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CARBON CAPTURE – WHY, WHO, WHAT AND HOW?

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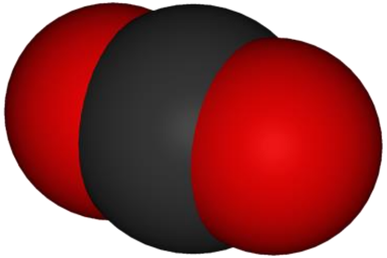


SAFETY TOPIC – CO_2 TOXICOLOGY

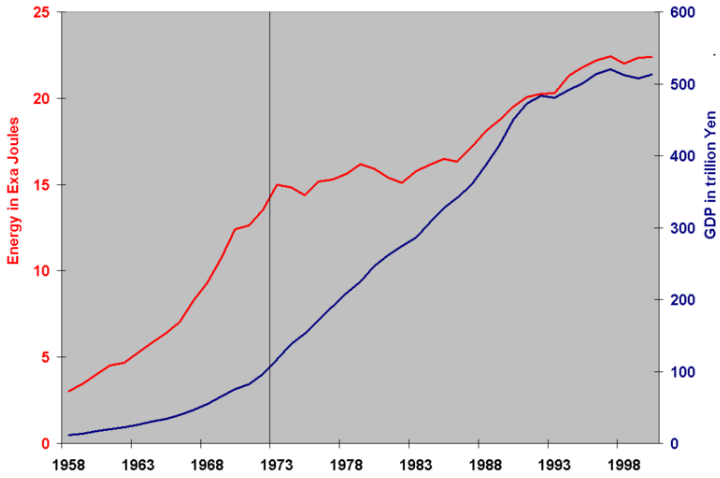
- At what levels is CO_2 dangerous
  - 400 ppmv (0.04%v) is the atmospheric concentration
  - 5000 ppmv (0.5%v) is tolerable 8 hrs/day
  - 30-40,000 ppmv (3-4%v): dangerous
  - 100,000 ppmv (10%v): lethal (note: O_2 % still fine)
- Mitigation
  - Design
  - Detectors (permanent & portable)
  - Ventilation
  - Limited access, multiple egress routes
  - Training

AGENDA

- Why carbon capture?
- Who else is capturing carbon – and where?
- Where does all that CO_2 go?
- What technical options are available?
- How does it fit into the existing facility?
- How much is it going to cost - and how can cost be minimized?
- Take-aways: What to do next?

WHY CARBON CAPTURE?

- Fire invented (stolen, in fact) some 0.4-0.8 million years ago (Prometheus)
- Consequence: explosion of wealth – and of CO_2 emissions



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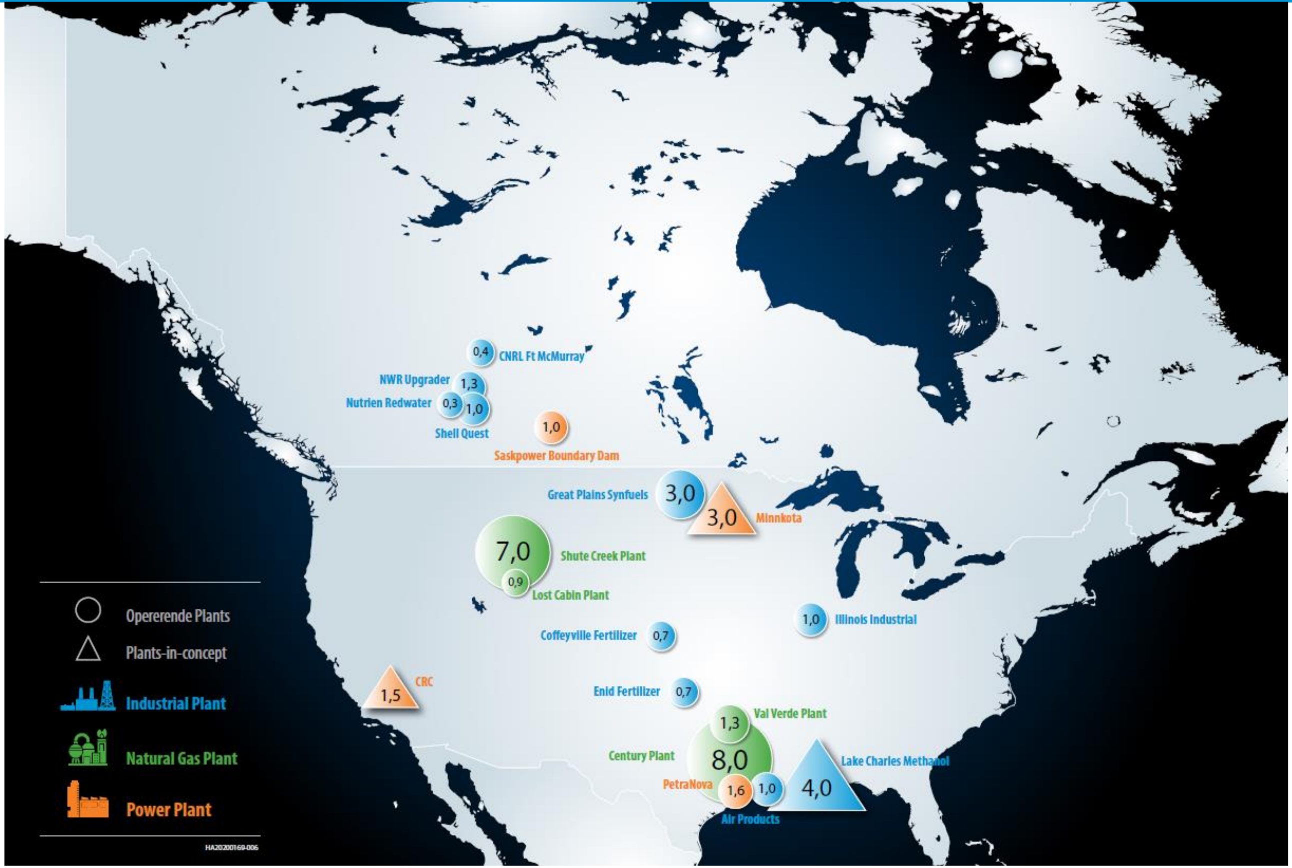
WHY CARBON CAPTURE?

- Educated guess #1 : we cannot suddenly reduce our energy demand
- Educated guess #2: transition to zero-carbon fuels (or other zero-carbon energy) will not happen overnight
- However, ‘the pressure is on’ from legislators and public
- Carbon capture

- is technically feasible and proven
- enables adaptation – with continuation of the core business
- hedges against CO_2 taxes and caps

WHO ELSE IS CAPTURING CARBON – AND WHERE?



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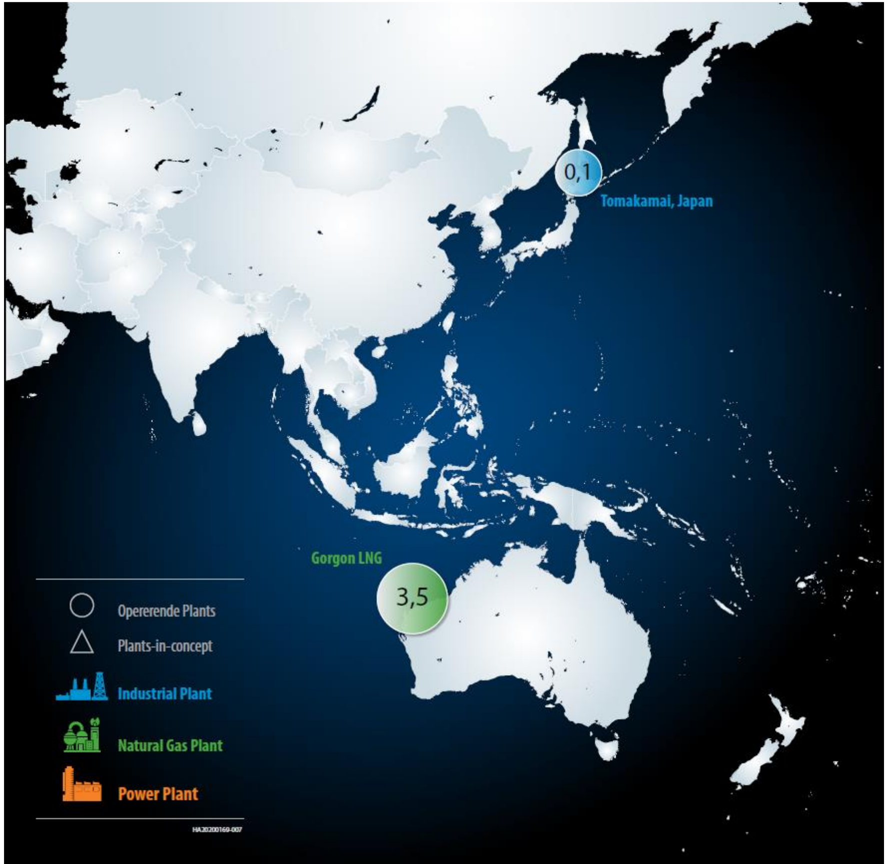

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WHO ELSE IS CAPTURING CARBON – AND WHERE?

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WHO ELSE IS CAPTURING CARBON – AND WHERE?

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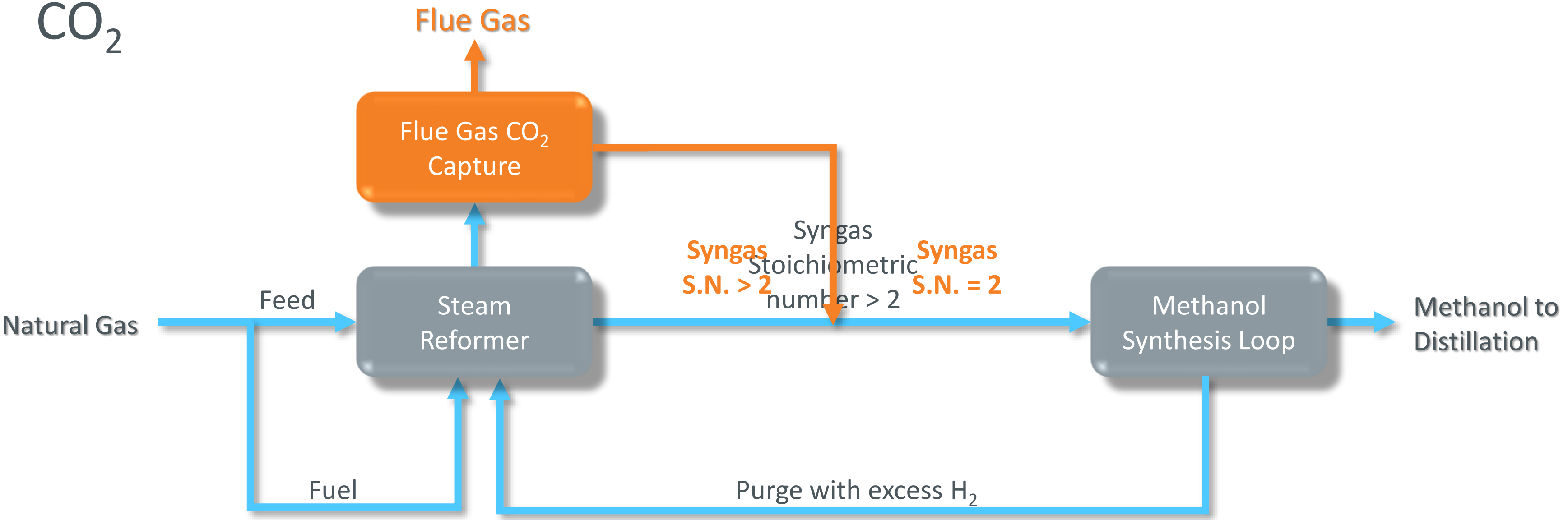
CARBON CAPTURE – WHERE DOES ALL THE CO_2 GO?

- Common denominator: CO_2 must go somewhere
  - Use in existing chemical processes
  - New chemistries: combine with “green H_2” to e-Fuels
  - Greenhouses
  - Food & Beverage industry
  - Injection into active oil field (Enhanced Oil Recovery)
  - Geological sequestration: empty oil / gas field
  - Geological sequestration: saline aquifer

WHERE DOES THE CO_2 GO – METHANOL

- Methanol and NH_3-Urea plants can benefit from additional CO_2



WHERE DOES THE CO_2 GO – NEW CHEMISTRIES

- CO_2 has a very low 'energy level'
- Making something good from CO_2 requires considerable energy input
- Green H_2 (from electrolysis) could be that energy
  - $3\ H_2 + CO_2 \rightarrow$ e-Methanol + H_2O
  - $4\ H_2 + CO_2 \rightarrow$ e-Methane + $2\ H_2O$
  - $3\ H_2 + CO_2 \rightarrow 2\ H_2 + CO + H_2O \rightarrow -(CH_2)- + 2\ H_2O$ (e-Kero / e-Gasoline)
  - 2 Green $NH_3 + CO_2 \rightarrow$ e-Urea

Iceland: George Olah MeOH plant

https://www.chemistryworld.com/news/carbon-dioxide-to-methanol-catalyst-ignites-fuel-from-air-debate/9339.article

WHERE DOES THE CO_2 GO - GREENHOUSES

- Greenhouses require CO_2 notably in summer
- OCAP pipeline system captures CO_2 from Shell refinery and bio-ethanol fermentation plant – scale: >0.3 million ton/year

https://egyptindependent.com/egypt-builds-1300-greenhouses-as-part-of-the-largest-greenhouse-project-in-the-middle-east/

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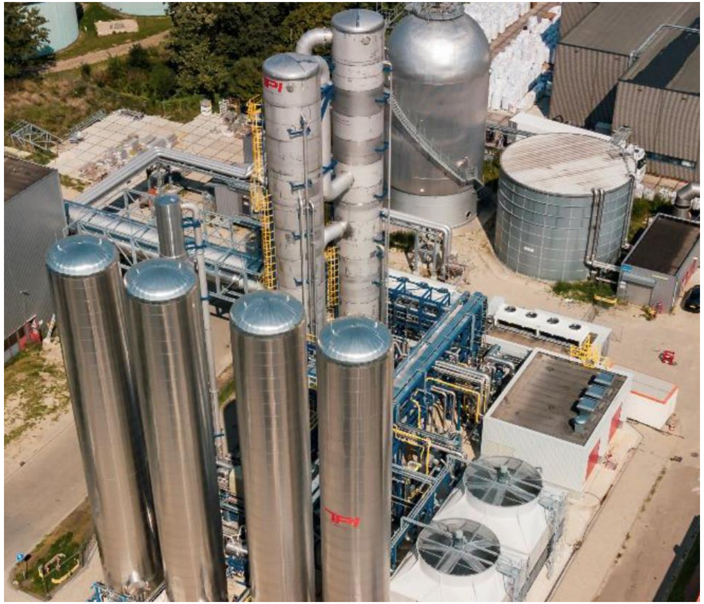
https://energeia.nl/energeia-artikel/40081707/tuinders-stoken-weer-aardgas-wegens-storing-in-co2-levering-via-ocap-leiding

https://www.researchgate.net/figure/OCAP-pipeline-in-green-with-possible-extensions-in-blue_fig2_272380887

WHERE DOES THE CO_2 GO - GREENHOUSES

- AVR in Duiven, Netherlands (waste incineration plant)
- Up to 100 KTA CO_2 capture, main export (by truck) to greenhouses



WHERE DOES THE CO_2 GO?

Much of the world has not been studied in detail for CO_2 capture potential. However, thick sedimentary basins are some of the best candidates

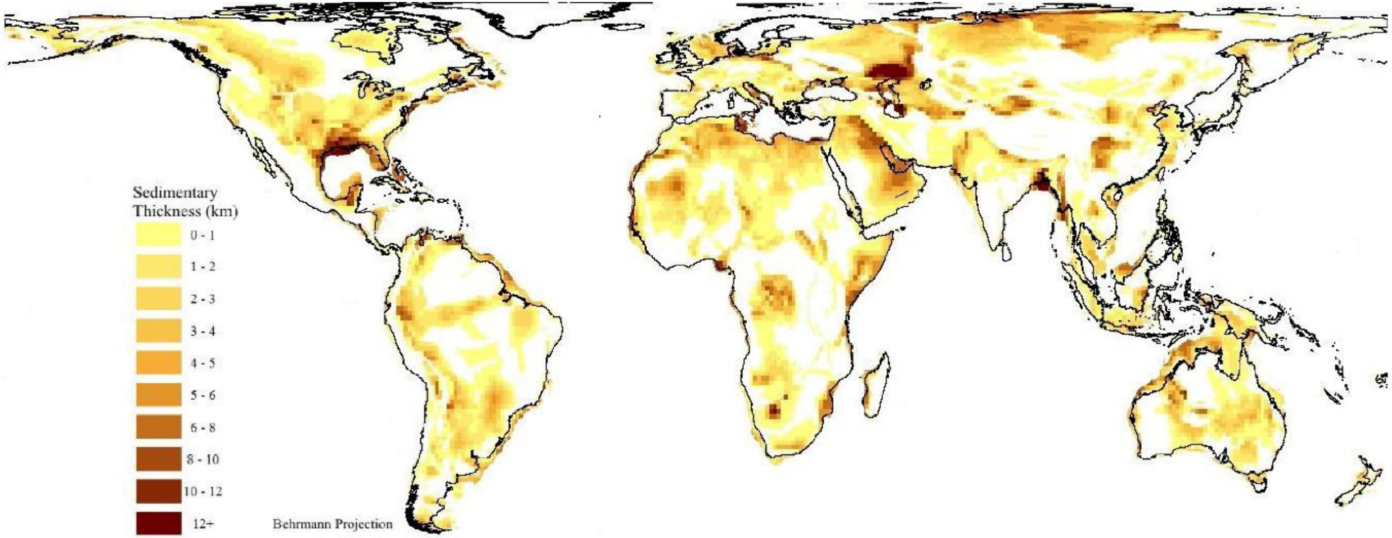
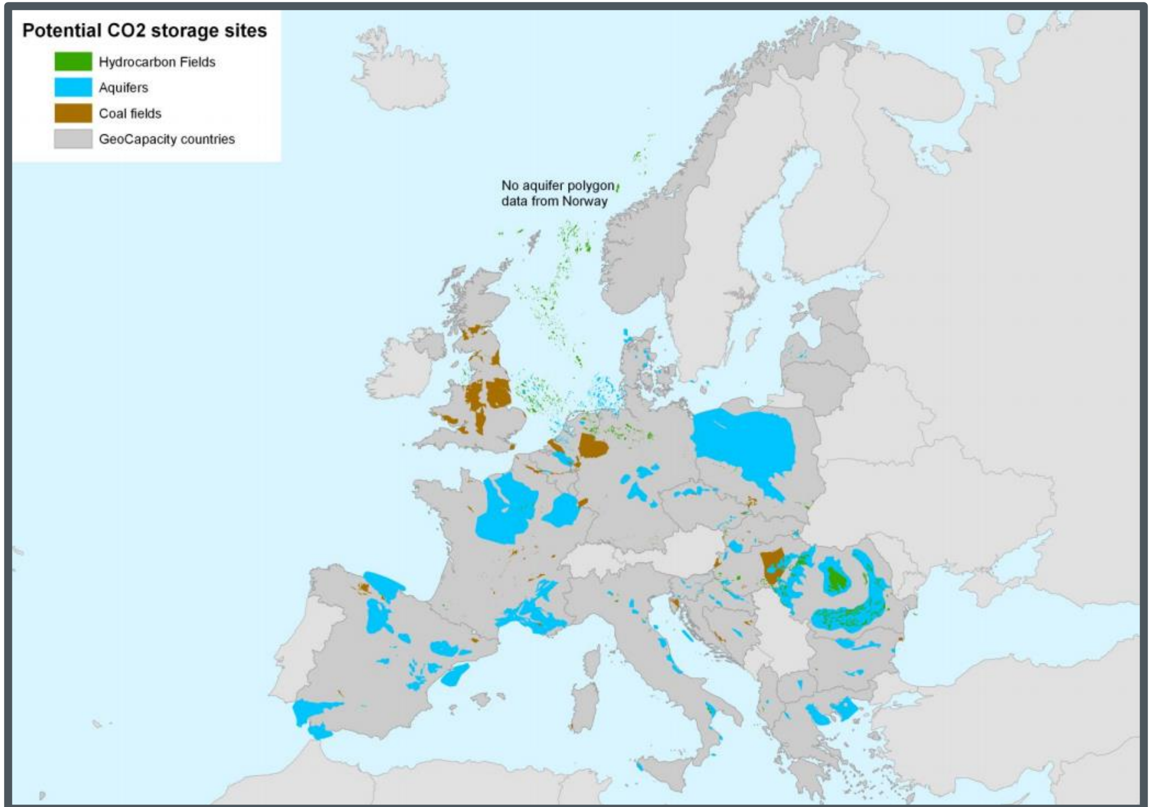


Figure 9. Global sedimentary basins. Map shows onshore basins and practically accessible basins. Regions with high volumes of sedimentary basin are correlated to higher CO_2 storage capacities. Source: Jordan Kearns et al., "Developing a Consistent Database for Regional Geologic CO2 Storage Capacity Worldwide", *Energy Procedia* 114 (2017) 4697 – 4709

WHERE DOES THE CO_2 GO?



GEOLOGICAL SURVEY OF DENMARK AND GREENLAND

Map Reference: https://www.sintef.no/globalassets/sintef-energi/nordiccs/d-6.1.1205-1-mapping-and-estimating-the-potential-for-geological-storage-of-co2-in-the-nordic-countries_web.pdf/

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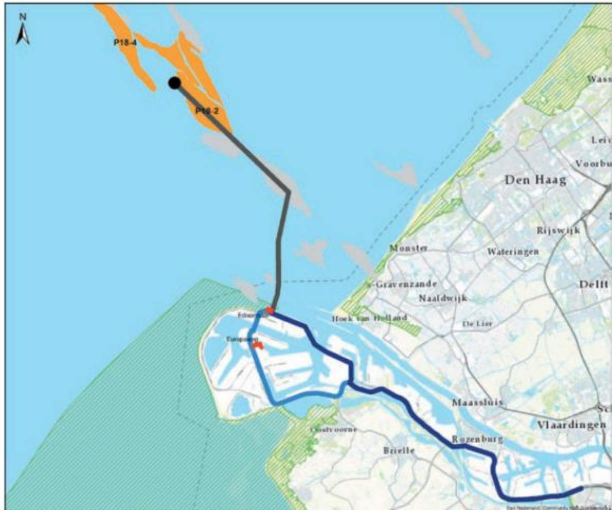
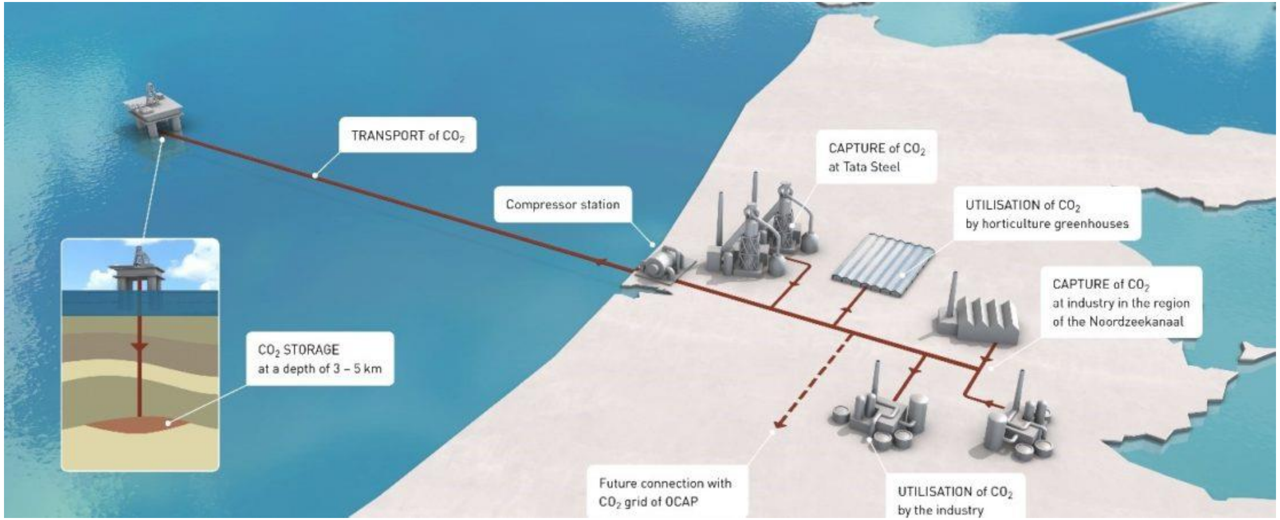
WHERE DOES IT GO - PIPELINES

- Porthos and Athos pipelines from Rotterdam and Amsterdam regions to offshore fields

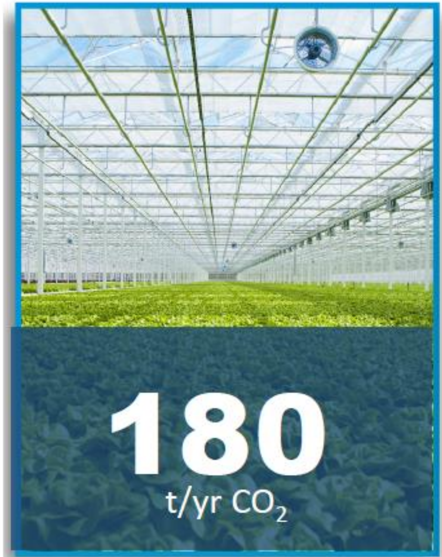


https://www.porthosco2.nl/en/project/



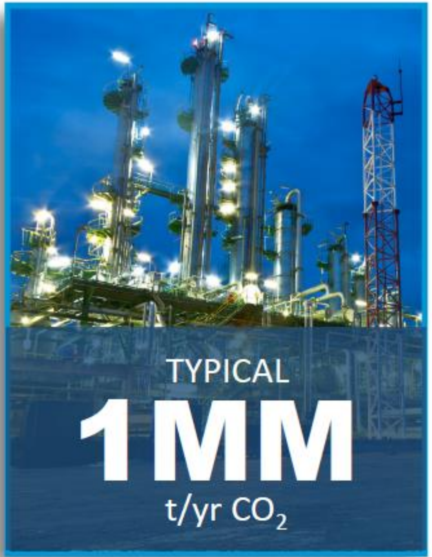
https://athosccus.nl/project-en//

ORDERS OF MAGNITUDE….



Greenhouse
(1 hectare)

Algae Farm
(400 hectares)



Commercial Facility

Brewery

CARBON CAPTURE OPTIONS

What Configuration Options are Available?

CARBON CAPTURE - HOW

- Three main types of Carbon Capture
  - Pre-combustion capture
  - Post-combustion capture
  - Oxy-combustion
  - Direct Air Capture
- Each situation has its own specific “best fit”

CARBON CAPTURE – HOW - PRECOMBUSTION

- Pre-combustion capture

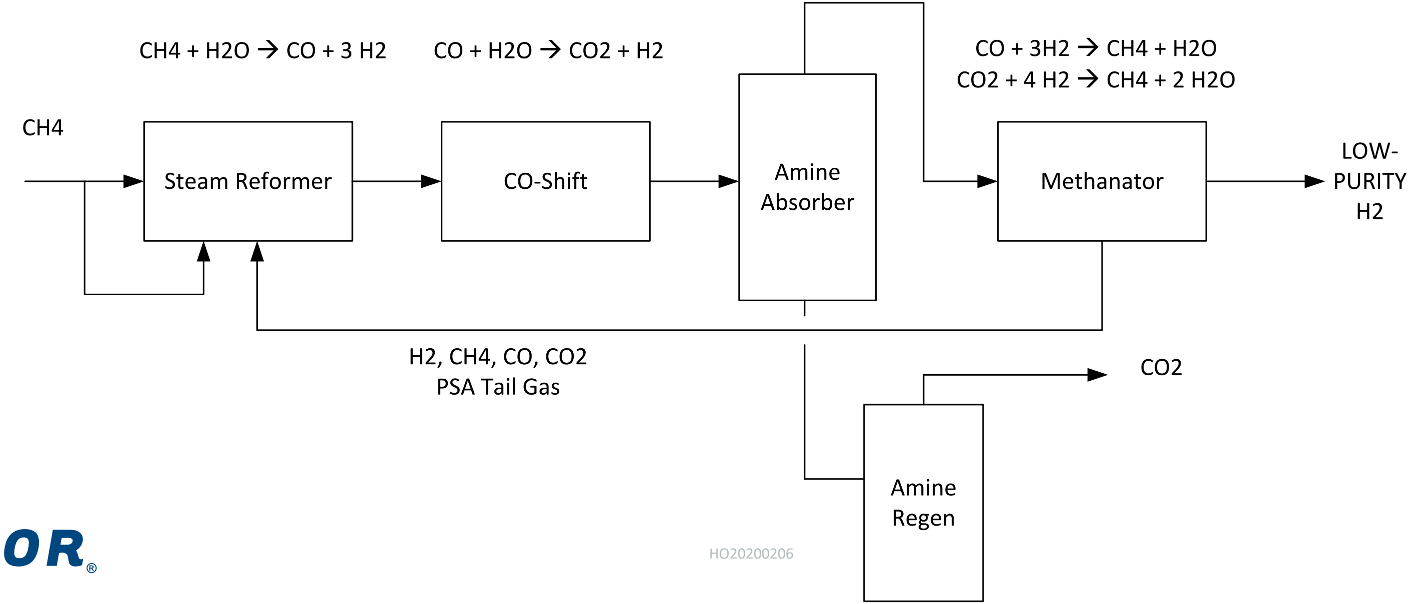
- From natural gas or syngas (NH_3 plants, old-fashioned H_2 plants)

- Today, most ‘captured CO_2’ is from pre-combustion capture
- Options

- Amines
- Physical solvents
- Hybrid solvents
- Membranes
- Cryogenics
- VSA

CARBON CAPTURE – HOW - PRECOMBUSTION

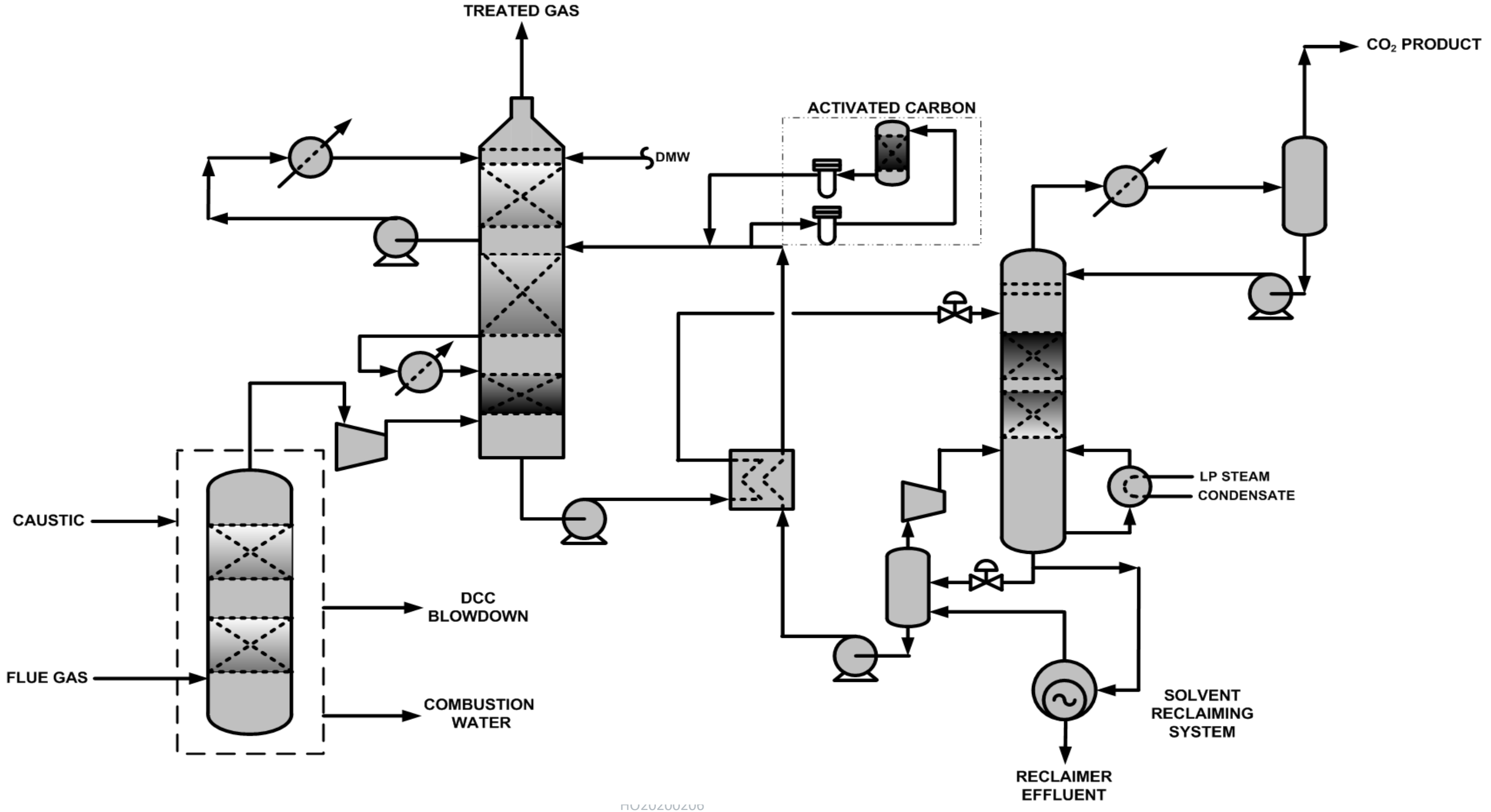
- Pre-combustion capture in old-school H_2 plants and NH_3 plants
- Vast quantities of CO_2 already ‘captured’ then vented to atmosphere → low-hanging fruit!



POST-COMBUSTION CAPTURE

- Post-Combustion: remove CO_2 from flue gas to stack, i.e. after combustion
  - The most versatile solution – universally applicable
  - “Add-on” to existing plant
  - Example: Fluor Econamine FG Plus^{SM} (EFG+) Technology
- Example applications
  - Powerplants (gas-fired, coal-fired, gas engine)
  - Refineries (FCC, Hydrogen Plant, Fired heaters)
  - (Petro)chemical plants (fired heaters)
  - Waste incinerators
  - Limestone calciners (Cement industry…)
  - Hydrogen Plants
  - Blast Furnaces
  - Etc. etc. etc.

POST-COMBUSTION CAPTURE (AMINE-BASED)



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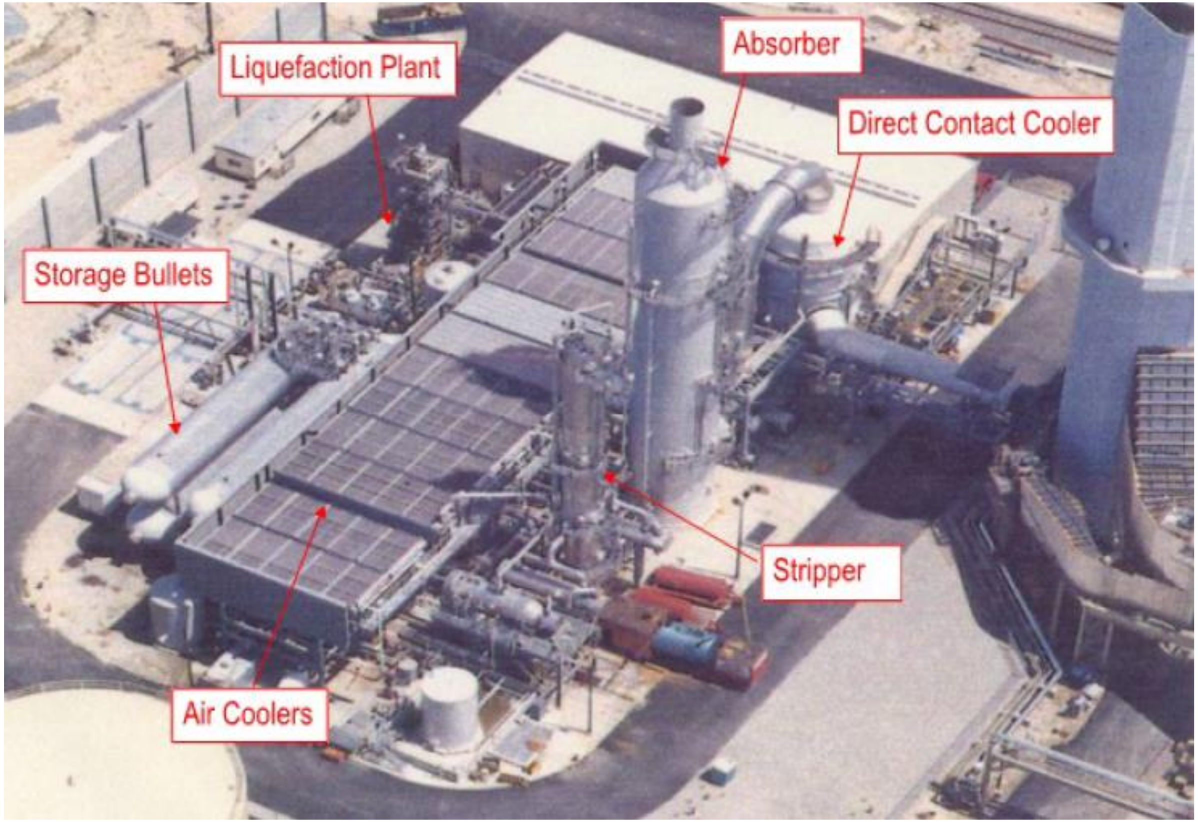
ECONAMINE FG PLUS^{SM} PLANT



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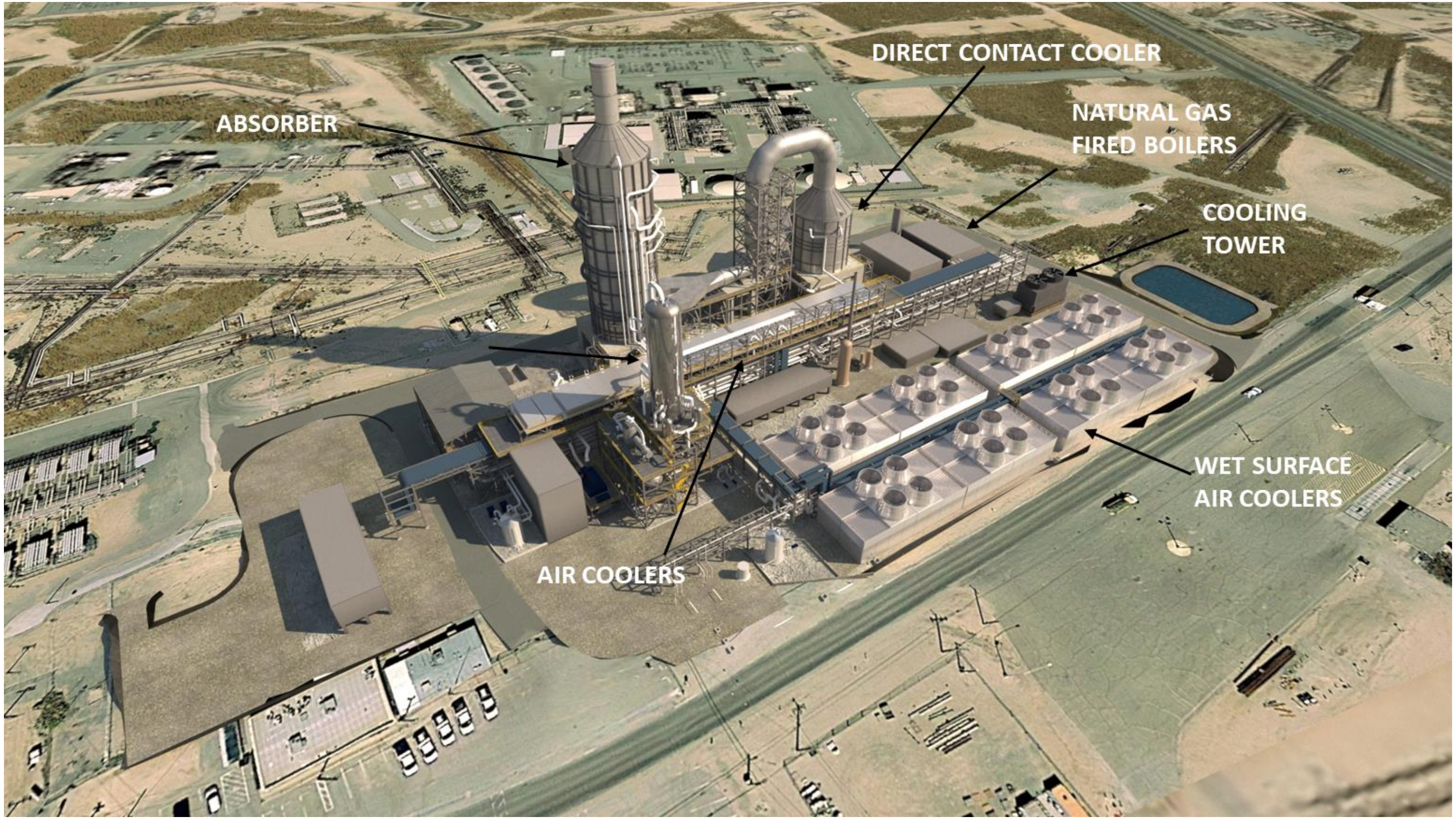

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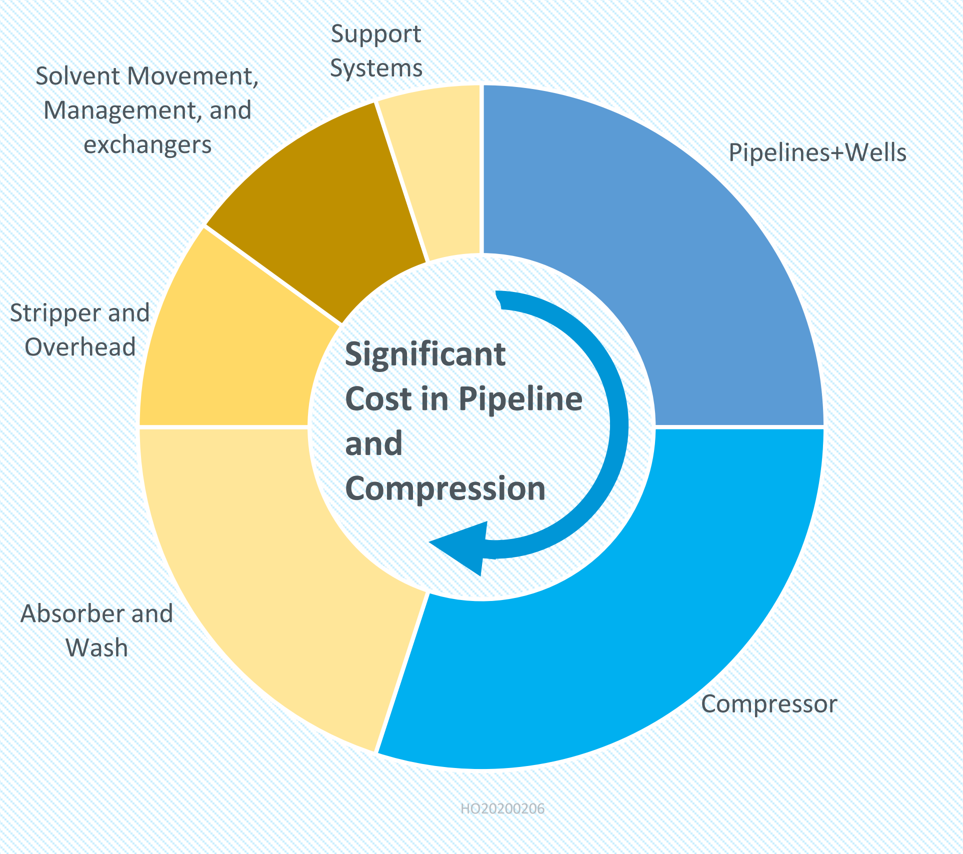
WHAT DOES CAPTURE COST?

COST OF CARBON CAPURE

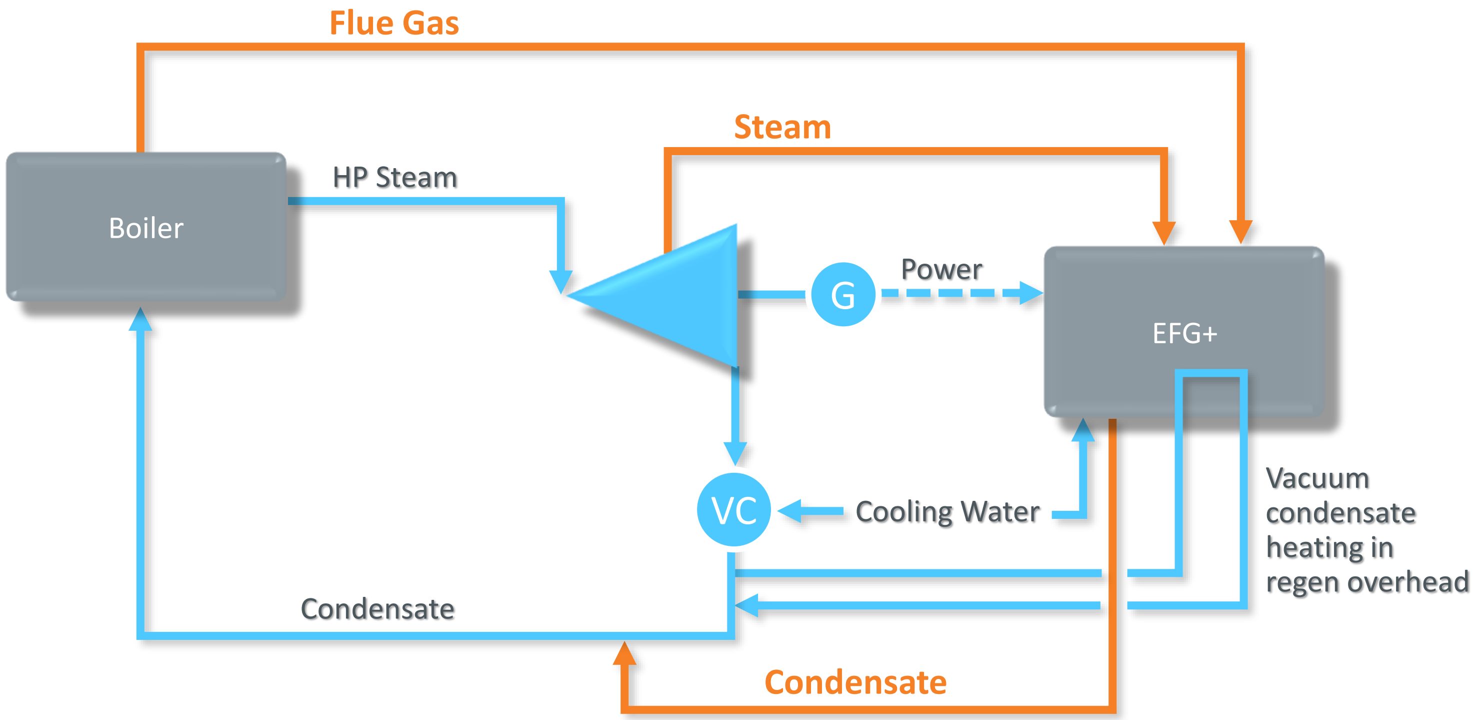
- Made up of capital cost AND operating cost
- Often ‘wrapped up’ in a cost per ton CO_2 captured
- Cost depends completely on
  - Scale
  - Location
  - Pre- or Post-combustion
  - Type of flue gas (% CO) for post-combustion
  - Pressure, % CO_2 for pre-combustion
  - Site integration possibilities, utilities ‘scope’
  - Heat and Power cost
  - CO_2 outlet (does plant include compression, liquefaction, pipeline etc.)

APPROXIMATE CAPITAL COST BREAKDOWN

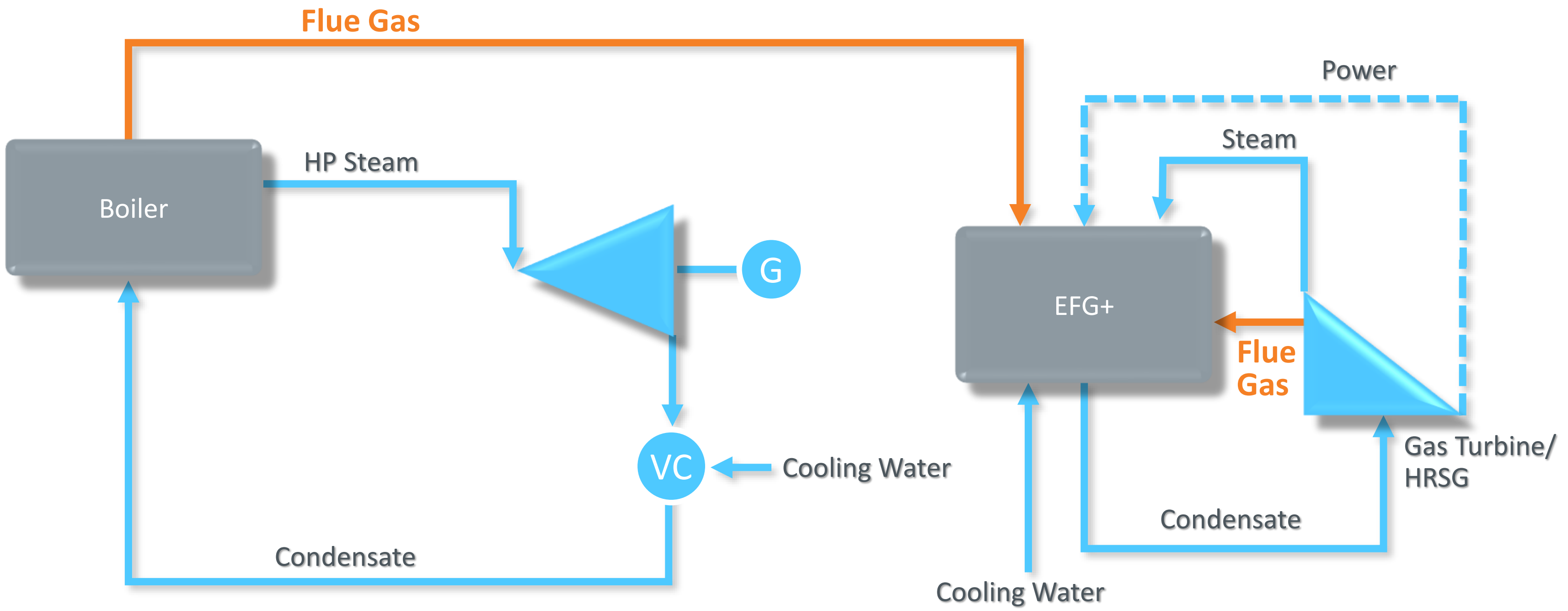


HOW DOES CARBON CAPTURE FIT INTO YOUR FACILITY?

HOW DOES IT FIT IN – POST-COMBUSTION

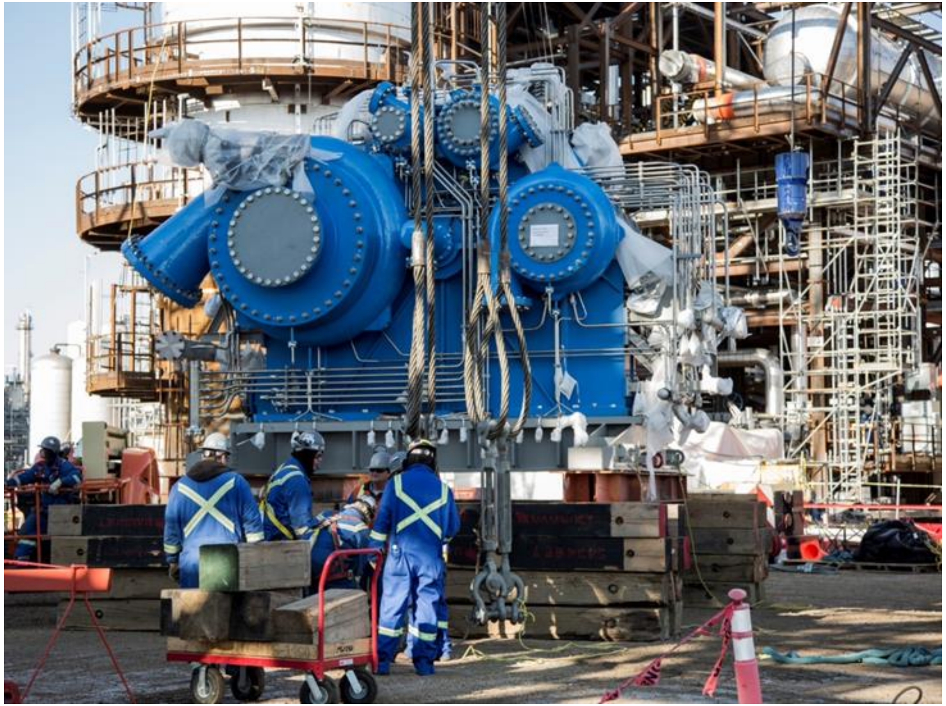


HOW DOES IT FIT IN – POST-COMBUSTION

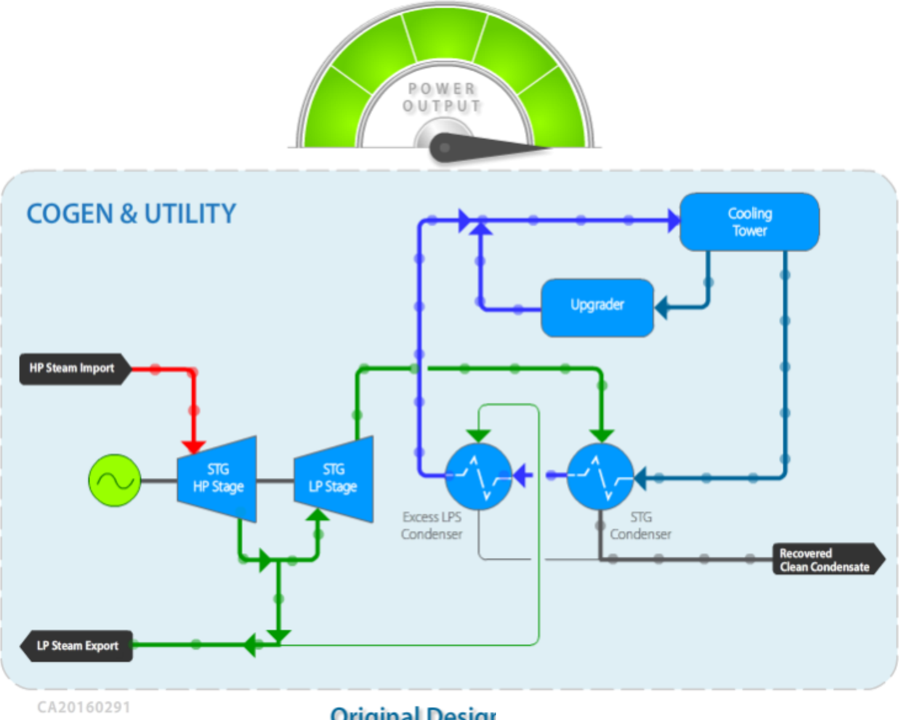


INTEGRATION ON A LARGE RETROFIT PRE-COMBUSTION PROJECT

- Study of existing plant utility system revealed:
  - Most o the time, significant LP steam excess
  - LP steam excess condensed, using cooling water
  - Possibility to supply sufficient LP steam and CW to new capture plant
  - No need to invest in major new utility systems
  - For a small % of the time when no surplus steam / CW was available, capture plant must stop



ORIGINAL DESIGN CASE



Original Desigr

- Maximum power output means maximum steam to LP steam turbine and condenser
- Result: minimum steam and cooling water available for other uses

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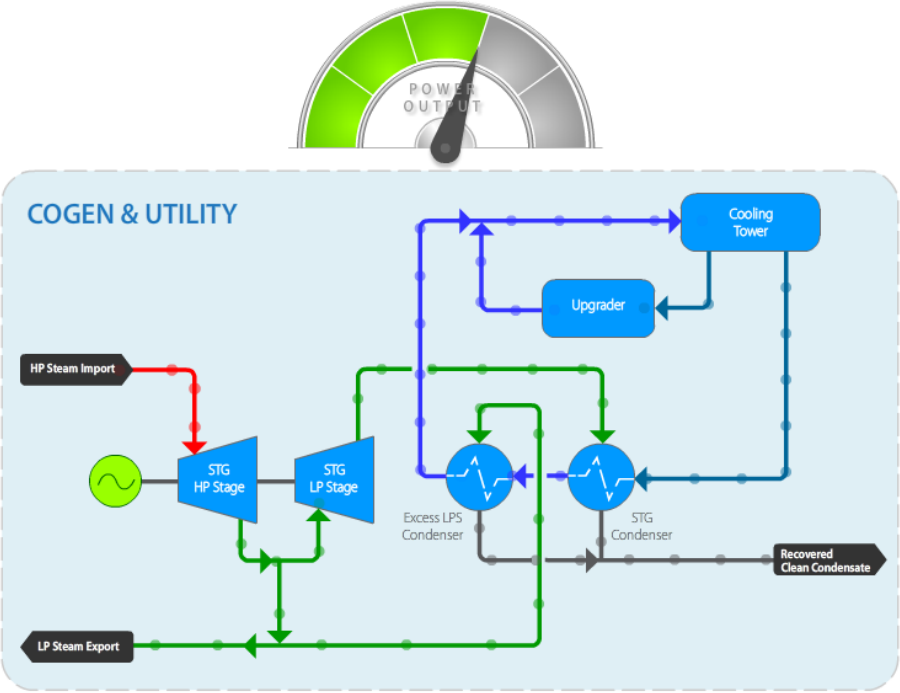
ACTUAL OPERATION CASE



Actual Operation

- Actual operation > 95% of the time
- Limited power production
- Surplus LP steam condensed using CW

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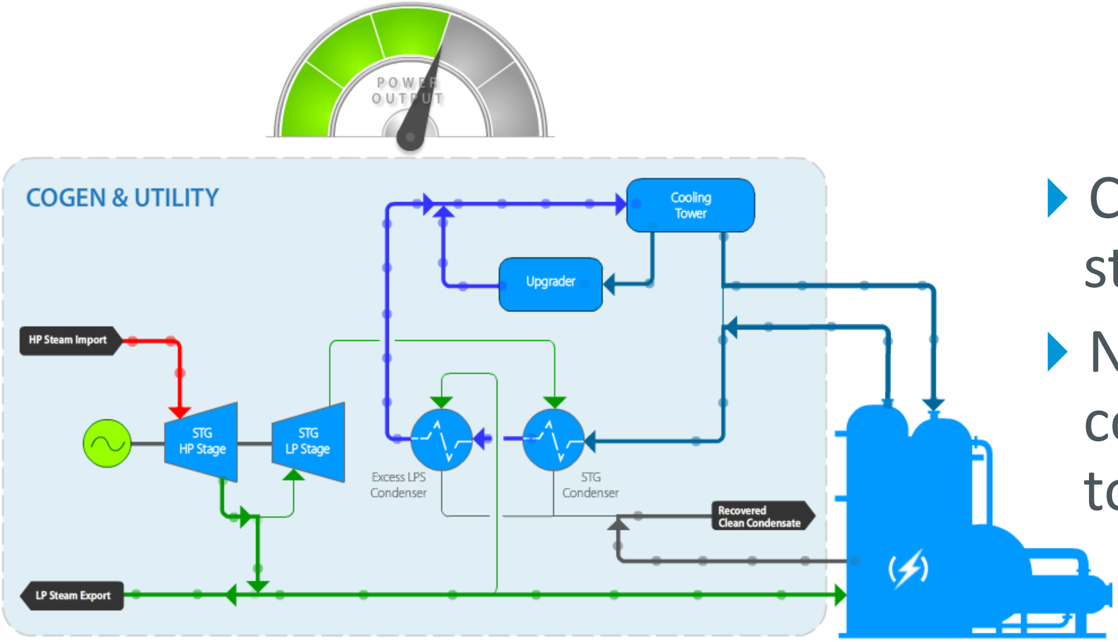
TIE-IN



Shell Quest Operation

- Capture Plant uses surplus steam
- No surplus steam condensing = CW available to Capture Plant

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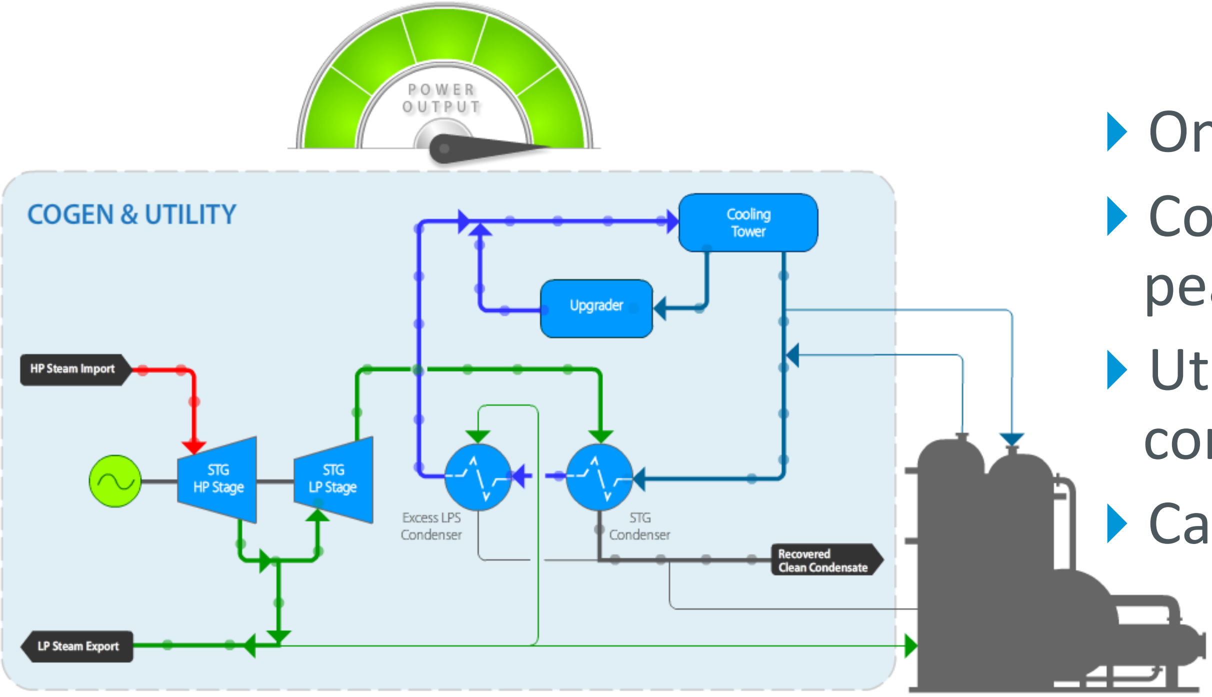
COGEN PEAK POWER – CAPTURE PLANT IDLE



Cogen Peak Power

- Only < 5% of time
- Cogen plant produces peak power
- Utilities to Capture Plant constrained
- Capture Plant idle

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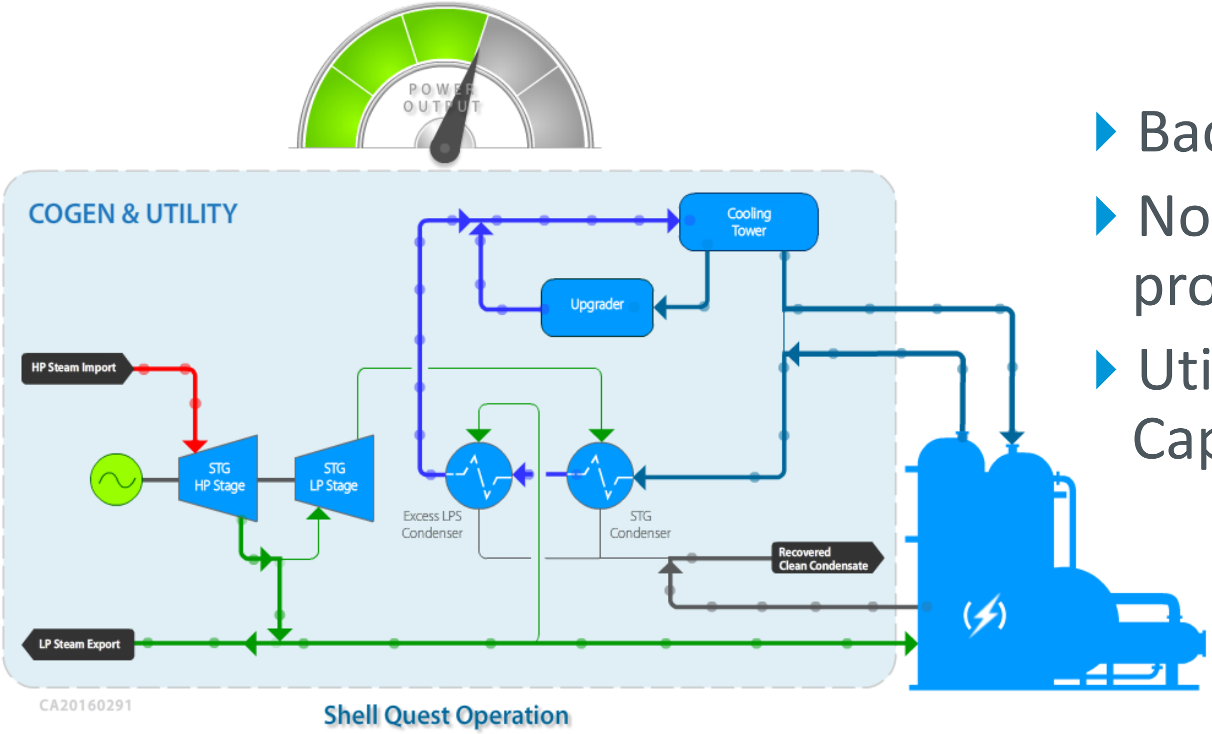
COGEN AND CAPTURE PLANT BACK TO NORMAL



- Back to normal
- No more peak power production
- Utilities available to Capture Plant again

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PRE-COMBUSTION CAPTURE – REAL RESULTS

SAVINGS OF 15%
FROM ADVANCED MODULARIZATION

LAST MODULE 5 MONTHS
TO MECHANICAL COMPLETION

PLOT REDUCED 27%
BELOW ORIGINAL ESTIMATE

COMPLETED AT 73%
OF INITIAL COST

CONCLUDING REMARKS

TAKE-AWAYS

- There are several
  - Good reasons to capture CO_2
  - Disposal options for the captured CO_2
  - Technology options for the capture process
  - Ways and means to fit the capture plant into the existing facility
- It is a good idea to start evaluating today

QUESTIONS?

COMMENTS?