TNChE ASIA 2023

Sustainable Olefin Technology Solutions

ENERGY Community of Practice

TIChE

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Pattaya, Thailand, June 22nd, 2023

Making our world more productive

Linde

Sustainable steam cracker design

Roadmap to net zero CO_2 emissions

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Linde Roadmap to net zero CO_2 Emissions in Steam Cracking – Stepwise Approach

CO_2

CO_2 scope 1 | CO_2 scope 2 | CO_2 scope 3

0 – Efficiency Improvement

- Energy efficiency
- Process efficiency
- Plant utilization

Maximize efficiency

Avoidance / Reduction

Elimination *(Carbon Capture)*

1 – zero Scope 1

CO_2 Avoidance / Reduction

- Furnace (Air preheat, firing concepts, …)
- Separation Section (Electrification, heat pumps, …)

CO_2 Elimination

- Post-combustion carbon capture
- Pre-combustion carbon capture (“blue H_2” from reforming)

Process intensification

2 – zero Scope 2

Electric energy

- Renewable
- Carbon neutral
- Low carbon

Max renew. el. energy

3 – minimized Scope 3

Feedstock

- Bio feed
- Plastic waste (Pyrolysis oil)

Fuel

- Firing of carbon neutral H_2

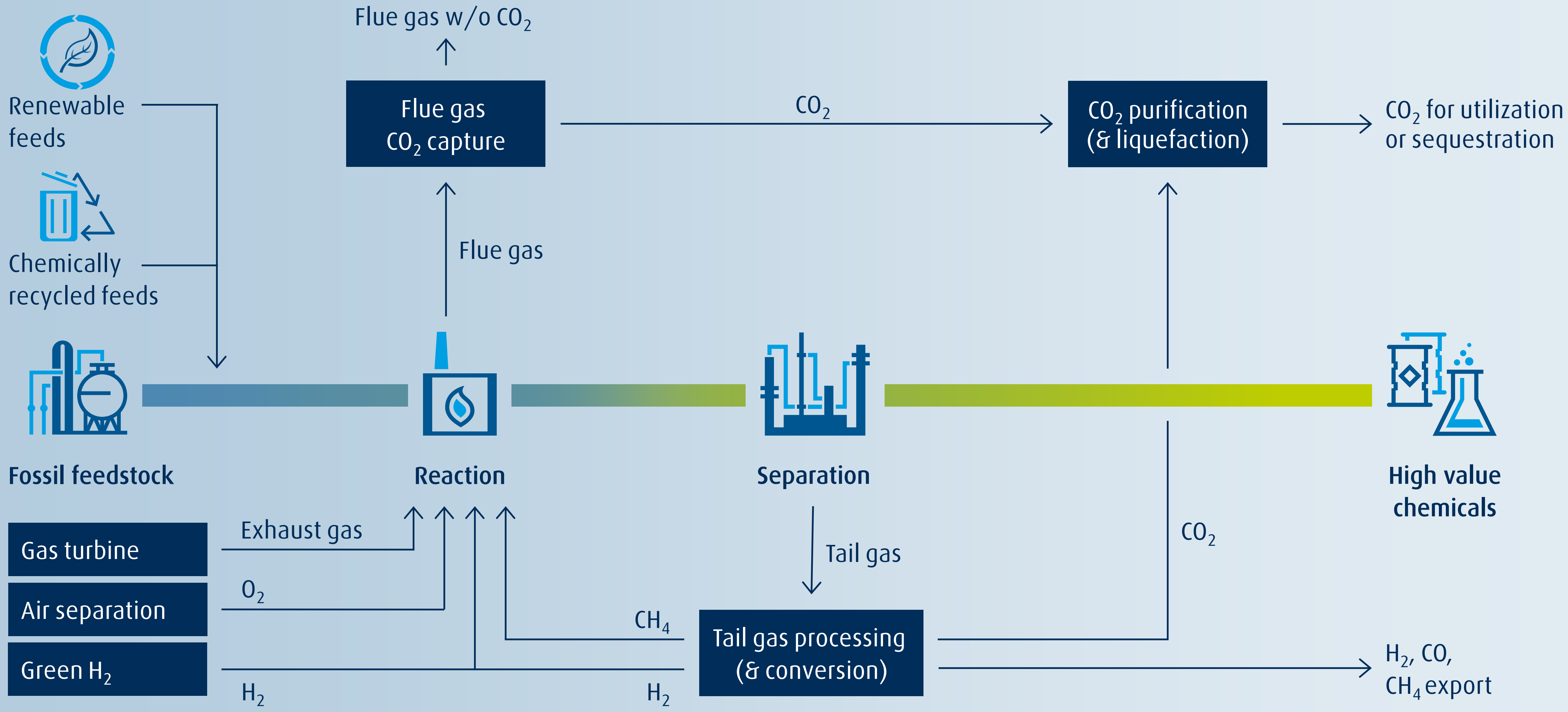
Products

- CH_4 utilization

Maximize circularity

CO_2 scope 1: *zero* | CO_2 scope 2: *zero* | CO_2 scope 3: *min*

Linde Sustainable Olefin Technologies:
The carbon management toolbox.



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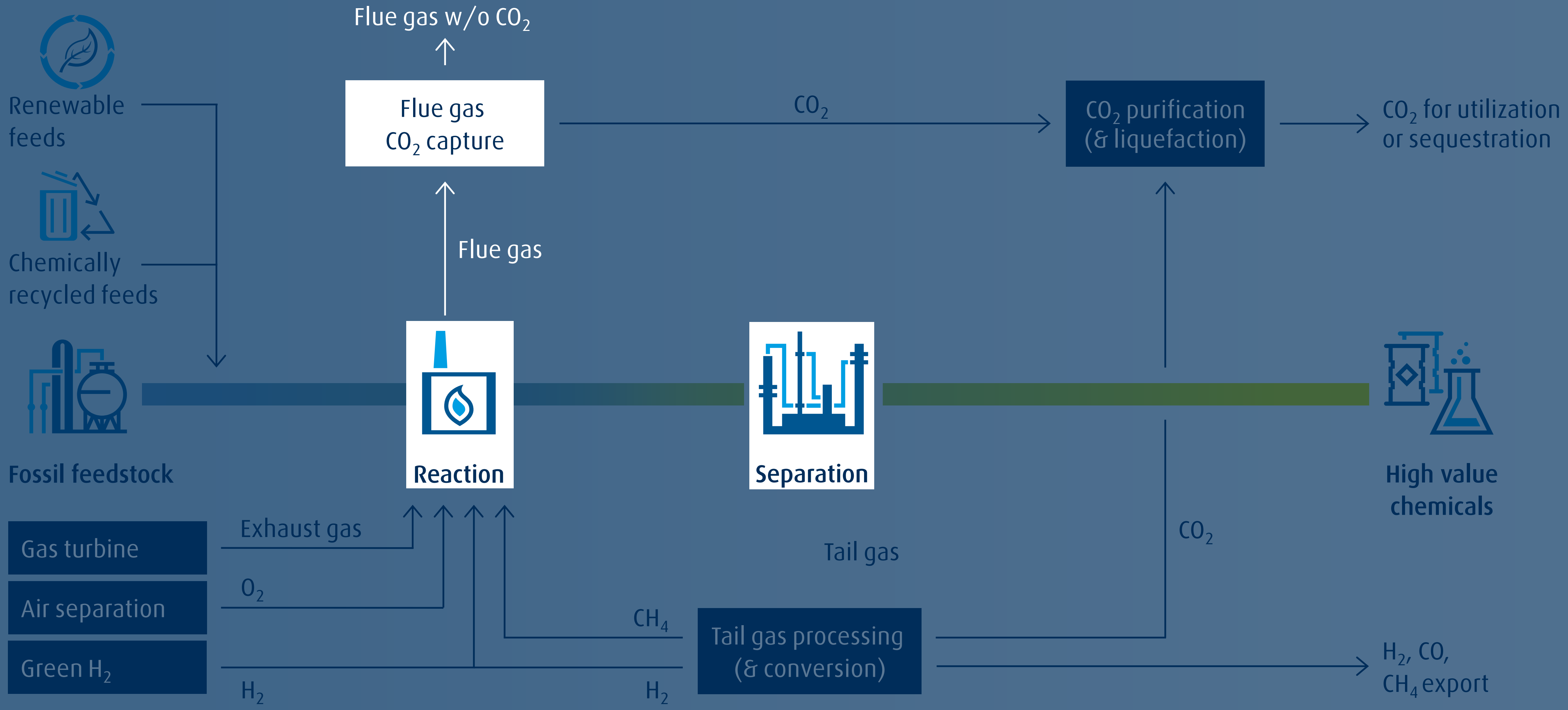
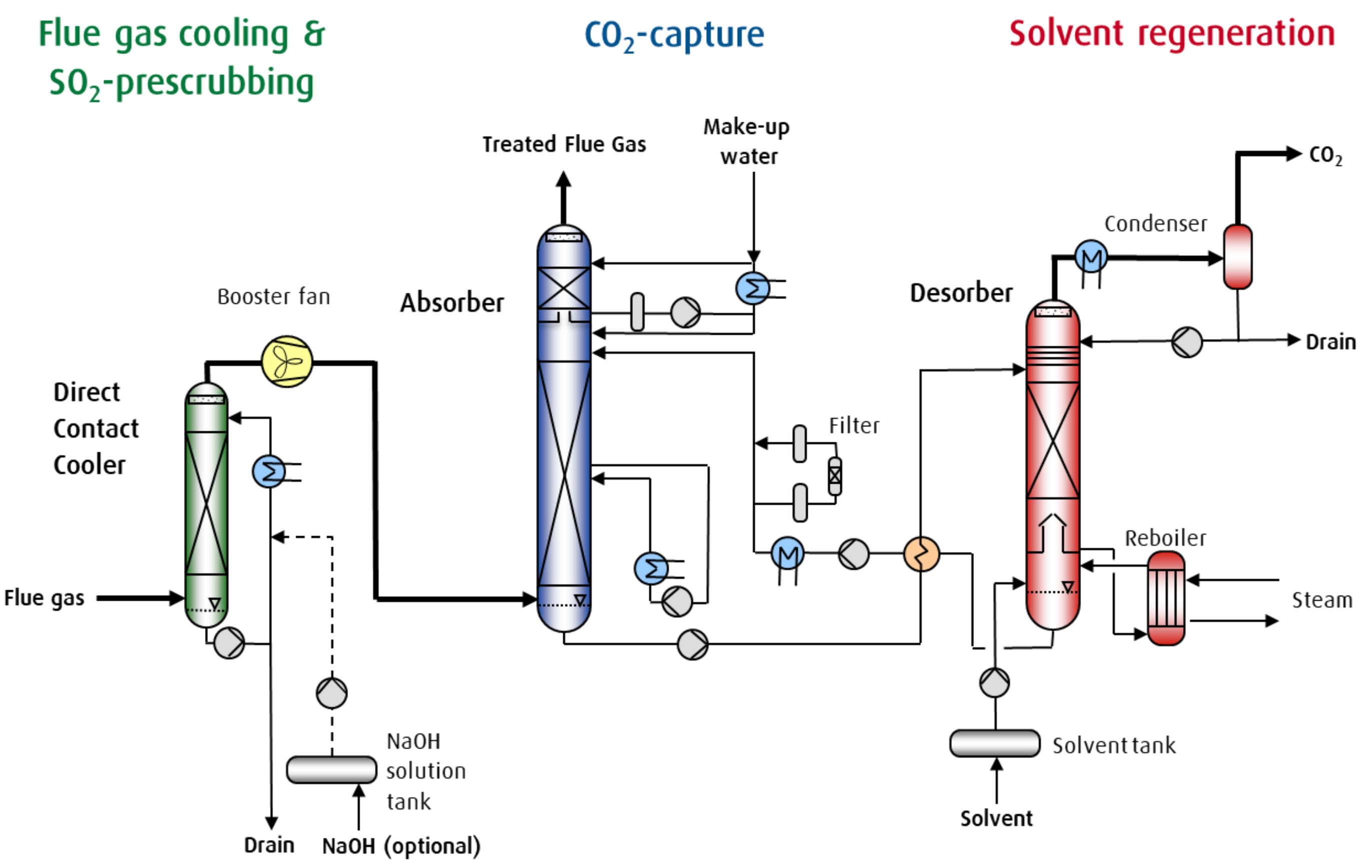


Flue Gas CO_2 Capture

Typical process concept



Process: BASF® OASE Blue Solvent

BASF® OASE Blue Characteristics:

- ✓ Suitable for flue gases with **low CO_2 concentration** O_2 (4 – 16 v%) / CO_2 (4 – 25 v%)
- ✓ **Demonstrated technology** since 2009, ~100.000 hours of operation
- ✓ **CO_2 removal rate ≥ 95%**
- ✓ Very high stability of solvent resulting in low make-up rates
- ✓ Patented emissions reduction system and Nitrosamines management
- ✓ **Minimum 20% reduction of regeneration energy** against conventional amine
- ! High steam consumer

Flue Gas CO_2 Capture

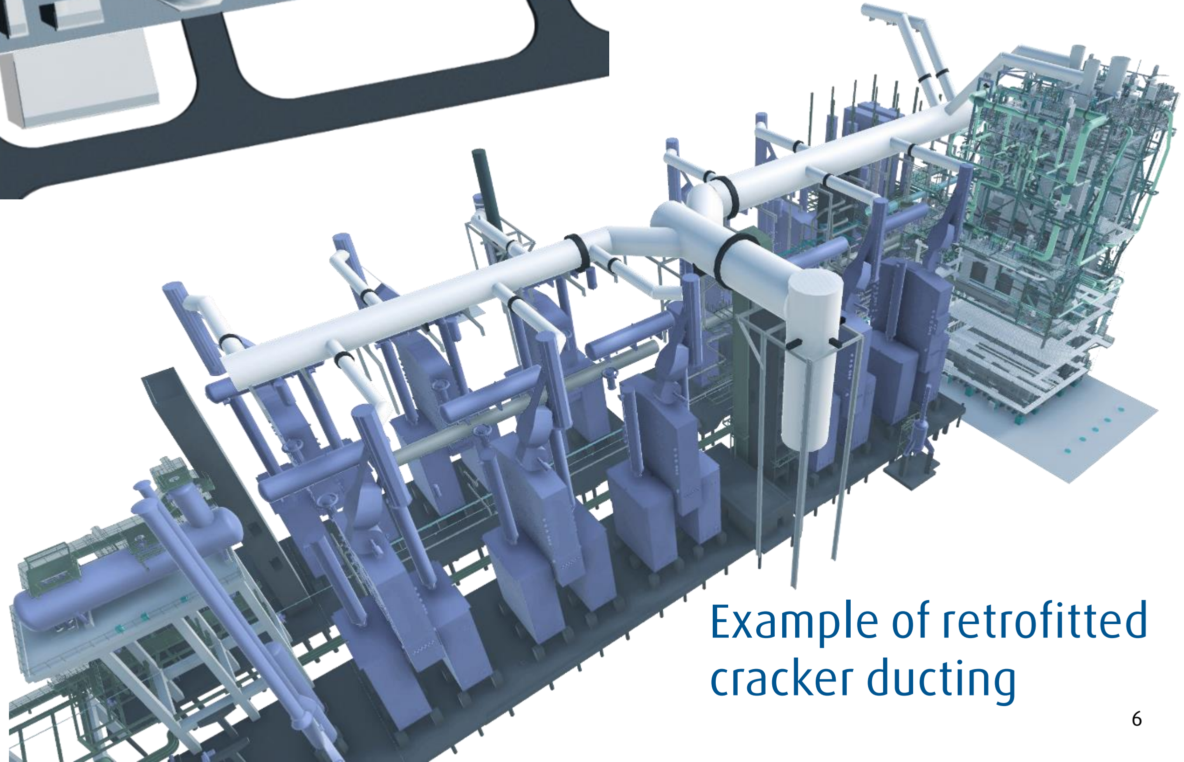
Required modifications ISBL cracker

- Flue gas ducting
  - ✓ Design and procure the required modifications
  - ✓ Implementation in regular plant turnaround

- Impact steam system, energy- and utility integration
  - ✓ Find the right solutions for (re)balancing
  - ✓ Offers opportunities in combination with compressor drive electrification

- System dynamics
  - ✓ Define sound control strategies to ensure continued stable and reliable plant operation also in upset scenarios

Flue gas capture unit design for world-scale liquid cracker



Example of retrofitted cracker ducting

Relevance on Energy-integrated Systems

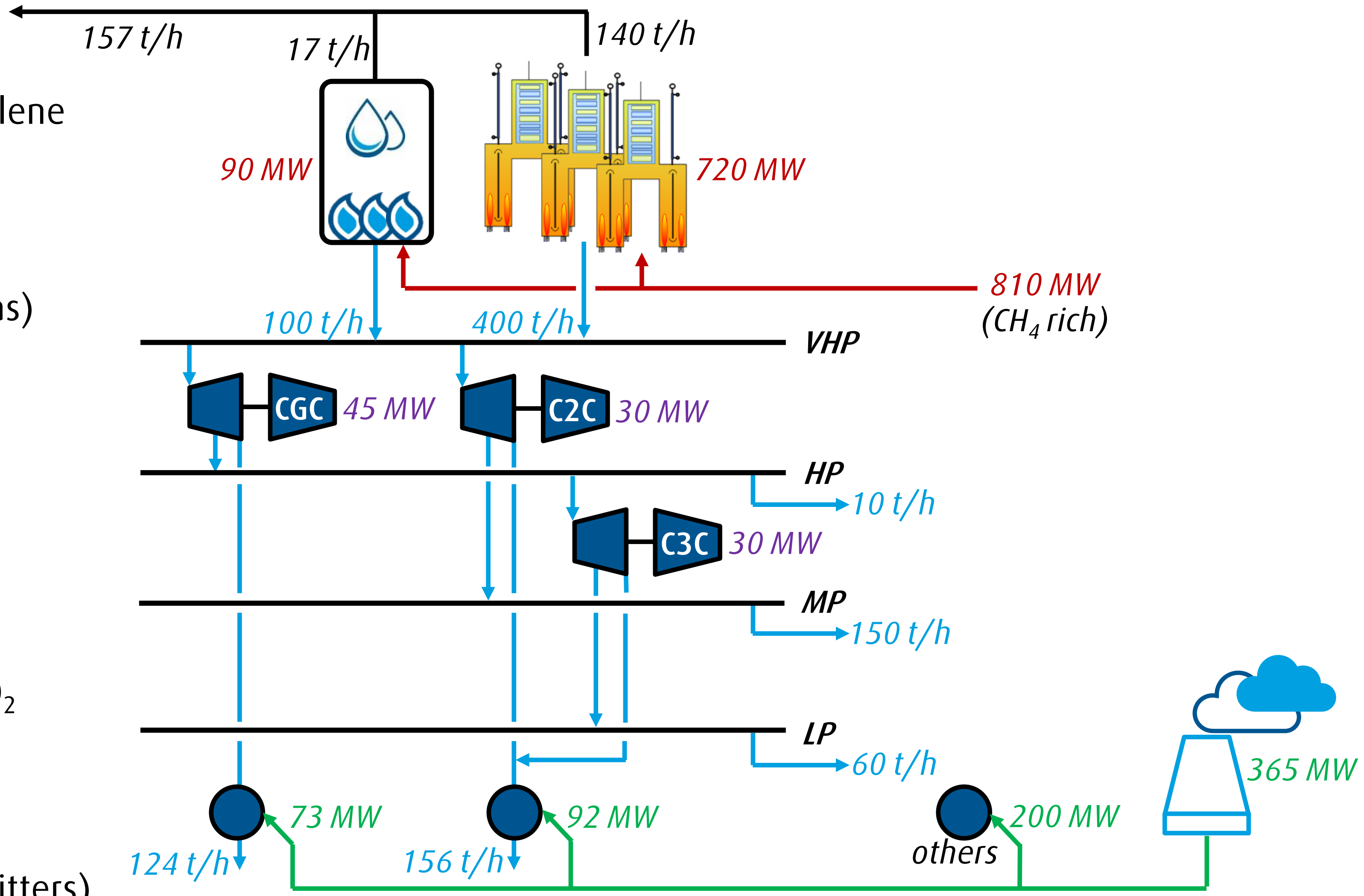
Liquid cracker, >1000 kta ethylene and >500 kta propylene.

Typical boundary constraints

- World-scale liquid cracker, >1000 kta ethylene
- Methane-rich firing in furnaces (and auxiliary boilers)
- CO_2 concentration ~7-9 mol% (wet flue gas)
- Total CO_2 quantities of 150-200 t/h

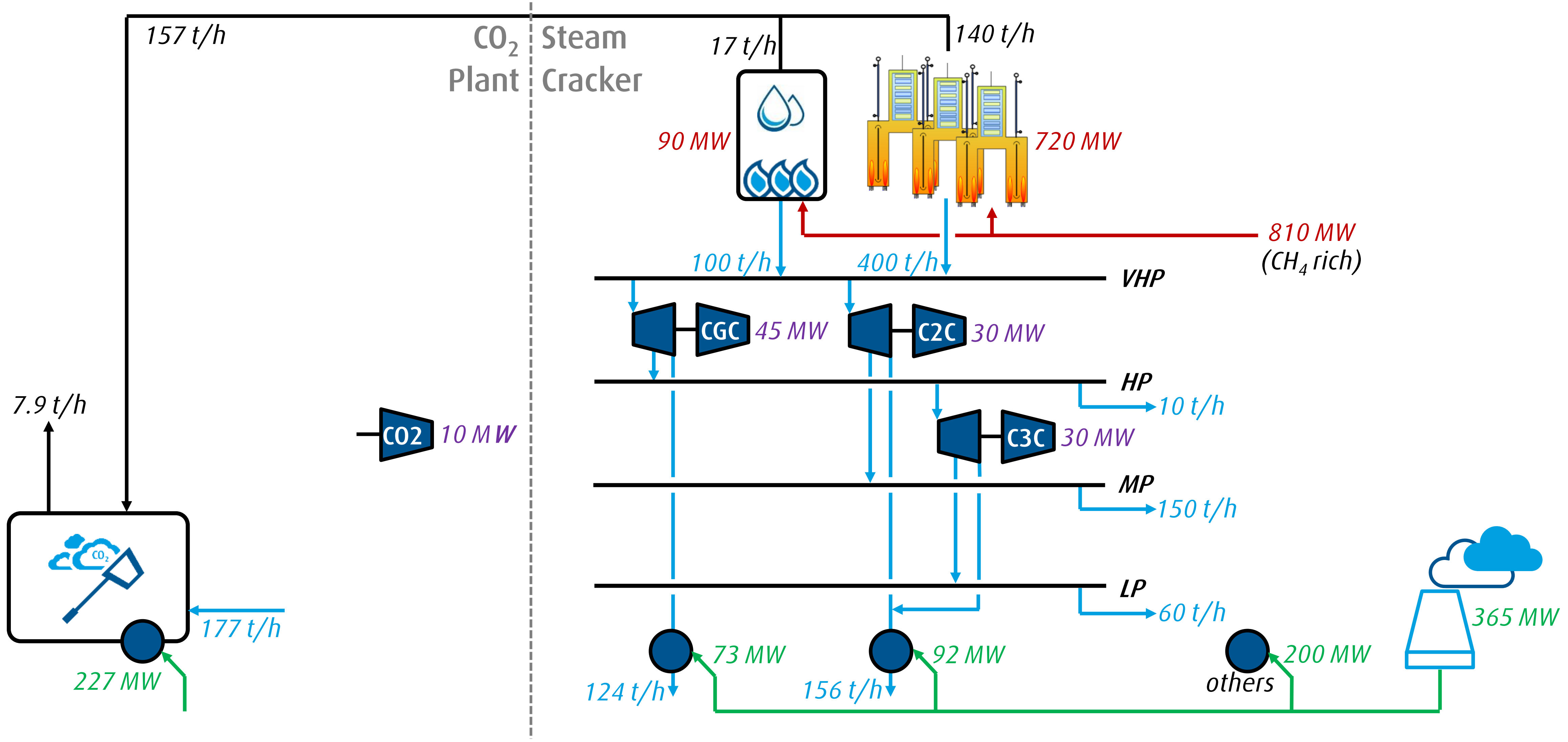
Resulting selected design features

- Large single train design, absorber diameter 12-14 m
- Thermal energy demand ~2.5 GJ/ton of CO_2
- Cooling by air or cooling water
- Make-up below 0.4 kg amine / ton of CO_2
- Approx. plot ~5000 m² (in proximity of emitters)



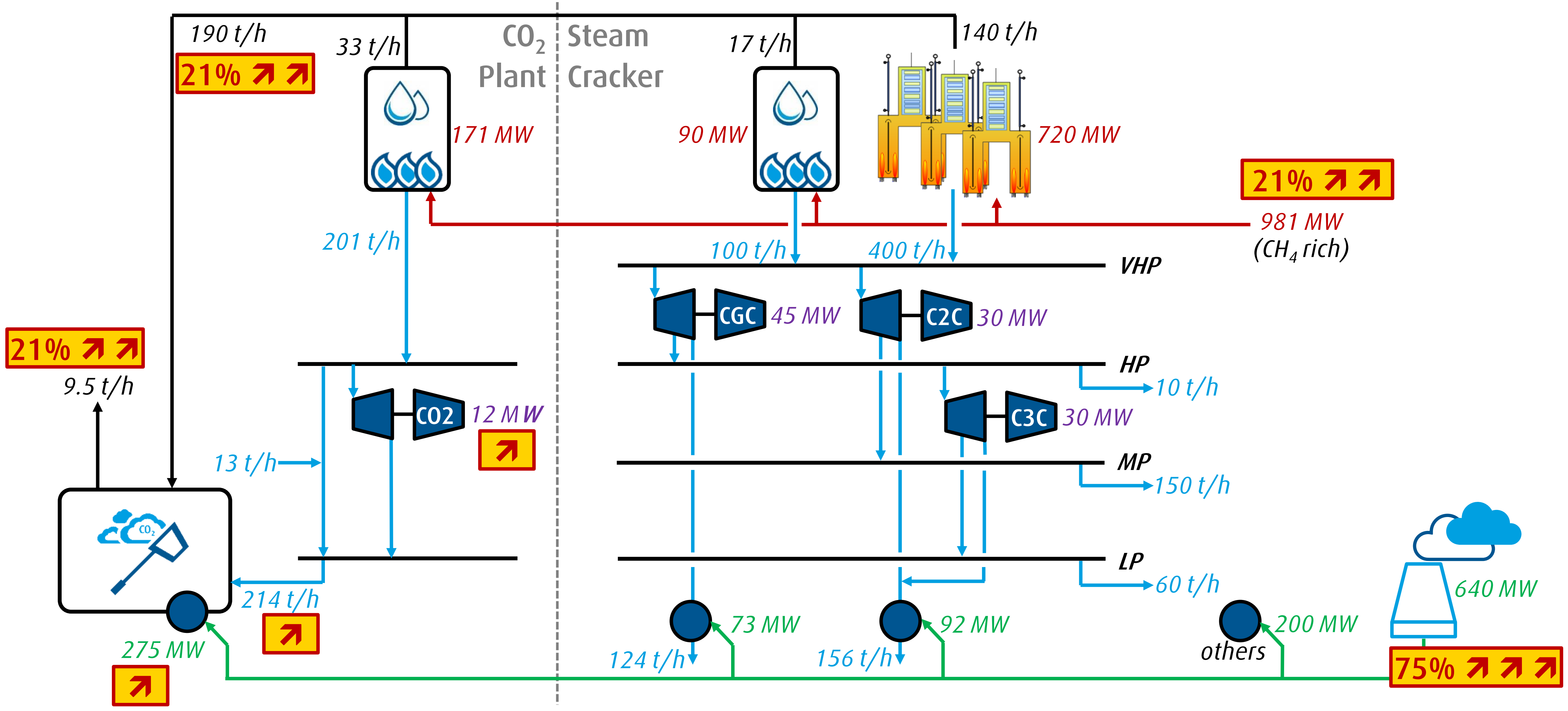
Relevance on Energy-integrated Systems

Addition of flue gas carbon capture plus CO_2 compression (35 bar)



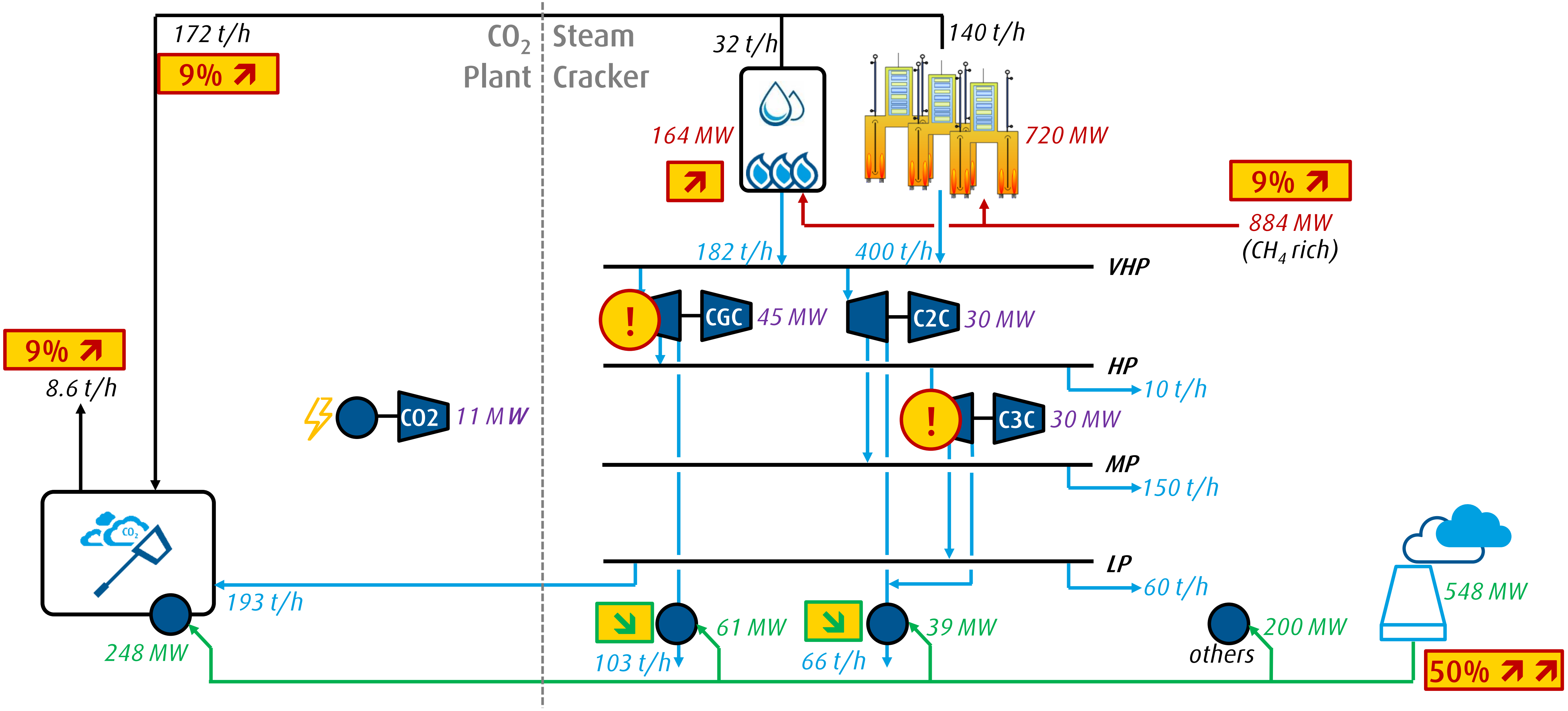
Relevance on Energy-integrated Systems

Unintegrated heat supply to flue gas CO_2 capture



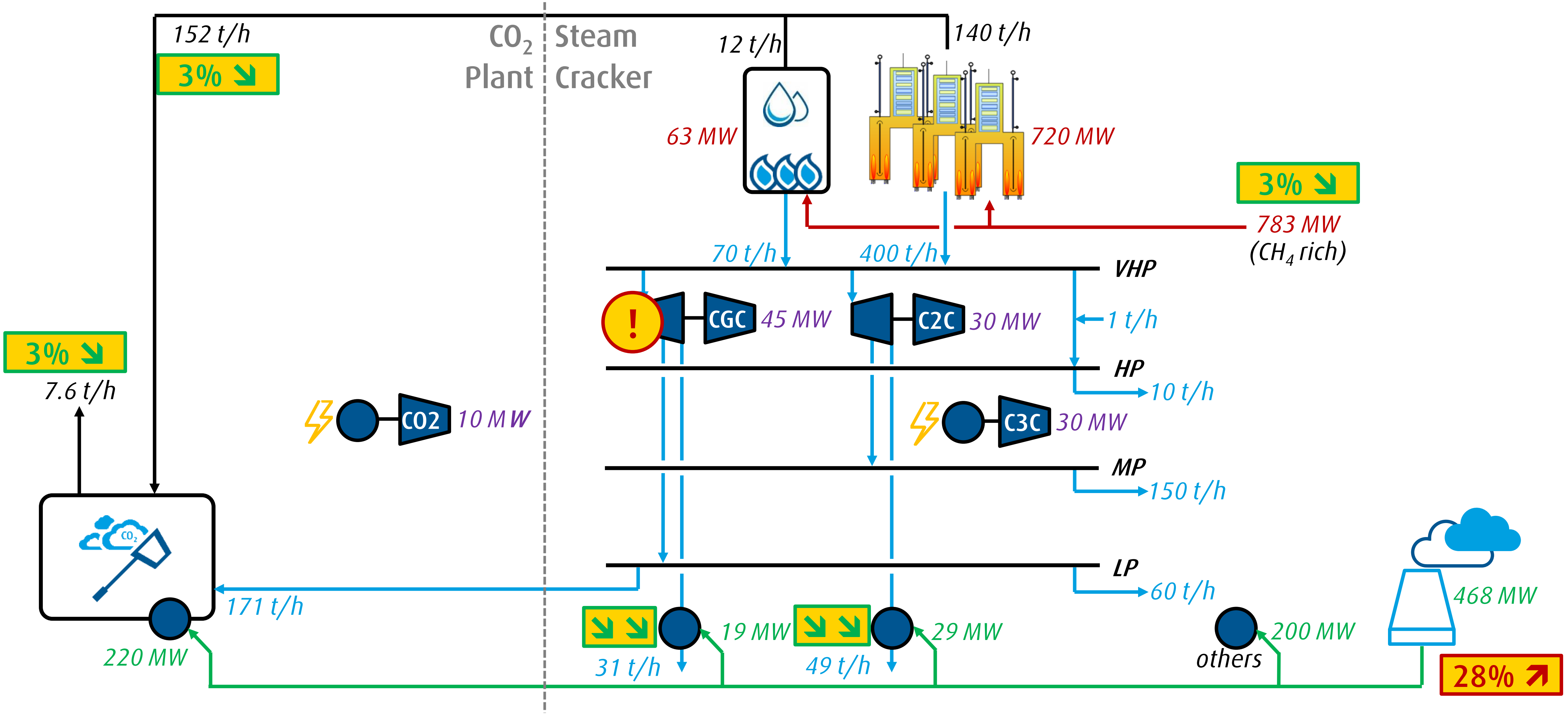
Relevance on Energy-integrated Systems

LP steam for CO_2 capture from cracker, CO2-C electrified



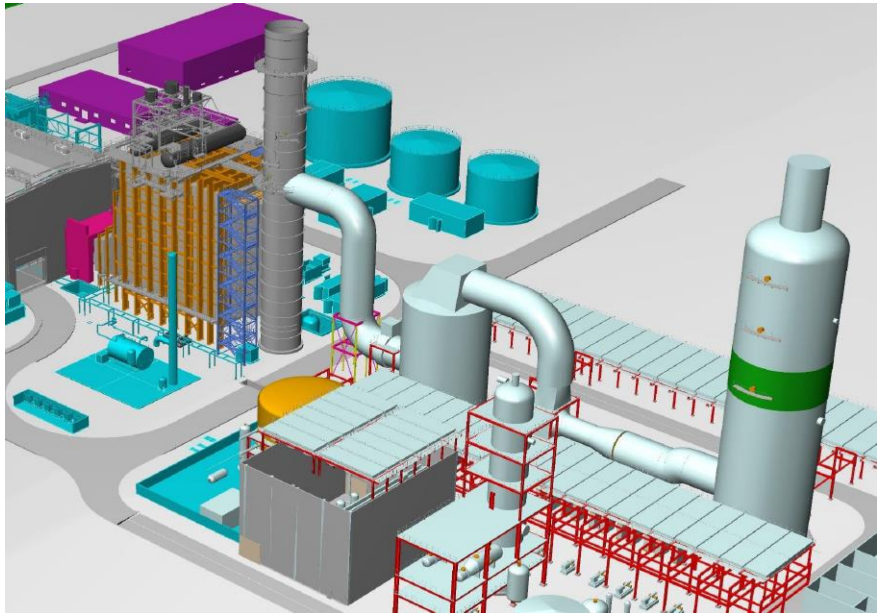
Relevance on Energy-integrated Systems

LP steam for CO_2 capture from cracker, CO2-C & C3C electrified



Flue Gas CO_2 Capture
Summary

- Amine-based systems are the most mature technology for flue gas CO_2 capture, reaching **CO_2 removal rates ≥ 95%**
- The close development partnership between BASF and Linde ensures **flawless project execution and process integration** within cracker sites or overall industry complexes
- Operating companies benefit from a licensor having **experience with the full chain** from flue gas ducting, CO_2 removal & liquefaction and storage
- **Energy integration opportunities** of CO_2 capture and petrochemical units **may drastically impact the business case**



1) Does your capital fired equipment generate a flue gas with "decently high" CO_2 concentration?
2) Is your petrochemical site characterized by a surplus of low-temperature heat and/or large amounts of vacuum steam generation?
   → **flue gas carbon capture may be a promising solution**

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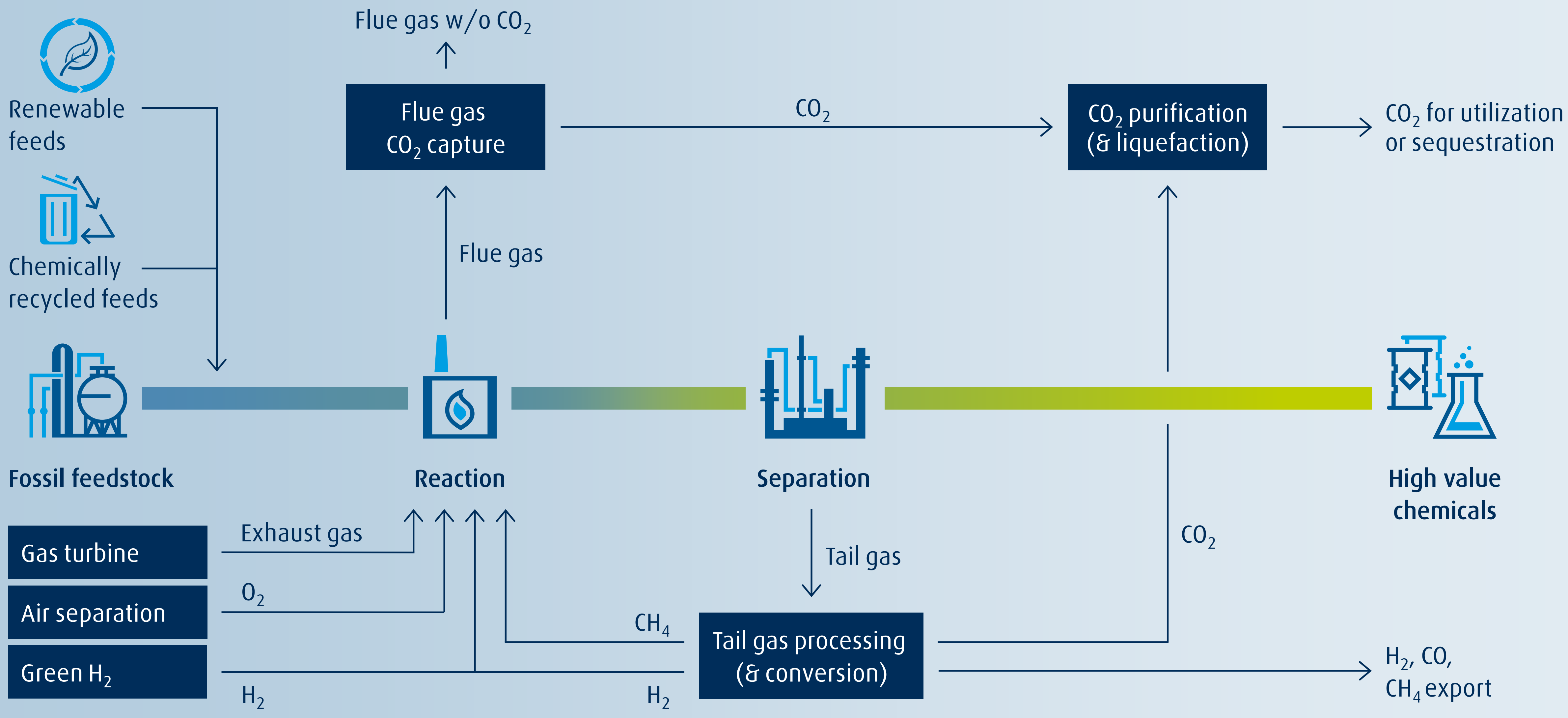

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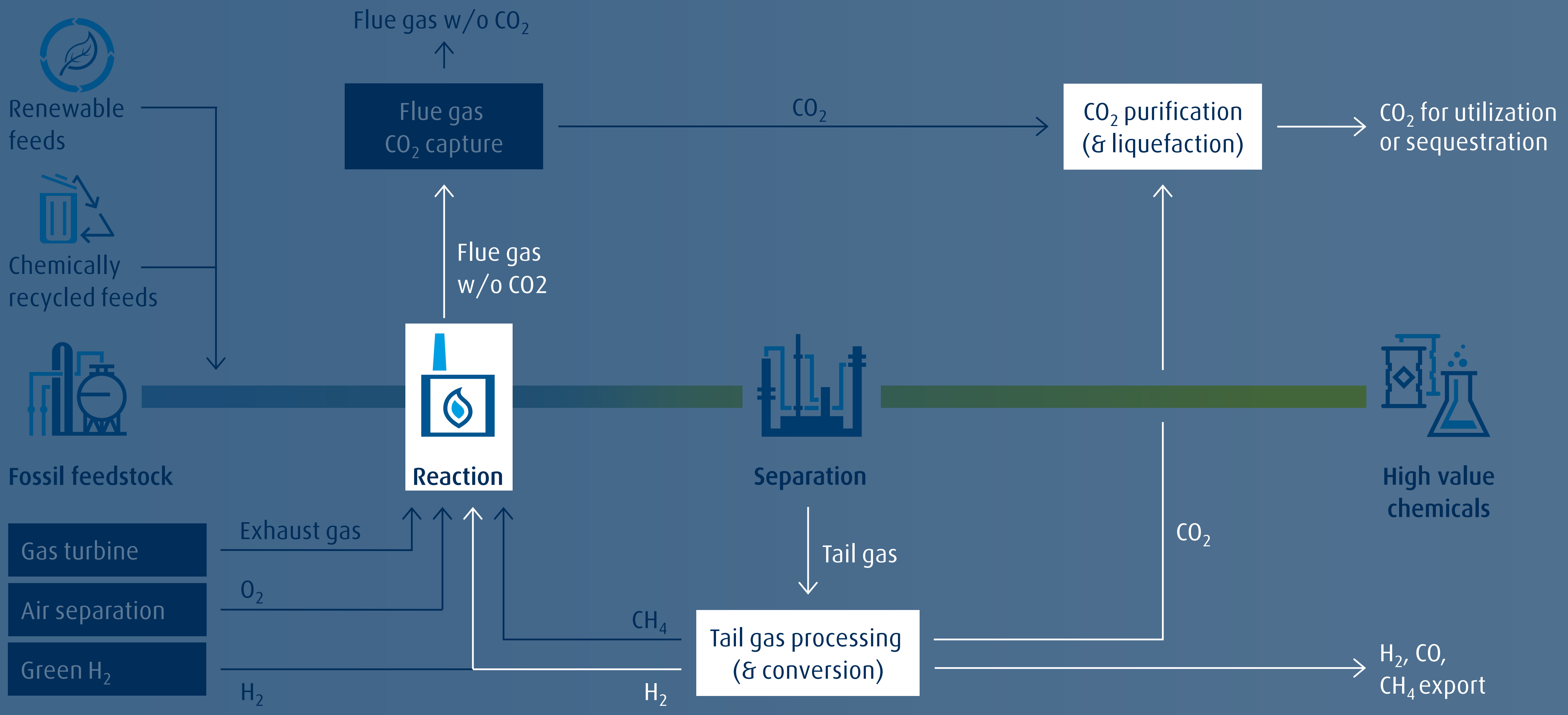
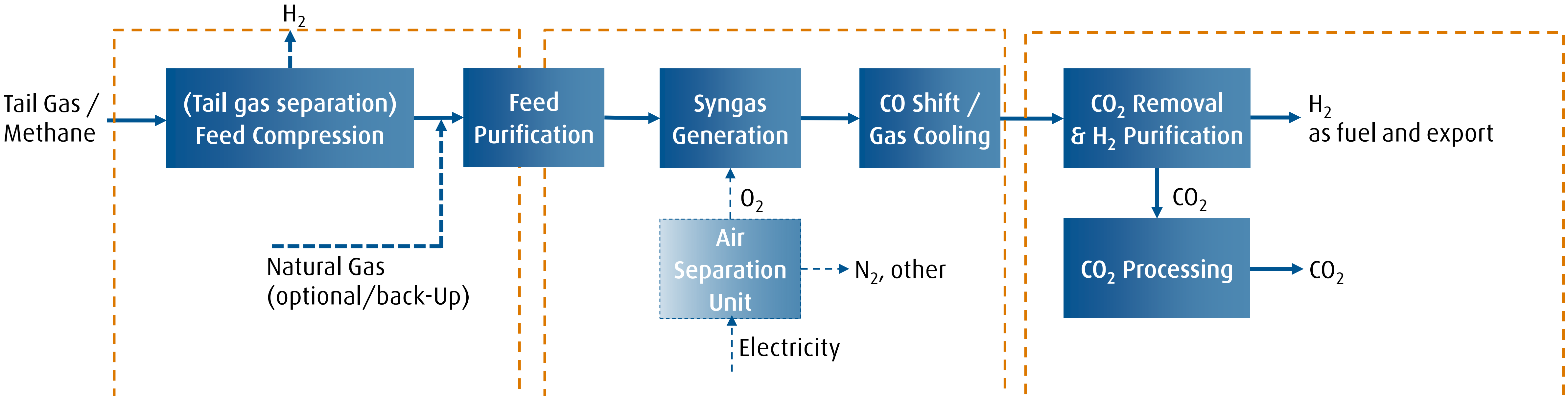


Hydrogen Fuel Switching

Technology selection based on boundary constraints



Technology Options

- PSA
- Membranes
- Cryogenic (within cracker)

- Reformer: SMR, ATR, or POX?
- Green H_2 extensions

- CO_2 removal: Amine washing or PSA (HISORP© CC)
- H_2: Fuel-grade or high purity?

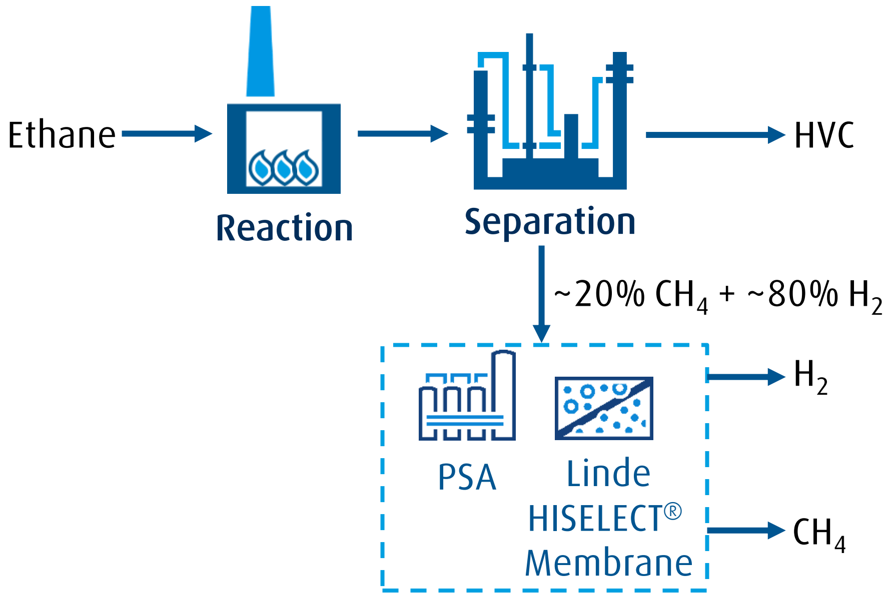
A fully integrated solution considers

- Total Cost of Ownership (TCO) optimisation, considering CAPEX, OPEX, availability and maintenance
- Highest reliability, integrating operational experiences
- Granting wrap-around guarantees & warranties

Hydrogen Fuel Switching

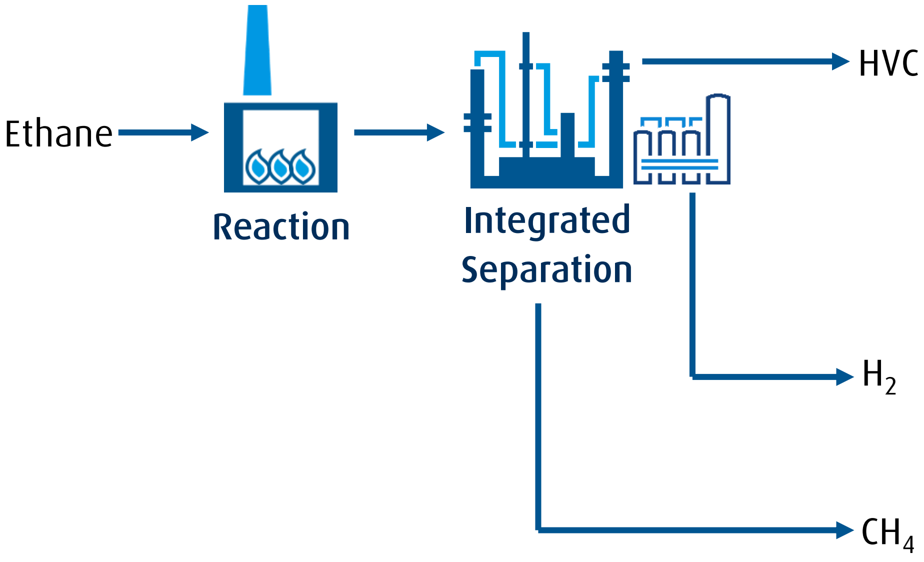
Technology example 1: H_2/CH_4 separation (for ethane cracker) and selection criteria

"Bolt-on" design



- H_2 yield up to 90% (PSA) or 98% (PSA / HISELECT®)
- Can be added later as "add-on"
- Can be centralized for more than one tail gases

Integrated design



- H_2 yield up to 99%
- More compact and CAPEX/OPEX optimized design

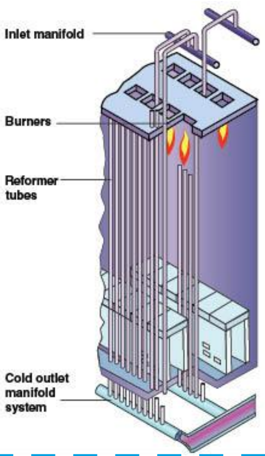
Hydrogen Fuel Switching

Technology example 2: Reforming step and selection criteria

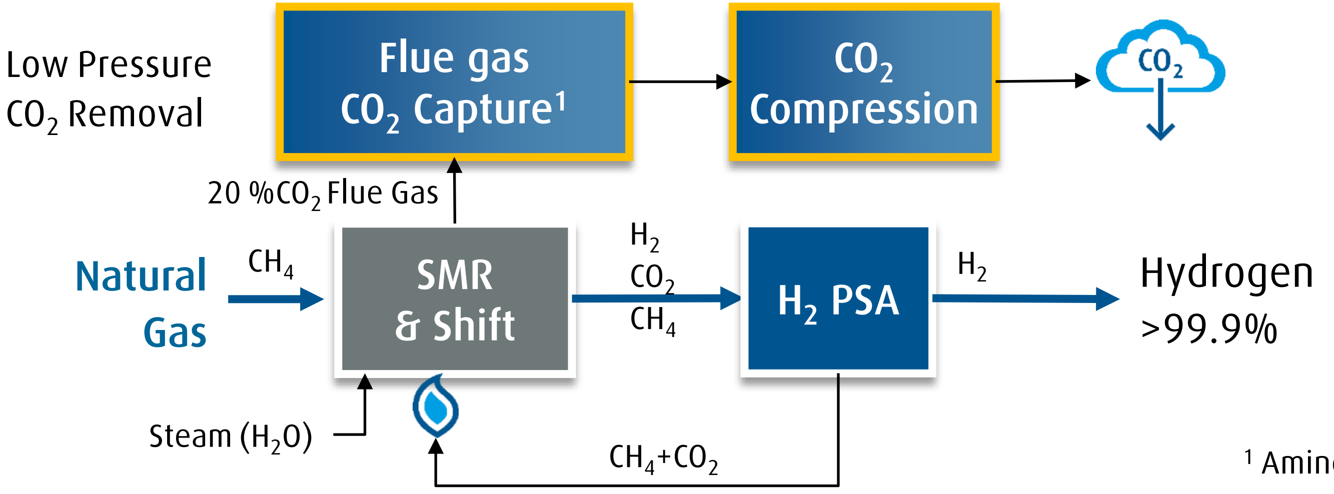
Historically Most Gray H_2

Brownfield Blue Conversion

Steam Methane Reformer (SMR)

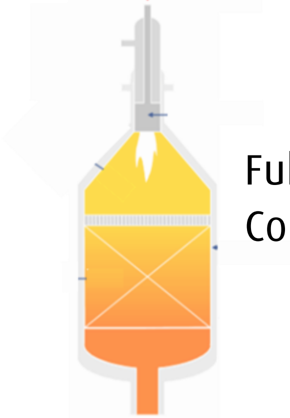


Partial CH_4 conversion



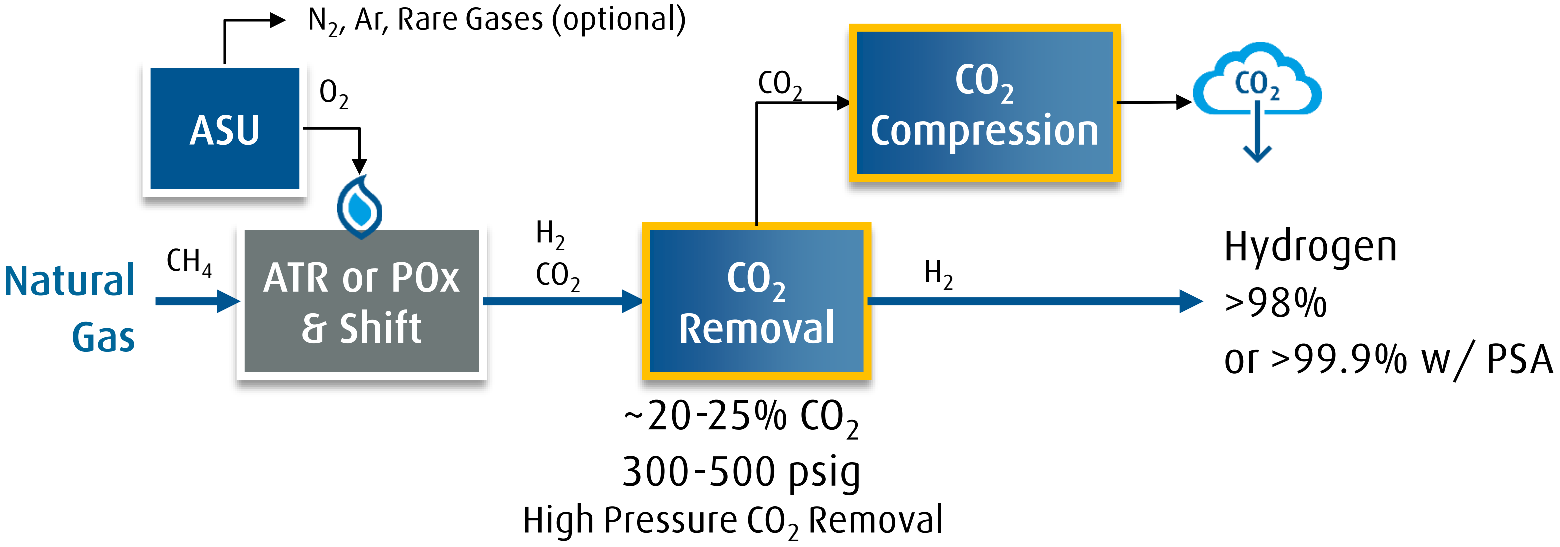
[1] Amine or HISORP CC potential

Future of Blue H_2



Full CH_4 Conversion

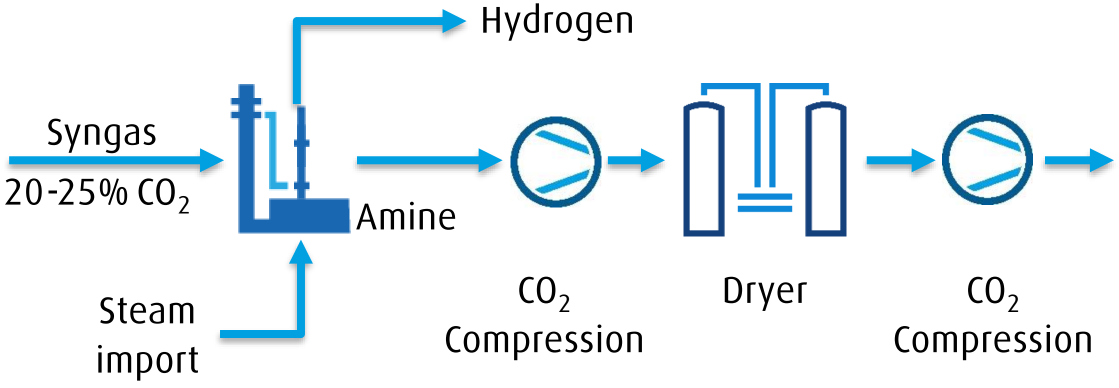
AutoThermal Reforming (ATR) Or Partial Oxidation (POx)



Hydrogen Fuel Switching

Technology example 3: CO_2 removal from syngas and selection criteria

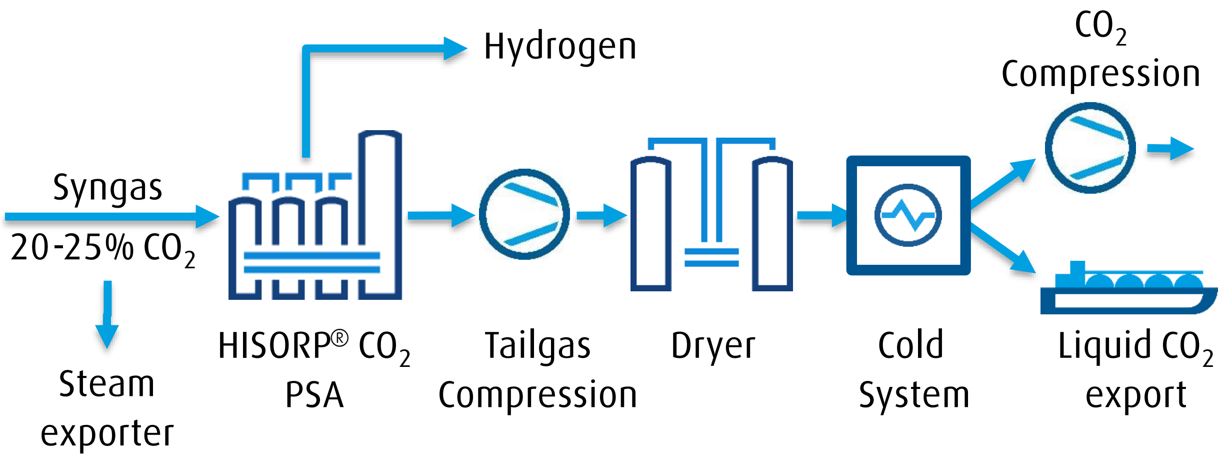
Conventional Amine



- Conventional technology
- Multiple amines available
- Requires thermal energy
- Less electrical power requirement

→ Suited for low thermal energy cost scenarios and/or where steam export is unappreciated

Adsorption-based HISORP® CC



- Entire H_2 plant avoids solvents
- Leverages on low-carbon electrical power
- No steam consumption; higher steam export
- Highly modular, supply as packaged units

→ Suited for low electrical energy cost scenarios and/or where steam export is appreciated

Dow selects Linde as partner for supply of clean H_2 and N_2 for its proposed net-zero carbon emissions site in CAN

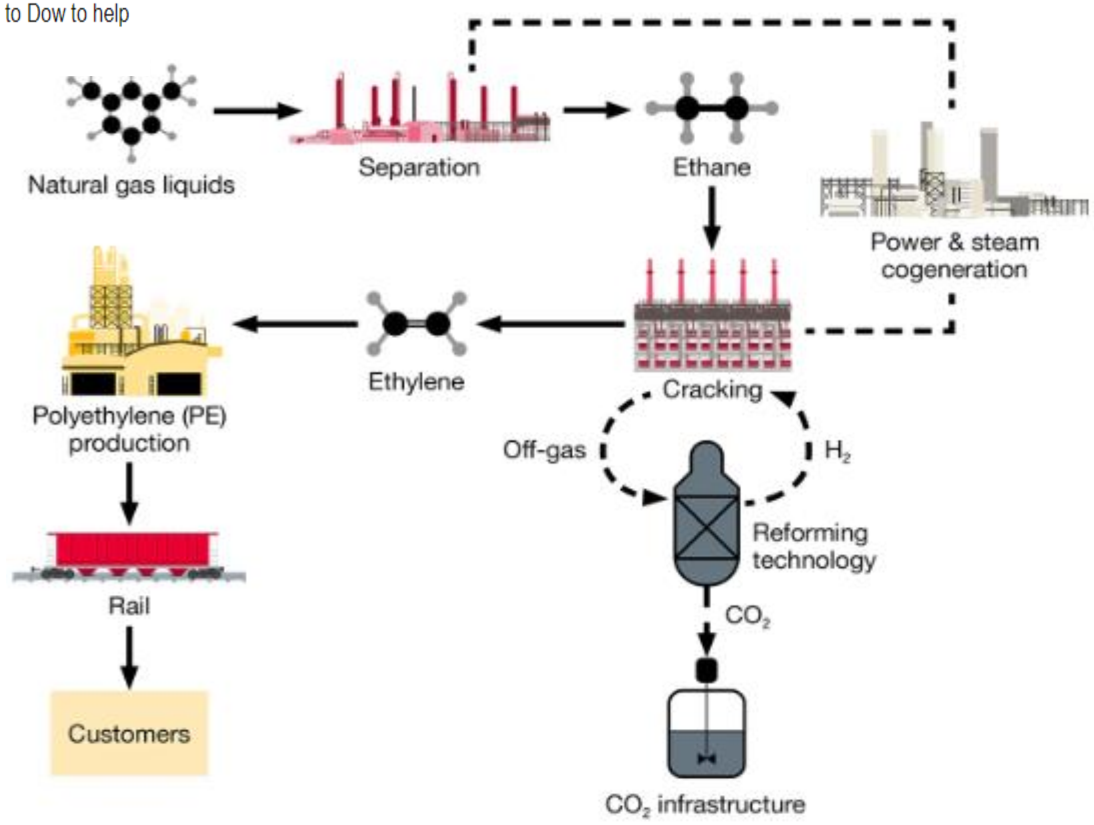
MIDLAND, Mich., April 25, 2023 /PRNewswire/ -- Dow (NYSE: DOW) announced today it has selected Linde (NYSE: LIN) as its industrial gas partner for the supply of clean hydrogen and nitrogen for its proposed net-zero carbon emissions1 integrated ethylene cracker and derivatives site in Fort Saskatchewan, Alberta, Canada. Final investment decisions for both the Dow and Linde projects are subject to approval by both companies' respective Board of Directors and various regulatory agencies. Final investment decisions are expected in fourth quarter this year for a potential startup of phase 1 in 2027.

Under the parties' framework agreement, Linde will complete the design and engineering for a Linde-owned and operated world-scale air separation and autothermal reformer complex. This complex would be integrated with Linde's existing operations in Fort Saskatchewan.

"Linde's partnership is critical in enabling Dow to advance its plans to decarbonize our Fort Saskatchewan site while growing our business," said Edward Stones, Dow's business vice president, Energy and Climate. "Our customers are looking to Dow to help lower the carbon footprint of their products, and this is an important step in that direction."

- **Dow's proposed Fort Saskatchewan Path$_2$Zero expansion project will create the world's first net-zero carbon emissions integrated ethylene cracker and derivatives site with respect to scope 1 and 2 carbon dioxide emissions.**
- **Decarbonize approximately 20 percent of Dow's global ethylene capacity**
- **Produce and supply approximately 3.2 million metric tonnes of certified low- to zero-carbon emissions polyethylene and ethylene derivatives**

How the Site Will Work



Decarbonizing World-scale Petrochemical Sites

Summary

- Solutions for flue gas CO_2 capture ("post-combustion") and blue hydrogen fuel switching ("pre-combustion") are commercially ready
- For each solution, reduction of direct CO_2 emissions of 95% can be achieved
- Solutions can significantly vary, depending on site- and client-specific as well as economic constraints
  - A multi-criteria decision process is required to identify the most promising solution(s)
  - Selection of suitable technology elements and integration of petrochemical and H_2/CO_2 processing facilities play a vital role

Volume & Concentration
Carbon Capture %
Emitter Distribution & Restricted Access
Existing vs. new assets
Economy of Scale
Capital Allocation
Impact on & suitability to existing assets
Reliability & Flexibility aspects

Thank you for your attention

Making our world more productive