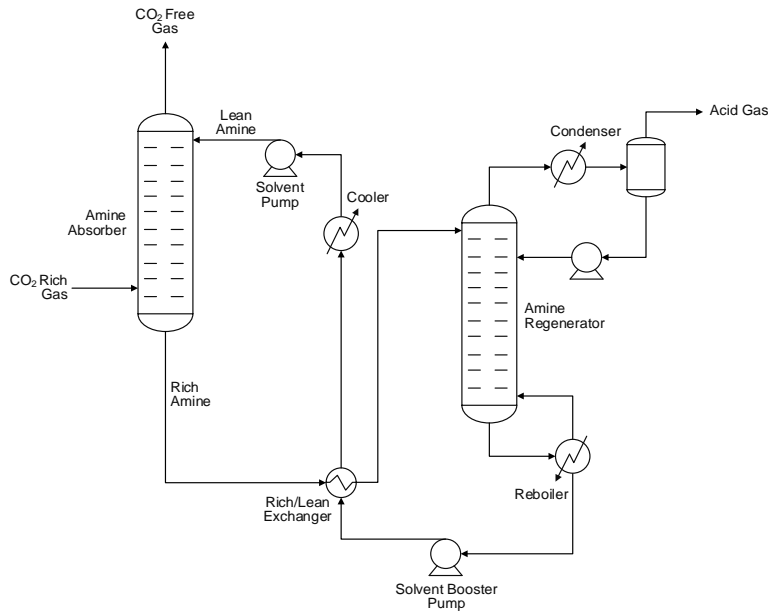
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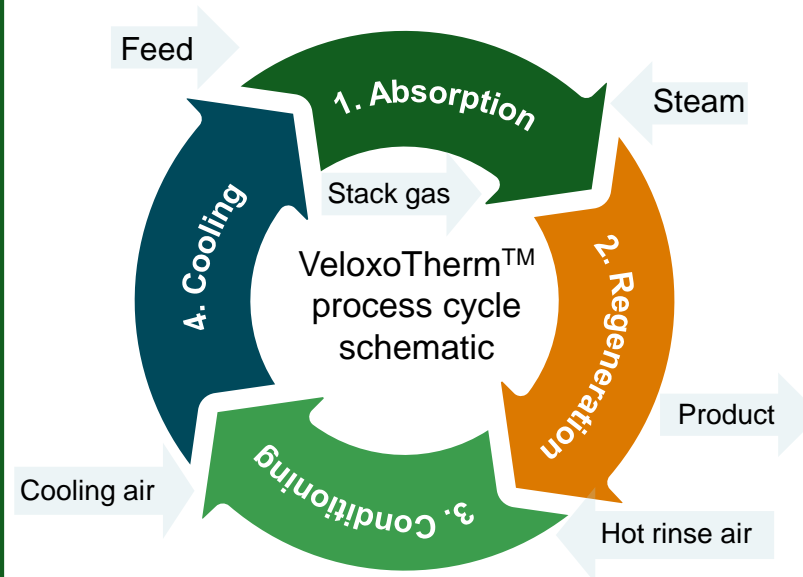
Notes: H₂ = hydrogen, list of options shown non-exhaustive
Source: S&P Global

Carbon capture solution from big to small concentrations are available and in development

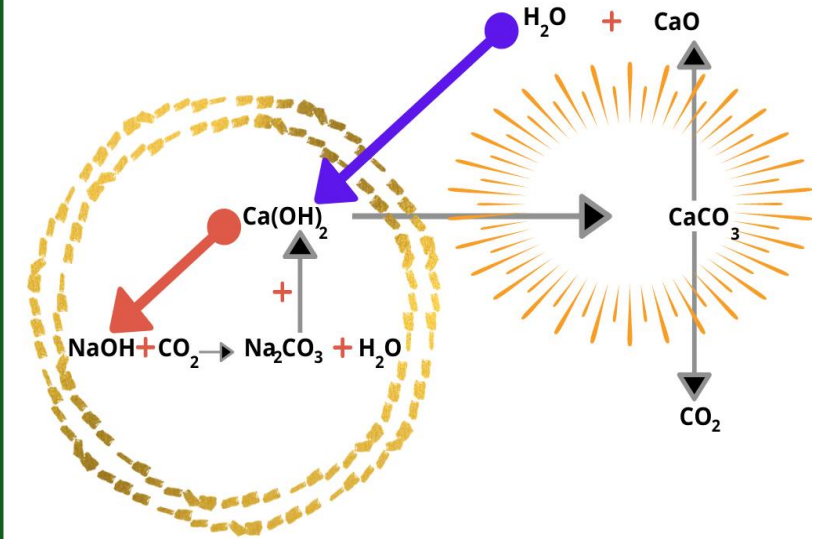
Solvent absorption



Rapid temperature swing absorption



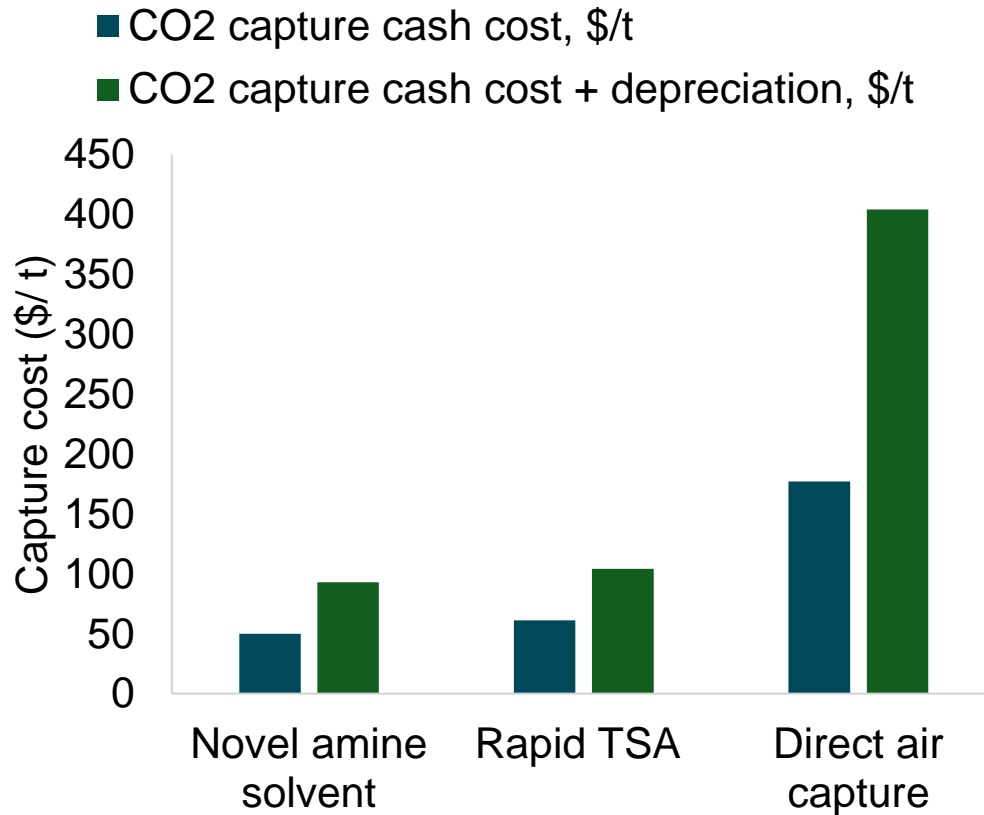
Direct CO₂ capture with caustic absorber



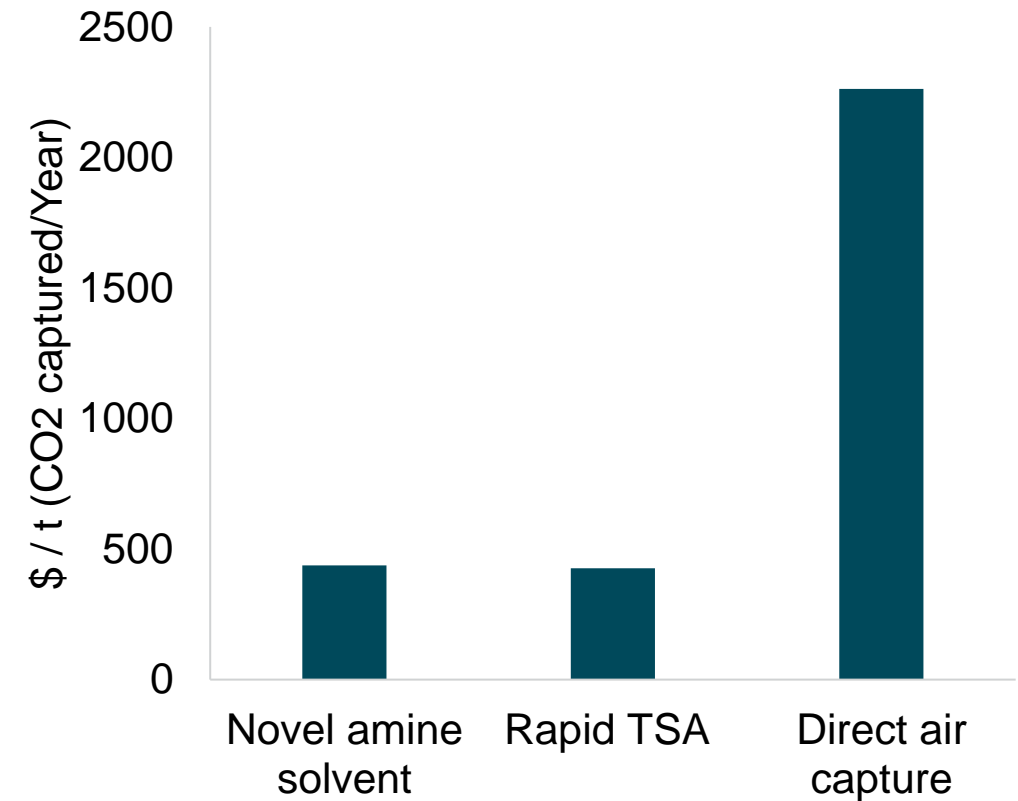
Source: S&P Global Markit Process Economics Program (PEP) Report 180F Next Generation Carbon Capture

Carbon capture economics (US, 2024) show decreasing CO₂ concentrations lead to increasing cost

Carbon capture costs

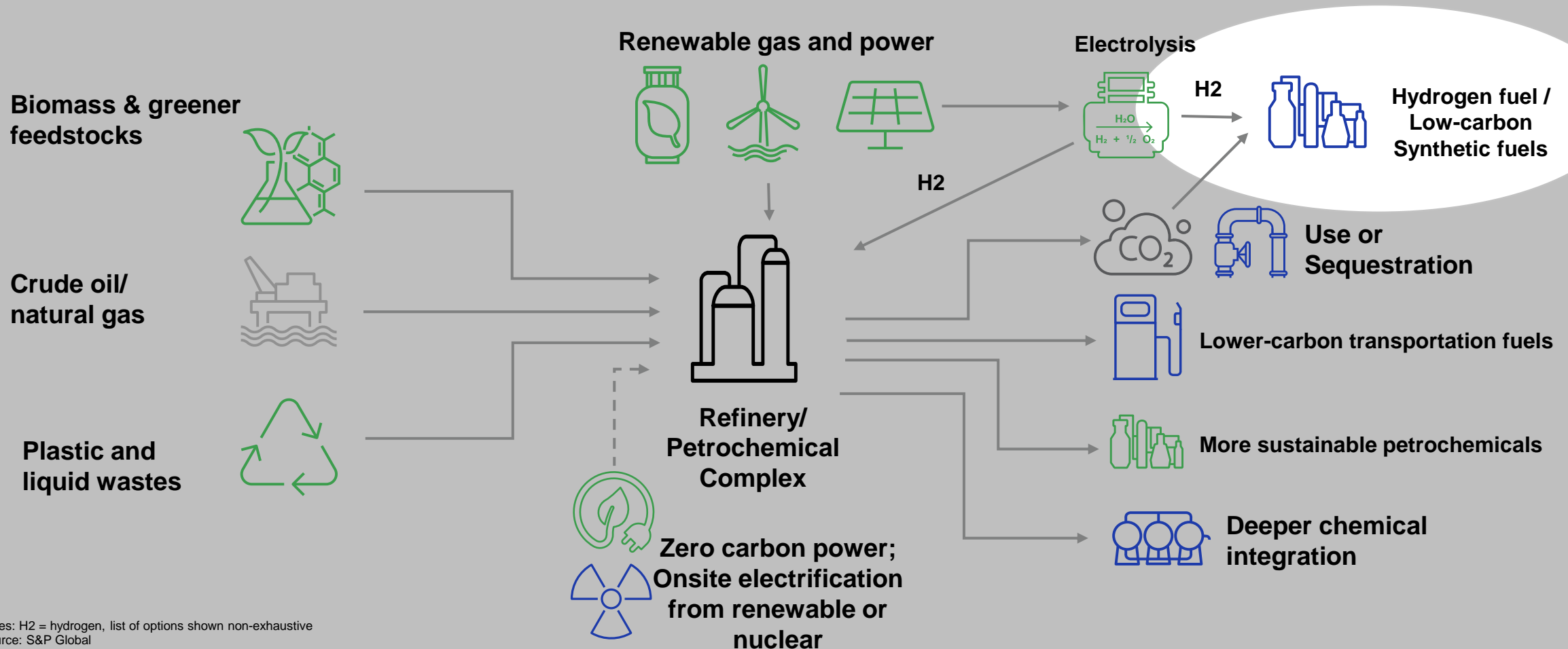


Capital cost intensity, \$/t (CO₂ captured/y)



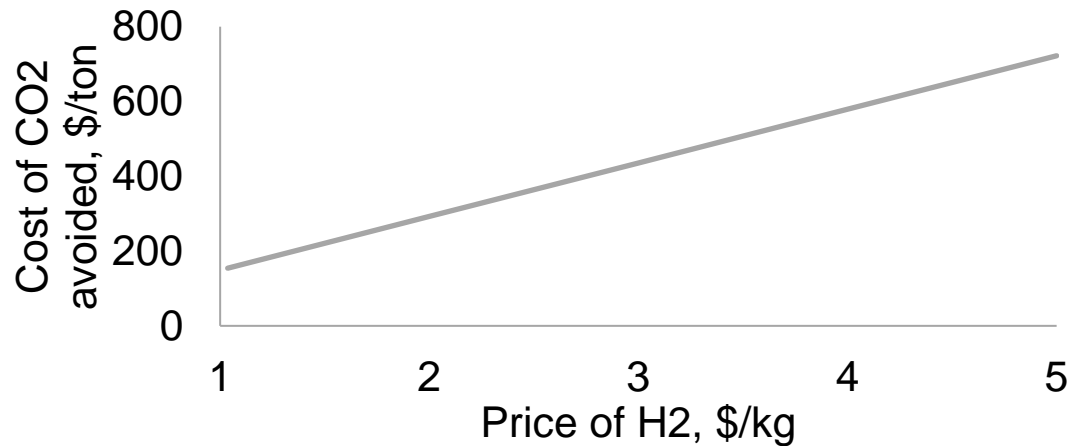
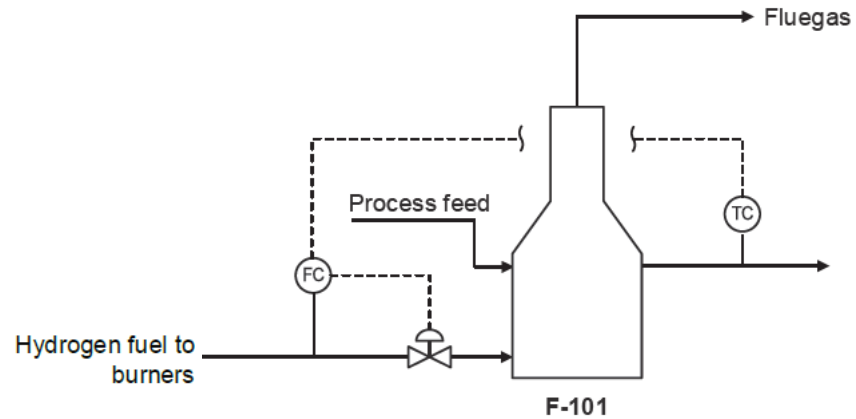
Source: S&P Global Markit Process Economics Program (PEP) Report 180F Next Generation Carbon Capture

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Source: S&P Global

Retrofitting cracker furnaces for hydrogen as fuel is feasible but expensive, even with low-cost hydrogen



Source: S&P Global Markit Process Economics Program (PEP) Report 32H Retrofitting for Hydrogen as a Fuel

Optimal performance requires case-by-case evaluation of factors

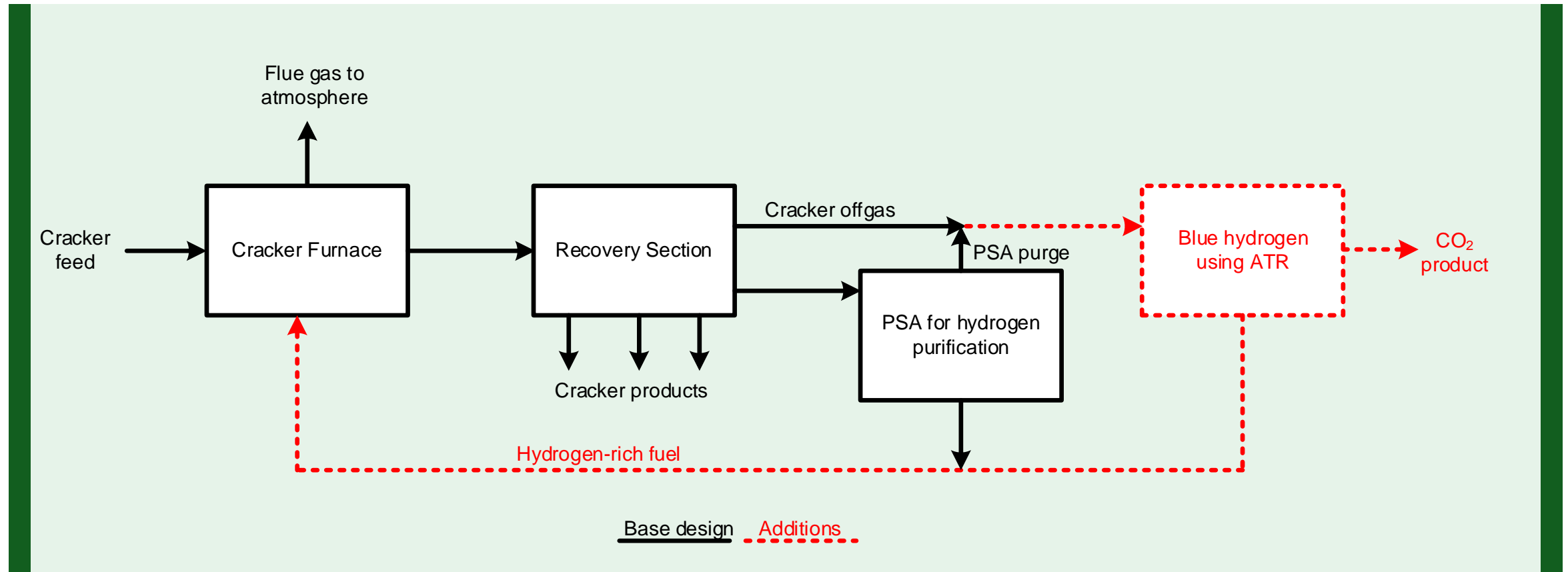
- Flame length
- Flame speed

Hydrogen as fuel impacts radiation heat transfer

- No soot reduces radiation produced by solid particles
- Higher emissivity of H₂O in hydrogen combustion increases flue gas radiation

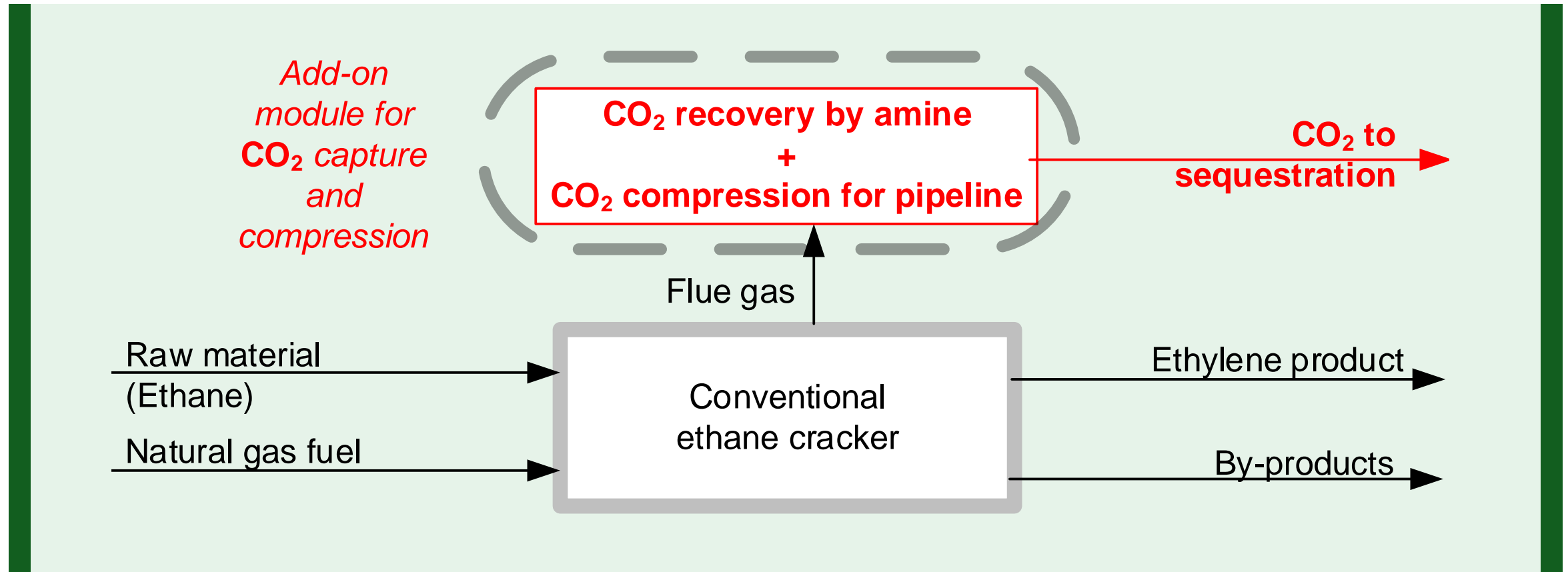
Increased NO_x emissions from higher flame temperatures require mitigation by burner replacement with low-NO_x burners

Dow is aiming for net zero for its new project in Fort Saskatchewan, Alberta, Canada



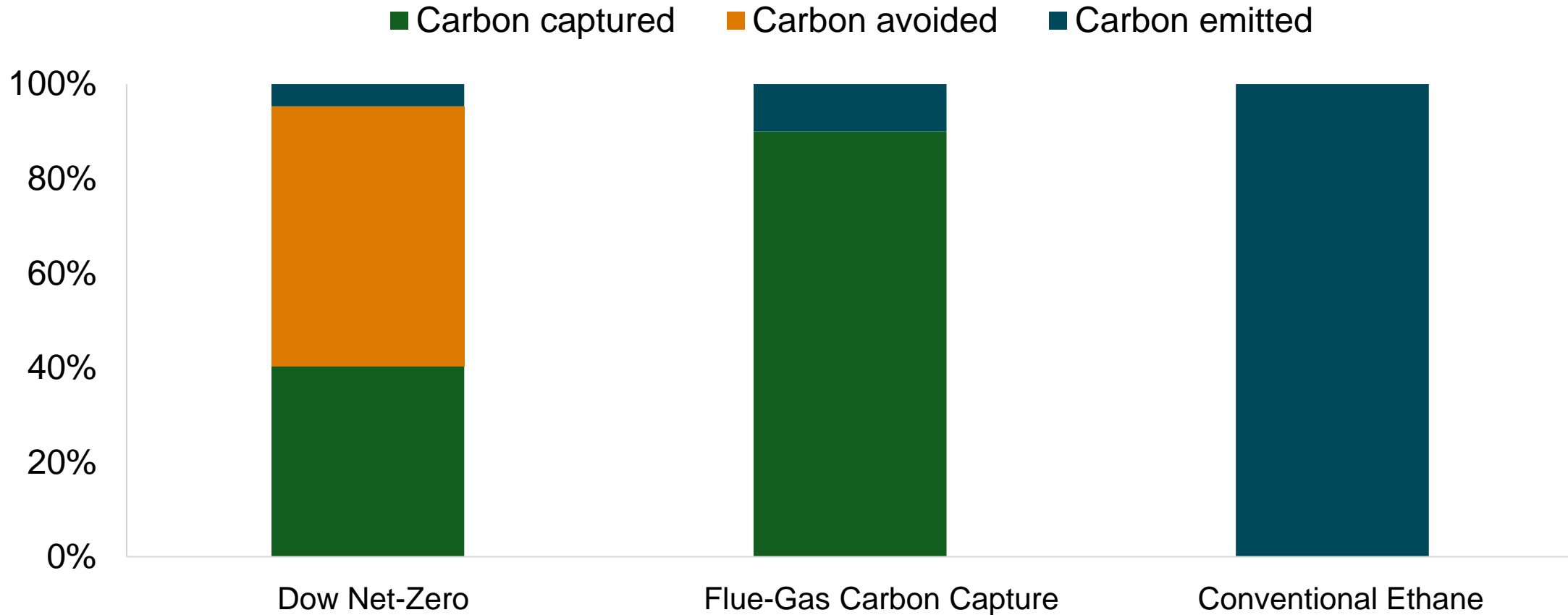
PSA: Pressure Swing Adsorption, ATR: Auto thermal reforming
Source: Process Economics Program (PEP) Review 2022-05: Dow Net-Zero Olefins from Ethane

Alternative is a CO₂ separation section as an independent unit added to an existing facility



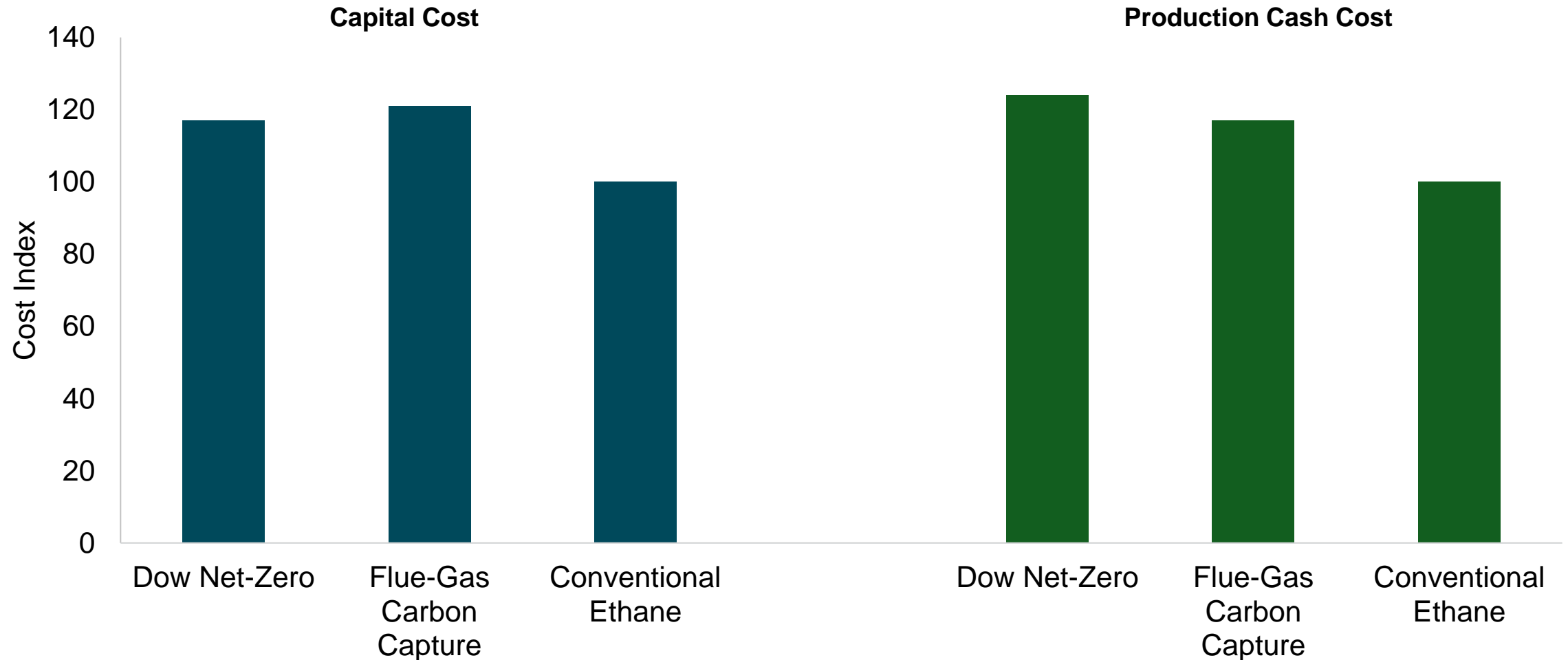
Source: Process Economics Program (PEP) Review 2022-05: Dow Net-Zero Olefins from Ethane

Dow Net-Zero avoids and emits substantially less carbon than conventional ethane cracking



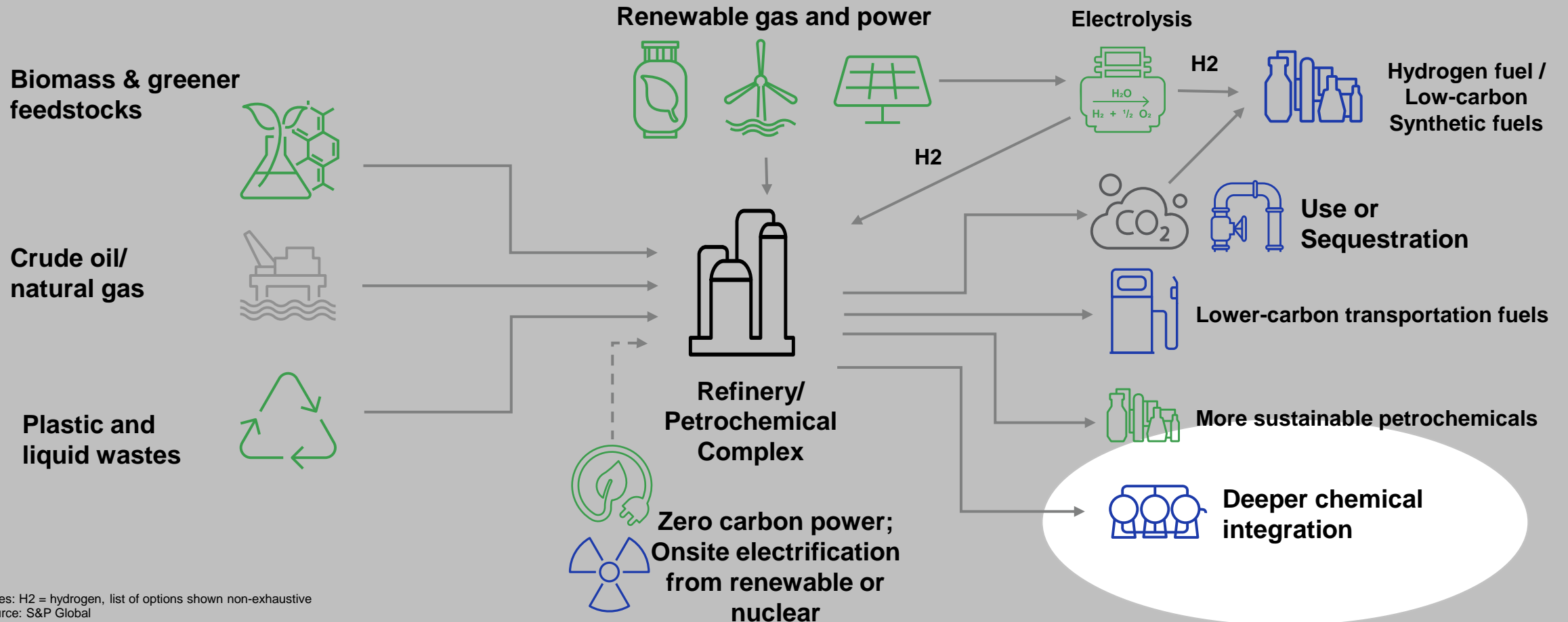
Source: Process Economics Program (PEP) Review 2022-05: Dow Net-Zero Olefins from Ethane

Reduction comes at higher CAPEX and OPEX than standard ethane cracking



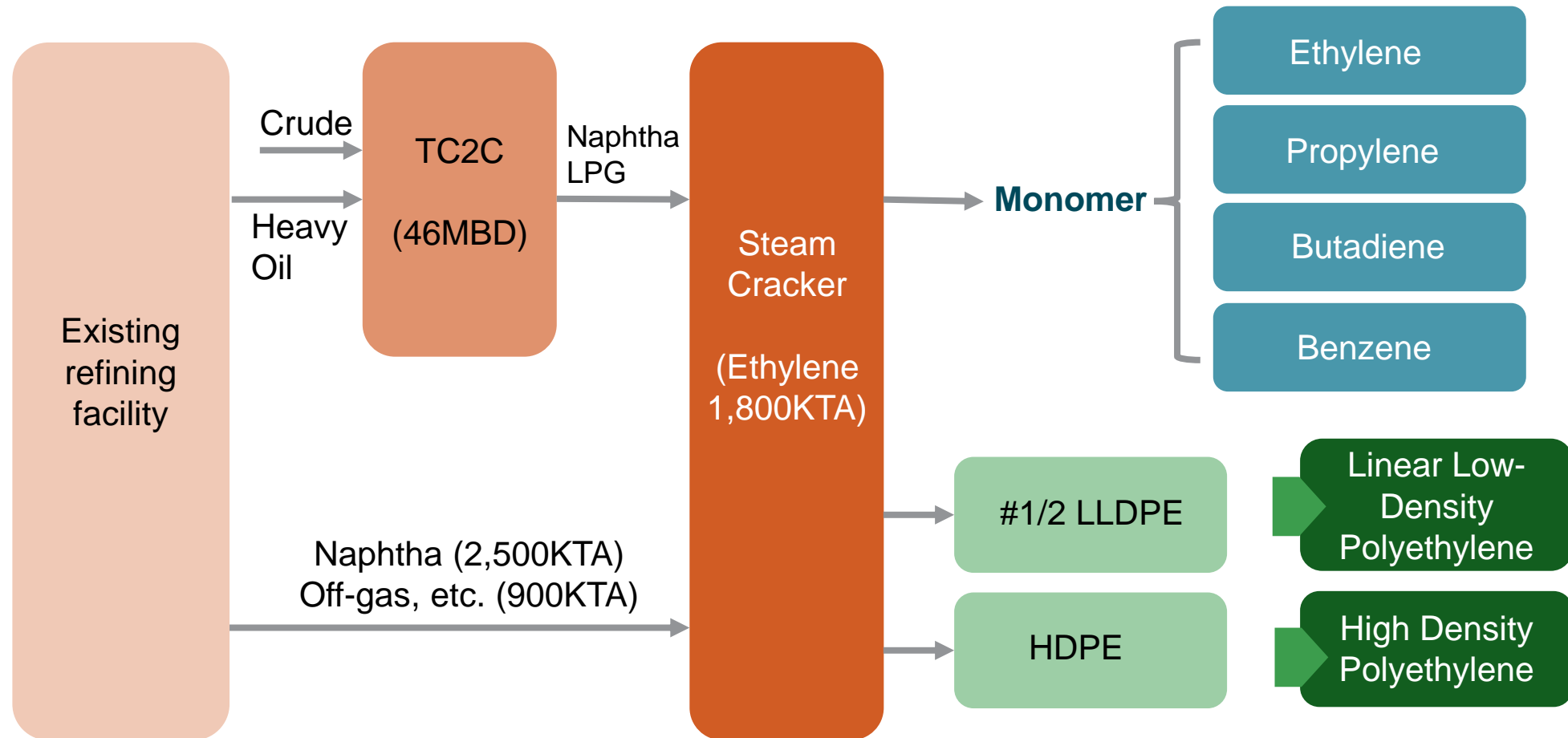
Source: Process Economics Program (PEP) Review 2022-05: Dow Net-Zero Olefins from Ethane

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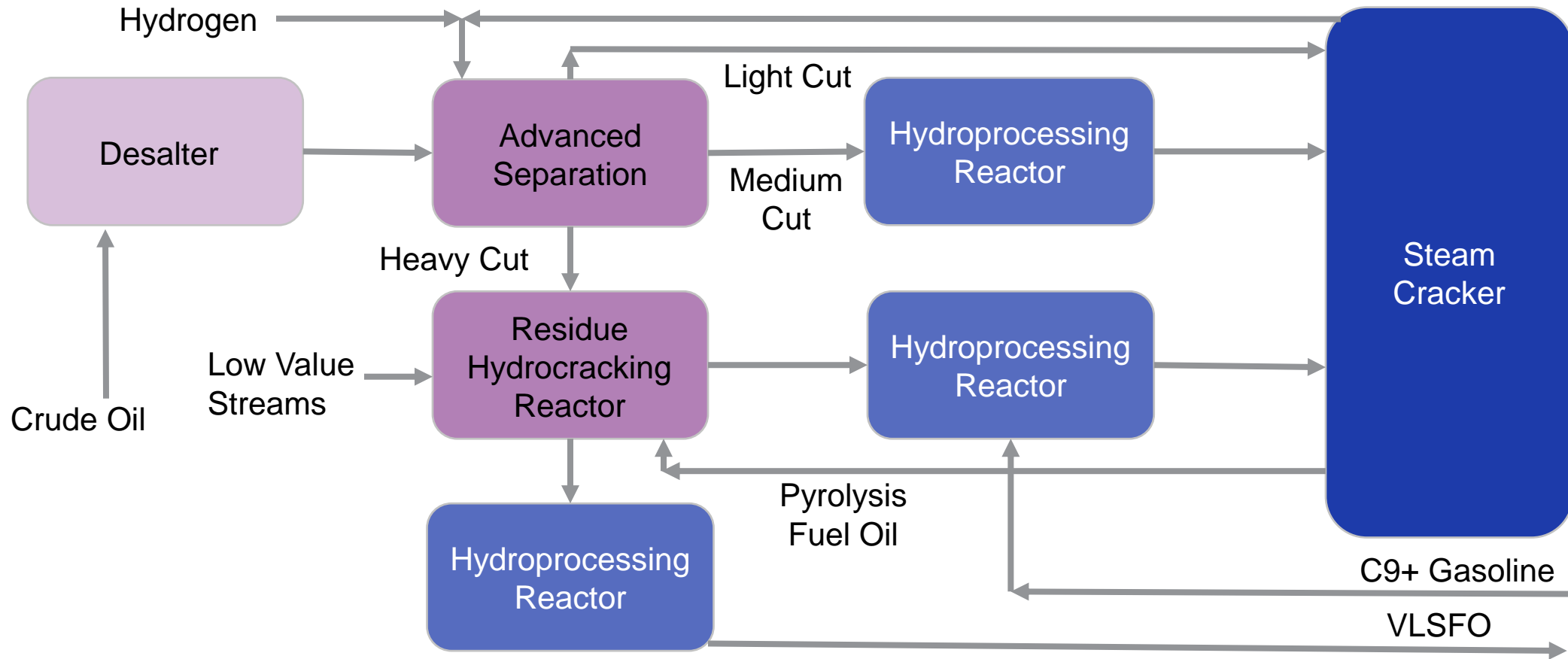
Notes: H₂ = hydrogen, list of options shown non-exhaustive
Source: S&P Global

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 (TC2T) technology involves several unit operations



Source: Aramco MEPEC 2024 Presentation, TC2C™ More Carbon Effective Conversion of Crude into Chemicals

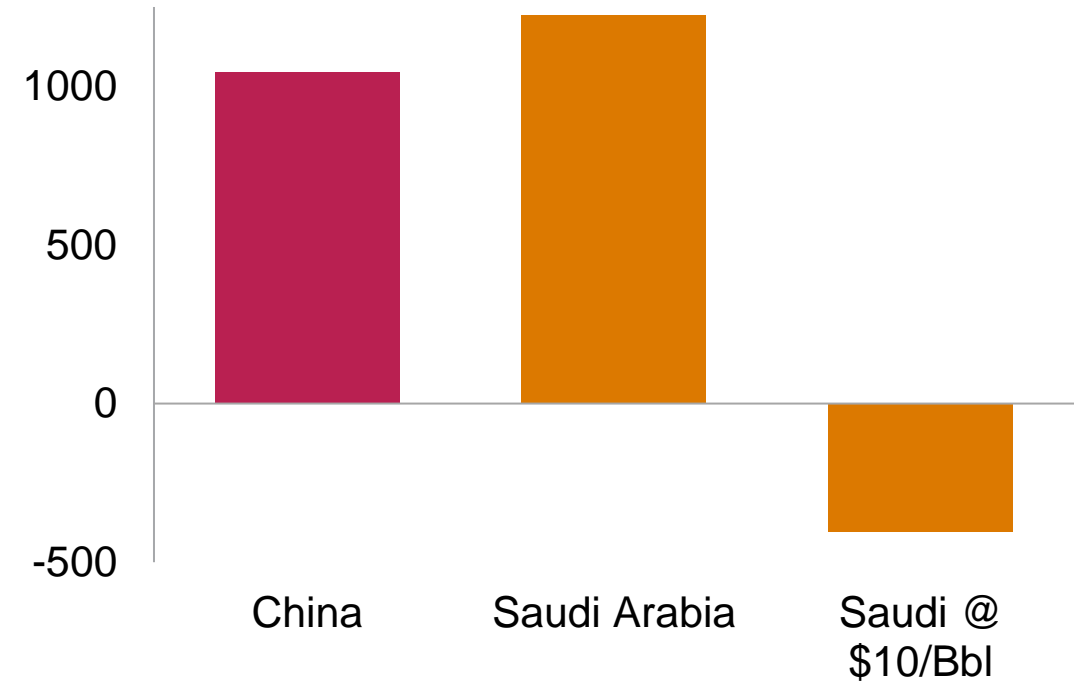
Despite its scale, COTC for olefins is at best mid-quartile on the cost curve at market price oil

Saudi gas initiatives will increase ethane/NGL availability for petchems

Nevertheless, Saudi Aramco plans to convert up to 4 million b/d of crude oil to chemicals, both in Kingdom and in destination markets

COTC is CAPEX intensive and cash cost is similar to naphtha cracking at a market price for oil

TC2C™ cash cost of production (US\$/Ton)



*Based on Q3 2024 prices
Data compiled 8 Jan 2025
Source: S&P Global Commodity Insights, Process Economics Program (PEP)

Honeywell have developed naphtha to ethane & propane (NEP) as a step-change in olefins production efficiency and bankable investments

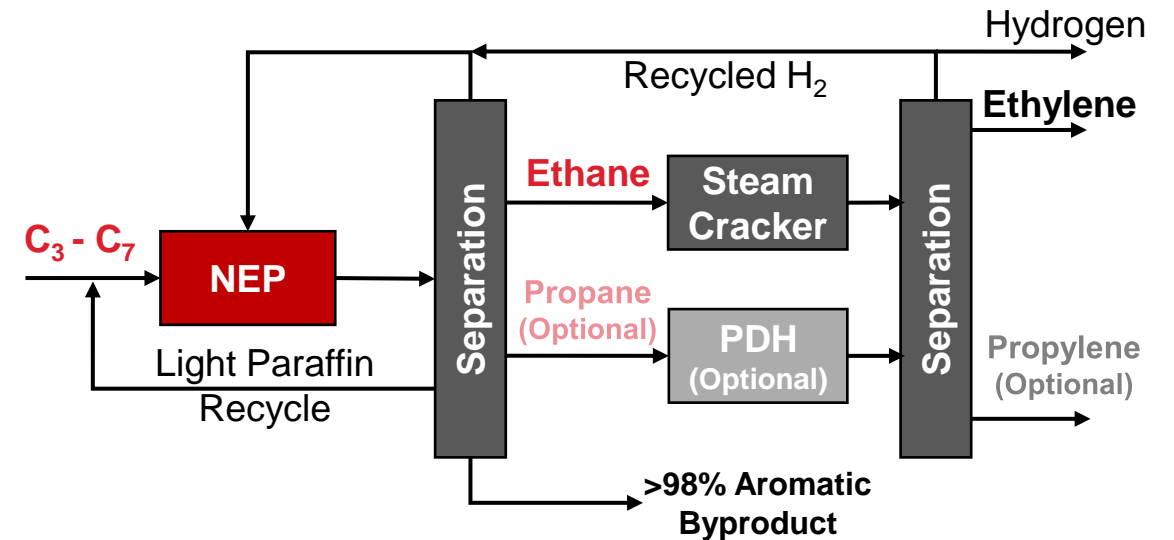
+ 3.7% IRR & +\$1.1 Billion NPV10
 ~ 79% conversion of crude to chemicals
 > 35% Net Cash Margin per bbl of crude
 > 25% improved capital efficiency/ton

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

NEP-Based Light Olefins Complex



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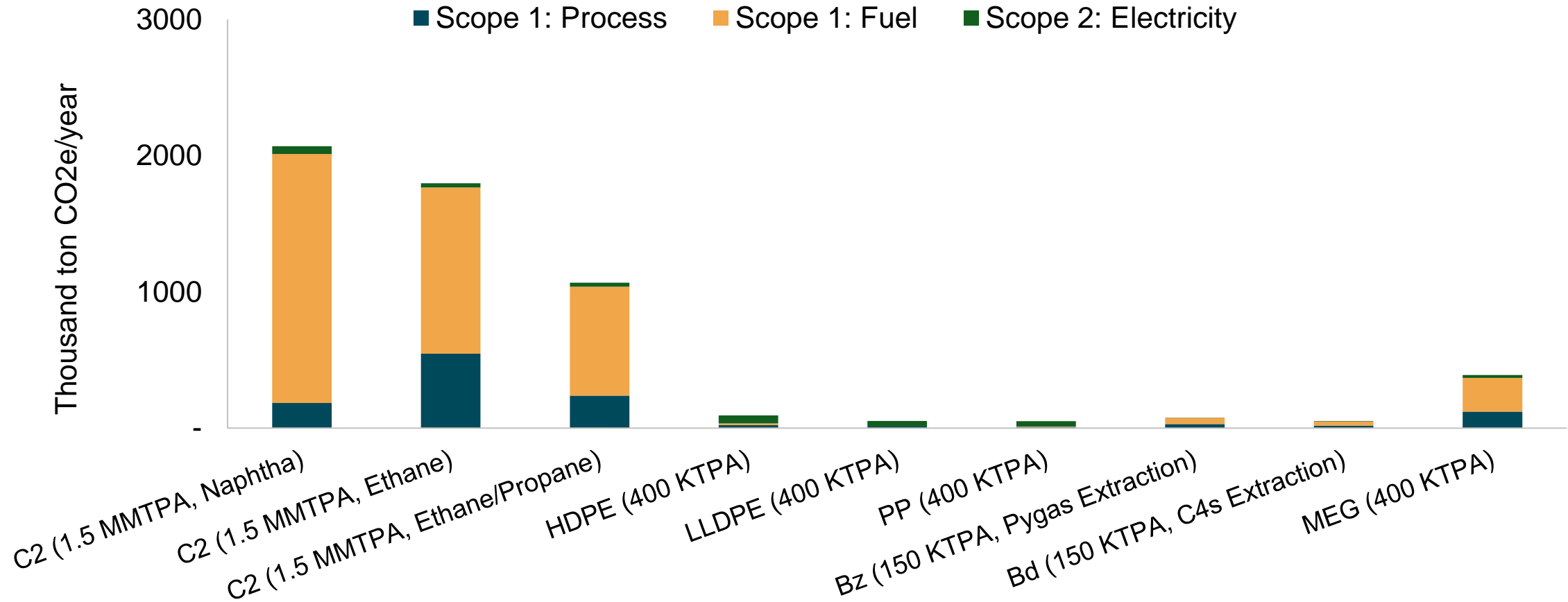
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Key takeaways



Within a petrochemical complex, emissions from other plants of typical capacity are dwarfed by those from a cracker



Source: S&P Global Refinery & Petrochemical Integrator & Decarbonizer (RAPID)

Another certainty: Decarbonizing the industry will cost a lot! But how much?

Case Study: Existing cracker and derivatives complex in SE Asia

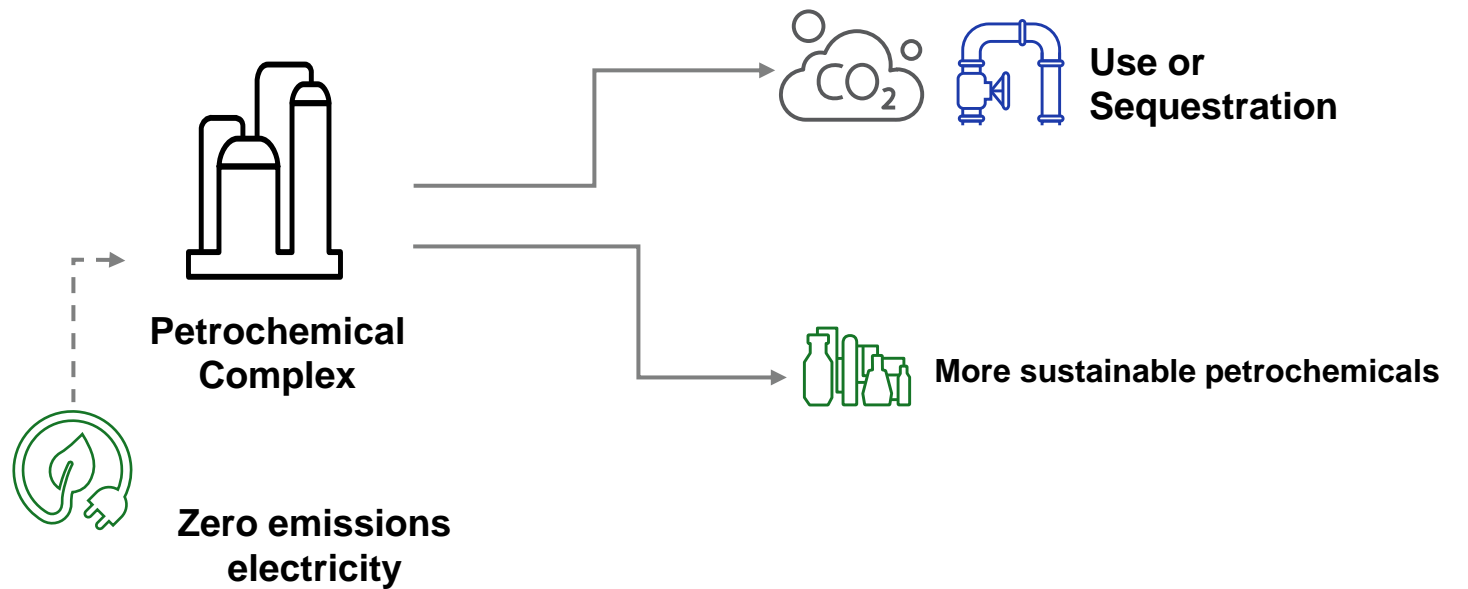
1 million tons/year ethylene from naphtha

Corresponding LLDPE, HDPE, PP, Benzene & Butadiene production

Scope 1 and Scope 2 emissions abatement from 2028

Carbon capture and sequestration

Zero-emissions electricity production



Source: S&P Global Refinery & Petrochemical Integrator & Decarbonizer (RAPID)

Substantial product premiums and/or carbon credits will be needed to maintain future financial performance

Substantial CAPEX and increased OPEX



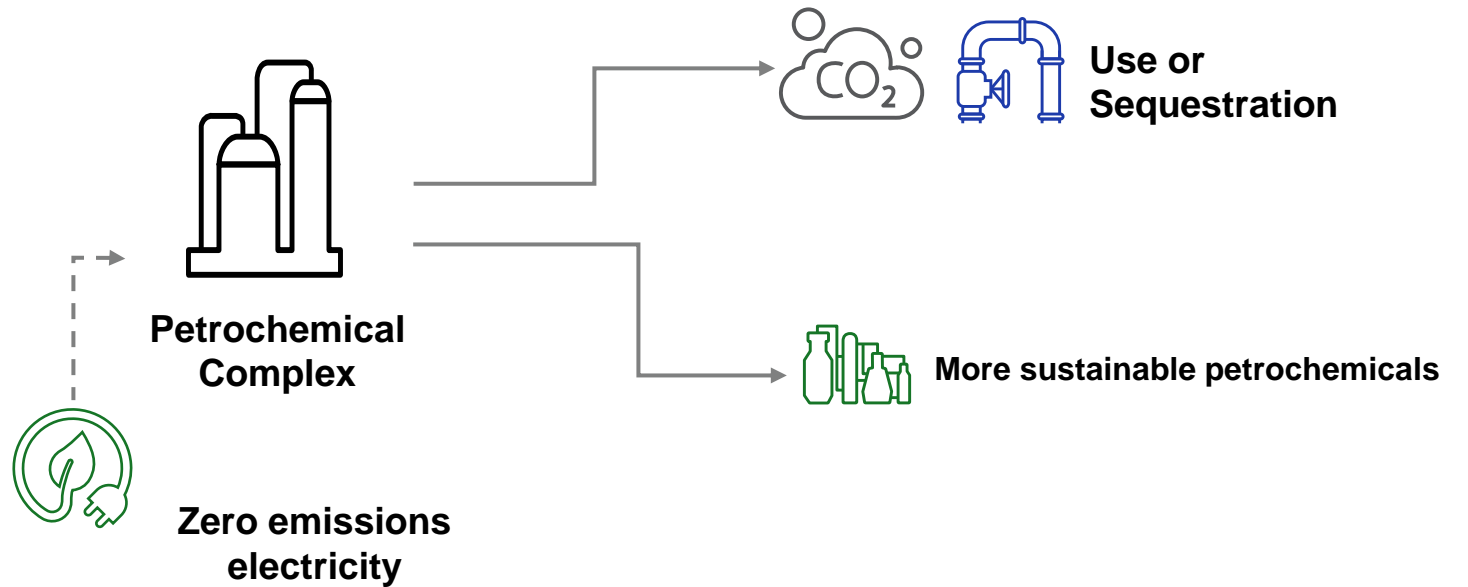
CAPEX of well over \$1 billion to achieve 70% carbon emissions reduction



25-year EBIT reduced by over \$5 billion



EBIT parity:
~150 \$/ton “low-carbon” polymer product premium or
~130 \$/ton of CO2 credit for emissions avoided



Source: S&P Global Refinery & Petrochemical Integrator & Decarbonizer (RAPID)

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Key Takeaway: Setting up a petrochemical industry for the future will require huge investment for decarbonization and mechanisms to offset the costs

The future petrochemical industry will be a decarbonized one albeit the pace is slowing

Multiple decarbonization technology options available but vary in commercialization

Substantial CAPEX and OPEX is required to achieve decarbonization targets

Government policy-driven carbon credits and/or green-product premiums will be needed to offset the EBIT decline

