Shell Catalysts & Technologies

TOWARDS YOUR LOW-CARBON REFINERY

Proven technologies for capturing CO_2 from both low- and high-pressure streams

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Outline

- Refiners' CCS challenge, and how it can be approached
- The four steps of CCS
- The major CO_2 emitters in the refinery
- Shell's CO_2 capture technologies
- Case studies

As a consequence of the Paris Agreement on climate change, refiners must reduce their CO_2 emissions substantially

2°C

Limit the increase of the global average temperature to well below 2°C

1.5°C

Stretch target of 1.5°C also agreed

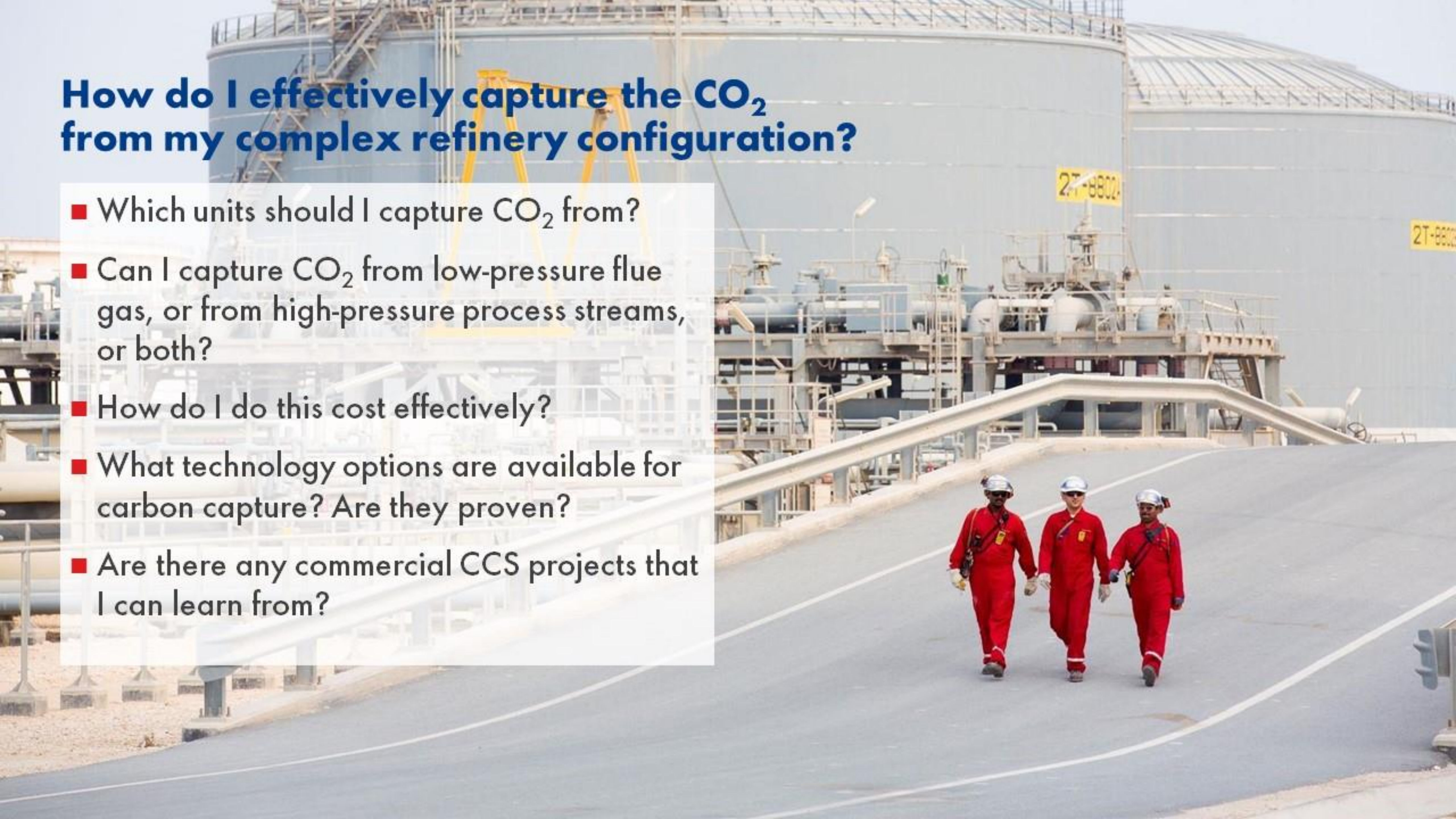
For most businesses, a mosaic of solutions will be required

- Energy efficiency initiatives
- Fuel switching
- Process optimisation
- Best available technology

- **Carbon capture and storage**

"CCUS is one of the most cost-effective solutions available to reduce emissions from some industrial and fuel transformation processes"

International Energy Agency


How do I effectively capture the CO_2 from my complex refinery configuration?
Which units should I capture CO_2 from?
Can I capture CO_2 from low-pressure flue gas, or from high-pressure process streams, or both?
How do I do this cost effectively?
What technology options are available for carbon capture? Are they proven?
Are there any commercial CCS projects that I can learn from?

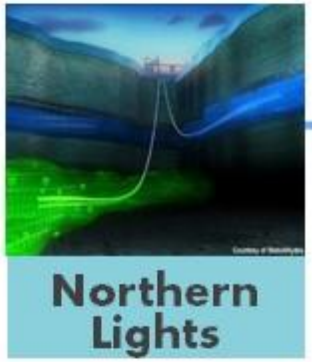
Fortunately, refiners can leverage the experience of other sectors

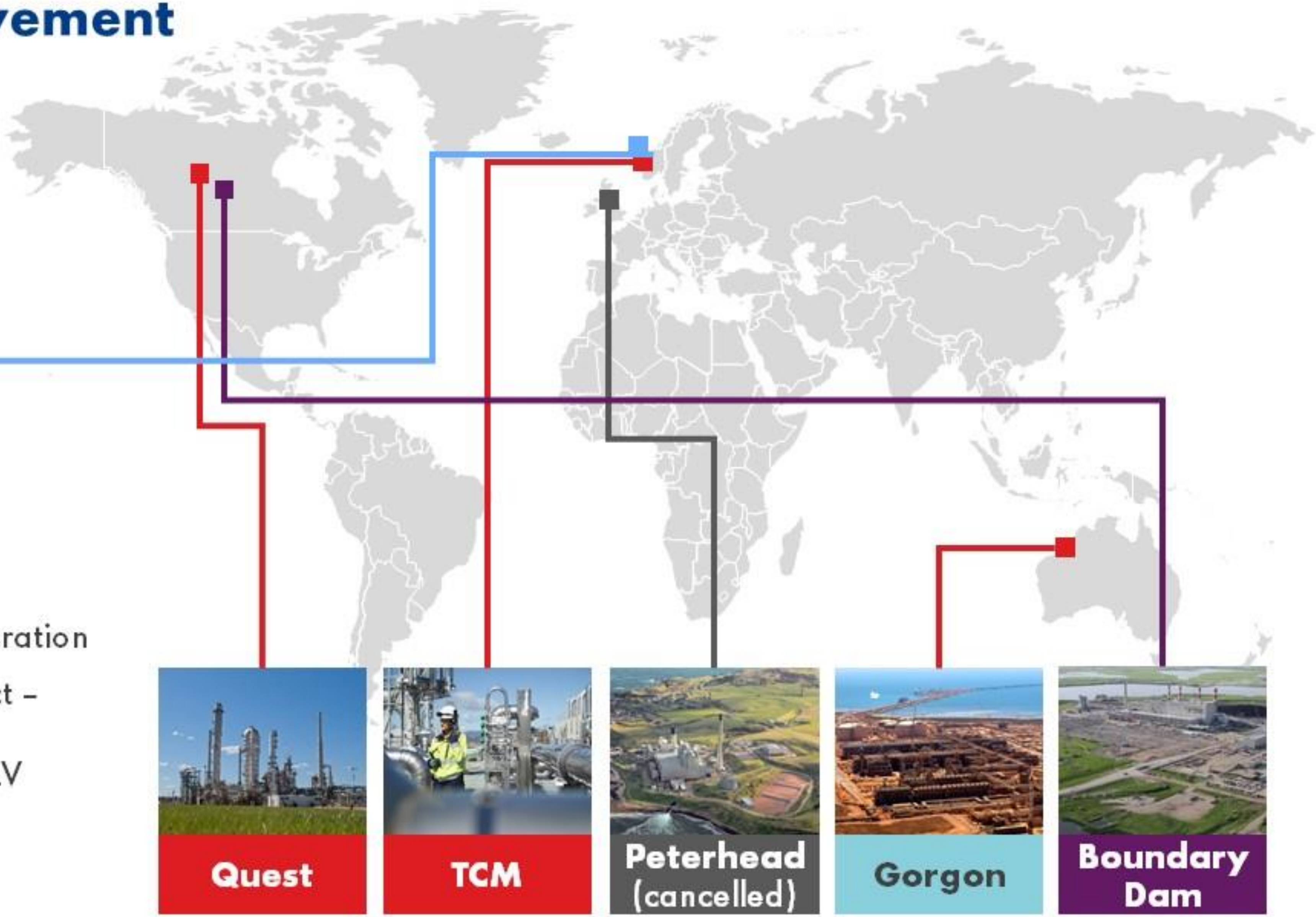
- Power (coal, residue, gas, waste)
- Upstream oil and gas
- Oil sands
- Cement
- And… yes, refining

Managing carbon at Shell

- Sustainability and carbon risk management
- Credits and offsets
- Capture, transport, sub-surface, sequestration and EOR core competence:
  - Large-scale commercial projects
  - Mature CO_2 capture technologies
  - Research partnerships
  - Provisions for CCS retrofit in current projects

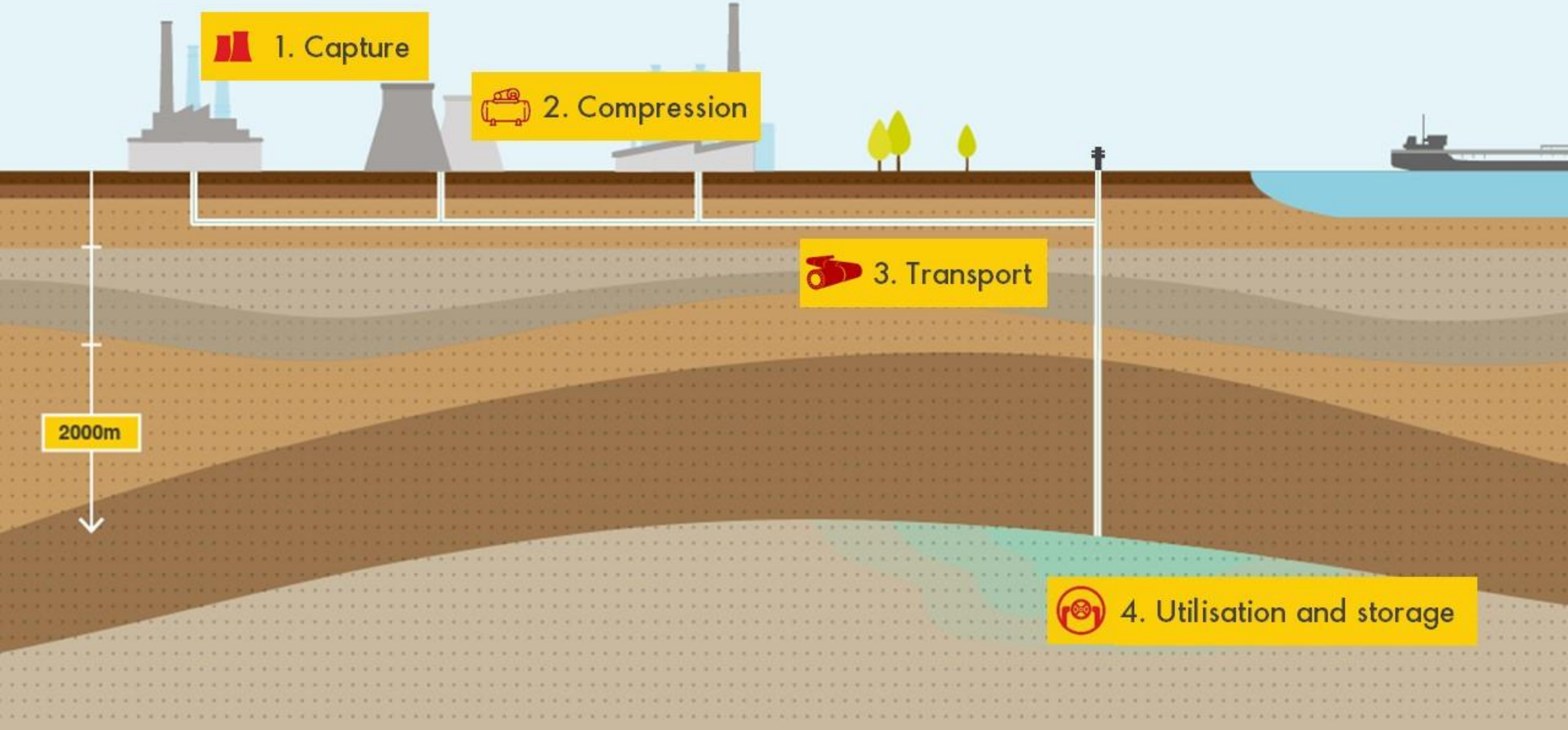
Global Shell involvement in CCS projects





- Industrial scale projects in operation
- Planned industrial scale project – FEED completed
- Involvement through CANSOLV technology – no Shell equity
- CCS project under construction/planning

CCUS: The four-headed monster



Step 1: Capture – Flue gas CO_2 capture

Vol% CO_2 in flue gas: LOWER CO_2 → HIGHER CO_2

Source	Vol% CO_2	Fluegas precleaning		Output
Combined cycle gas turbine power plant/CHP	3-4% CO_2	Minimal	Amine unit	Pure CO_2
FCCU/FCU/furnace offgas	7-9% CO_2	Significant	Amine unit	Pure CO_2
Open cycle gas turbine power plant/CHP	9-10% CO_2	Minimal	Amine unit	Pure CO_2
Coal-fired power plant	11-13% CO_2	Significant	Amine unit	Pure CO_2
Sulphur recovery unit tail gas offgas	17-22% CO_2	Medium	Amine unit	Pure CO_2
HMU offgas (post-combustion)	18-22% CO_2	Minimal	Amine unit	Pure CO_2
Cement kiln offgas	20-24% CO_2	Significant	Amine unit	Pure CO_2

Step 1: Capture

- Three different CO_2 capture routes:
  - Pre-combustion (high pressure)
  - Post-combustion (low pressure)
  - Oxyfuel

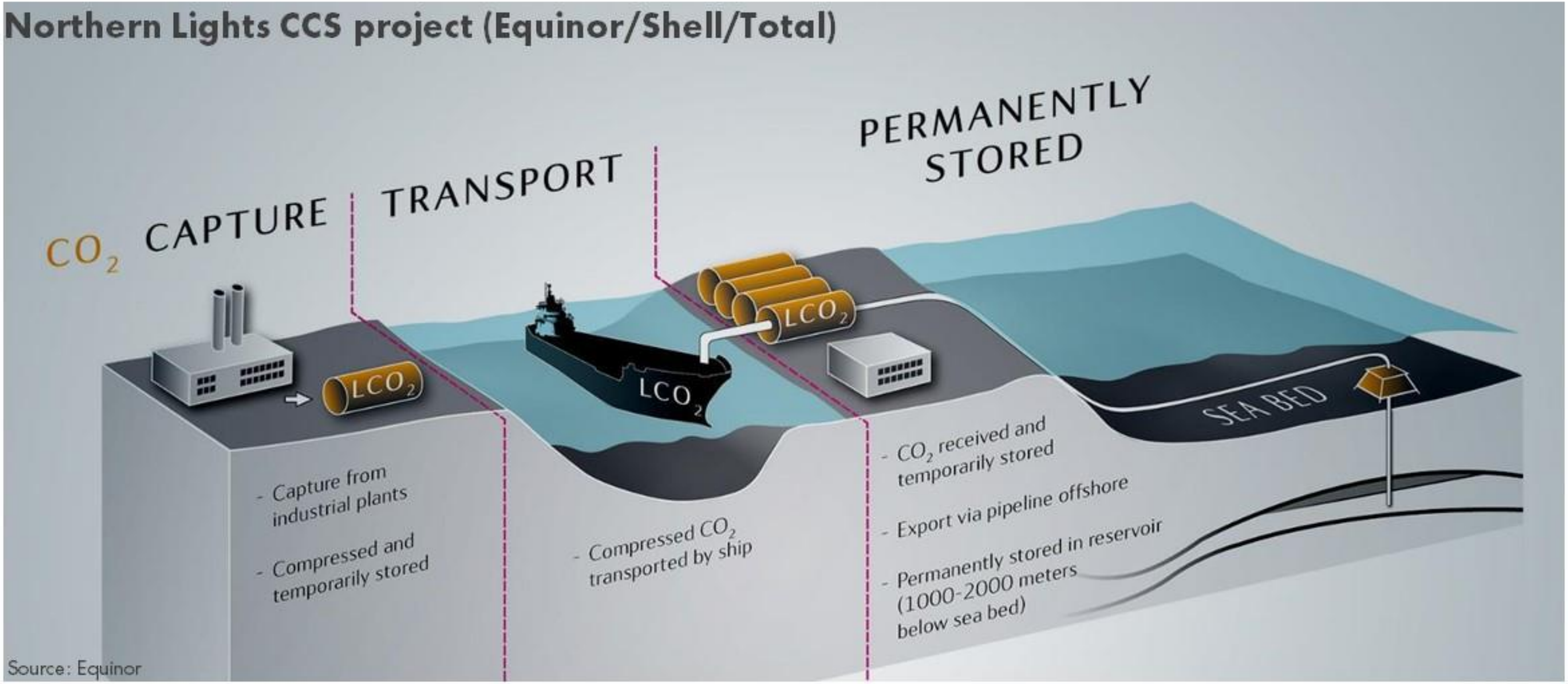
- CO_2 capture relevant for pre- and post-combustion routes

- CO_2 is separated from the gas using a solvent

Step 2: CO_2 compression

- Deep dehydration is often required
- Project specific specifications – TEG or mol sieve
- Approx 1200 psig (84 Bar)
- Commercial, fully available technology
- 9–12MW electricity consumption per 1MM tpa

Step 3: Pipeline may be most the cost-effective transportation option for many projects, but ship transport will also play a role

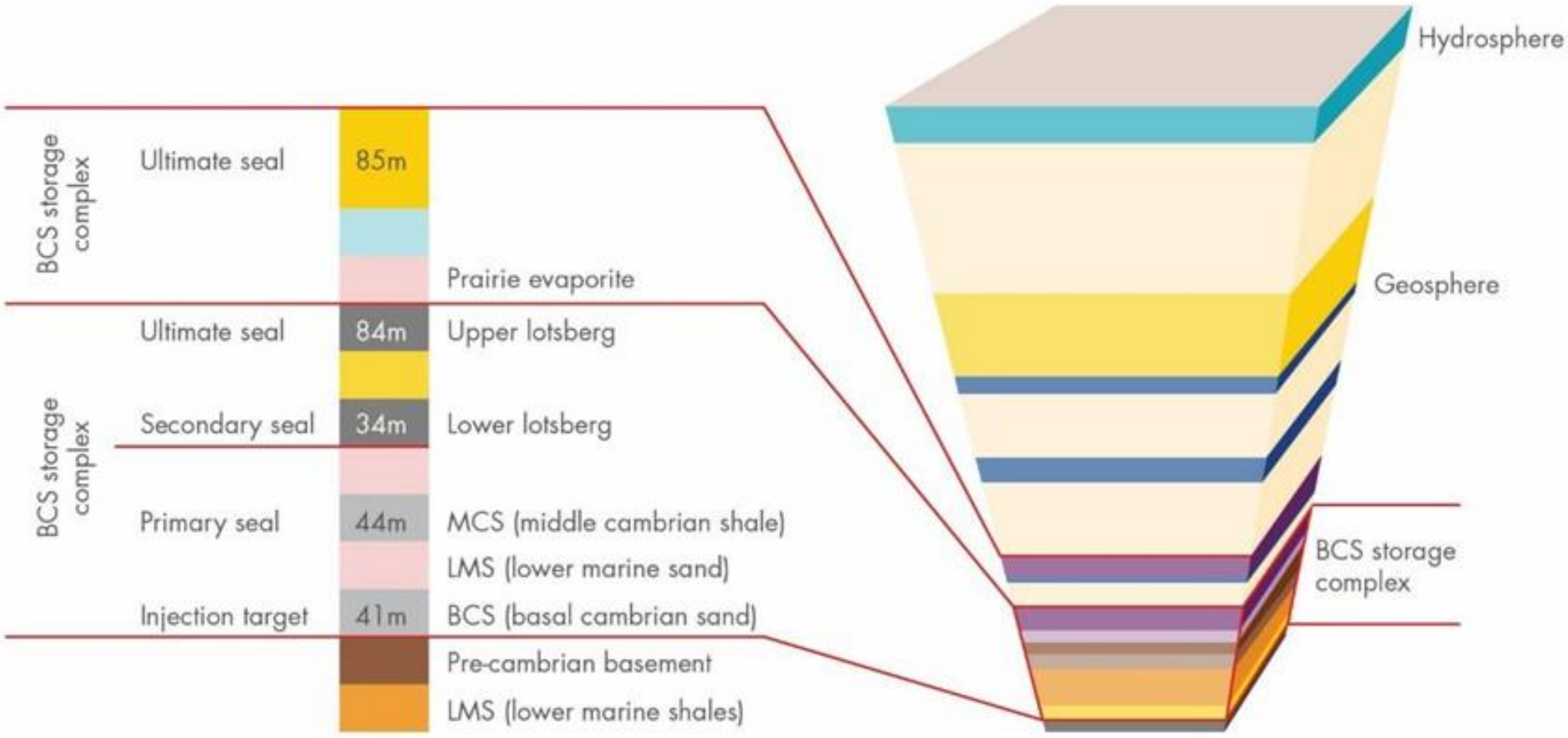


Step 4: Utilisation and storage

Ultimately, to address climate change, all captured CO_2 must be sequestered

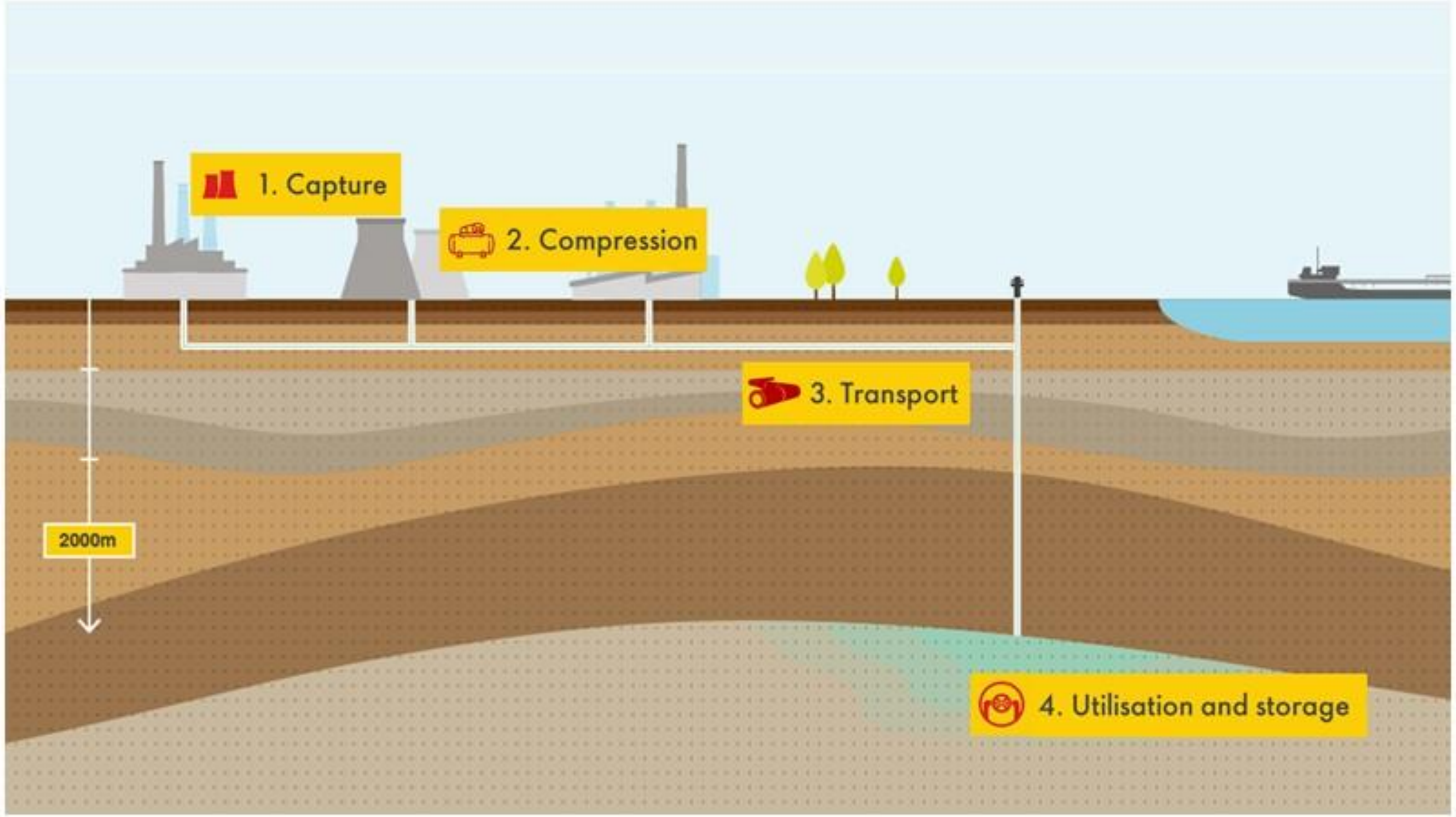
Other than possible new utilisation options (building materials, asphalt/paving material, etc) only two options exist today:

1. CO_2 sequestration deep underground
2. EOR with sequestration



CCUS: Some key considerations for refiners

- Clustering
- Assessing transport costs
- Nearest point to sequester
- Nearby users of CO_2



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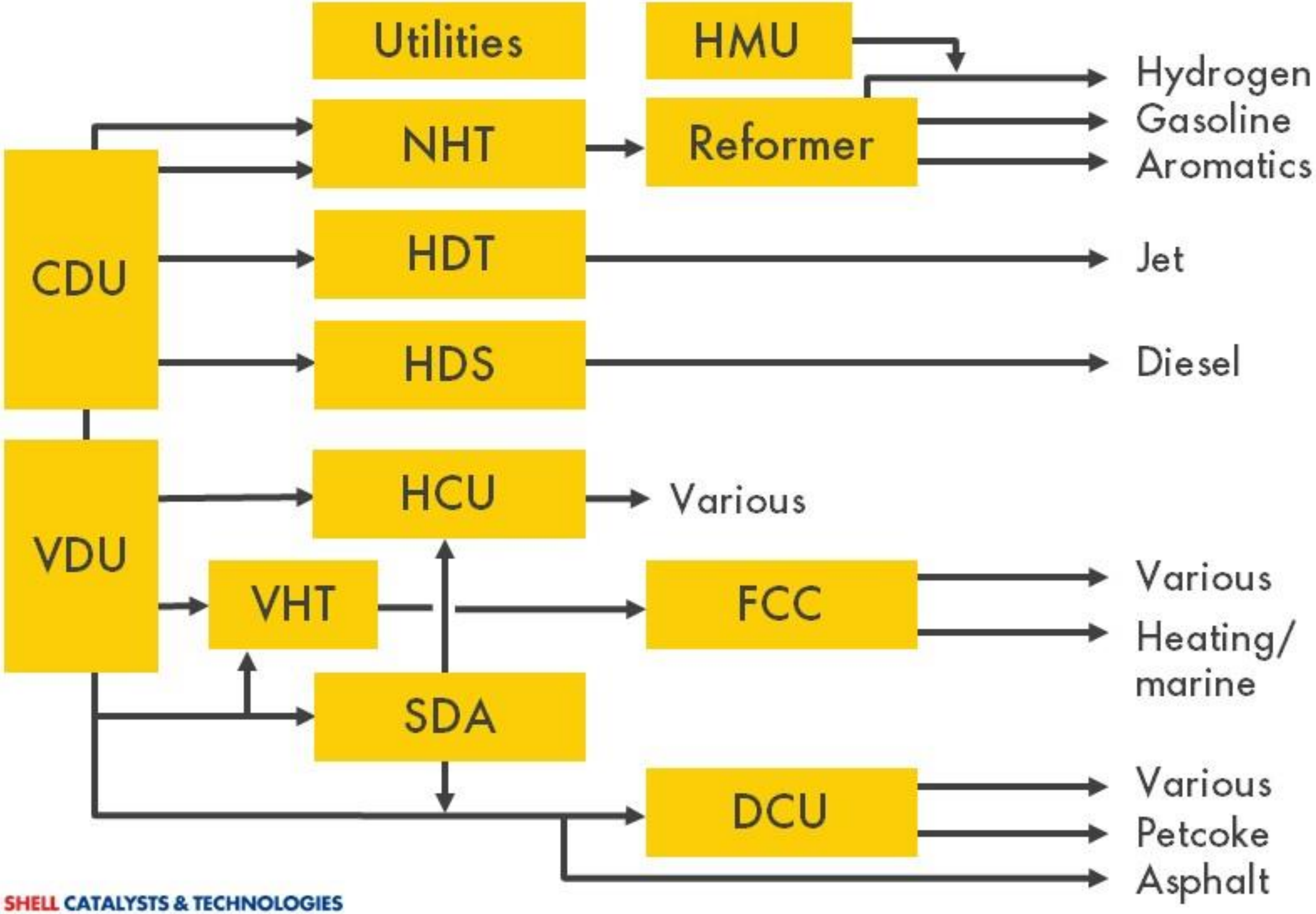
TRANSFORMING ENERGY TOGETHER

CO_2 CAPTURE

Which are the main CO_2 sources in a refinery?



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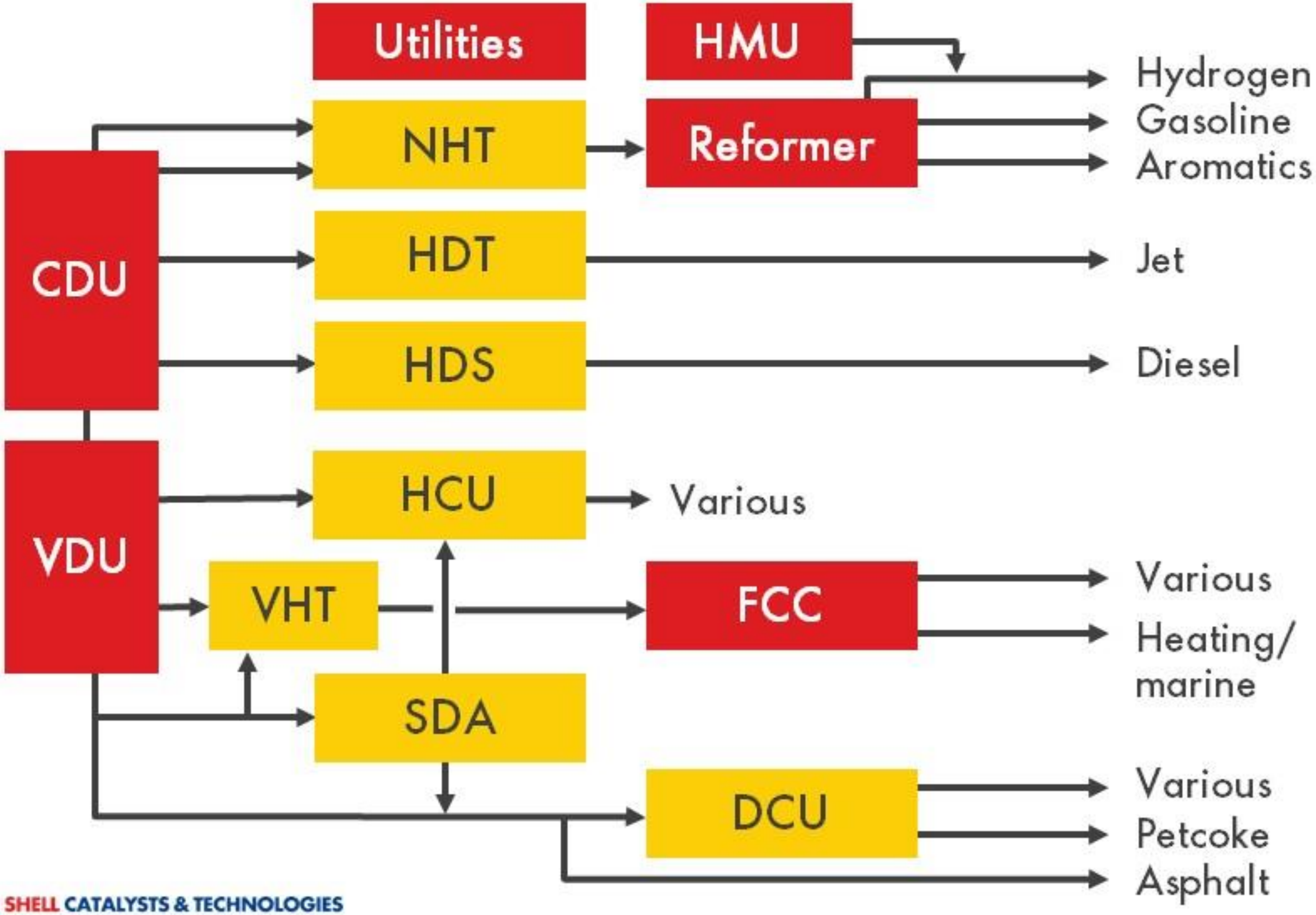
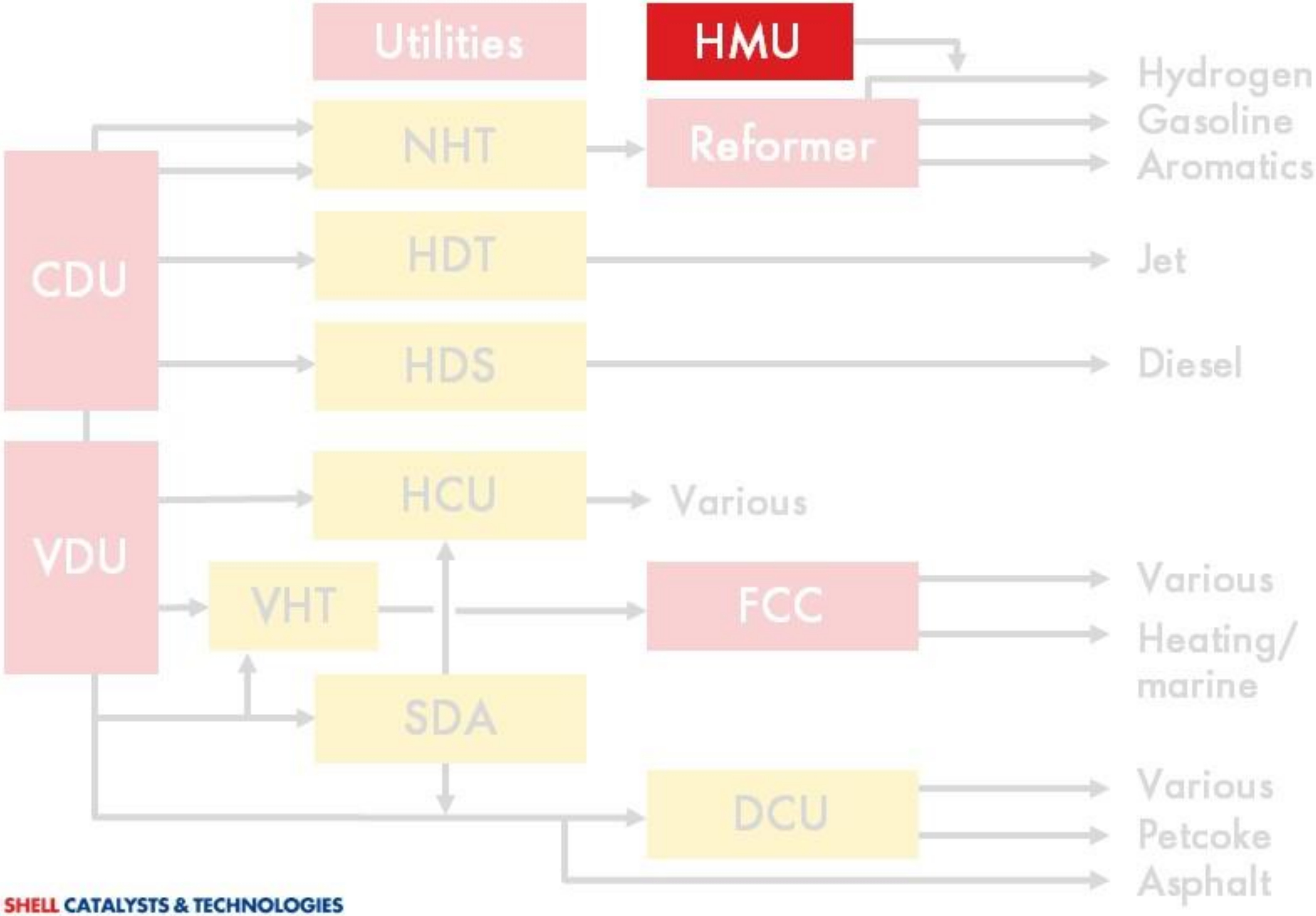
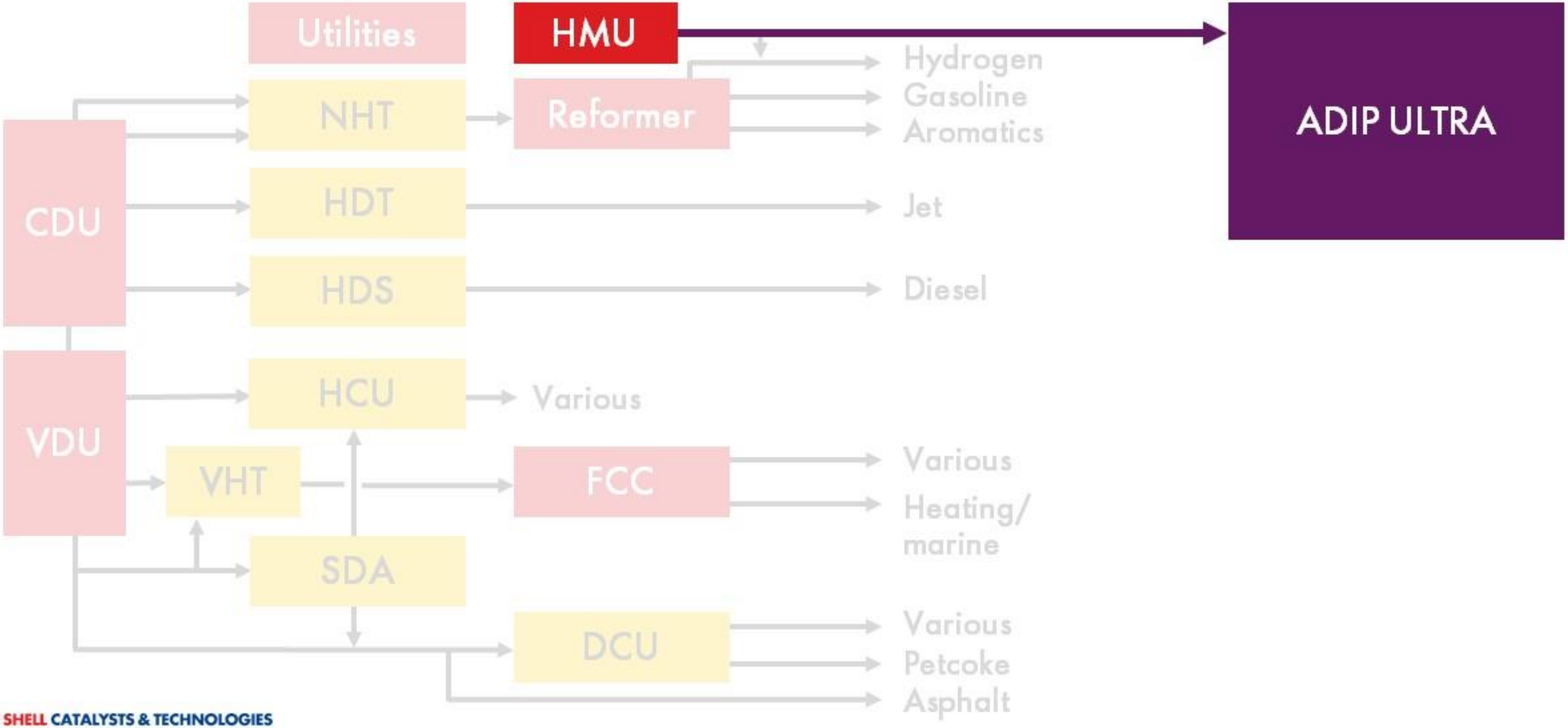


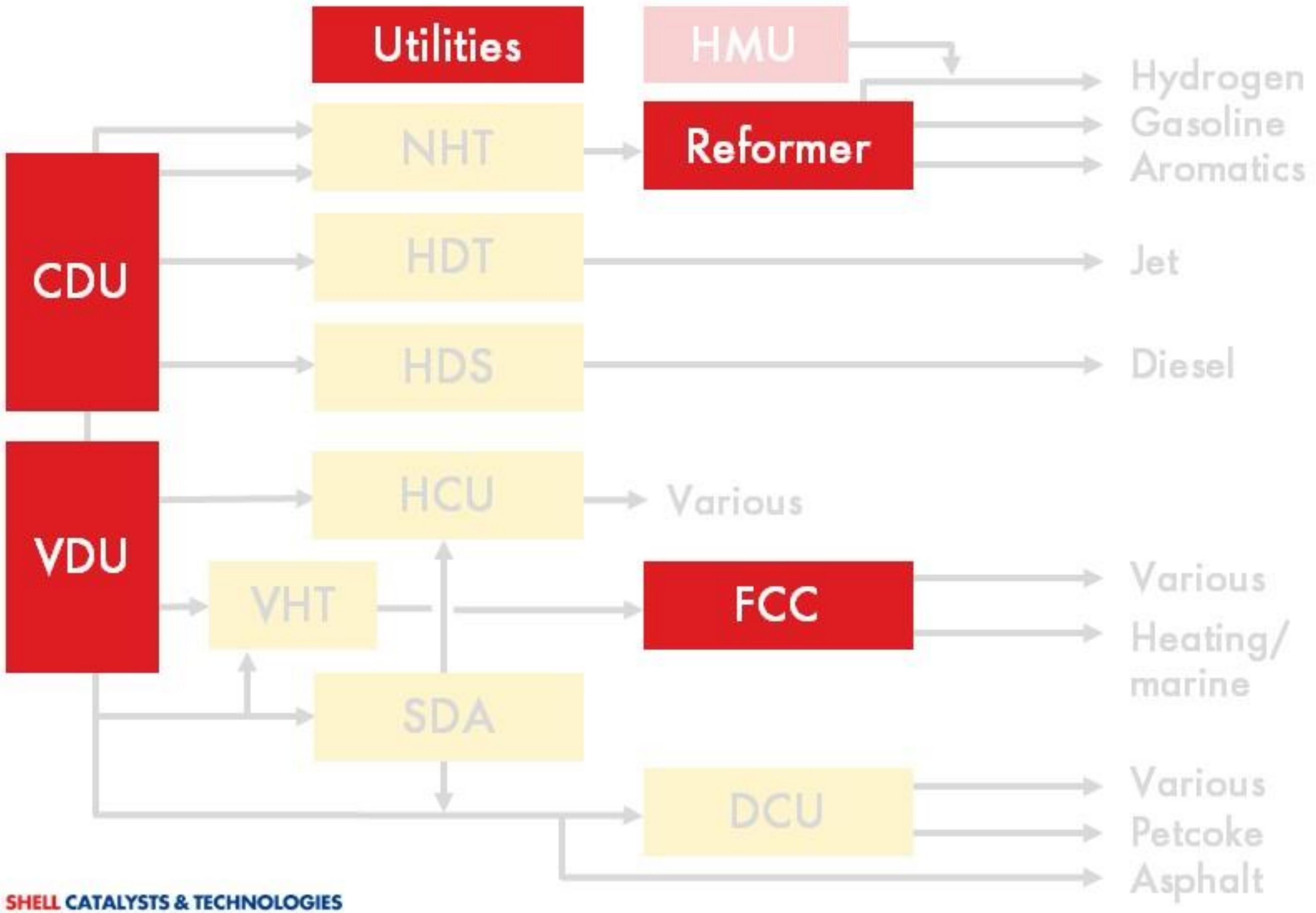
Capturing CO_2 from high-pressure process streams



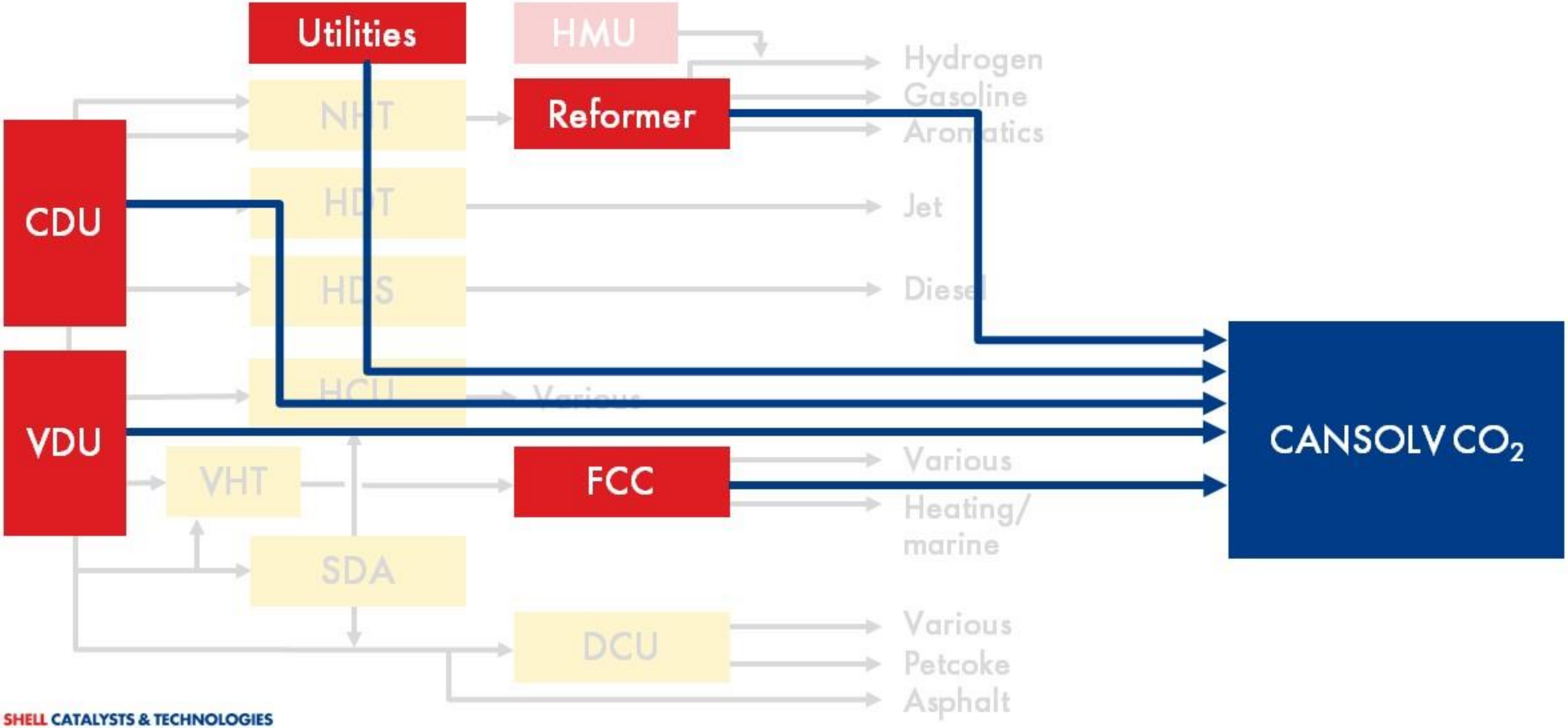
Capturing CO_2 from high-pressure process streams



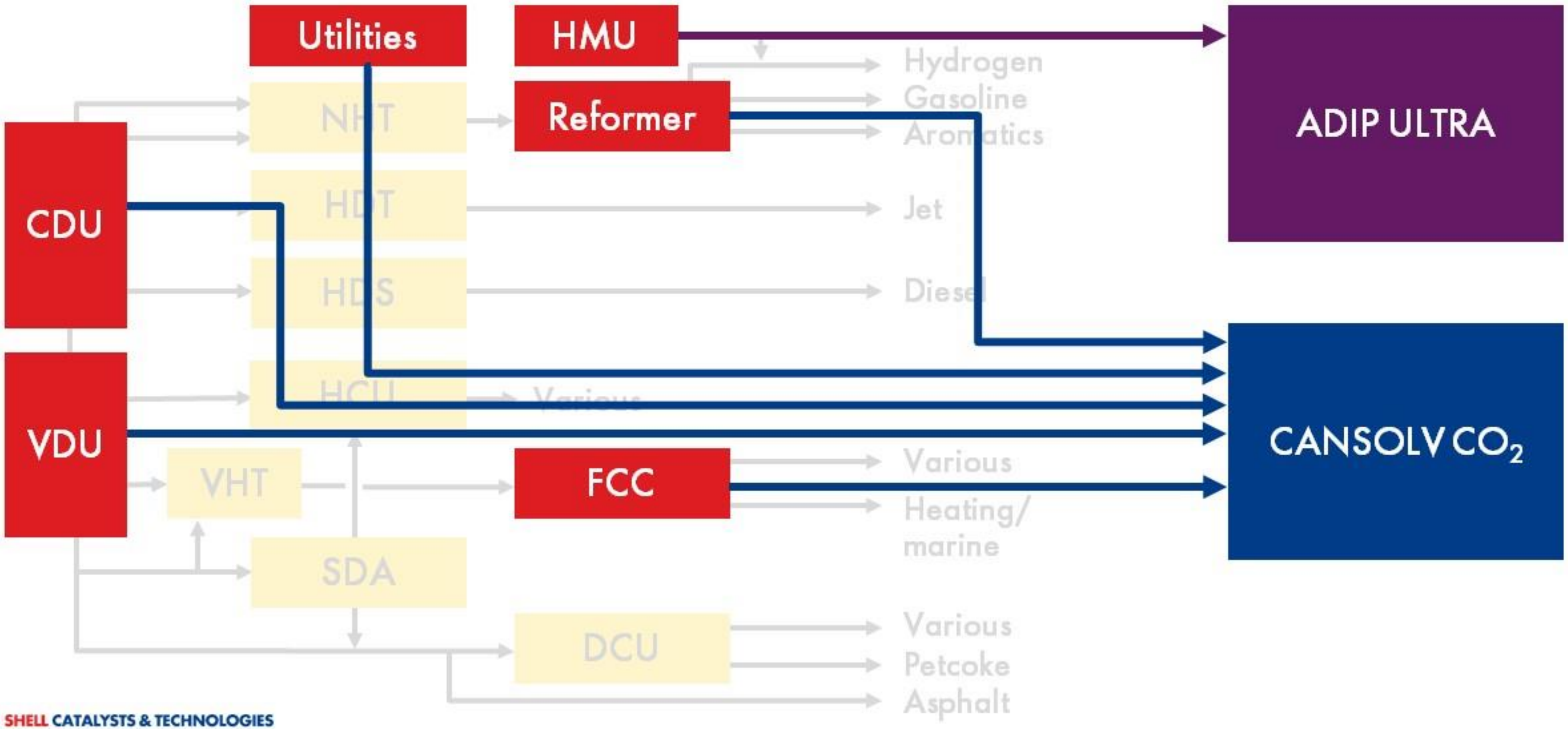
Capturing CO_2 from low-pressure flue gases



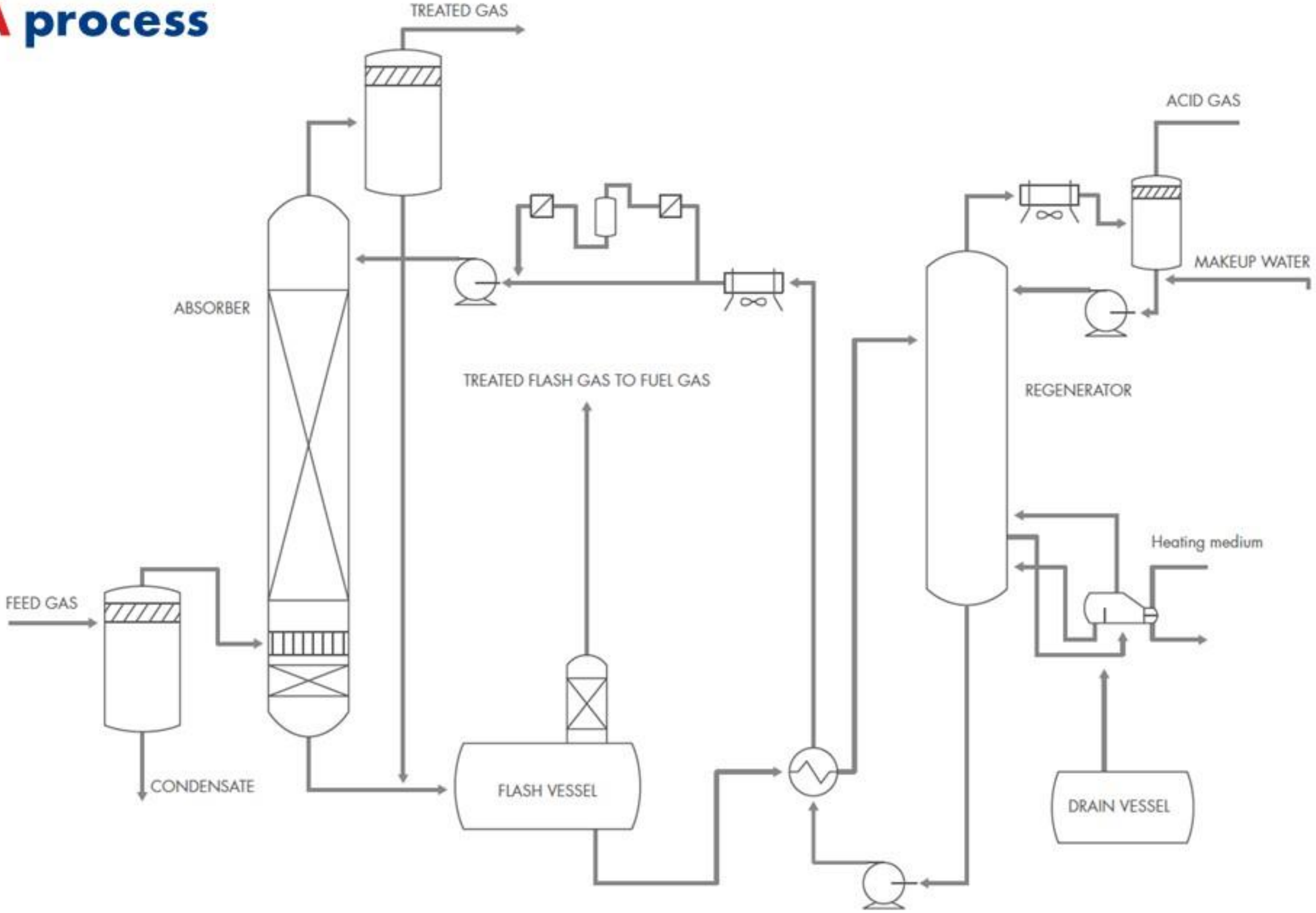
Capturing CO_2 from low-pressure flue gases



Technologies for both high- and low-pressure streams



The ADIP ULTRA process



ADIP ULTRA technology – for high-pressure process streams

Track record

Next generation

Performance advantages

ADIP has been deployed at 500 Shell and non-Shell sites worldwide

ADIP ULTRA technology – for high-pressure process streams

Track record

Next generation

Performance advantages

ADIP ULTRA uses an optimised solvent formulation, proprietary equipment and improved design

ADIP ULTRA technology – for high-pressure process streams

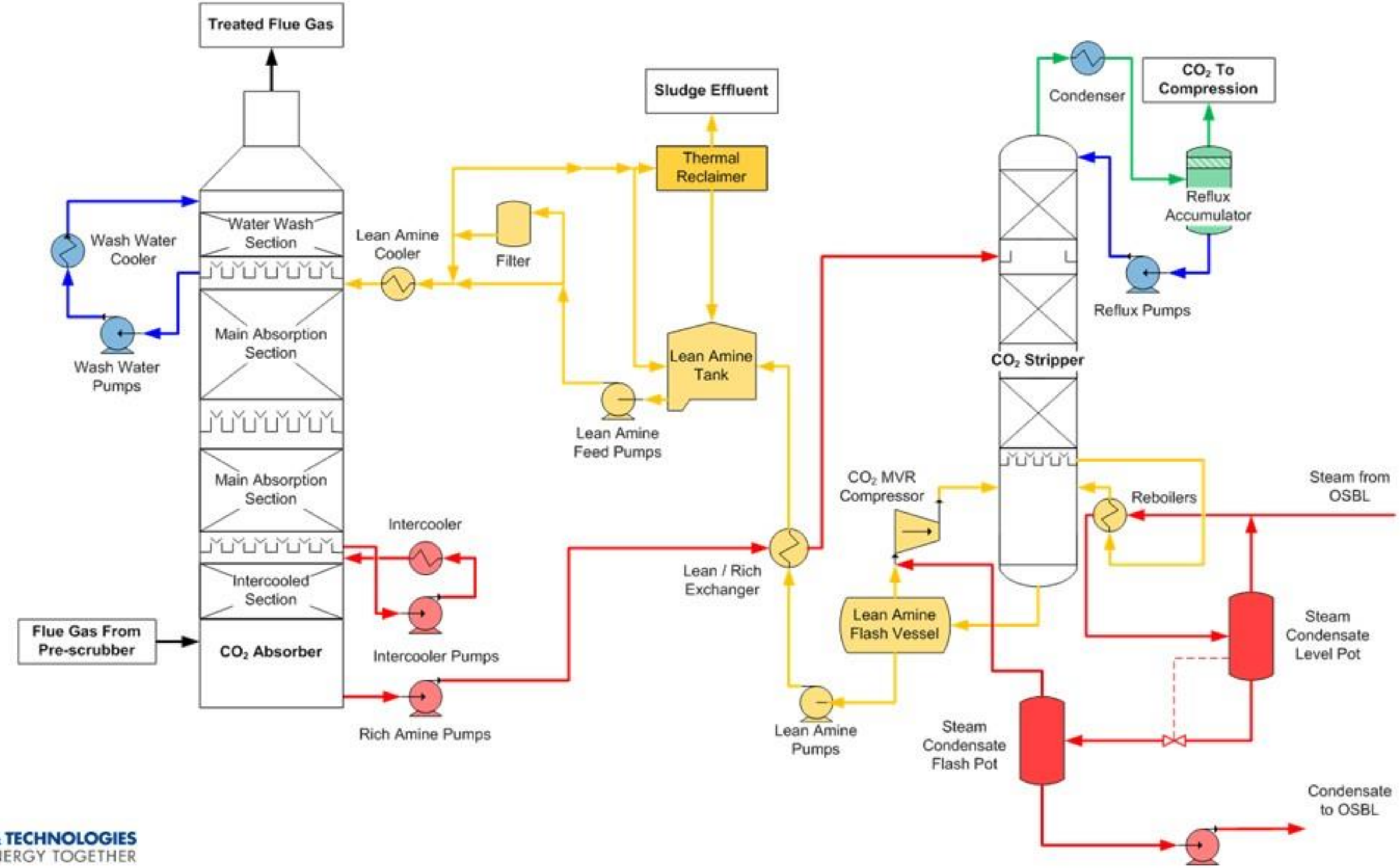
Track record

Next generation

Performance advantages

90+% bulk CO_2 removal – **30%** lower capex – 30% lower energy – **25%** more CO_2 captured

The CANSOLV CO_2 process



CANSOLV CO_2 technology – for low-pressure streams

CO_2 purity

Low waste

Low operating costs

Track record

The pure CO_2 product enables EOR, CCS or carbon capture and utilisation downstream of the plant

CANSOLV CO_2 technology – for low-pressure streams

CO_2 purity

Low waste

Low operating costs

Track record

The process uses a regenerable solvent so no direct waste by-products are generated, which can reduce project costs, as the effluents are minimal

CANSOLV CO_2 technology – for low-pressure streams

- CO_2 purity
- Low waste
- **Low operating costs**
- Track record

Low parasitic energy consumption, fast kinetics and extremely low volatility help to reduce the costs of operation and amine consumption

CANSOLV CO_2 technology – for low-pressure streams

CO_2 purity

Low waste

Low operating costs

Track record

Case study 1: QUEST

Situation: The Scotford upgrader at the Athabasca Oil Sands Project generates its own hydrogen, which creates CO_2

So Shell launched Quest – the world's first commercial-scale CCS project for an oil sands operation

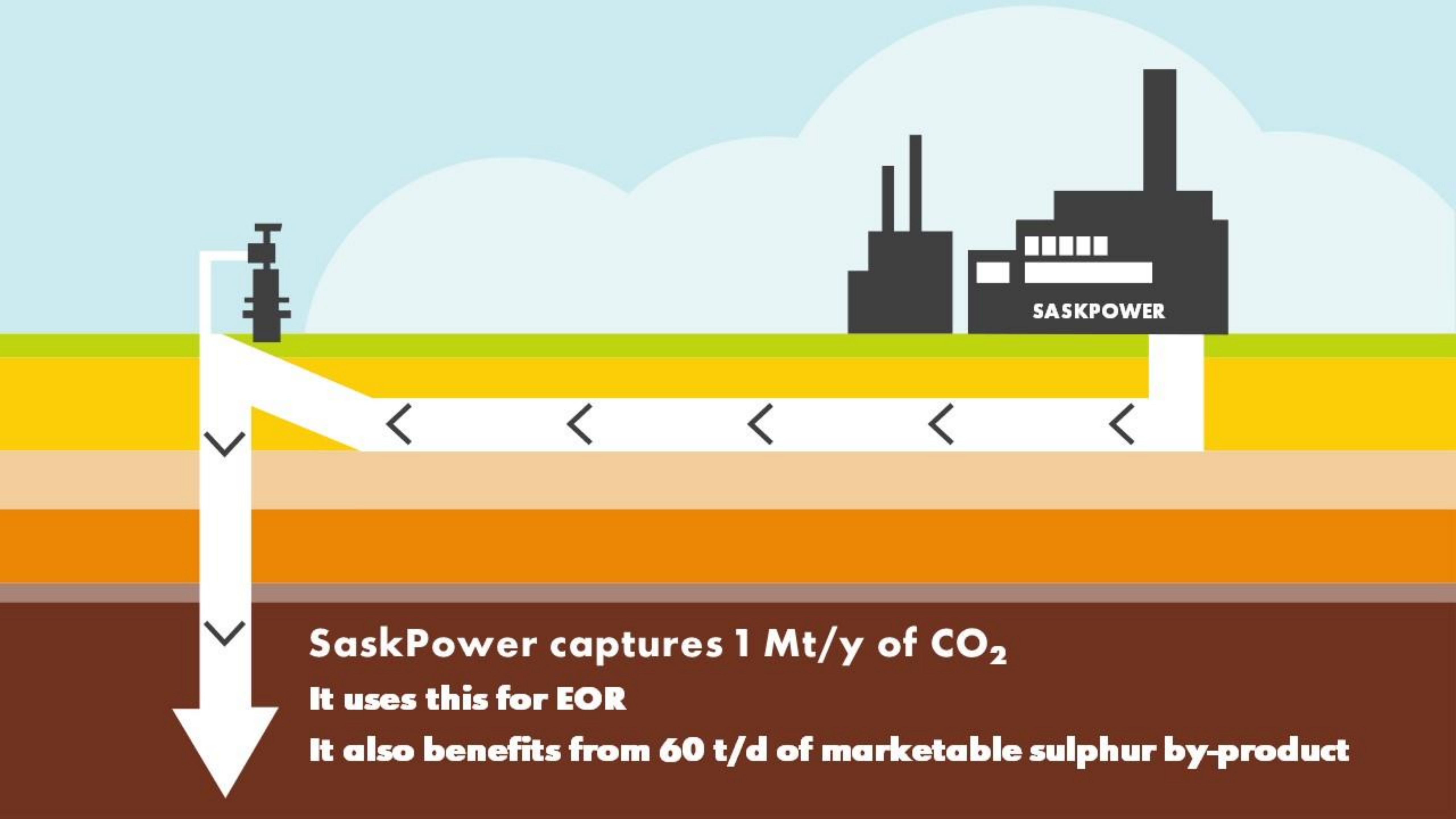

Solution: Quest installed Shell's ADIP ULTRA technology, which captures about 80% of the CO_2 from the HMUs' process gas streams
SCOTFORD UPGRADER


SCOTFORD UPGRADER
Quest captures 1 Mt/y of CO_2
Equivalent to taking 175,000 North American cars off the road

Case study 2: SASKPOWER

Situation: The Canadian power company needed to reduce both CO_2 and SO_2 emissions

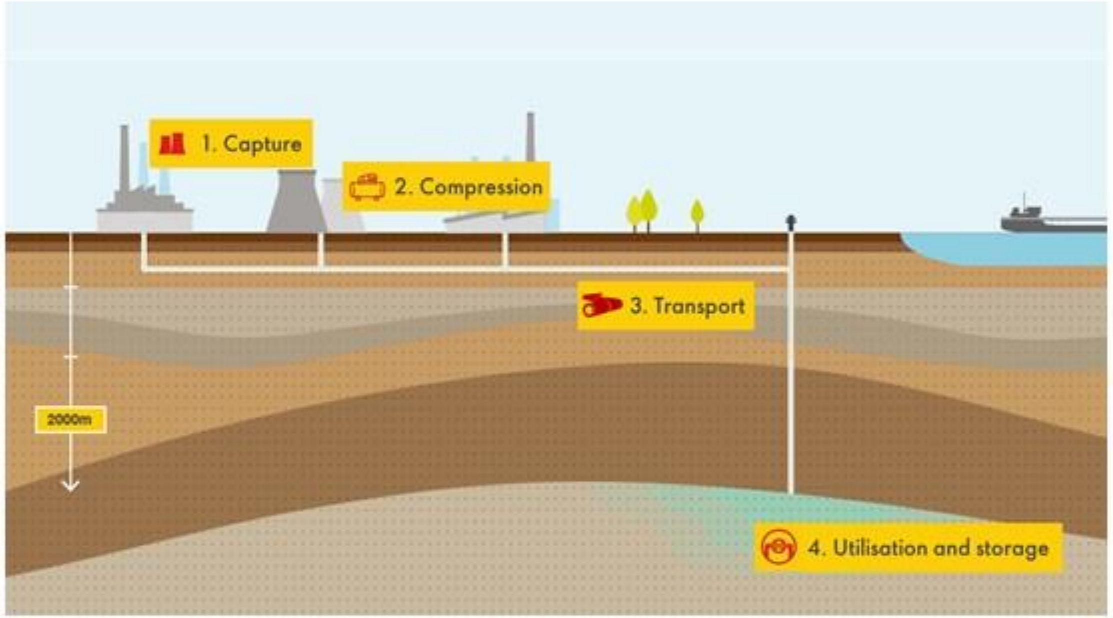
Solution: SaskPower installed the CANSOLV SO_2–CO_2 Integrated Capture System for combined carbon capture and flue gas desulphurisation was added


SASKPOWER
SaskPower captures 1 Mt/y of CO_2
It uses this for EOR
It also benefits from 60 t/d of marketable sulphur by-product

KEY TAKEAWAYS

1 Any serious ambitions to reduce a refinery's carbon intensity are likely to be spearheaded by CCUS

2 Shell's CO_2 capture technologies, **ADIP ULTRA** and **CANSOLV CO_2**, are robust, proven and cost effective



3 Shell has wide experience of CCS projects, and has key insights at each of the four major steps – capture, compression, transport, and utilisation and storage