CO₂ capture in energy-intensive industry
Integration and adaptation

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Outline

- Energy intensive industries
  - Why do we need them?
  - How much CO₂ are they producing?
- CO₂ capture
  - Why is it in the picture?
  - CO₂ capture technologies
  - CO₂ capture in energy intensive industry – What is the main challenge?
- What can we do?
  - The starting point
  - Examples of what we can do
- A dynamic world
- Final thoughts on opportunities and challenges for CO₂ capture in industry
Energy intensive industries

Cement

Metal production

Chemicals and petrochemicals

Some figures from Freepik

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Energy intensive industries
Why do we need them?

Cement
Metal production
Chemicals and petrochemicals

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Energy intensive industries
CO₂ they are producing

Cement
Metal production
Chemicals and petrochemicals

~15% of CO₂ emissions in Europe
~ 25% of CO₂ emissions globally

https://unece.org/sustainable-energy/cleaner-electricity-systems/carbon-neutral-energy-intensive-industries
https://single-market-economy.ec.europa.eu/industry/strategy/energy-intensive-industries_en

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Some figures from Freepik
CCS
CO₂ Capture and Storage

CO₂ Capture
transport and
Storage

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CO₂ capture
Is it in the picture?

IEA – Net Zero by 2050:
A roadmap for the Global Energy Sector

2050 looks like this...


March 2023

Key actions to drive net-zero technology manufacturing investments

- Setting enabling conditions: the Act will improve conditions for investment in net-zero technologies by enhancing information, reducing the administrative burden to set up projects and simplifying permit-granting processes. In addition, the Act proposes to give priority to Net-Zero Strategic Projects, that are deemed essential for reinforcing the resilience and competitiveness of the EU industry, including sites to safely store captured CO₂ emissions. They will be able to benefit from shorter permitting timelines and streamlined procedures.

- Accelerating CO₂ capture: the Act sets an EU objective to reach an annual 50Mt injection capacity in strategic CO₂ storage sites in the EU by 2030, with proportional contributions from EU oil and gas producers. This will remove a major barrier to developing CO₂ capture and storage as an economically viable climate solution, in particular for hard to abate energy-intensive sectors.

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Energy intensive industries
Capturing their CO₂

Cement
Metal production
Chemicals and petrochemicals

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Some figures from Freepik
CO₂ capture technologies

Credit: Rahul Anantharaman

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CO₂ capture
The main challenge

Separation with solvents or sorbents:

Membranes

Phase separation

Oxyfuel combustion

Credit: Rahul Anantharaman

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CO₂ capture
The main challenge

Absorption

Adsorption

Membranes

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What can we do?
Systems perspective

Flue gas → CO₂ lean flue gas → CO₂ capture and conditioning
Energy integration

- Surplus heat
- Heat
- Electricity
- CO₂ to transport and storage

CO₂ capture and conditioning

- Plant modifications
- Industry
- Products & byproducts
What can we do?

Systems perspective

- Industrial conditions and constraints
- Energy recovery
- CO₂ Capture

Integration & Adaptation

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What can we do?
The starting point

Credit: Rahul Anantharaman
CO$_2$ emissions in energy intensive industry
An example in the cement industry

**CaCO$_3$ → CaO + CO$_2$**

CO₂ emissions in energy intensive industry
An example in the cement industry

CaCO₃ → CaO + CO₂

CO₂ emissions in energy intensive industry
An example in the cement industry

Andersson et al “Heat integration for oxyfuel cement plants”. ESCAPE-33. AC²OCem Project
What can we do?
An example in the metal industry: ferroalloy casting

- Batch wise process – e.g. tapping metal from each furnace every 2 hours
- Different casting concepts are used, no heat recovery
- Significant HSE challenges
  - Crane operations, liquid metal
  - Dust emissions

Ferro-silicon "Bed casting"
What can we do?
An example in the metal industry: ferroalloy casting

Ferro-silicon "Bed casting"

Trond Andresen, «Dynamic Analysis of Energy Recovery Utilizing Thermal Storage from Batch-wise Metal Casting». Rankine Conference 2020
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What can we do?
An example in the metal industry: ferroalloy casting

- Varying fluid properties
- Challenging heat source prone to scaling

Think of new configurations for known unit operations

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What can we do?
An example in the metal industry: ferroalloy casting
What can we do?

Low carbon H₂

- Most H₂ is produced from natural gas
- With sufficient CO₂ capture ratio, H₂ from natural gas can reach parity with hydrogen from renewable power

Think of new configurations for known unit operations

\[
\begin{align*}
\text{CH}_4 + \text{H}_2\text{O} & \rightleftharpoons \text{CO} + 3\text{H}_2 \\
\text{C}_2\text{H}_6 + 2\text{H}_2\text{O} & \rightleftharpoons 2\text{CO} + 5\text{H}_2 \\
\text{C}_3\text{H}_8 + 3\text{H}_2\text{O} & \rightleftharpoons 3\text{CO} + 7\text{H}_2 \\
\text{C}_4\text{H}_{10} + 4\text{H}_2\text{O} & \rightleftharpoons 4\text{CO} + 9\text{H}_2 \\
\text{CO} + \text{H}_2\text{O} & \rightleftharpoons \text{CO}_2 + \text{H}_2 \\
\text{CH}_4 + 2\text{O}_2 & \rightleftharpoons \text{CO}_2 + 2\text{H}_2\text{O} \\
\text{C}_2\text{H}_6 + 3.5\text{O}_2 & \rightleftharpoons 2\text{CO}_2 + 3\text{H}_2\text{O}
\end{align*}
\]
What can we do?
Low carbon H₂

- H₂ production process with integrated CO₂ liquefaction.
  - Efficiencies of up to 84.7% (based on the higher heating value)
  - CO₂ capture ratios of up to 97.2%

Reforming producing syngas fed to WGS

WGS also processing tail gas from H₂ and CO₂ separation

H₂ and CO₂ separation

CO + H₂O ⇌ CO₂ + H₂

Straus et al. (2022) “Novel approach for low CO₂ intensity hydrogen production from natural gas”. Sustainable Energy and Fuels DOI: 10.1039/d2se00862a
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- Effects.
  - Increased equipment size
  - Reduced electricity generation (less tail gas to furnace)

Main concept from Straus et al. (2022) “Novel approach for low CO₂ intensity hydrogen production from natural gas”. Sustainable Energy and Fuels DOI: 10.1039/d2se00862a
Some more opportunities

CCS from industrial clusters and multi-sources industrial sites → key opportunity to enable cost-efficient of CCS

- Models for planning of a multi-source/multi-sink transport and storage have been investigated
- Less effort has been put in the planning of capture and conditioning part from multi-industry clusters or multi-sources industrial sites

Credit: Simon Roussanaly
The CO₂ capture process will be in a dynamic world

**Process & Plant Dynamics**
- Unplanned stops
- Batch processes
- Different operational modes
- Variations in fuel
- Seasonal variations
- ...

**World Dynamics**
- Changing demands
- Changing available raw materials and fuels
- Changing prices
- ...

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Final thoughts...

Opportunities and challenges for CO$_2$ capture in energy intensive industry

• Critical to understand the industrial process and CO$_2$ capture process and interactions
  – Thermodynamics as a starting point
  – Consider «real-life» constraints and economics – adapt design
  – Find synergies and take advantage of them – integration

• Systems perspective
  – Consider industrial process together with CO$_2$ capture (and conditioning) process
    ... and the rest of the world

• Dynamic environment – the CO$_2$ capture process needs to adapt
  – Intrinsic to several industrial processes
  – Changing prices and world dynamics
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