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Introduction to Carbon Capture Processes

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Contents

Essential and relevant topics in CCUS

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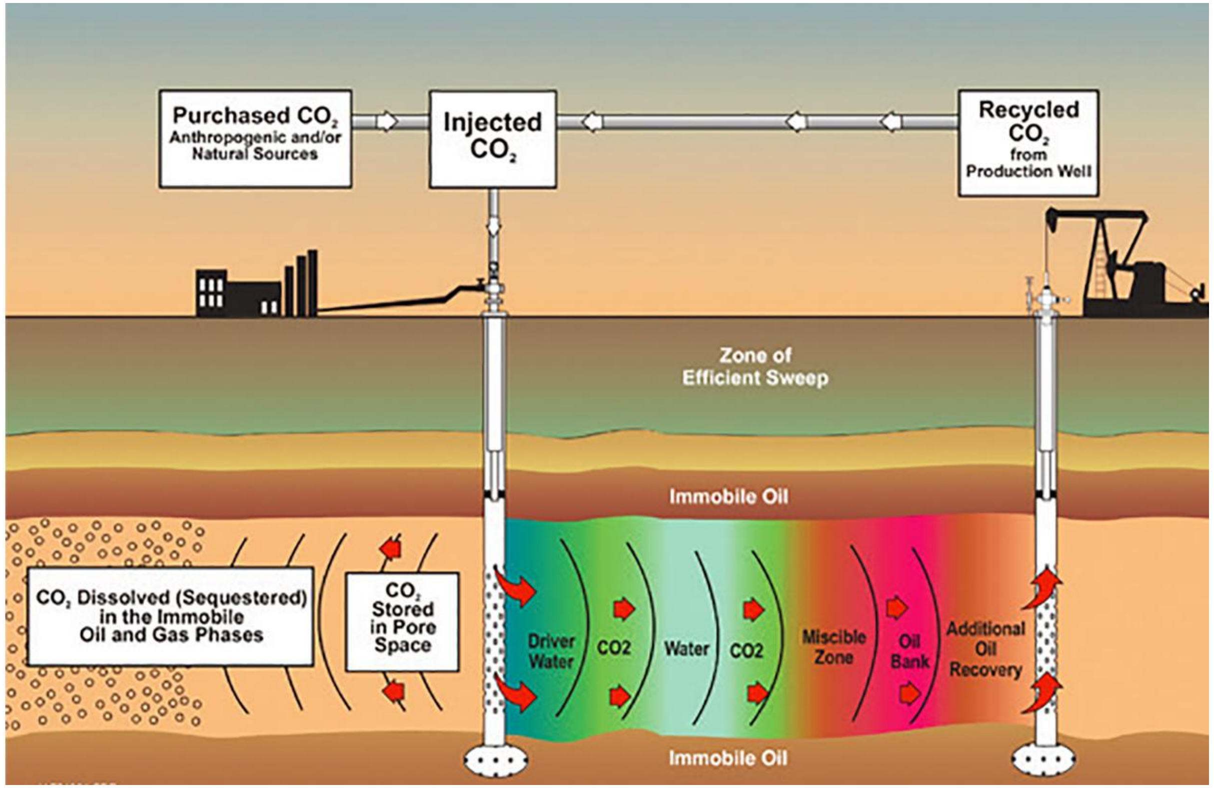
Introduction to CCUS

CCS? CCU? CCUS?

- Carbon capture and storage/sequestration (CCS)
- Carbon capture, utilization and storage (CCUS)
  - Synthetic fuel (MeOH, etc.)
  - Enhanced Oil Recovery (EOR)



Enhanced oil recovery (ATACAN energy)

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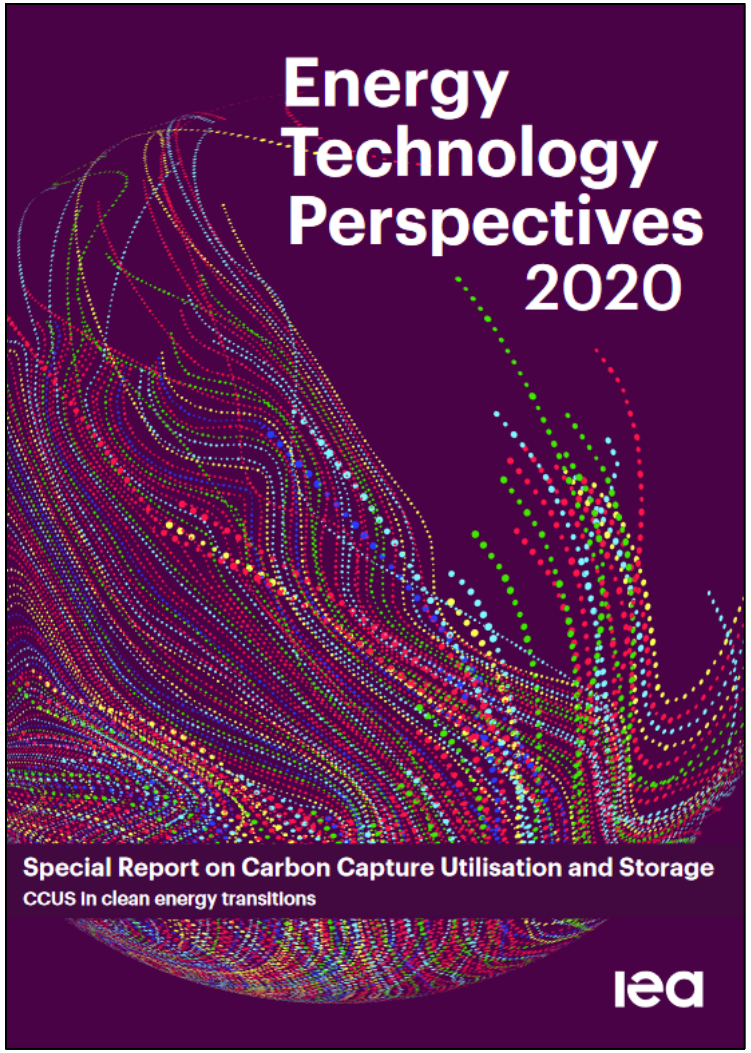
Introduction to CCUS

Why carbon capture?

- "Reaching net zero will be virtually impossible without CCUS" (International Energy Agency, 2020)
  - Tackling emissions from existing energy infrastructure – **retrofittable**
  - A solution for some of the most challenging emissions – **heavy industries** (cement, iron and steel, chemicals, synthetic fuels)
  - A cost-effective pathway for low-carbon hydrogen production – "**blue hydrogen**"
  - Removing carbon from the atmosphere – **emissions that cannot be avoided or reduced directly**



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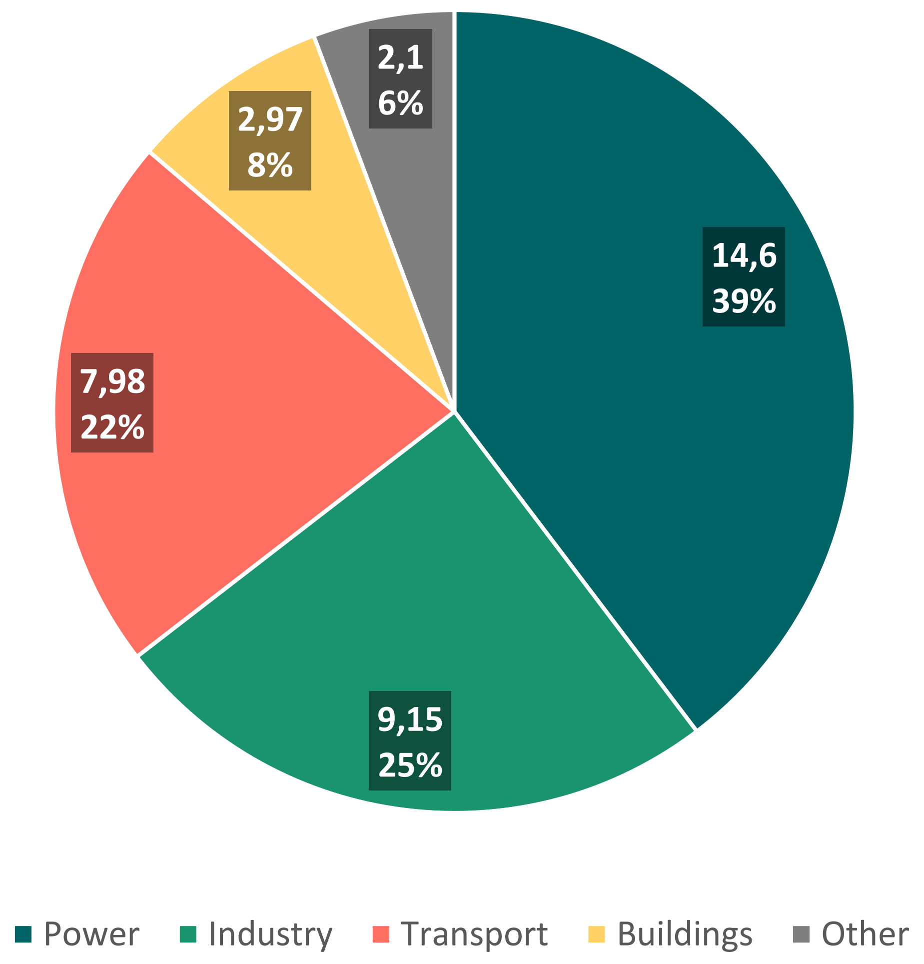
Introduction to CCUS

Why carbon capture?

- 64 % of global emissions come from **power** and **industry** sectors that are very difficult to decarbonize.
- CCUS allows continued use of existing infrastructure

Global CO2 emissions by sector (Gt), 2022 (IEA)



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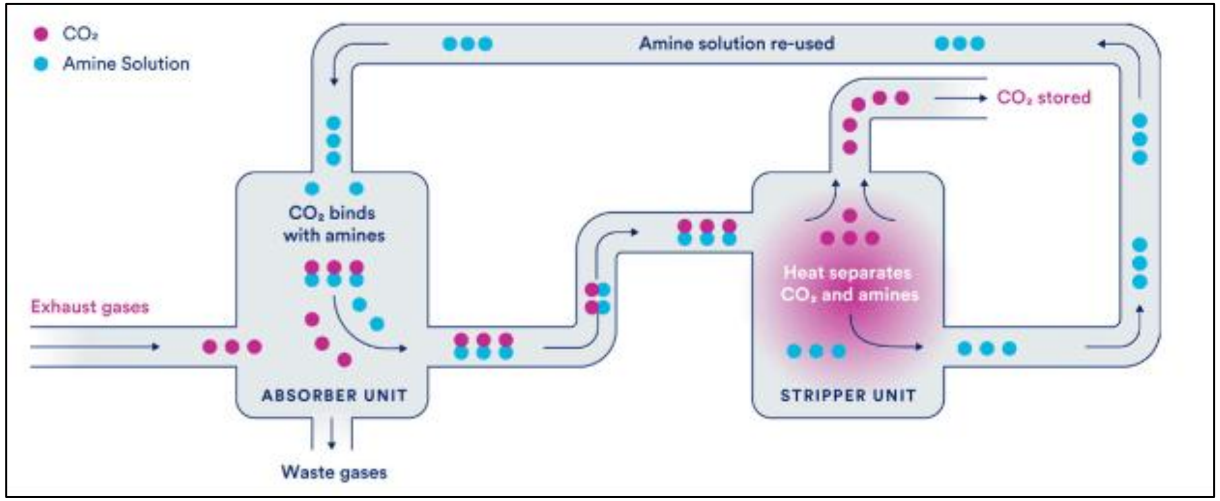
Introduction to CCUS

Types of CCUS

- Post-combustion
  - Most mature technology
  - Selective absorption of CO_2 in flue gases using amine solvents
  - “Acid gas treating” dates back to 1970s
- Pre-combustion
  - Fuel gasification to produce syngas (mostly $CO + H_2$)
    followed by water-gas shift reaction ($CO + H_2O \rightarrow CO_2 + H_2$)
- Oxyfuel
  - Pure oxygen injection
- Direct air capture (DAC)
  - Filtering CO2 from atmosphere
    (very low concentration ~400 ppm)



CO2 capture/release reaction in post-combustion carbon capture (Clean Air Task Force)

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Types of CCUS – **Post-combustion** carbon capture

- Gorgon Plant
  - Barrow Island, Australia
  - World's biggest carbon capture plant
  - CO2 from LNG plants
  - 2 Mt-CO_2/yr

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Types of CCUS – **Oxyfuel** carbon capture

- Callide Oxyfuel Project
  - Queensland, Australia
  - World’s first oxyfuel process
  - Retrofitted to a coal power station
  - 27,300 t-CO2/yr

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Types of CCUS – **Direct air capture**

- ORCA Plant
  - Hellisheidi, Iceland
  - Heat and electricity supplied by the Hellisheidi Geothermal Power Plant
  - 4000 t-CO_2 /yr

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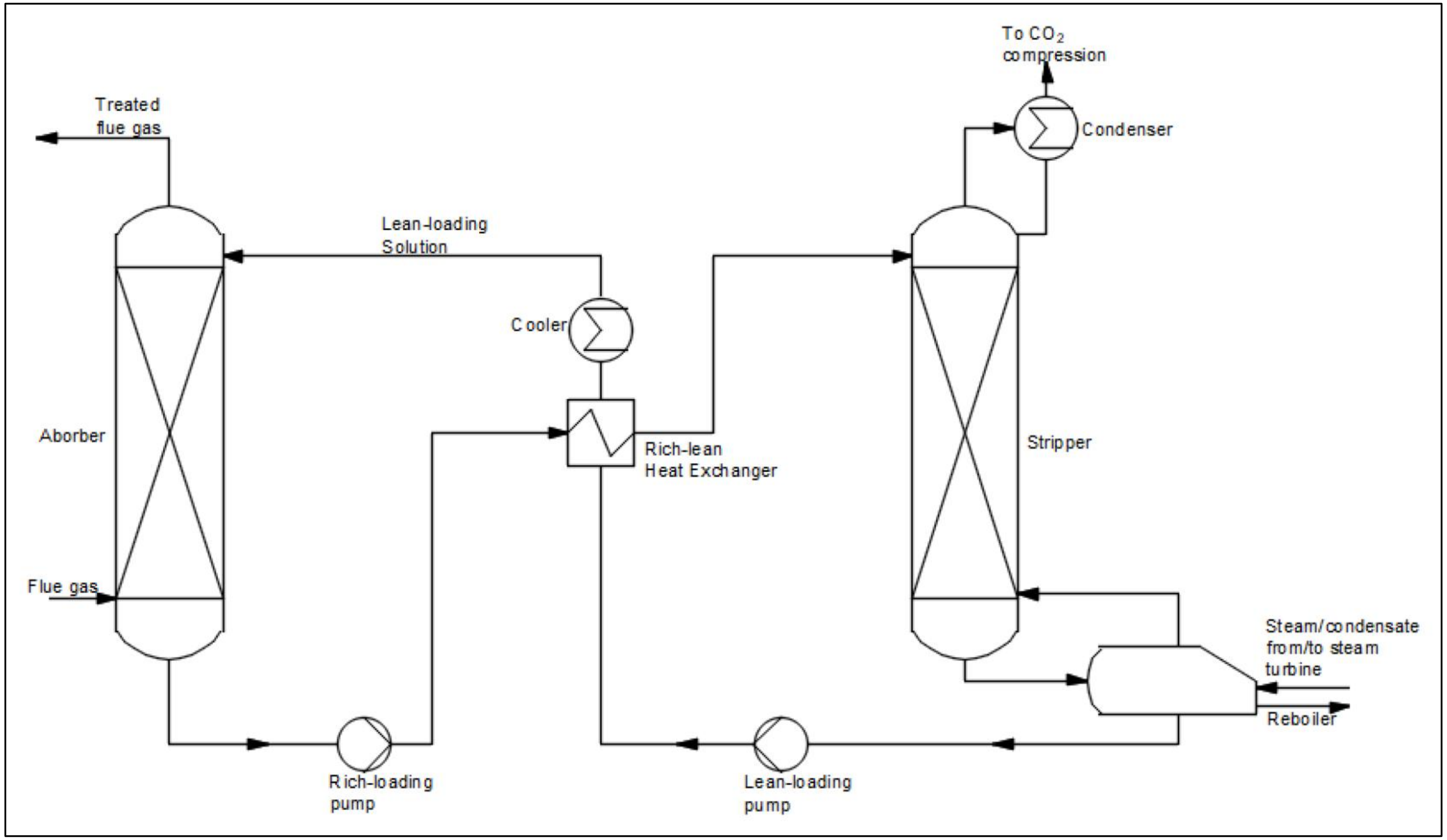
Post-combustion Carbon Capture

Process flowsheet



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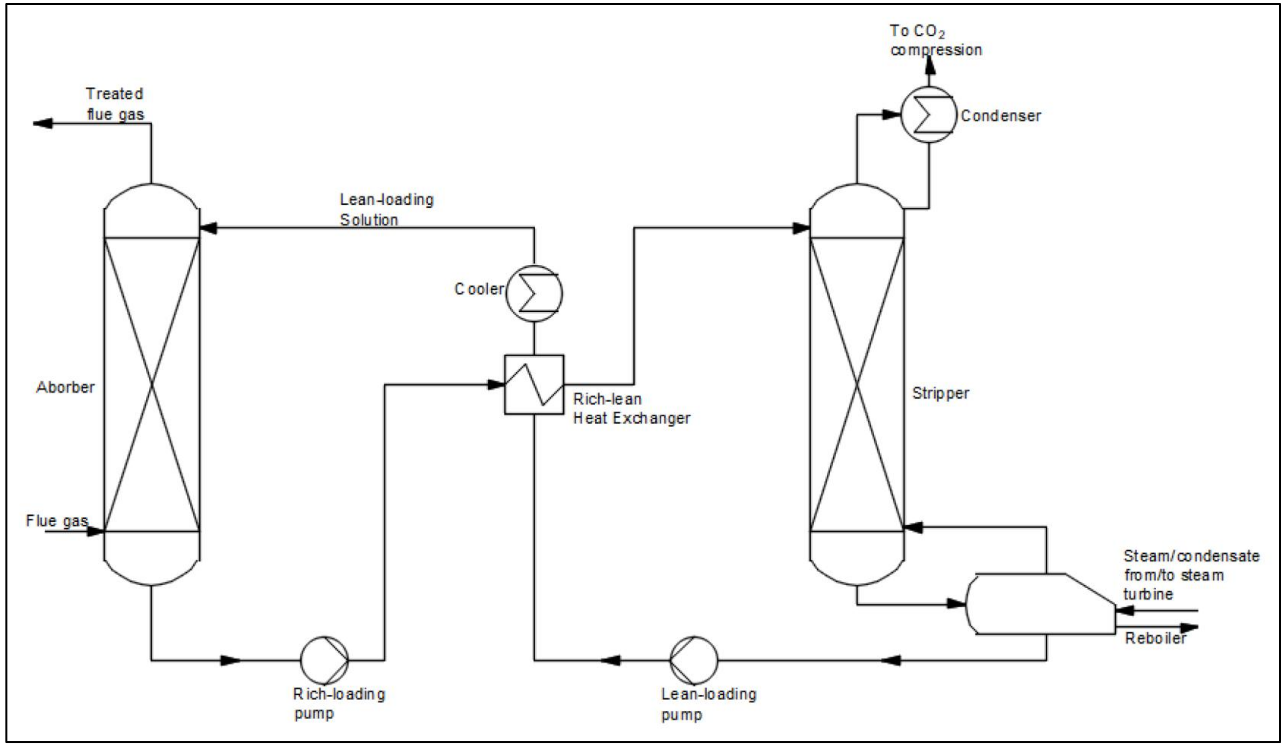
Post-combustion Carbon Capture

Important process units

- Absorber
  - Inlet: Flue gas & lean solvent
  - Outlet: Treated gas & rich solvent
  - Solvent: MEA, MDEA, DEA, K_2CO_3, etc.
  - Blending solvents, additives (PZ)
- Regenerator (or stripper)
  - Separation of CO_2 from the solvent
- Heat exchanger
  - Absorber T: ~30 °C
    - Trade-off between absorption rate and solvent degradation
  - Regenerator T: ~110 °C
    - Trade-off between yield and energy demand



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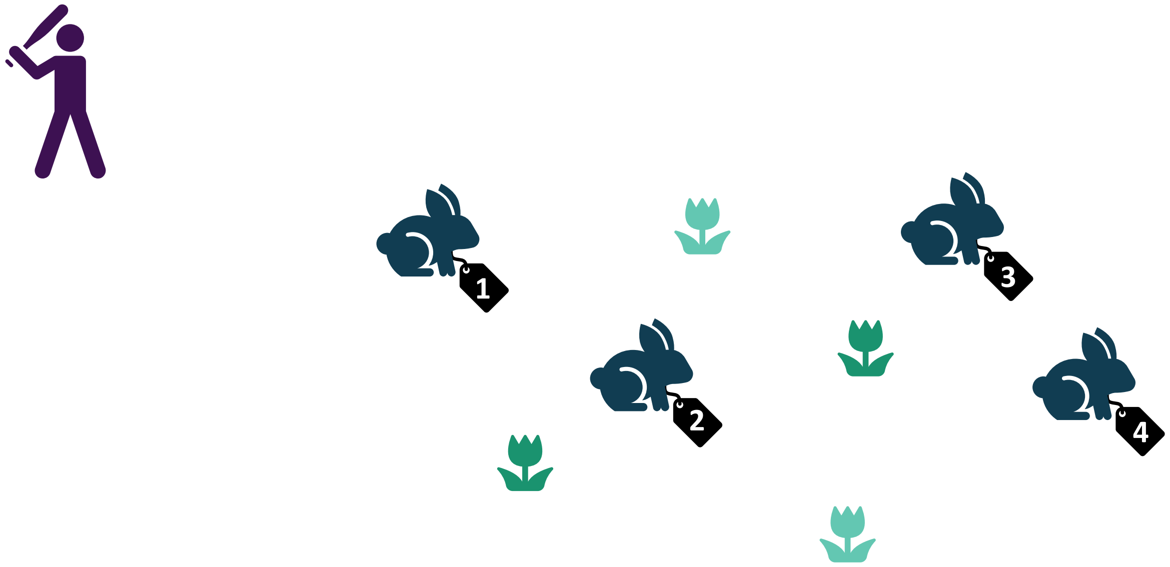
Post-combustion Carbon Capture

Important process parameters



- L/G ratio in the absorber
  - Depends on the solvent
  - 5–20
- CO_2 loading in the lean solvent
  - [mol-CO2 / mol-amine]
  - 0.1–0.5
- CO_2 recovery
  - 80–90 %
- Specific reboiler duty (SRD)
  - [GJ/ton-CO_2]
  - 2.5–4.5 GJ/ton-CO_2
  - Related to “energy penalty” in power plants

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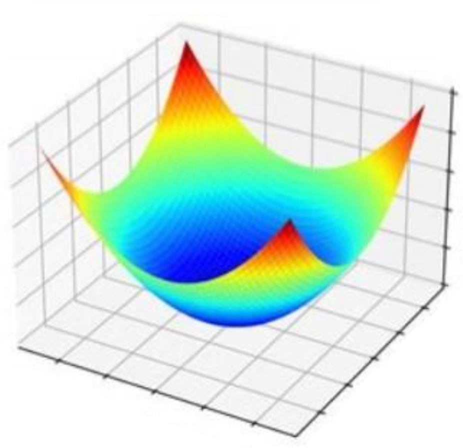
Importance of Process Simulation

From data to decisions

- Controlling/monitoring important process variables
  - Custom variables/equations (CO_2 loading, SRD, energy penalty…)
  - Economic insight (feed cost, utility cost, OpEx, CapEx, product value, NPV, EAOC, …)
- Predicting process behavior
  - What if energy consumption drops? Less flue gas is produced, changing the plant's dynamics. How does the process adapt to ensure stability?
- Optimizing system performance
  - How do critical process parameters impact the system? Case studies reveal the relationships and inform operational decisions.
  - Economic analysis: Simulation helps identify cost-efficient improvements.
- Common chemical process simulation tools:
  - Aspen HYSYS, Aspen PLUS, AVEVA PRO/II, AVEVA Process Simulation, DWSIM, etc.



AVEVA™ PRO/II Simulation

DWSIM Pro

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Importance of Process Simulation

Development

- Stage 1: Collecting experimental data, importing to simulation software
  - Thermophysical properties ($C_p, \Delta H_f^0, \Delta G_f^0, K_{eq}, \ldots$)
- Stage 2: Adding fluid and reaction models to the software
  - Data validation (vapor pressure, mean ionic activity coefficient, osmotic coefficient, etc.)
- Stage 3: Constructing an example simulation with the fluid/reaction models
  - Matching reference process parameters in literature

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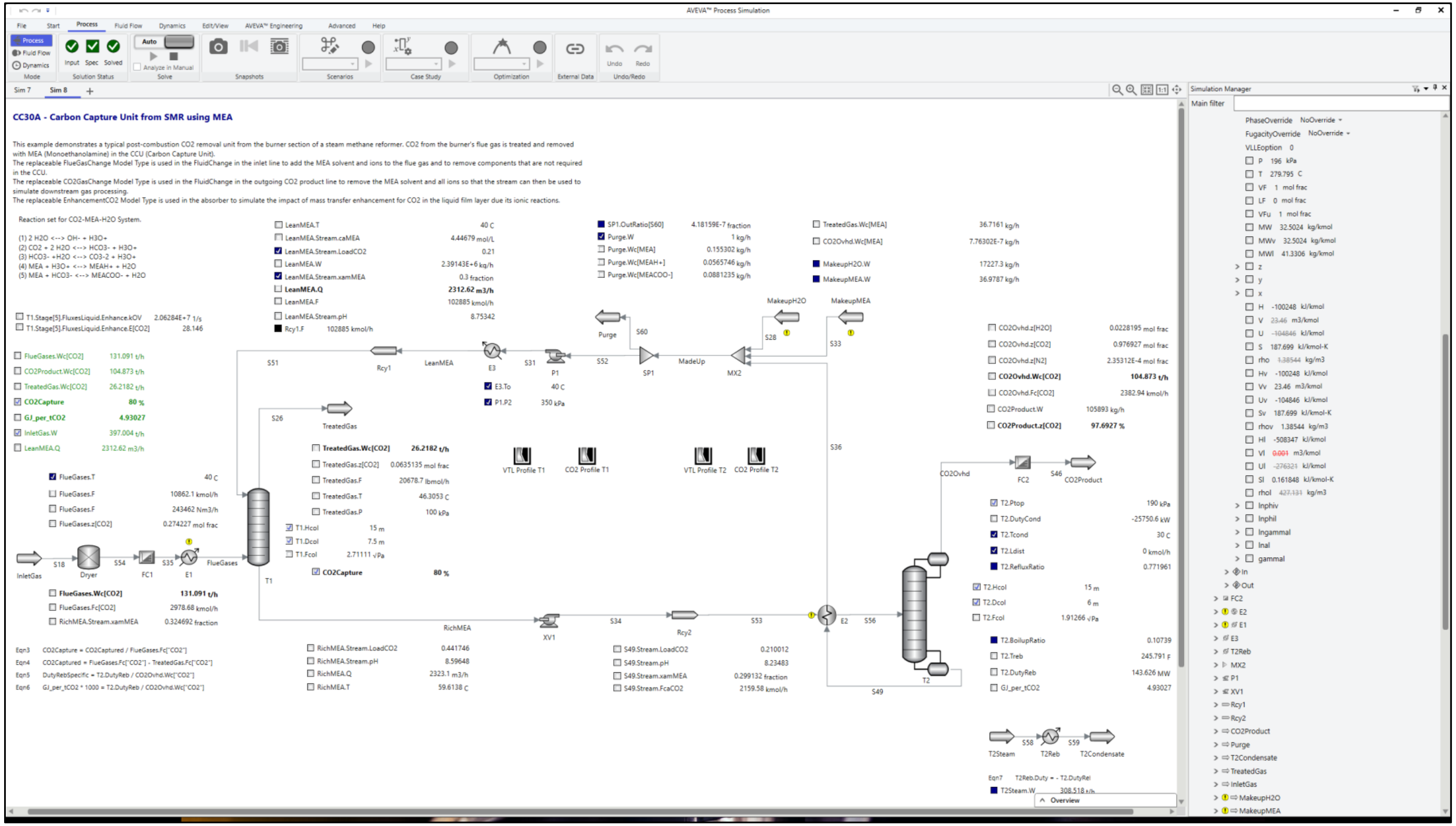
Importance of Process Simulation

Example – Simulation environment



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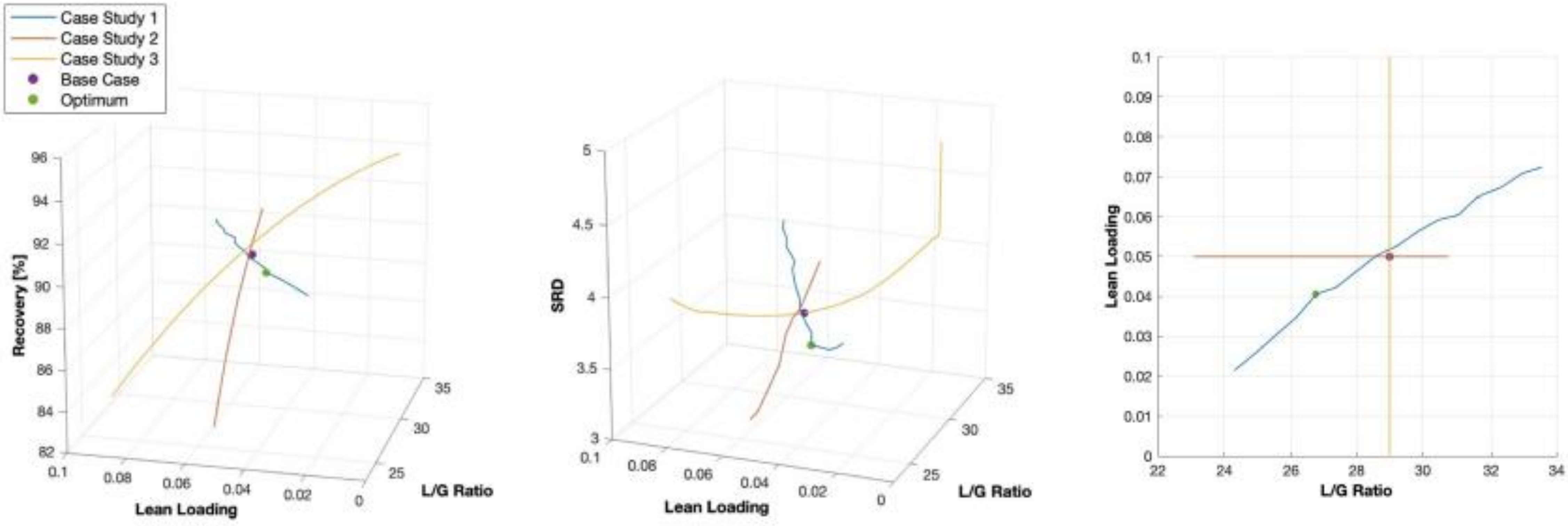
Importance of Process Simulation

Example – Relationship between the process parameters



(a) z-axis as CO_2 recovery (b) z-axis as SRD (c) Bird-eye view

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Prospects

On the road to decarbonization

- Growing importance
- Technological advances
  - Next-generation solvents, DAC, solid sorbents (e.g., K2CO3 “Benfield process”)
  - Dynamic simulation (vs. steady-state simulation)
- Integration with other technologies
  - Hydrogen production
- Policy and economic incentives
  - European Union: Emissions Trading System (EU ETS)
  - European Commission: Carbon Border Adjustment Mechanism (CBAM) (December 2021)
- Bad news, good news
  - Gorgon carbon capture (Australia) operating at one-third capacity due to technical difficulties (injection pressure, geology, etc.)
  - Norwegian Longship CCS with EOR expected to operate in early 2025 with the potential to capture 70 Mt-CO_2 /yr.

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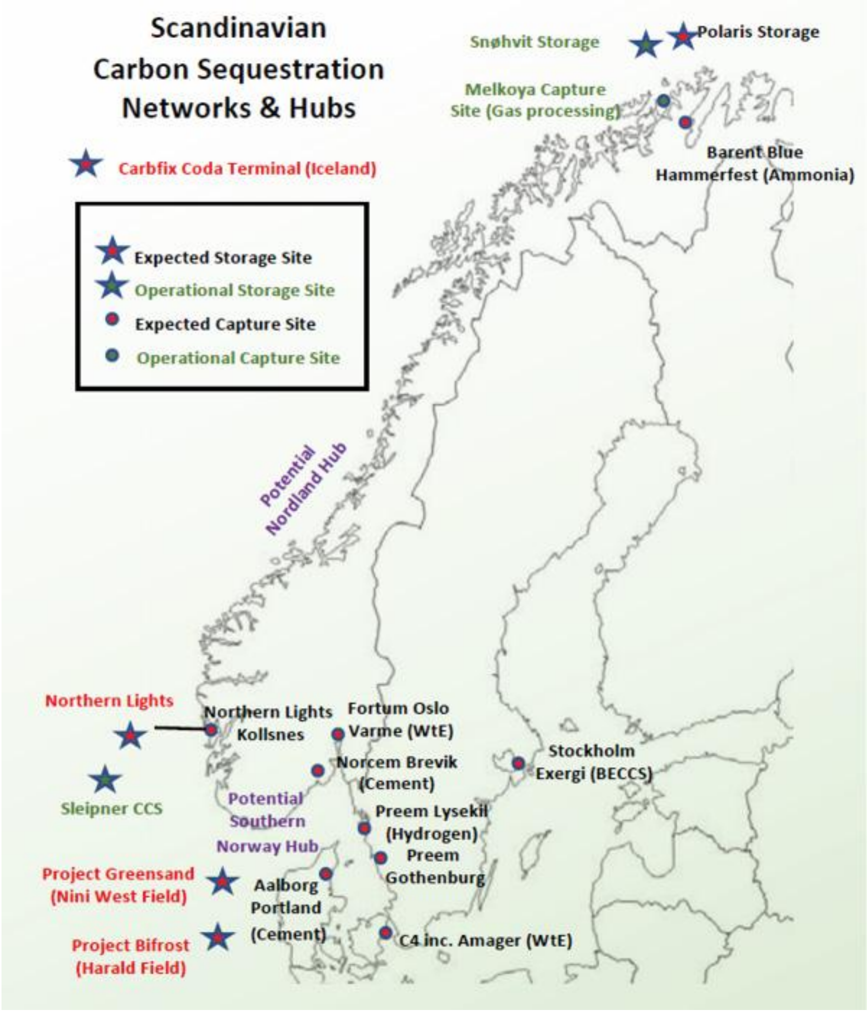
CCUS in Scandinavia

What's happening around *here*?

- Sweden: Bioenergy with Carbon Capture and Storage (BECCS)
  - "Negative emissions" can be achieved
- Norway: Longship Project, expected to operate by Early 2025
  - Source: Heidelberg Materials' cement factory, Hafslund Oslo Celsio's waste incineration plant.
  - Liquefied CO_2 is transported by ships and stored 2,600 meters beneath the seabed.
  - Initial capacity: 1.5 Mt/yr, with pipeline infrastructure sized for 5 Mt.
  - Future expansion: Northern Lights plans to increase storage capacity to 5 Mt/yr in Phase 2
- Denmark: Aalborg Portland
  - Source: cement plant
  - Aiming to capture at least 0.4 Mt by 2030



Scandinavian CCS networks and hubs (David Pickering)

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CCUS in Scandinavia

Stockholm Exergi BECCS in Stockholm

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CCUS in Scandinavia

Longship project in Norway

NORCEM
HEIDELBERGCEMENT Group

fortum
Oslo Varme

Northern Lights

equinor

TotalEnergies

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GreenCem project in Aalborg, Denmark

aalborgportland
CEMENTIR HOLDING

Aalborg Forsyning

PORT OF AALBORG
gate to great

REintegrate

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