S&P Global
Commodity Insights

Decarbonization Strategies and Deployment

"However beautiful the strategy, you should occasionally look at the results"

Dr. Richard Charlesworth, Executive Director,
Industry Processes and Cost Analytics (IPCA)
S&P Global Commodity Insights

APIC, Seoul, S. Korea, 30-31 May 2024

Agenda

- Beautiful Strategies!
- Measuring Success?
- Costs from Hell!
- Net Zero too Difficult?
- The End?

" However beautiful the strategy, you should occasionally look at the results "

– Sir Winston Churchill

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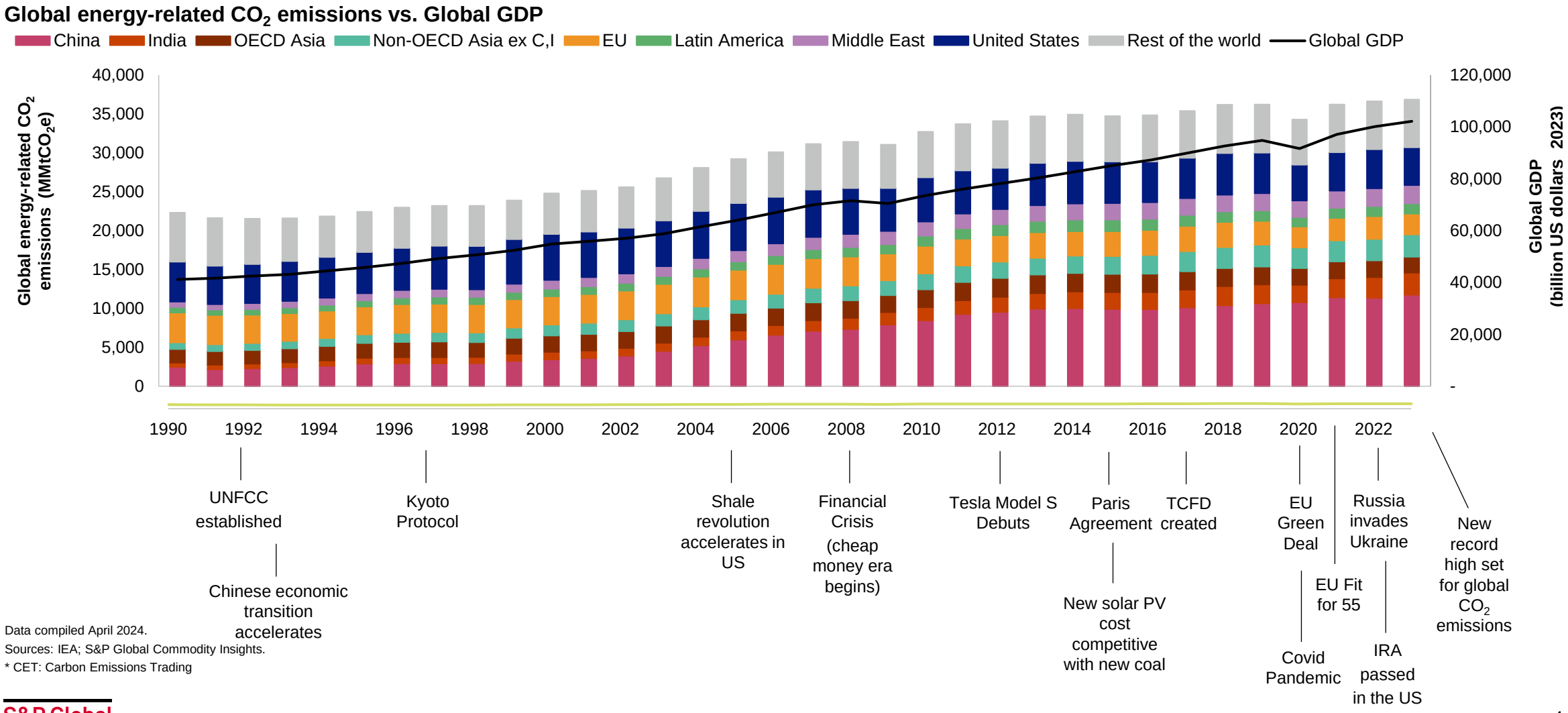
Global emissions have risen with GDP despite climate policies & CET advances



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

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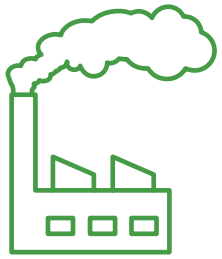
Emissions from industry come from multiple sources

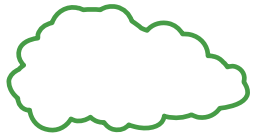
UNFCCC emissions scope definitions

Scope 1



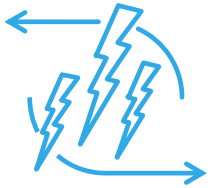
On-site fuel use

Venting and flaring



Fugitives

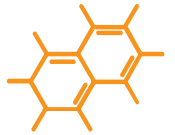
Scope 2



Energy trade

Scope 3

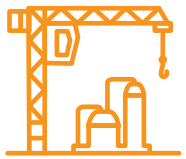
Land use



Co-products

Upstream emissions of fuel

Refined production use



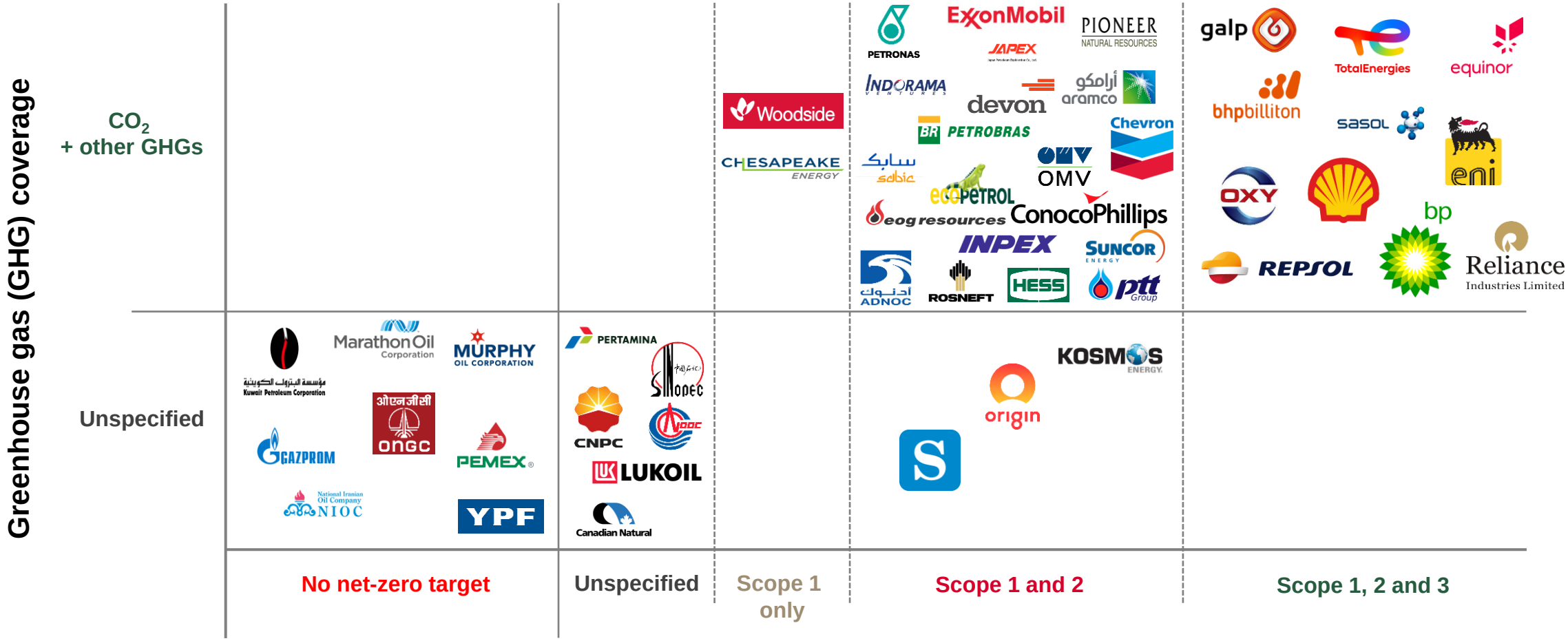
Construction

Downstream processing

Note: UNFCCC = United Nations Framework Convention on Climate Change

Beautiful decarbonization strategies! But targets range widely in scope, ambition and definition.

Select oil, gas, refinery & petrochemical companies' corporate emission reduction targets



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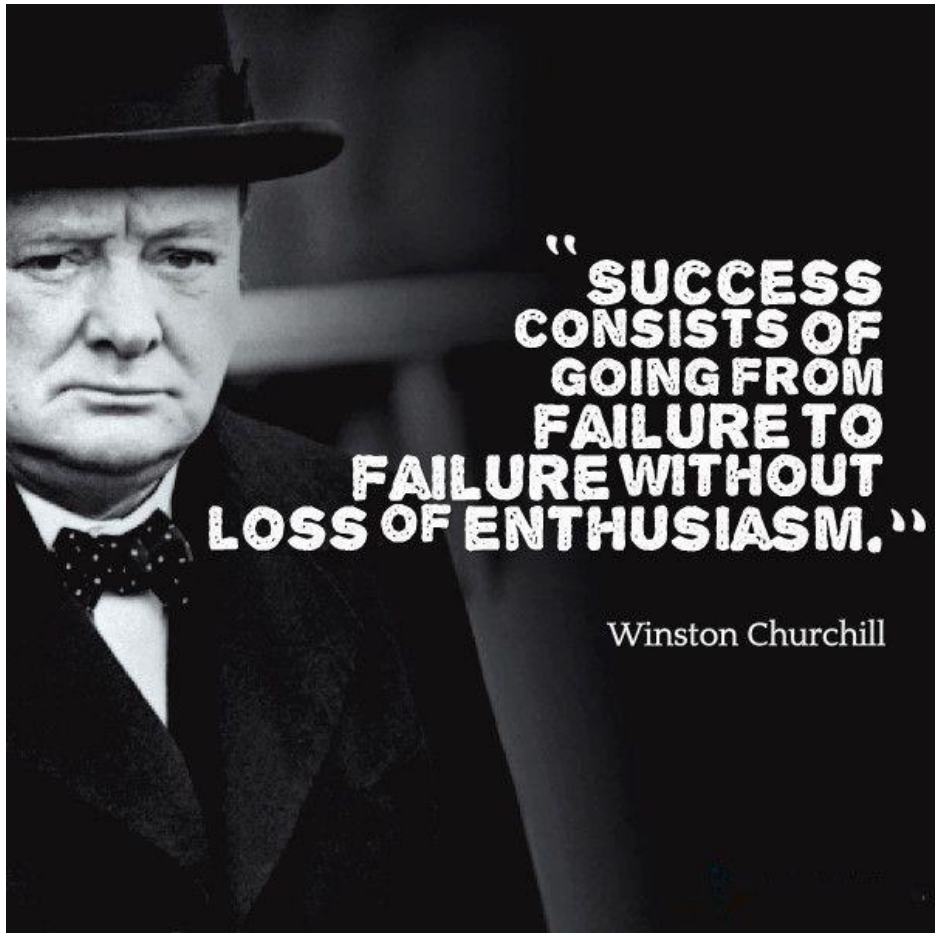
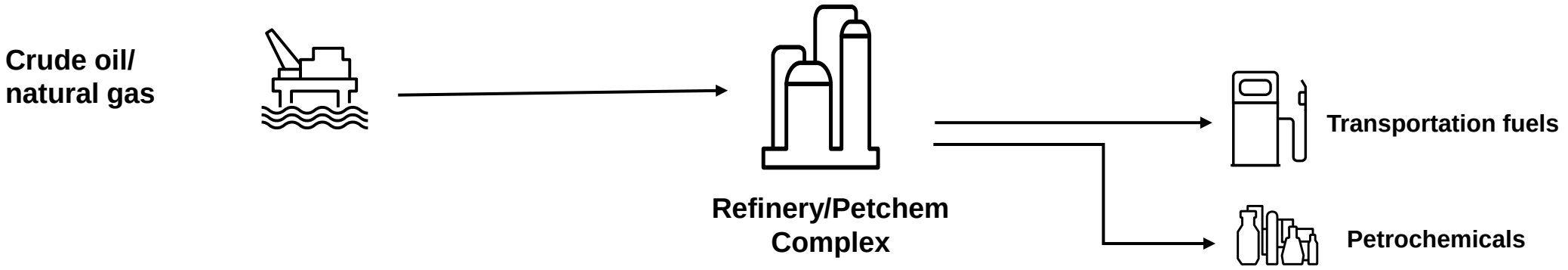


Pathways to Net Zero: multiple opportunities to manage carbon content and emissions along complex and ever-changing supply chain



Source: S&P Global

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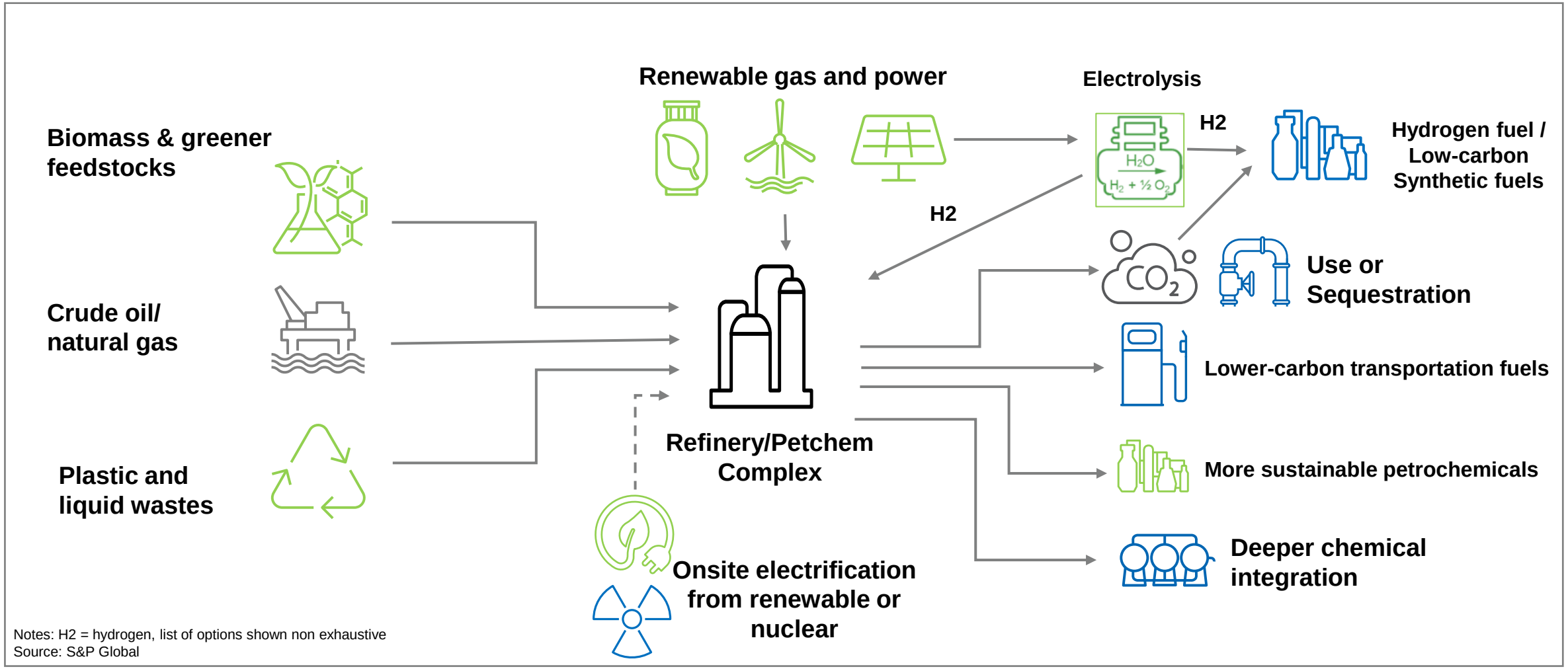
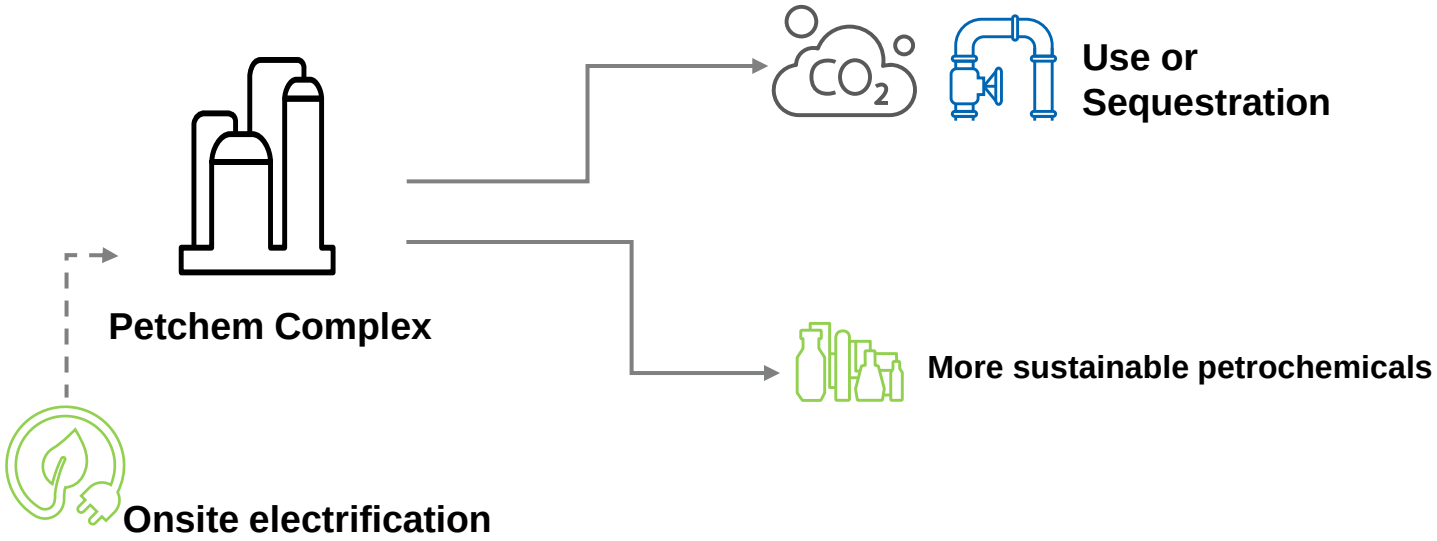


Notes: H2 = hydrogen, list of options shown non exhaustive
Source: S&P Global

Case Study – Northeast Asia Petrochemical Complex

- Existing cracker and derivatives complex
- 1 million tons/year ethylene from naphtha
- Corresponding PE, PP, Benzene & Butadiene production
- Scope 1 & Scope 2 emissions abatement from 2027
- Carbon capture and sequestration
- Zero-emissions electricity production



Source: S&P Global Refinery & Petrochemical Integrator & Decarbonizer

Case Study – Northeast Asia Petrochemical Complex

Substantial CAPEX & increased OPEX

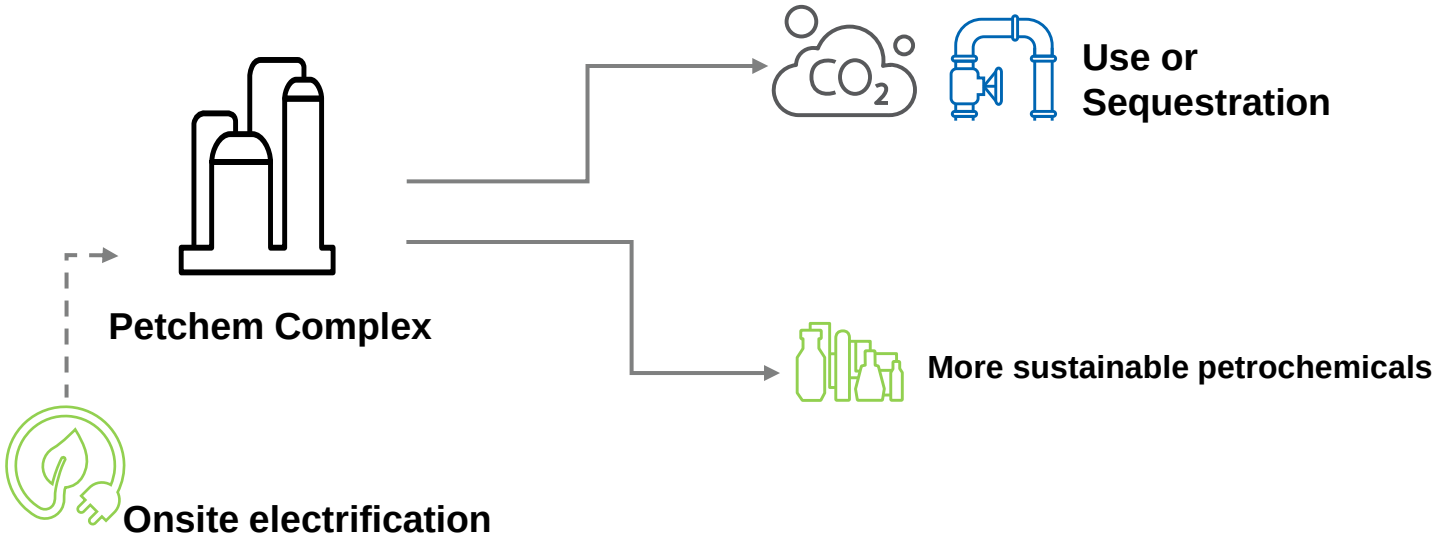
CAPEX of over $1.2 billion to achieve just 35% carbon emissions reduction

EBIT reduced by over $5 billion through higher OPEX

EBIT parity:

~130 $/ton “low-carbon” polymer product premium or

~300 $/ton of CO2 credit for emissions avoided



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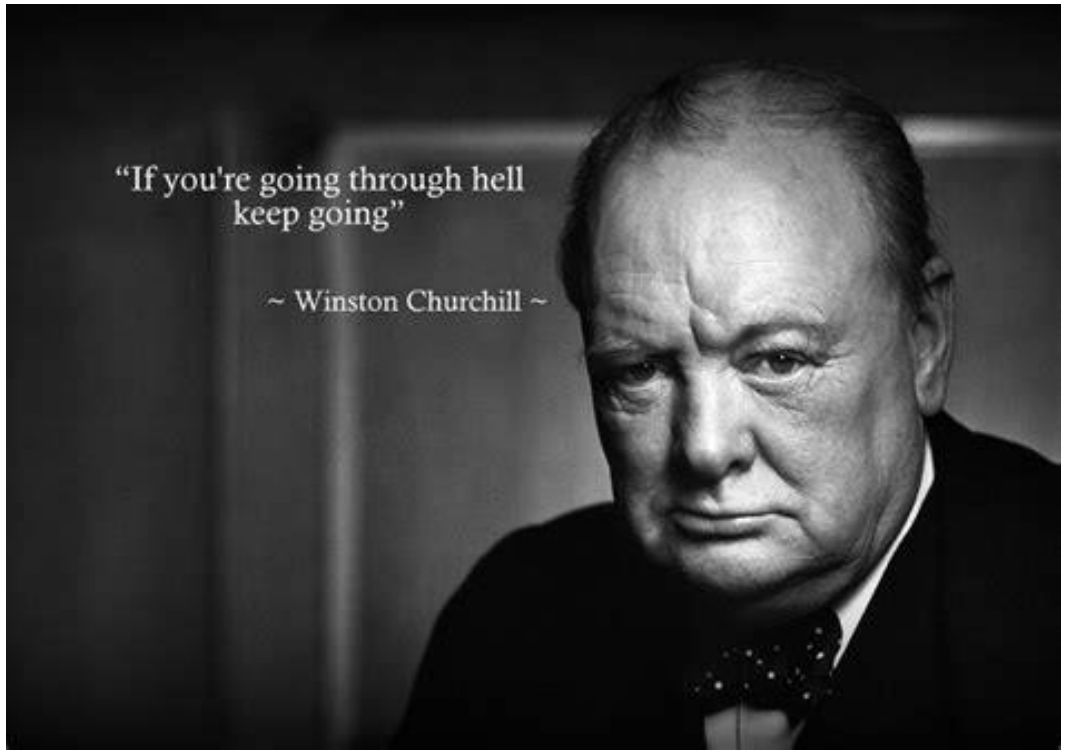
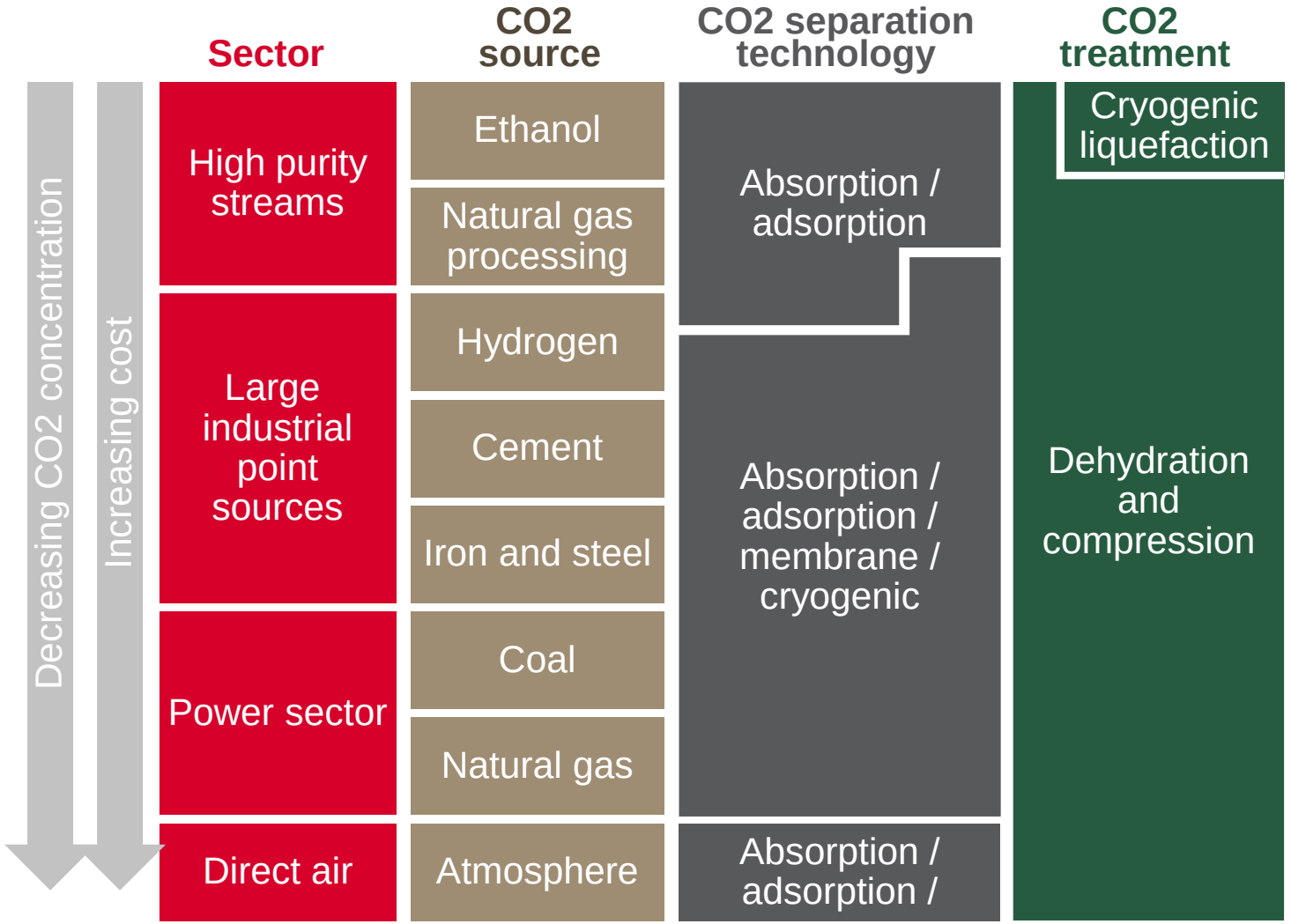


For CO2 emissions, there are multiple sectors, multiple sources, multiple technologies and treatment

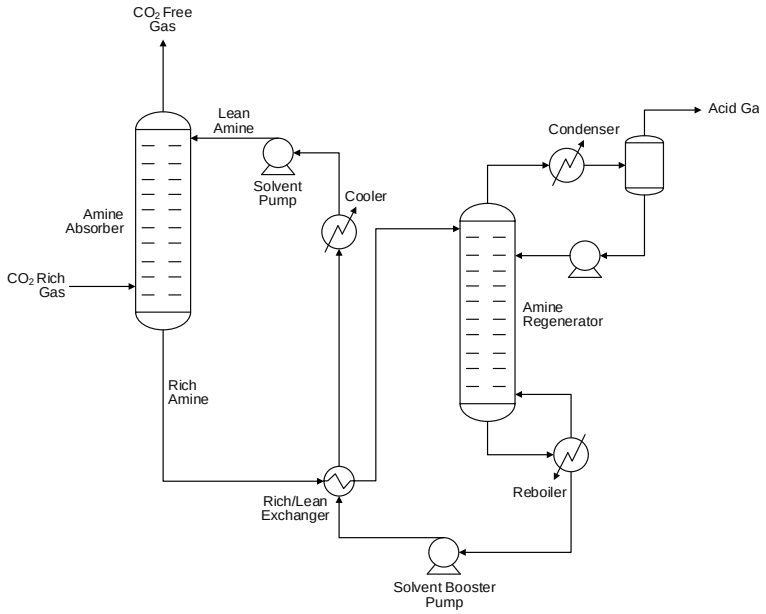


Note: Capture processes do not capture entire chemical treatment for each CO2 source.

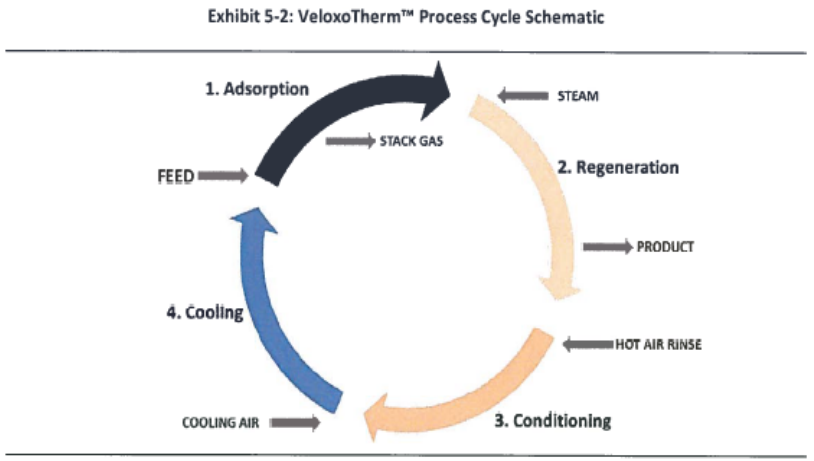
Source: S&P Global

Example 1: Carbon Capture - from big to small concentrations solutions are available and in development

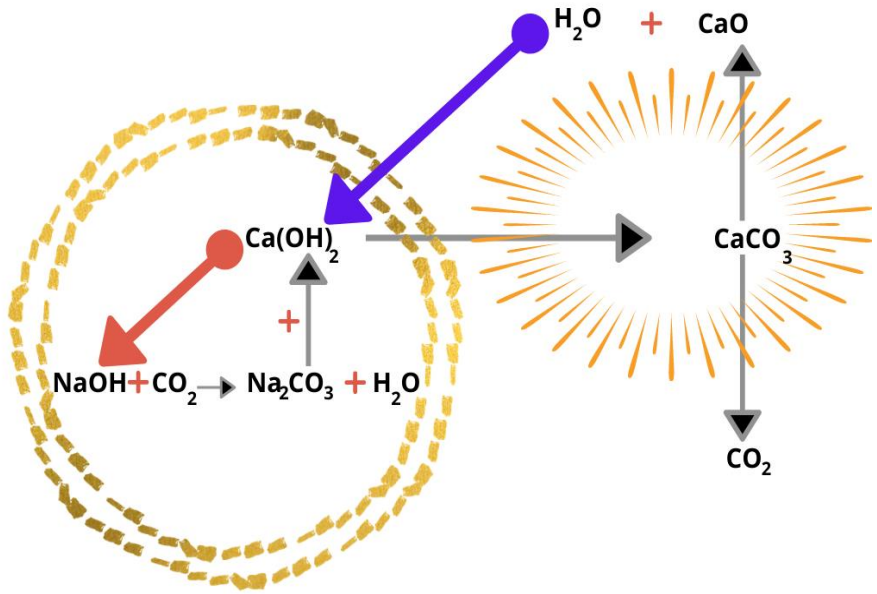
- Solvent Absorption



- Rapid Temperature Swing Adsorption



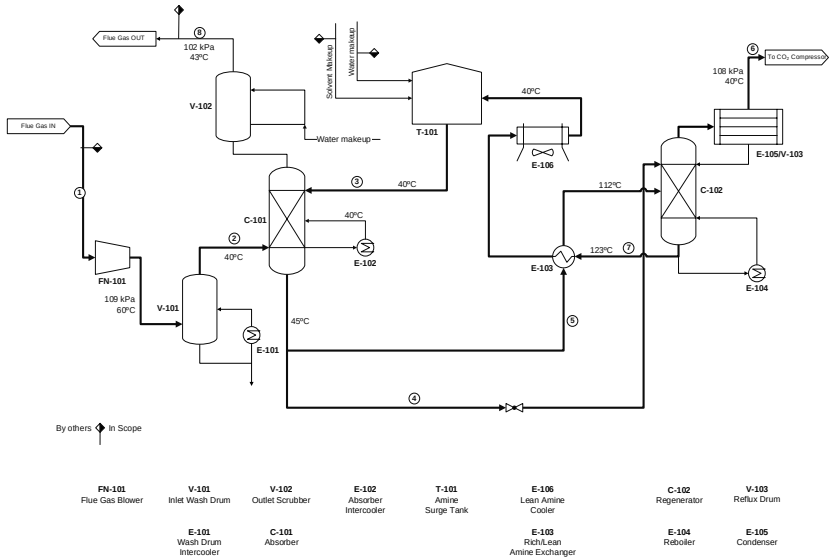
- Direct CO2 capture with Caustic Absorber



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

S&P's Process Economics Program (PEP) has developed full models for OPEX and CAPEX analysis

- Solvent Absorption



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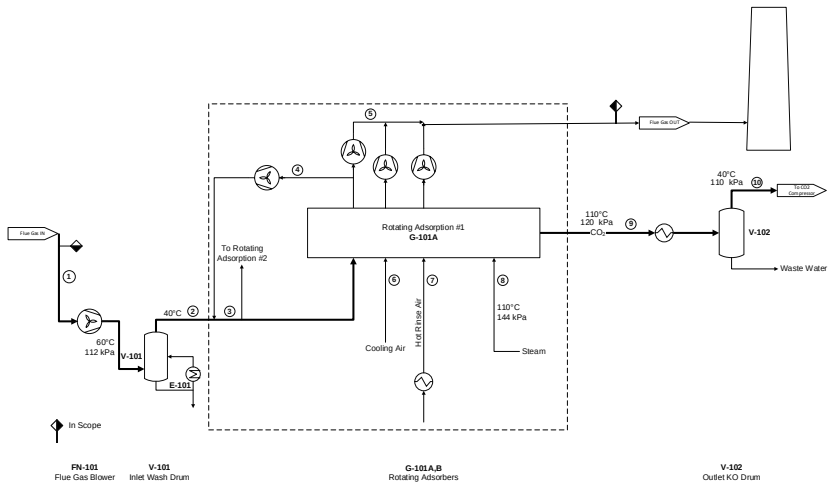
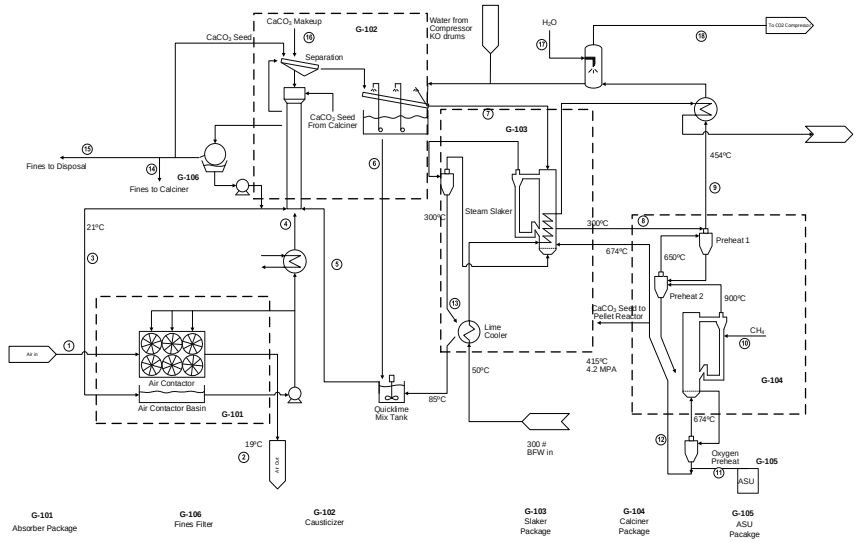


- Direct CO_2 capture with Caustic Absorber



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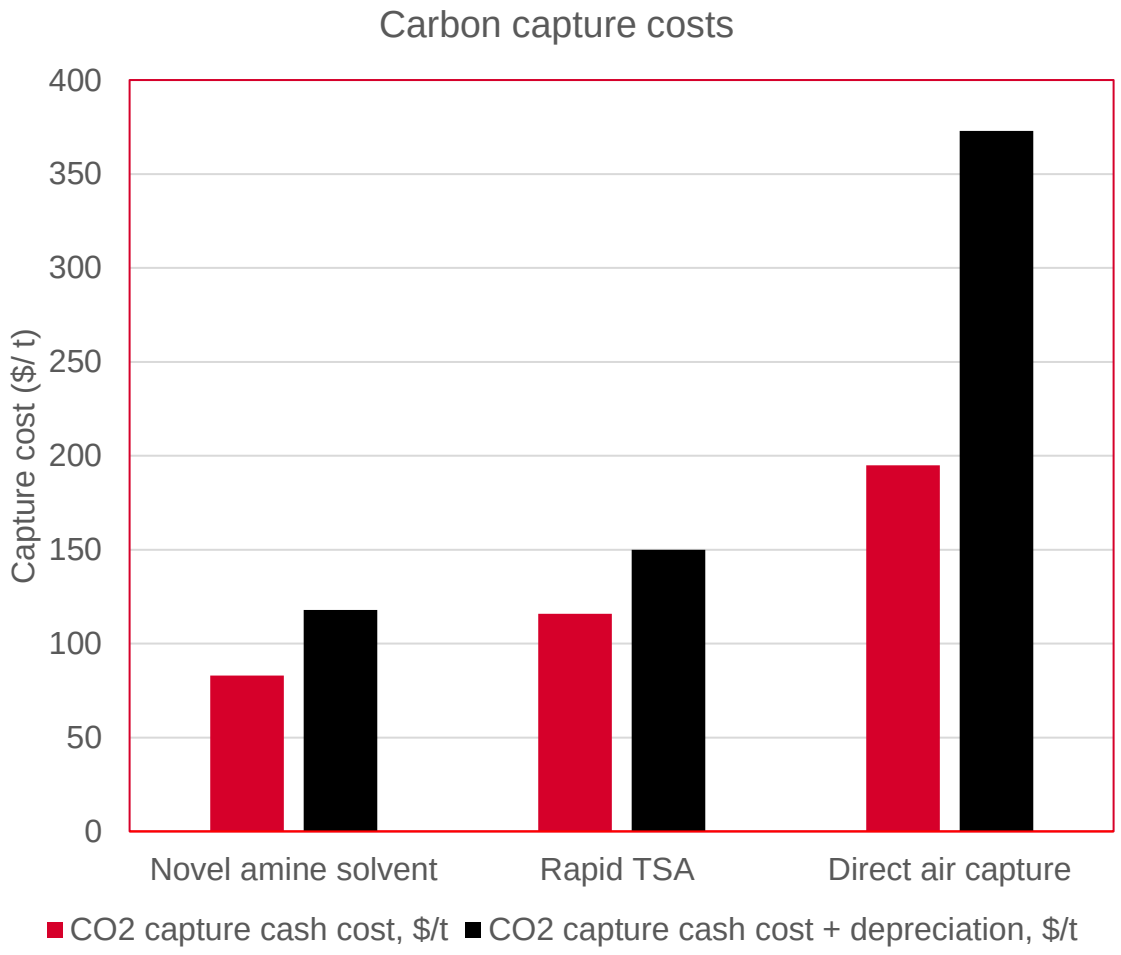
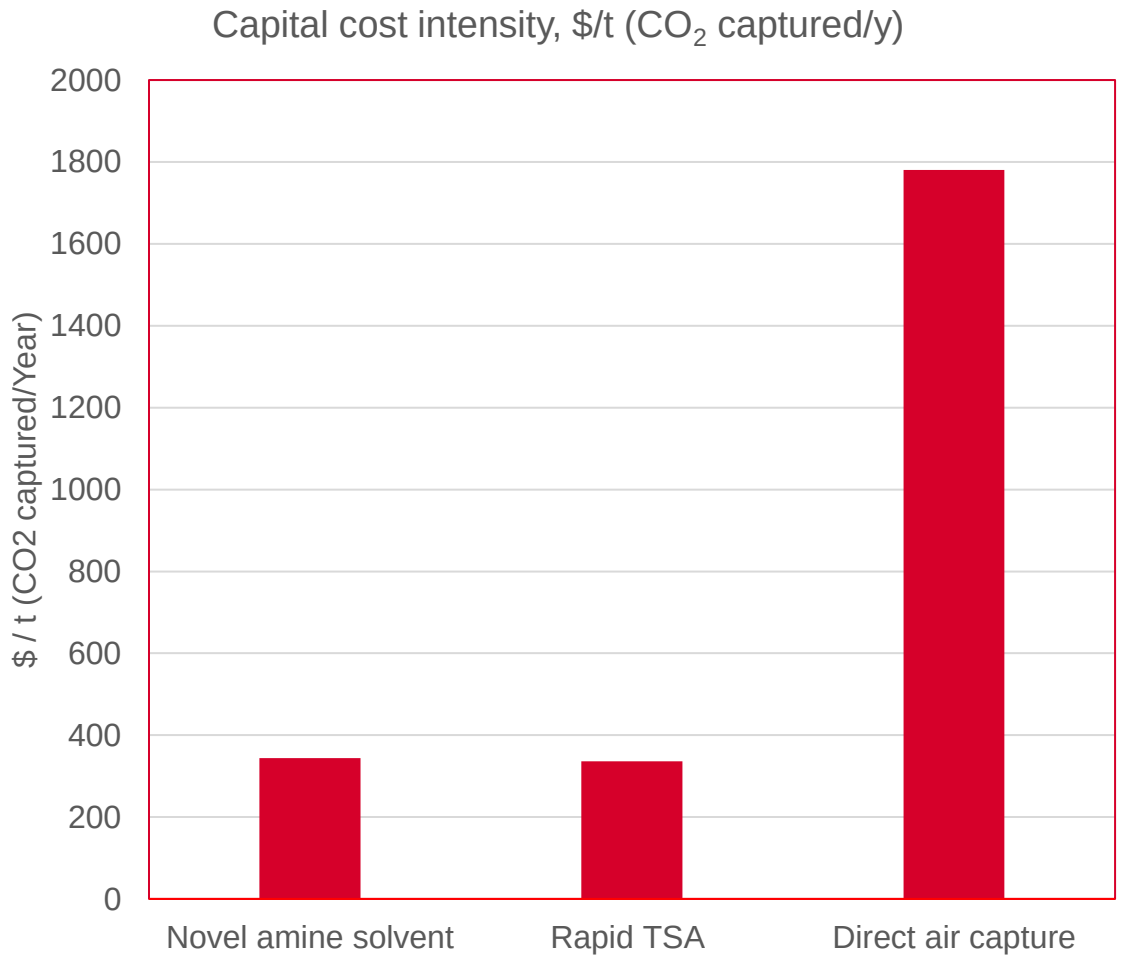
Source: S&P Global Markit Process Economics Program (PEP) Report 180F Next Generation Carbon Capture

Carbon capture economics (Japan, Q4 2023) show decreasing CO_2 concentrations lead to increasing cost.





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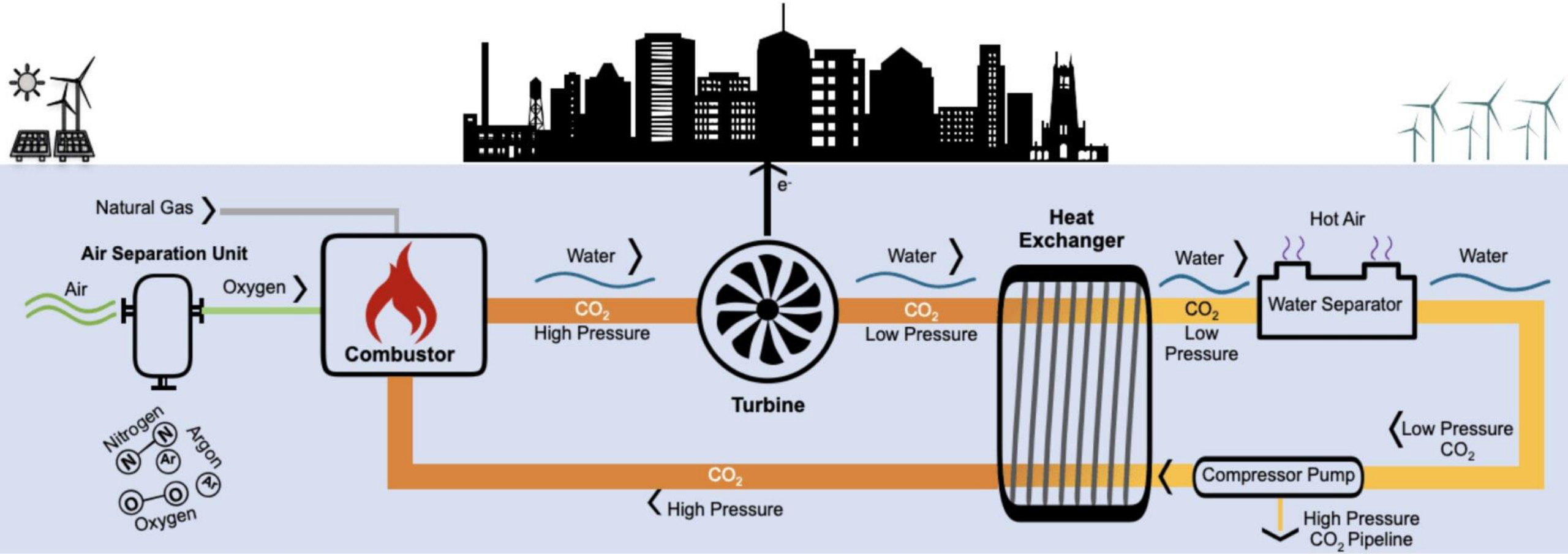
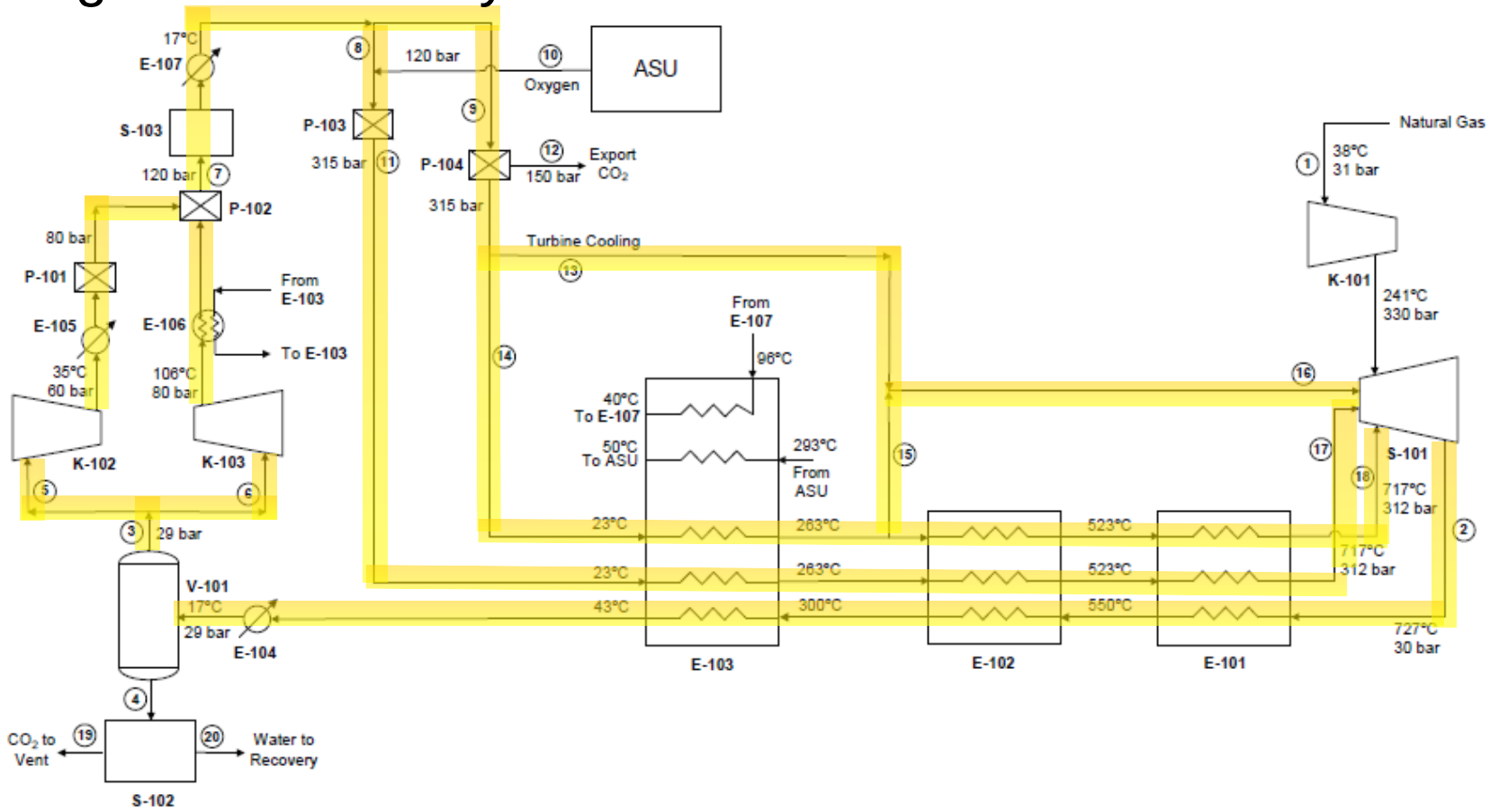
Example 2: Low Carbon Power - NET Power has developed a process using supercritical CO_2 as the operating medium for natural gas oxycombustion



Source: Powermag.com

For a potential commercial scale unit, the levelized cost of electricity is lower than a natural gas combined cycle if there is a CO2 credit.

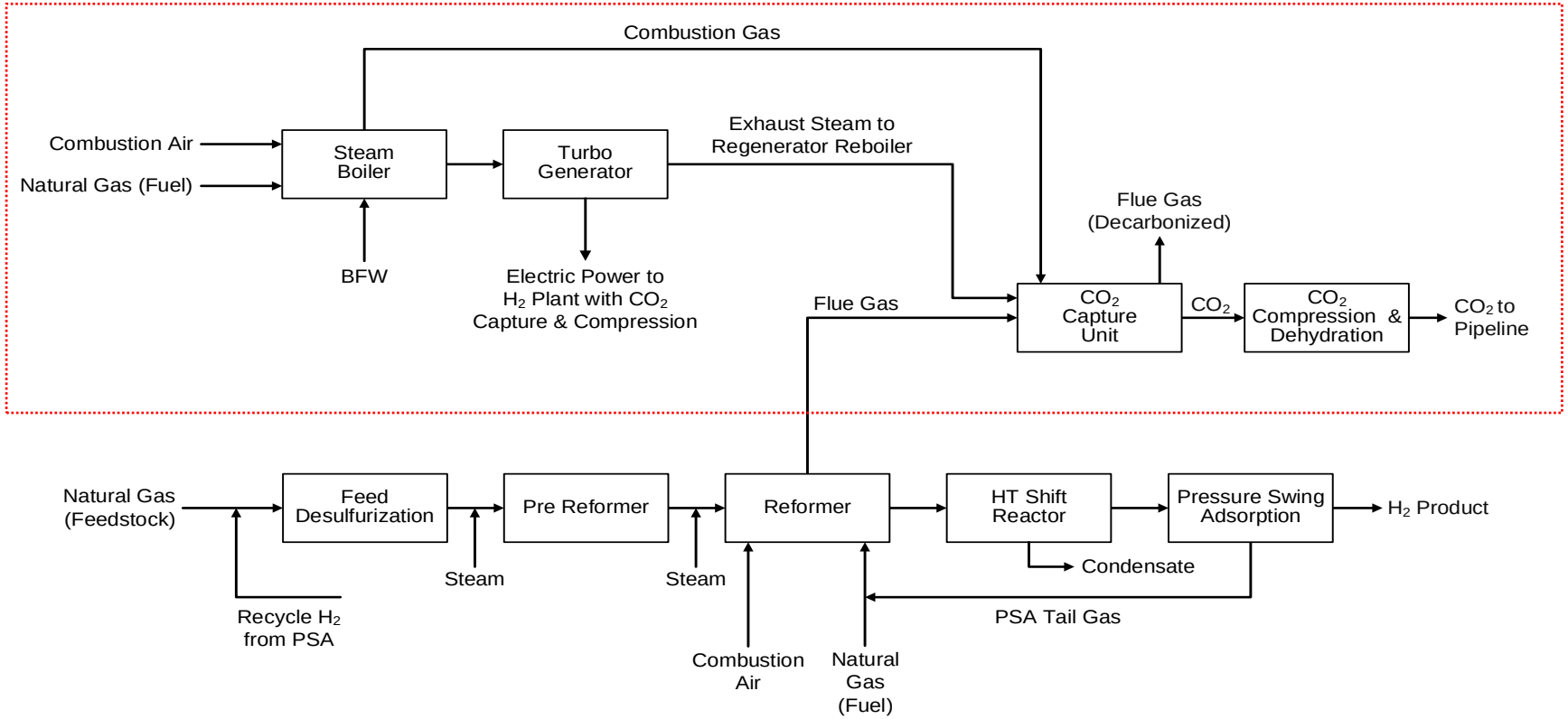


325 MW Plant	Natural Gas Combined Cycle	NET Power
Relative Capital Intensity, per KW	1.00	1.60
LCOE with CO_2 Credit, $/MWh	--	~$10-15 per MWh lower

S-102 Water Recovery
S-103 CO_2 Drying Unit
E-106 Adiabatic CO_2 Aftercooler
K-102 CO_2 Recycle Compressor
E-104, 105, 107 Coolers
P-101 thru 104 CO_2 Pumps
V-101 Disengagement Vessel
E-103 LTR
K-103 Adiabatic CO_2 Recycle Compressor
E-102 MTR
E-101 HTR
S-101 Turbo Combustor
K-101 Natural Gas Compressor

Source: PEP Review 2021-02, Electric Power via the Allam Cycle

Example 3: Blue Hydrogen – large capacity SMR of natural gas with CO_2 capture-compression and by-product steam/electric power generation



Carbon Capture	CAPEX	OPEX+ Depr.
90%	90% ↑	~50% ↑
60%	75% ↑	~40% ↑

Source: S&P Global Markit PEP Review 2021-15 Hydrogen from Natural Gas with Carbon Capture

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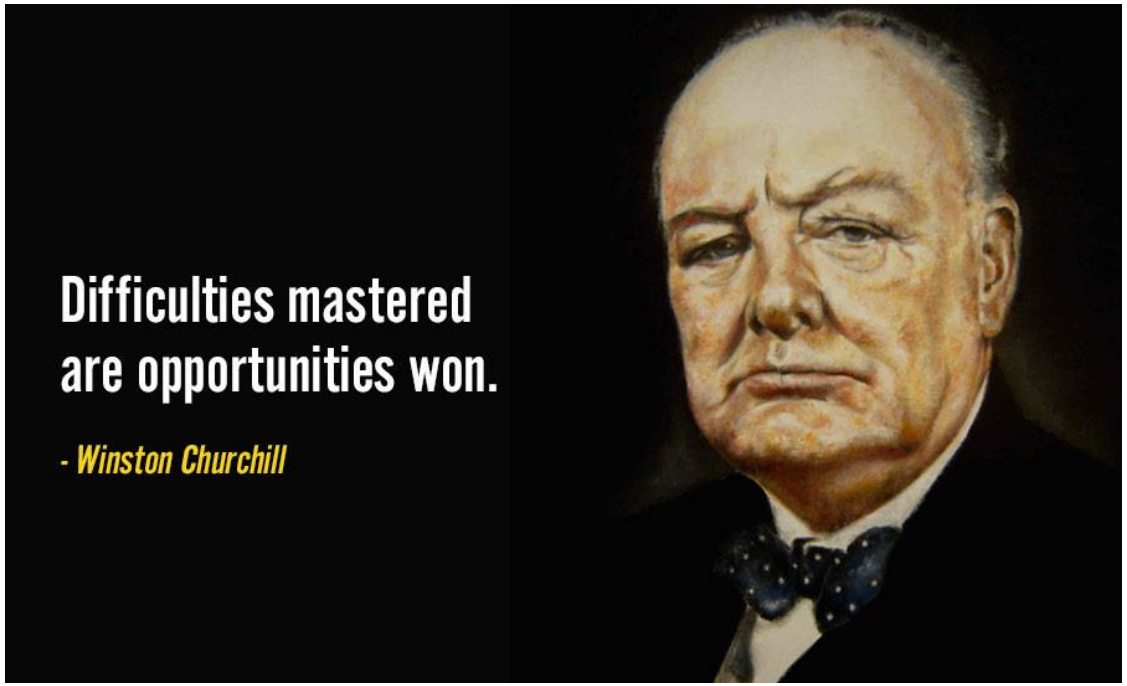
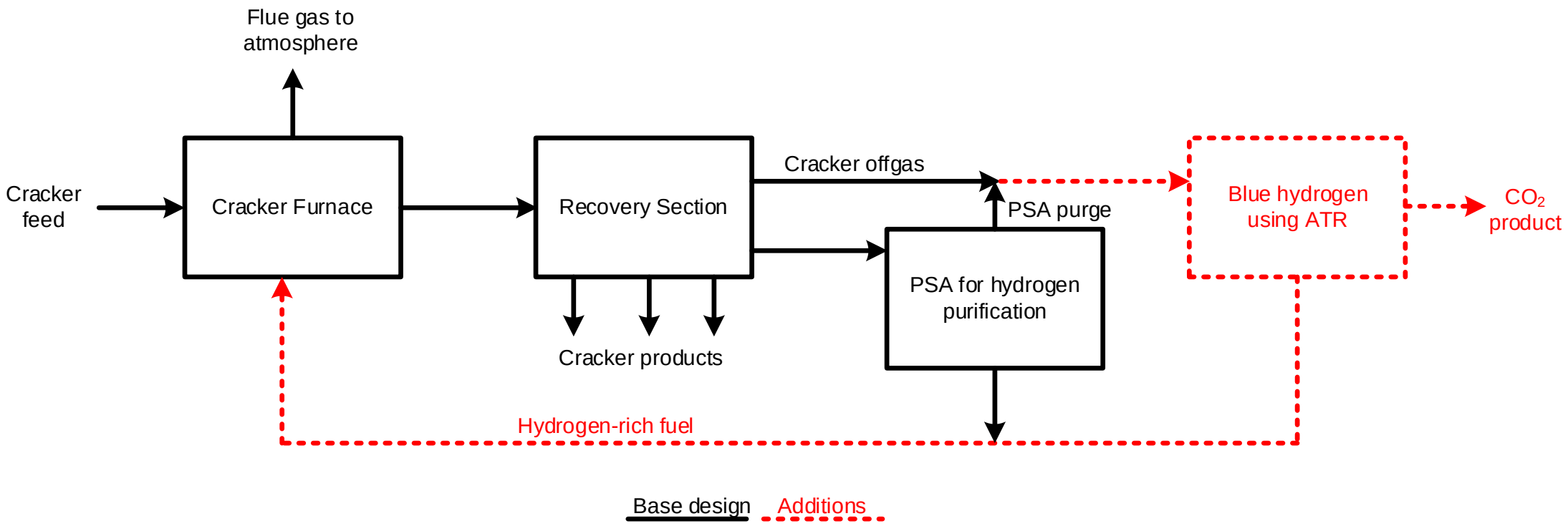
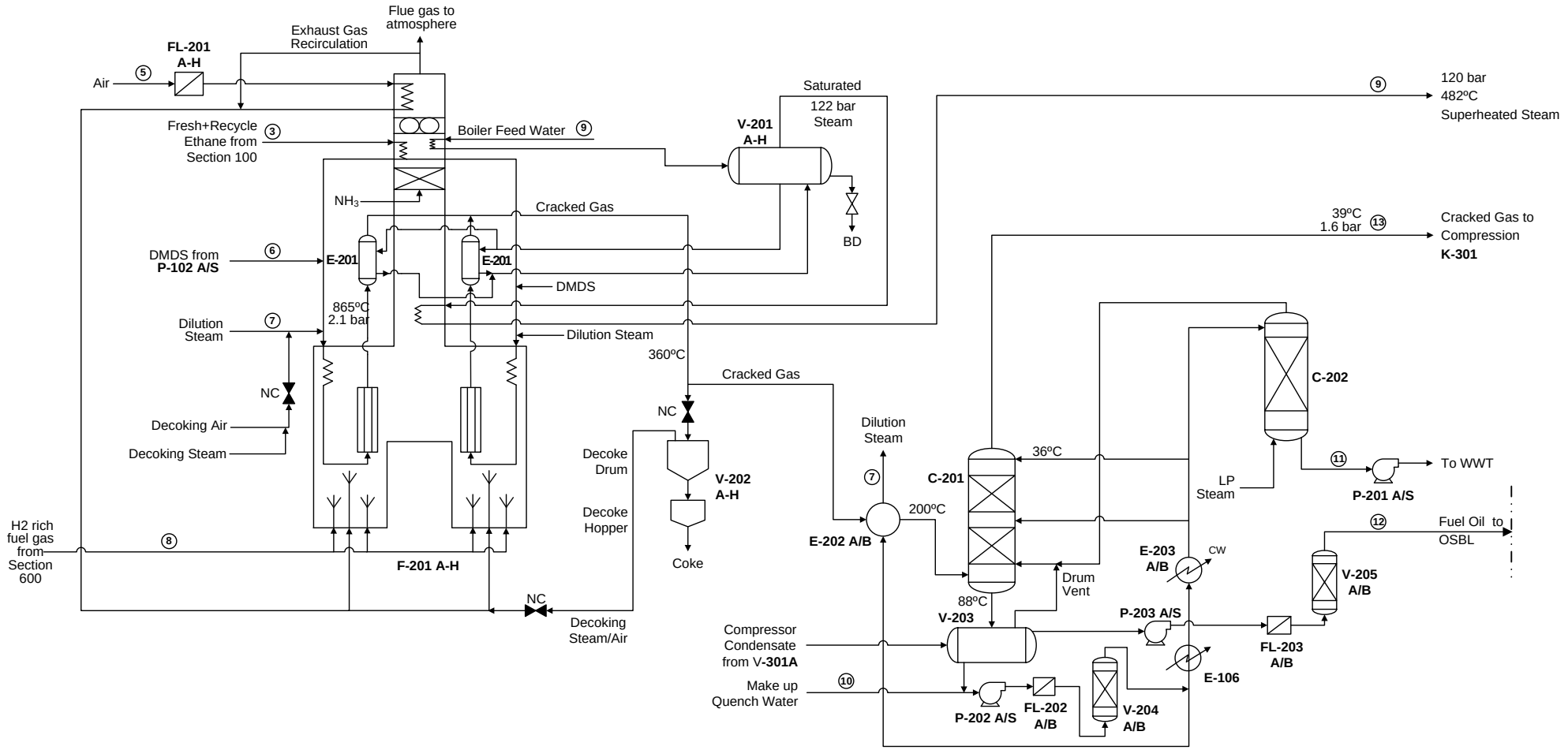


Dow is aiming for net zero for its plant in Fort Saskatchewan, Alberta, Canada



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

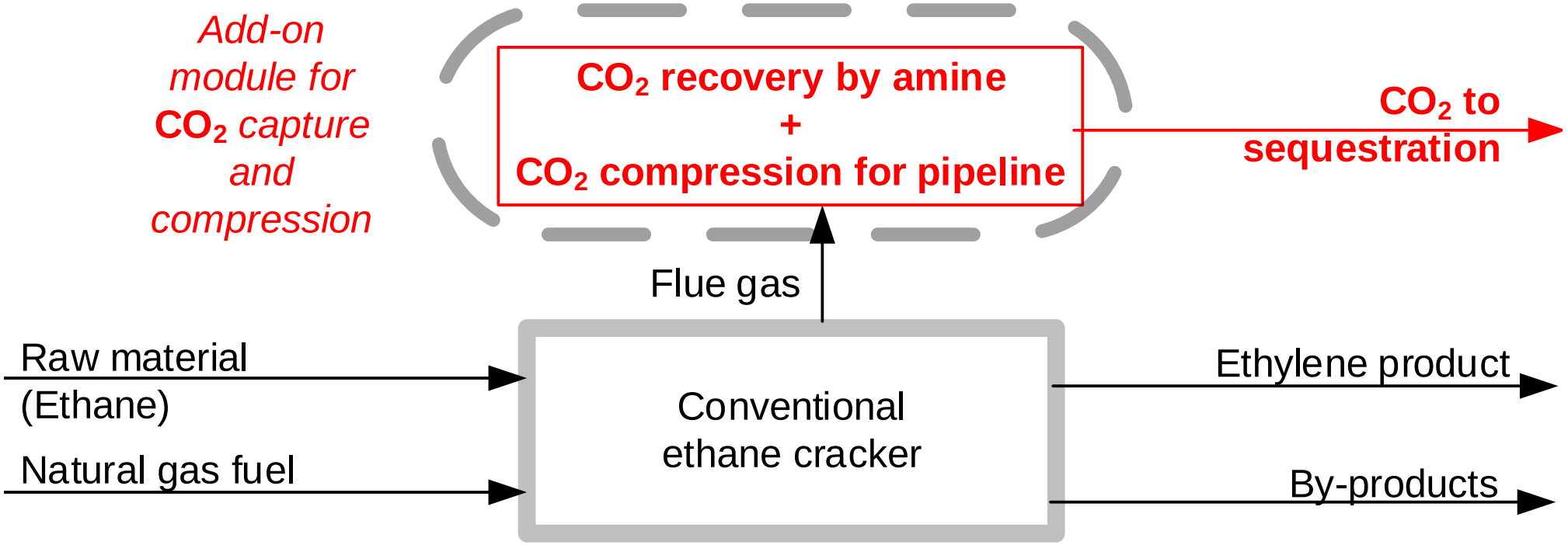
PEP has developed full models for OPEX and CAPEX analysis



FL-201 A-H Fresh Air Filters	**F-201 A-H** Cracking Furnaces	**V-202 A-H** Decoke Drum & Hopper	**V-201 A-H** SHP Steam Drums	**E-202 A/B** Dilution Steam Generator	**C-201** Quench Tower	**P-202 A/S** Quench Water Pumps	**V-203** Quench Receiver	**E-203 A/B** Quench water Cooler
E-201 A-P Transfer Line Exchangers	**FL-202 A/B** Quench Water Filters		**FL-203 A/B** Quench Oil Filters	**C-202** Sour Water Stripper	**P-201 A/S** Stripper Pumps	**V-205 A/B** Quench Oil Coalescers	**P-203 A/S** Quench Oil Pumps	**V-204 A/B** Quench Water Coalescers

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

The alternative is a CO_2 separation section as an independent unit added to an existing facility



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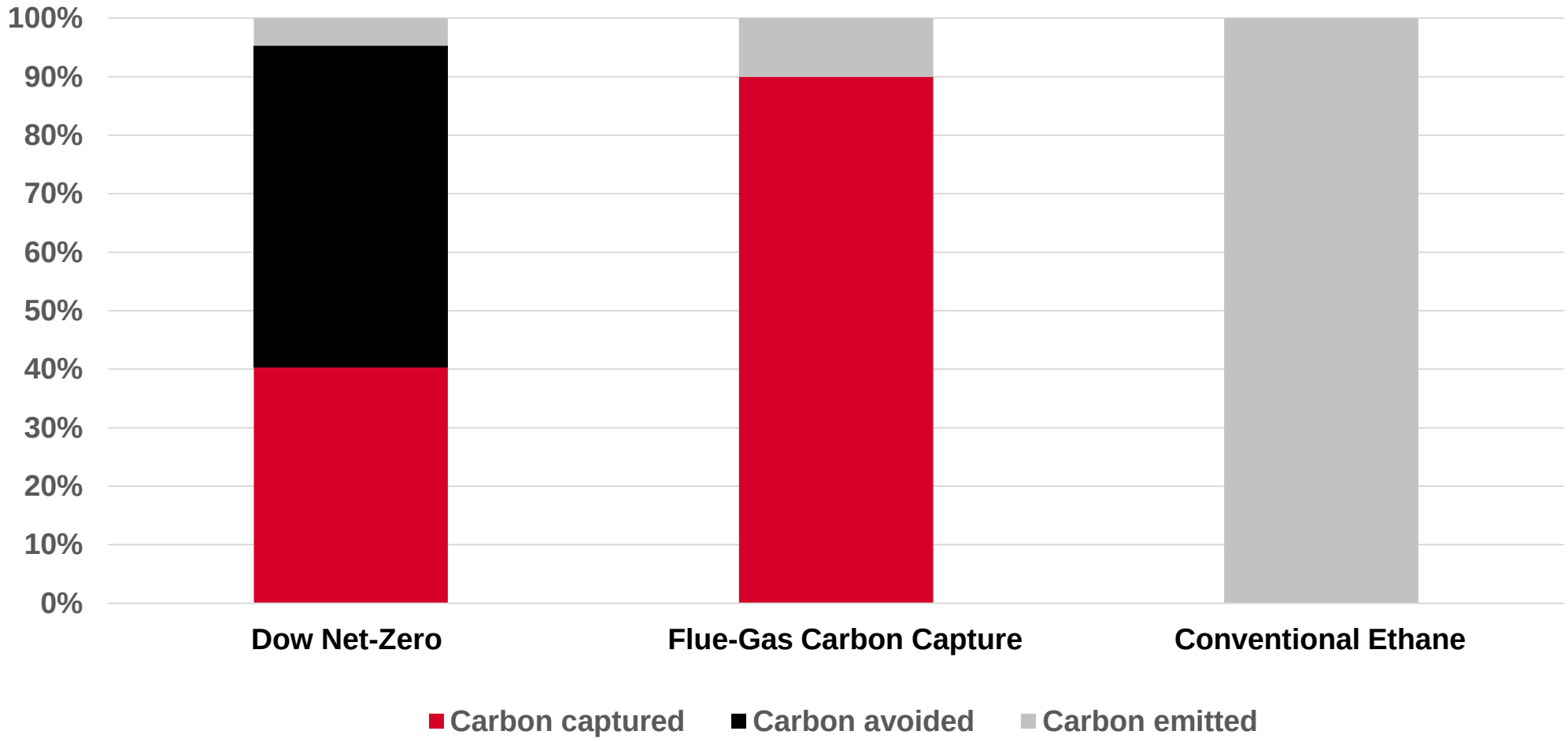
Dow Net-Zero avoids and emits substantially less carbon than conventional ethane cracking



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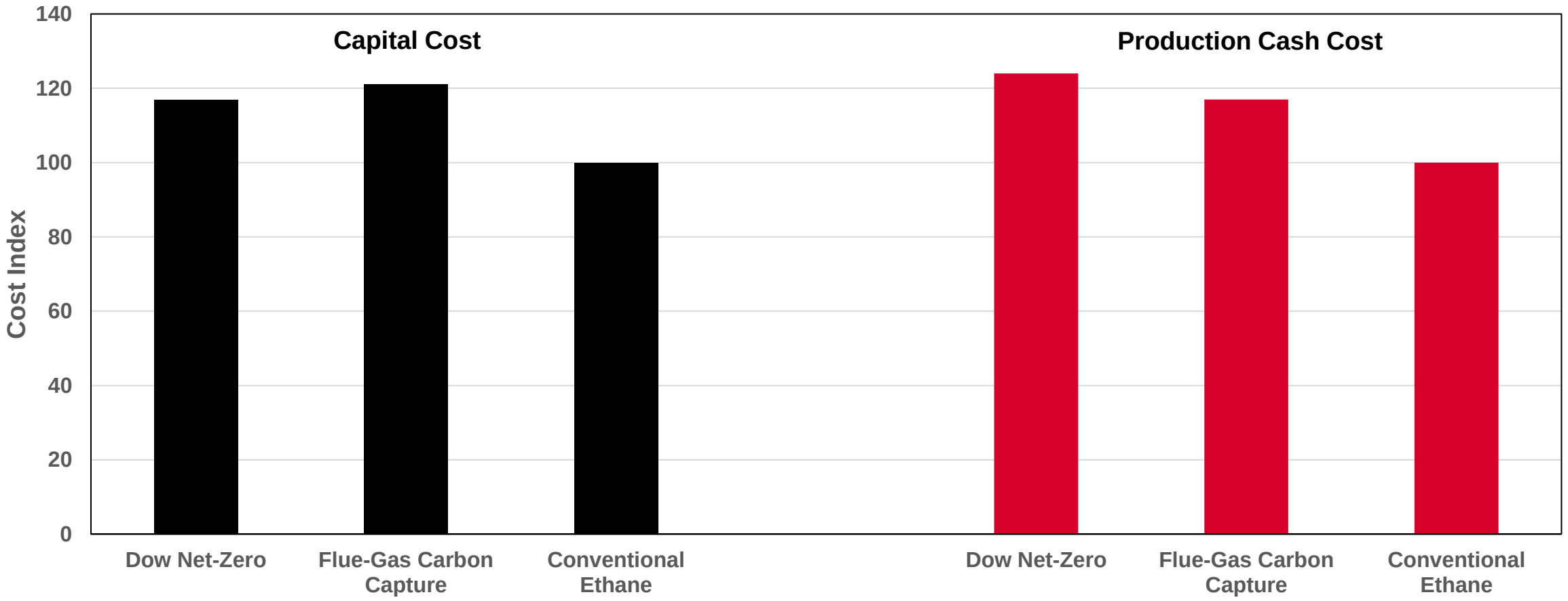
However, the reduction comes at a much higher CAPEX and OPEX than standard ethane cracking



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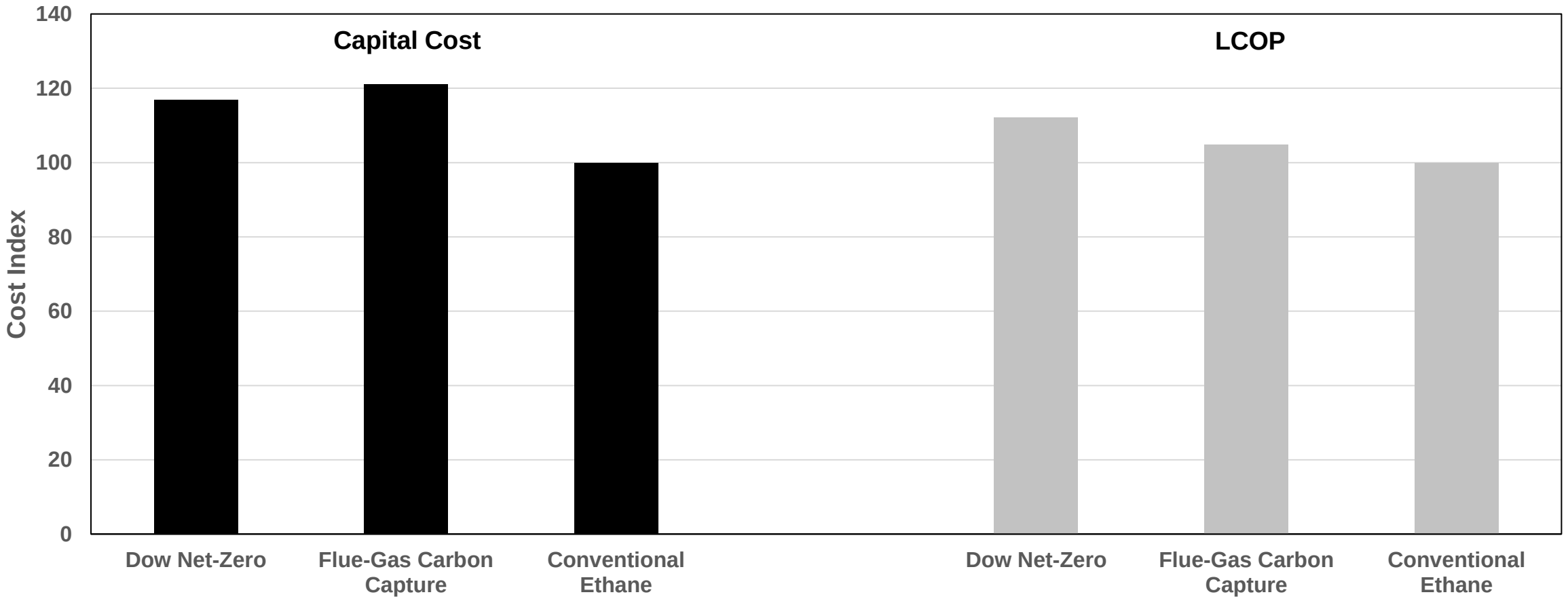
Nevertheless, the levelized cost of ethylene production (LCOP) compares more favourably



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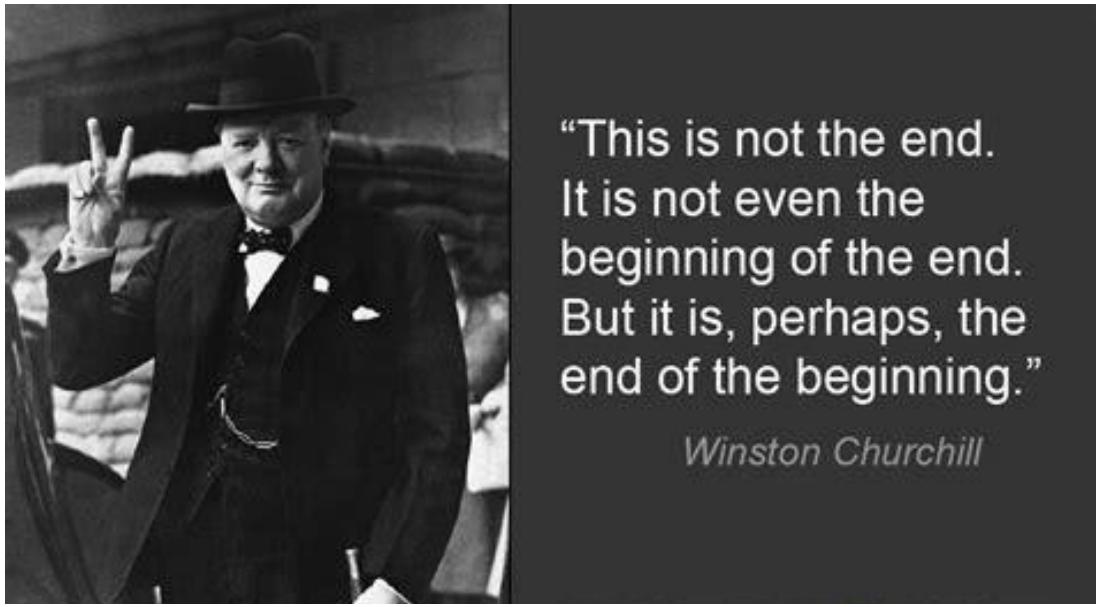
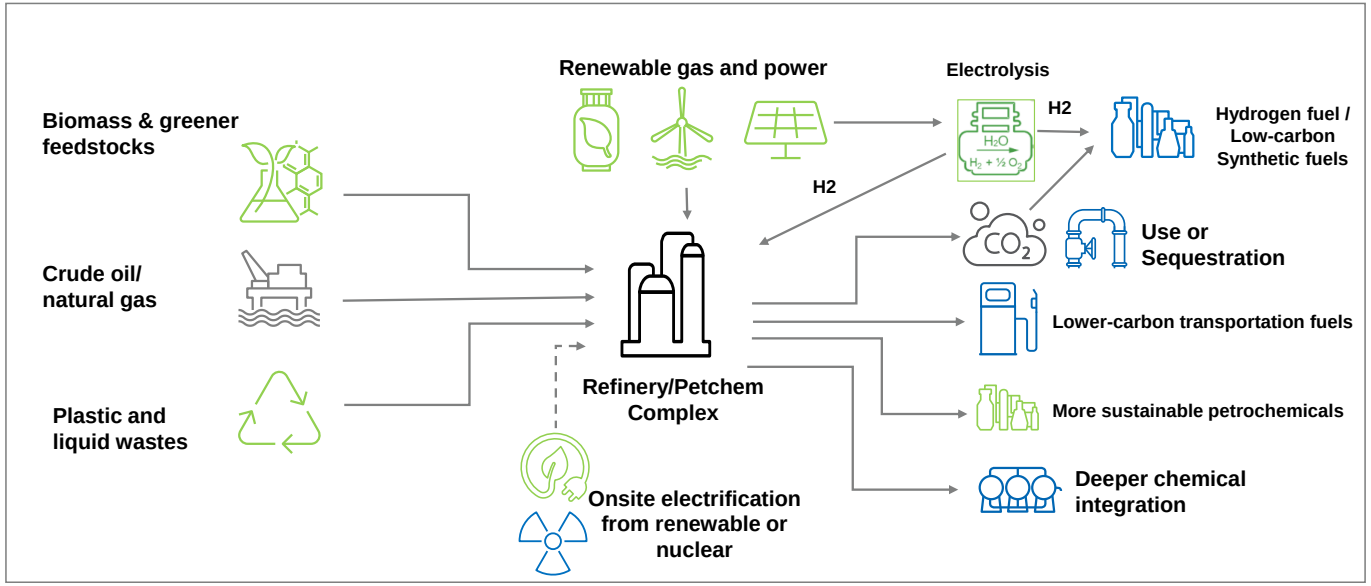


Key Takeaway: Net zero strategies will be expensive and complex to understand

- Top-down corporate strategies and targets must be met with detailed bottom-up plans
- Multiple decarbonization technology options are available to achieve reduction in CO2e emissions but not without substantial CAPEX and EBIT penalty
- Government policy-driven carbon credits and/or green-product premiums will be needed to offset the EBIT decline



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