Carbon Capture: How to Move Ahead & Minimise Your CAPEX/OPEX

Burçin Temel Mckenna
Global Head of Carbon Capture Competency Center

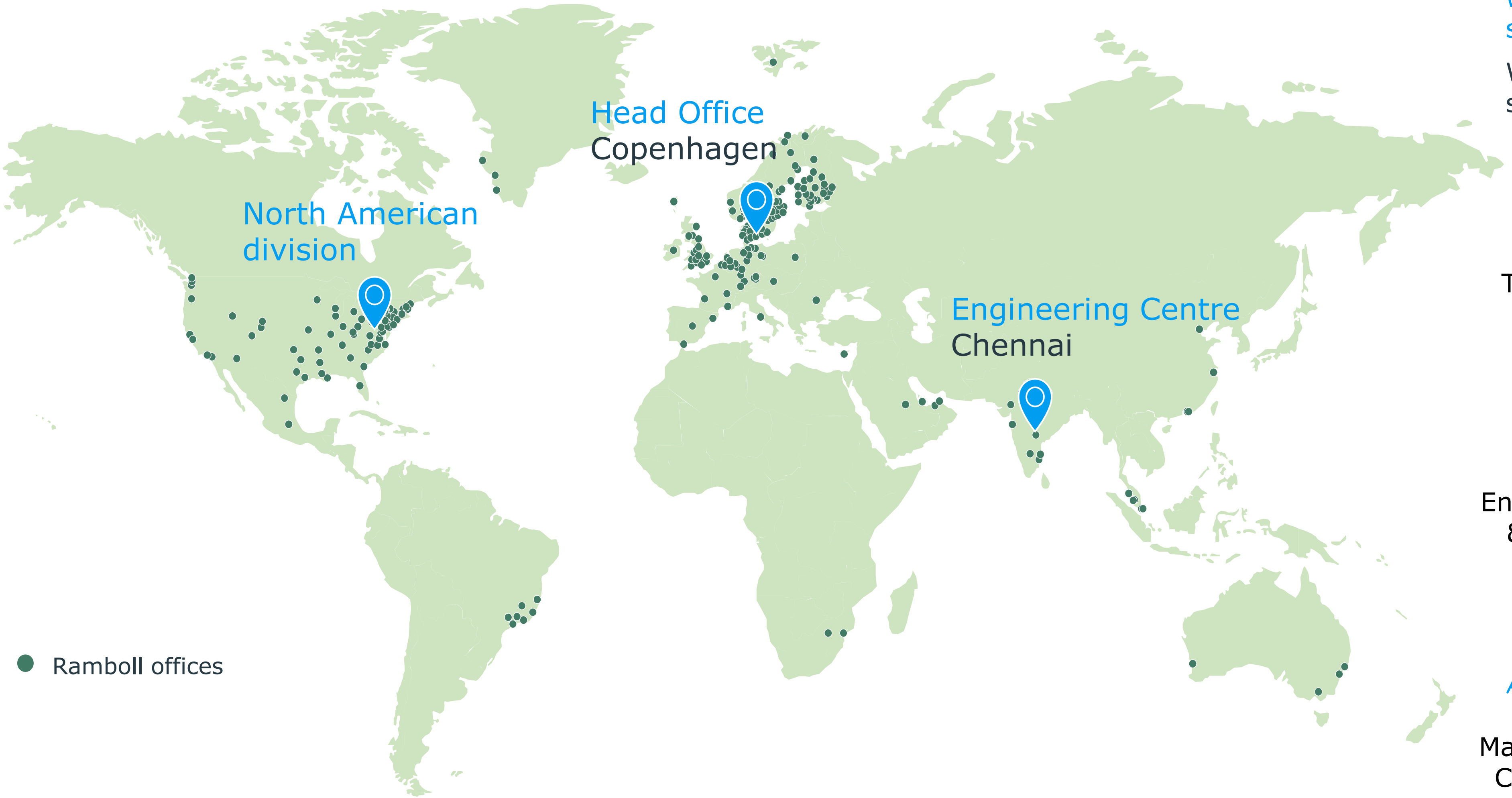
RAMBOLL

Bright ideas.
Sustainable change.

Topics

- Ramboll briefly
- Technology pros and cons
- Project development

Ramboll has 18,000 experts across 300 offices in 35 countries – including 2,000 in Energy



Ramboll combines local experience with a global knowledgebase to create sustainable cities and societies.

We work as one Ramboll across our seven markets:

- Transport
- Buildings
- Energy
- Environment & Health
- Water
- Management Consulting
- Architecture & Landscape

Ramboll is a world leading advisor within Carbon Capture Utilisation & Storage

Ramboll offers world-class experience in carbon capture, utilisation (PtX), transport, and storage as a frontrunner of the technologies used at all phases of CCUS.

Our expertise builds on many years of experience within e.g. capture of CO_2 from power- and Energy-from-Waste plants, on- and offshore handling and transport of gasses, on- and offshore oil- and gas operations and Power-to-X projects.

We are more than 50 dedicated carbon capture project managers and specialists serving the market through our centre of excellence in Copenhagen and more than 200 project manager and specialists offering transport, interim storage, shipping, geological storage, PtX services in connection to CC.

Globally in Ramboll, we have more than 2,000 specialists working with energy production, energy efficiency, renewable energy, power transmission, and district energy.

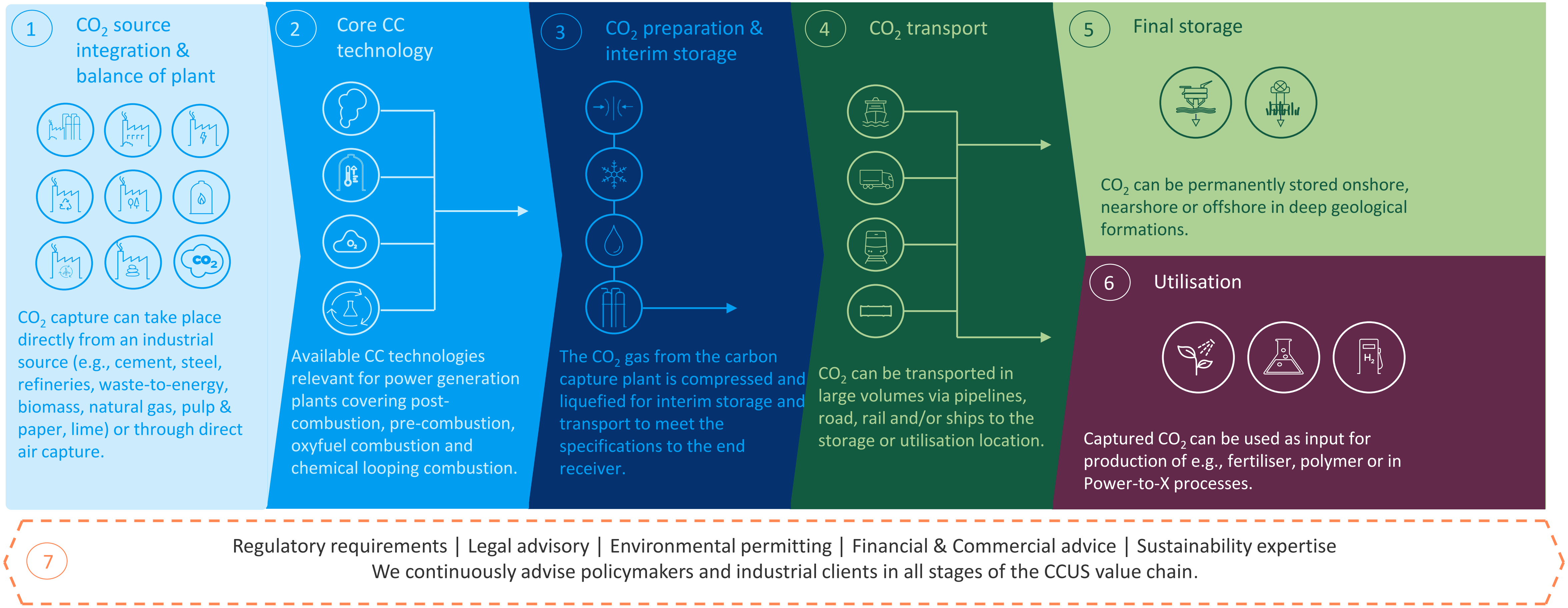
Ramboll has within the past few years worked on more than 180 carbon capture projects and more than 210 successful hydrogen projects.

14
Global offices in 9 countries

>200
Project managers and specialists

>180
CCUS projects

We have comprehensive and multidisciplinary expertise across the CCUS value chain



1 CO_2 source integration & balance of plant

CO_2 capture can take place directly from an industrial source (e.g., cement, steel, refineries, waste-to-energy, biomass, natural gas, pulp & paper, lime) or through direct air capture.

2 Core CC technology

Available CC technologies relevant for power generation plants covering post-combustion, pre-combustion, oxyfuel combustion and chemical looping combustion.

3 CO_2 preparation & interim storage

The CO_2 gas from the carbon capture plant is compressed and liquefied for interim storage and transport to meet the specifications to the end receiver.

4 CO_2 transport

CO_2 can be transported in large volumes via pipelines, road, rail and/or ships to the storage or utilisation location.

5 Final storage

CO_2 can be permanently stored onshore, nearshore or offshore in deep geological formations.

6 Utilisation

Captured CO_2 can be used as input for production of e.g., fertiliser, polymer or in Power-to-X processes.

7 Regulatory requirements | Legal advisory | Environmental permitting | Financial & Commercial advice | Sustainability expertise

We continuously advise policymakers and industrial clients in all stages of the CCUS value chain.

We have deep understanding of CO_2 source integration & Balance of Plant

We have expert knowledge on various industrial CO_2 sources

We assists client with CCS on industrial sources such as cement, waste-to-energy, biomass, steel, refineries, natural gas, pulp & paper, and lime factories. Our technical experts can also provide in-depth consultancy on Direct Air Capture (DAC).

Comprehensive experience with CC concept and integration

Our technical specialists have in-depth experience with technical CC concepts including energy modelling, process simulations, energy & mass balances, Process flow diagrams, master equipment lists, interface management, layout etc.

Engineering of Balance of Plant (BOP)

Our technical experts are highly skilled in Balance of Plant work for industrial power plants in order to produce the desired cost estimate of complete CC installations and conceptual design of key BOP equipment.

Detailed Design of the carbon capture plant

During the detailed design phase, our specialists will ensure that the plant is designed in accordance with the contract including final layout, detailed design review, review risk assessment, and update of budget & time scheduling.

Engineering, Procurement, Construction Management (EPCM)

Ramboll acts as the clients' Owner's Engineer/ EPCM, where Ramboll is responsible for contract and project management of the EPC project. This includes reviewing the engineering design, procurement, and managing the construction process to ensure that the project meets the client's specifications, budget, and timeline.

Key issues related to CC that we are experienced in dealing with

- Selection of the right CC technologies
- Understanding key cost drivers: high CAPEX due to CC immaturity and the "Energy Penalty" often mitigatable
- Dealing with HSE Risk assessment (e.g., CO_2 is an asphyxiant and solvent slippage)
- Understanding the business case

Integration of CC with the energy system

- Temperature of flue gas to be controlled (i.e. cooling of flue gas required for amine process)
- Energy to the CC process required (steam, electricity)
- Recovery of energy from CC - intercooling, compression units etc.

Ramboll's approach

- CC process modelling by in-house tool RAMCCS and supported by software such as ProMax.
- Energy performance estimated with in-house tool RAMsteam.
- Energy modelling of the complete process including district heating and CC integration, CO_2-compression, liquefaction, and purification using the commercial software Thermoflex®.

Technical pros and cons

> “CCUS is one of the few technology options that can significantly reduce direct CO_2 emissions (including process emissions) from the industry sector, which produces one-quarter of global CO_2 emissions.”
>
> The International Energy Agency (IEA)

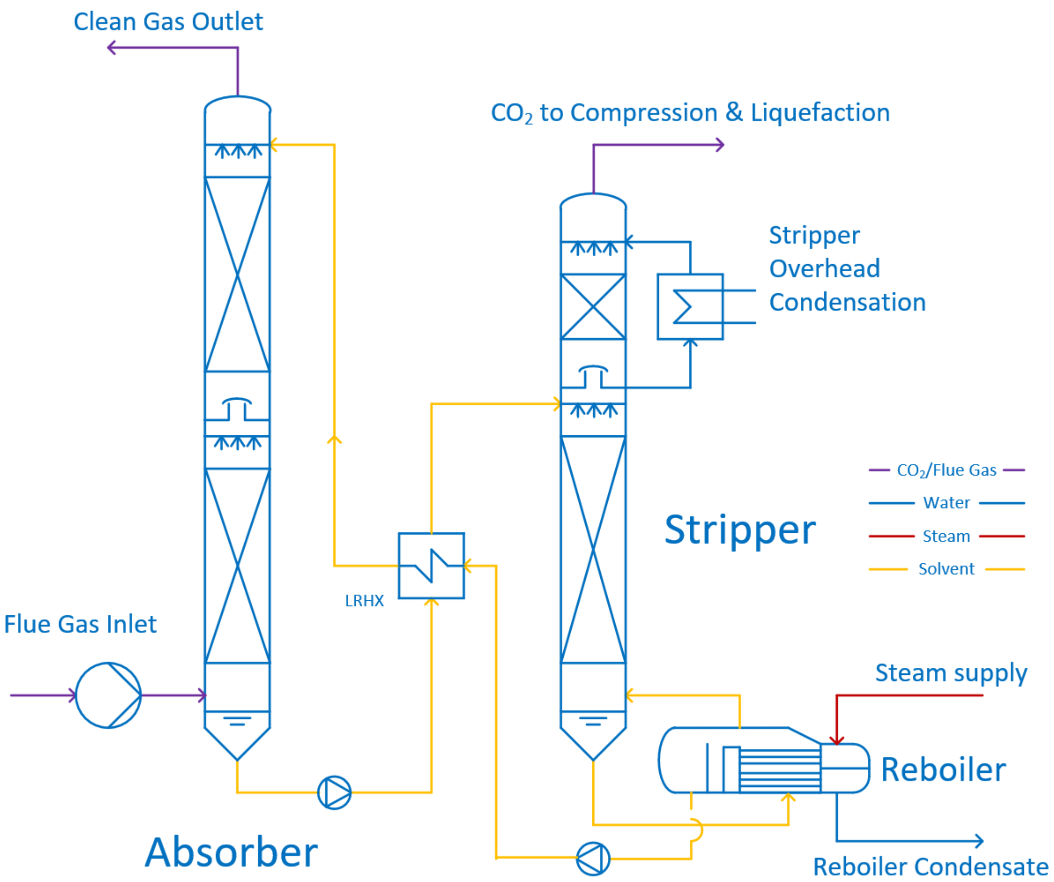
Amine-based CO_2 capture

Absorber

- Counter-current flow between flue-gas and liquid solvent
- Exothermal absorption reaction
- High temp. counteracts solvent performance → lowers CO_2 solubility:
- Temperatures 40-80°C

Stripper

- Solvent sprayed over a packing material and heated with steam in a counter-current flow, which causes the CO_2 to desorb from the liquid
- Stripping steam generated in the reboiler by heating the solvent, with an external heat source (usually steam)
- Reboiler temperature ~120-140°C
- Pressure ~1.5-2 bara
- Specific reboiler duty (standard amine) ~3.5-4.0 GJ/ton CO_2



Amine-based CO_2 capture – Absorption requirements

Clean and cold flue gas

- Clean to avoid solvent degradation
  - SO_X and NO_X removal required
- Cold to facilitate CO_2 absorption

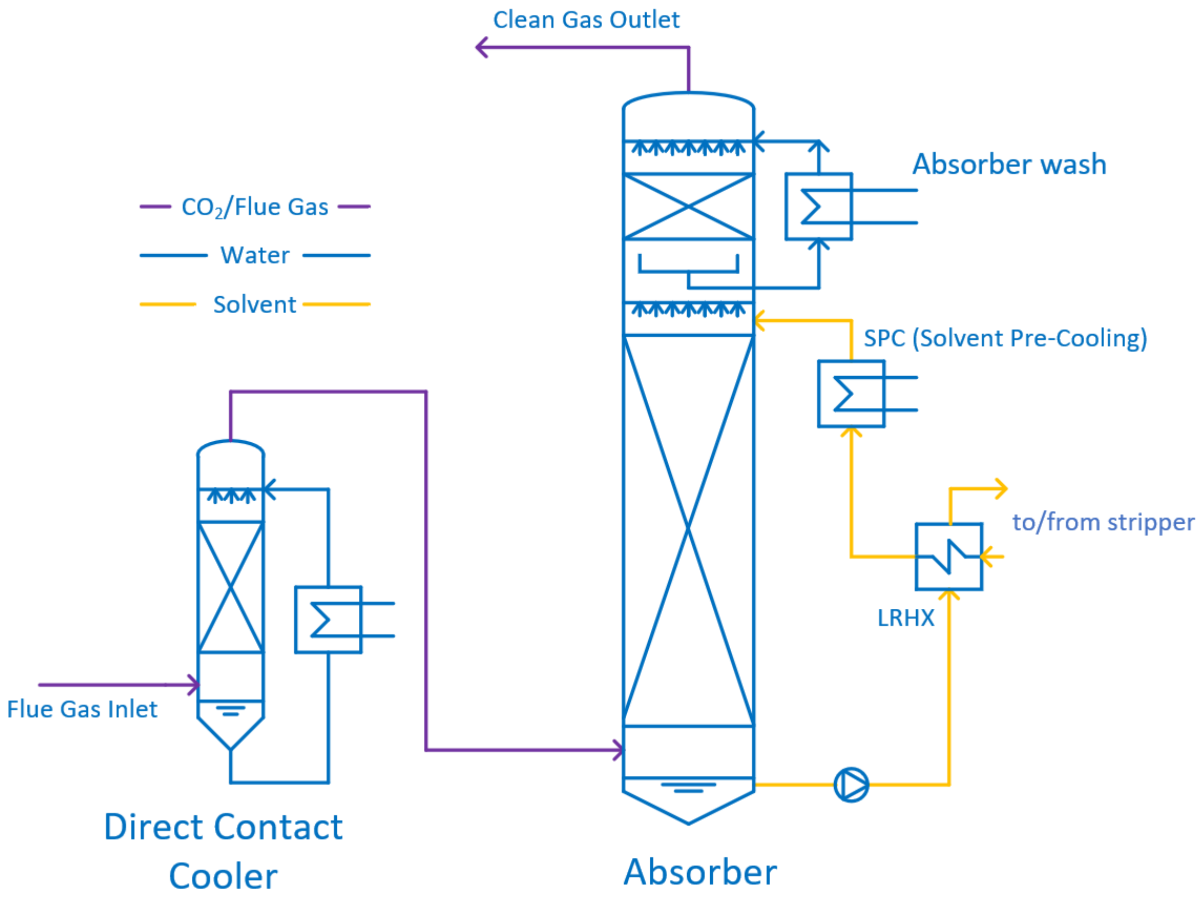
Extensive flue gas cleaning upstream the carbon capture plant a prerequisite!

Cold flue gas into absorber to optimise absorption process (~30-45°C)

Large cooling duty required!!

Absorber post-treatment – water wash

- Cooling to maintain water balance
- To avoid slip of amine
- To avoid volatile amine degradation products emissions



Amine-based CO_2 capture – Energy efficiency and optimisation

Cement plants do not have the steam needed for the reboiler, hence electricity based steam generation needed in the design

01

Simple solvent: MEA

Reference case

02

Advanced solvent:

10-20%

Reboiler duty reduction

03

As 02 + absorber optimisation

20-25%

Reboiler duty reduction

04

As 03 + stripper heat optimisation

25-45%

Reboiler duty reduction

05

As 04 + compressor heat optimisation

45-55%

Reboiler duty reduction

HPC (Hot Potassium Carbonate) process

General reaction

- $CO_2 + K_2CO_3 + H_2O \leftrightarrow 2\ KHCO_3$

Solvent advantages

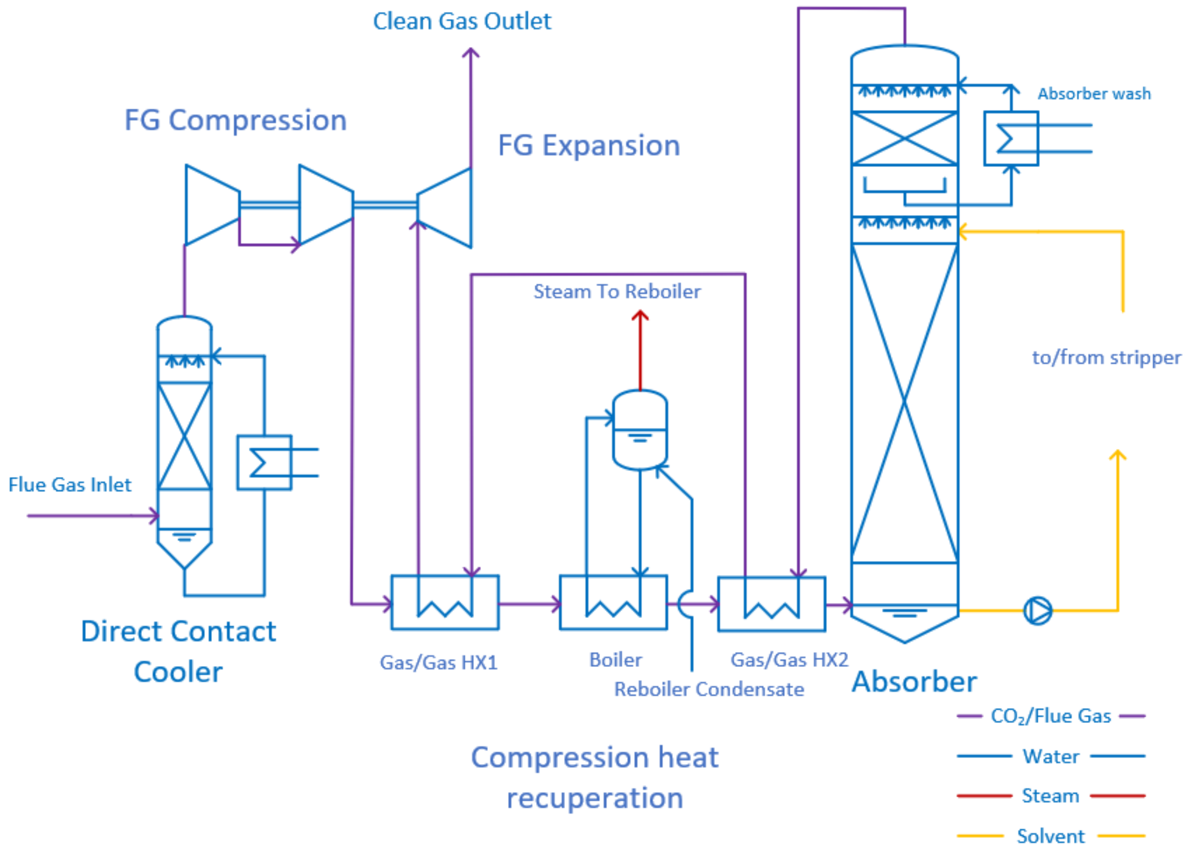
- Cheap
- Environmentally friendly – no emissions

Requirements

- Flue gas at higher pressure!!
- Flue gas compressors
- Large power consumption
    - 0.7-1.5 GJ/ton CO_2

Technology maturation needed

- Not proven in scale for a post-combustion case



Enzymatic carbon capture CPC (Cold Potassium Carbonate)

General reaction

- $CO_2+K_2CO_3+H_2O \leftrightarrow 2\ KHCO_3$
- Promoted with enzyme f.i. Carbonic Anhydrase
- CA helps transport CO_2 in the human body

Advantages

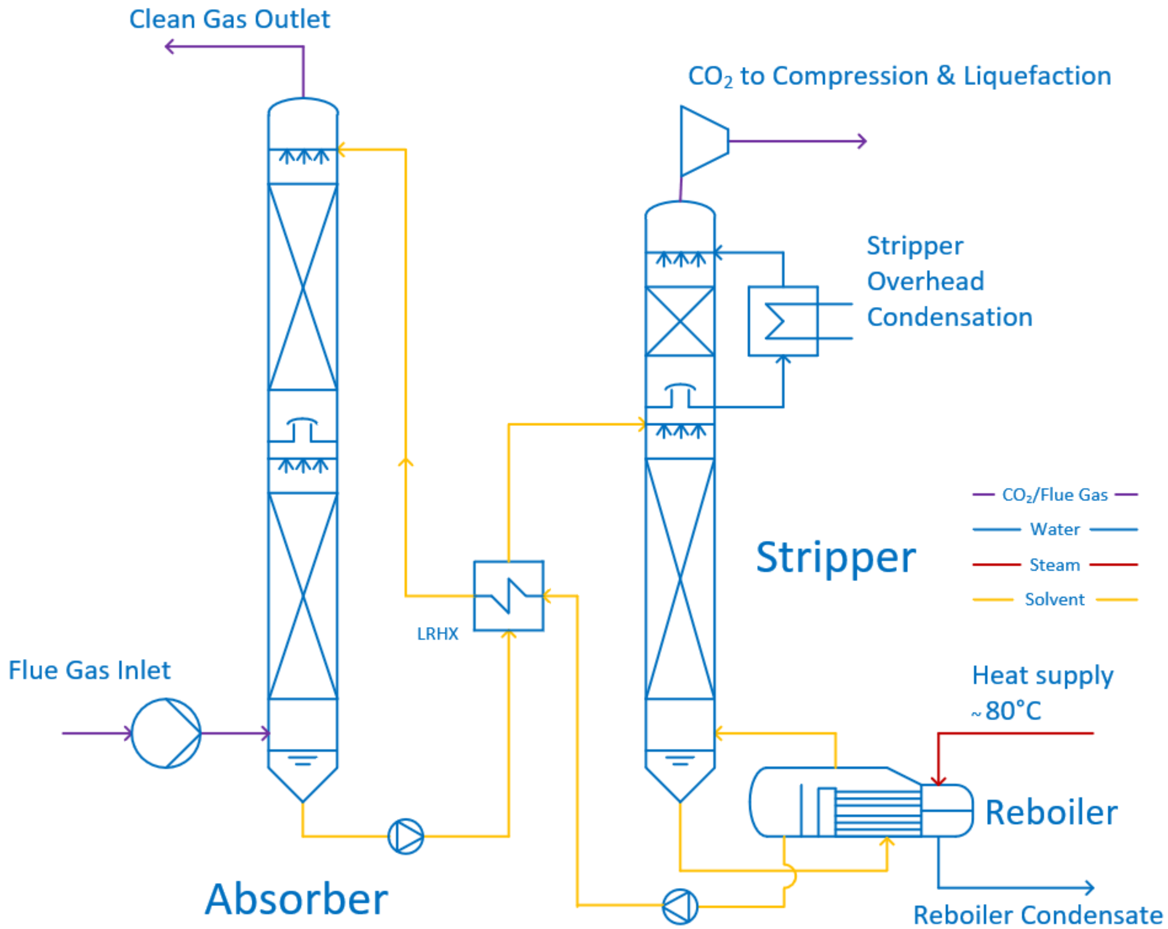
- Allows a lower temperature heat source for the reboiler (80 °C)
- Environmentally friendly

Challenges

- Enzyme consumption
- Stripper operating at low pressure (vacuum)

Technology maturation needed

- Not proven in scale for a post-combustion case



Cryogenic CO_2 capture

Working principle

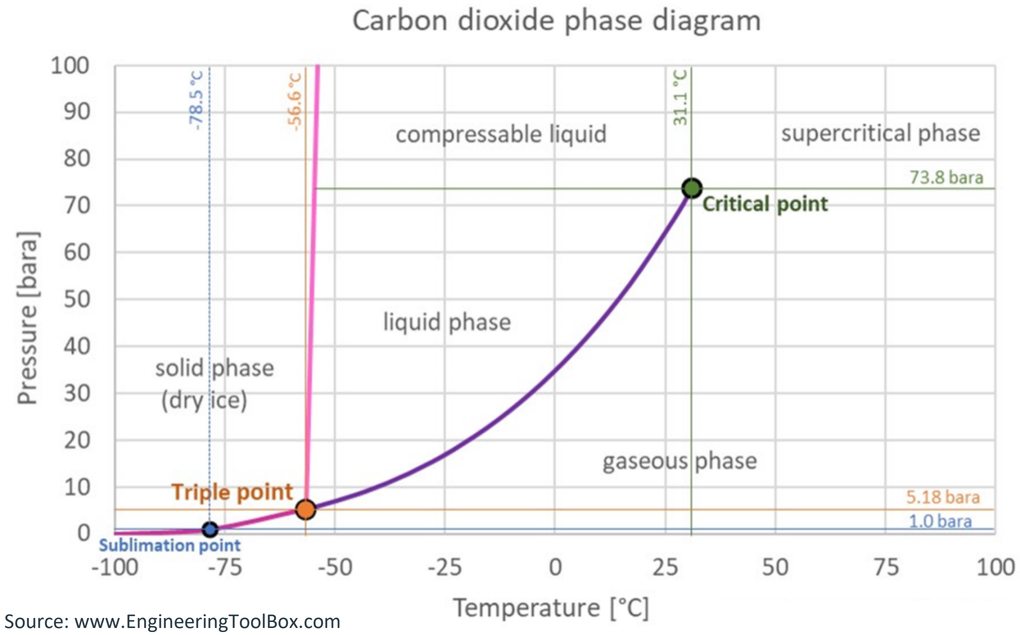
- Flue gas is cooled to -100 C to -135 C where CO_2 desublimates and becomes solid and is removed
- Heat integration ensures low energy penalty
- Flue gas constituents that condense at lower temperatures are also separated from the exit stream

Advantages

- Retrofit capability only requiring power and cooling
- High capture rate (+95%)
- Potentially low power requirement 0.9-1.2 GJ/ton CO_2

Challenges

- Not proven in scale



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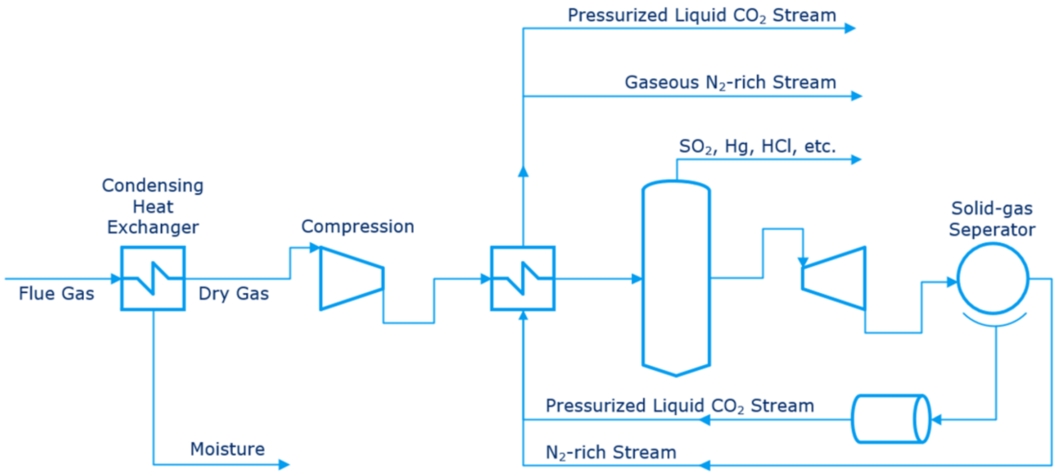


WORLD CEMENT®

BEYOND EMISSIONS

Jens Kristian Jørsboe, Jimmy Andersen, Christian Riber, and Burcin Temel McKenna, Ramboll, discuss various carbon capture technologies and their advantages and disadvantages.

Cement production is the foundation of global construction, indispensable for infrastructure projects ranging from towering skyscrapers to intricate road networks. However, the production of cement is emission-intensive and has a large environmental footprint. Despite significant progress, challenges remain in the widespread decarbonisation of cement production, where technical feasibility, cost considerations, and policy support are among the key factors. This article sheds light on the challenges and opportunities in achieving a more sustainable cement industry.

Ramboll is a global engineering consultancy with 18 000 experts based around the world. The carbon capture team has conducted over 125 studies ranging from feasibility to FEED, Balance-of-plant, and EPCM studies including projects being built in various geographies. Ramboll provides services for the whole value chain of CCUS: carbon capture, liquefaction, transport via rail or pipelines, utilisation into methanol or aviation fuel, storage and regulatory advisory.

Options for the mitigation of greenhouse gas emissions

The deployment of carbon capture in the cement industry is a significant area of interest when it comes to reducing greenhouse gas (GHG) emissions. According to the Global Cement and Concrete Association, cement production is responsible for approximately 7% of the global carbon dioxide (CO_2) emissions. This is due to the calcination process, which releases CO_2 from limestone (calcium carbonate) during clinker production. The production of clinker also requires high temperatures and combustion of fuels to provide energy for the process. Therefore, the emissions from cement production come primarily from the process and fuel consumption for the calcination process.

There are various options available to cement producers to reduce their environmental impact:

- Energy efficiency improvements: Implementing energy-efficient technologies and practices can reduce the energy consumption of clinker production, thereby lowering CO_2 emissions. This includes optimising kiln operations, improving heat recovery systems, and minimising energy waste.
- Alternative fuels (AF): Substituting traditional fossil fuels with AF such as biomass, waste-derived fuels, and non-recyclable plastics can reduce the CO_2 emissions from clinker production. These AF often have some biogenic carbon content and can help lower the overall fossil carbon footprint of the cement manufacturing process.
- Lower carbon products: Blending clinker with supplementary cementitious materials such as fly ash or slag can reduce the amount of clinker needed in cement production.
- Oxyfuel combustion: The cement kiln and/or calciner can be designed to use pure oxygen instead of air. This results in a flue gas stream with higher CO_2 concentration, making it easier to capture.
- Carbon capture and storage (CCS): This method captures CO_2 from the flue gases emitted during cement production. Carbon capture technologies are more widely applicable and can be retrofitted to existing cement plants.

While there are diverse options available, there are limitations to these approaches. For example, the energy efficiency of the cement plant has typically been optimised, and further optimisation or improvements may require considerable investments. AF vary in terms of their availability and quality, and the infrastructure for supplying them must be established.

Substituting clinker with supplementary materials can affect the performance and quality of the final cement product, potentially impacting properties such as strength, durability, and setting time. The availability and cost of supplementary materials, such as fly ash and slag, can vary regionally, limiting their widespread adoption as clinker substitutes.

These general improvement approaches reduce emissions but there will always be inherent release of CO_2 during the calcination process.

Oxyfuel combustion aims to produce a highly concentrated CO_2 stream by using pure oxygen for the combustion process. However, the false air ingress in the cement plant will pollute the highly concentrated CO_2 product and an added carbon capture unit might be needed.

CCS technologies are still relatively new as an application for cement plants and may require further development and optimisation to achieve widespread deployment. CCS implementation can be expensive, and the scale of deployment needed to achieve significant emission reductions in the cement industry may pose logistical and economic challenges. Finding suitable storage sites for captured CO_2 and ensuring their long-term integrity and security can be challenging. However, carbon capture technologies offer a significant reduction in CO_2 emissions, as it is possible to capture most of the CO_2 from the flue gas released from cement production.

Figure 1. Overview of carbon capture technologies.

Figure 2. Flow diagram of the cryogenic carbon capture process.

Overview of carbon capture technologies

Carbon capture technologies can be used to capture CO_2 emissions from various industries like cement, power generation, steel, biogas plants, and refineries. Currently, there is a wide array of carbon capture technologies available. The high CO_2 concentration in the flue gas from cement production is an advantage as the carbon capture technologies benefit from higher CO_2 concentrations. Another advantage is that cement plants are large CO_2 point sources, which allows for economies of scale, thereby reducing the capital investment per ton of CO_2. Moreover, the cement plants are operated at a steady base load thereby incurring low variation of CO_2 emissions. The location of cement plants can, however, be challenging for CO_2 infrastructure.

An overview of the carbon capture technologies is given in Figure 1.

Each carbon capture technology has advantages and challenges, including energy consumption, cost, scalability, and environmental impact. The carbon capture technologies apply either a chemical or physical separation principle.

The physical separation processes include adsorption, membrane separation, and cryogenic separation. Adsorption processes involve passing flue gases through a solid material, known as an adsorbent, which can selectively capture CO_2. Common adsorbents are either activated carbon or zeolites. Once the adsorbent is saturated with CO_2, it is regenerated by changing temperature or pressure, releasing the captured CO_2 for storage or utilisation. Membrane separation uses semi-permeable membranes to selectively separate CO_2 from flue gases based on differences in molecular size and solubility. Cryogenic separation involves cooling the flue gas to extremely low temperatures to condense and separate CO_2 from other gases.

Physical separation processes are widely applied for removal of CO_2 from biogas (biogas upgrading), which has a slightly higher concentration of CO_2 compared to flue gas from cement production. The physical separation processes can also be combined in hybrid systems to take advantage of their complementary strengths and to obtain higher CO_2 purity. However, there are limited references for these processes for large-scale application.

Currently, the amine-based absorption process is the most mature carbon capture technology with references for large-scale application. In this process, the flue gas, containing CO_2, is directed through an absorber column, and contacted with an alkaline solution denoted as solvent. The CO_2 reacts and is absorbed into the solvent. The solvent with the absorbed CO_2 is regenerated in a stripping column, typically conducted at elevated temperatures. Once the CO_2 is released, the regenerated solvent is returned to the absorber column to capture more CO_2 from the flue gas. The released CO_2 can then be compressed and transported for storage or utilisation.

Figure 3. Flow diagram of the absorber column for the hot potassium carbonate process.

Figure 4. Amine-based carbon capture with absorber intercooling (AIC) and lean vapour compression (LVC).

Cryogenic carbon capture

Cryogenic carbon capture is a physical separation process that separates CO_2 by cooling the gas stream to very low temperatures, typically between -100 and -135°C. The process diagram of the cryogenic separation is illustrated in Figure 2. In the flow diagram, the water content of the gas stream is removed by condensation. The gas stream then undergoes compression and subsequent cooling to achieve conditions where CO_2 desublimates, becoming solid from its gas phase, and the CO_2 can then be removed.

Due to costs associated with compression of the flue gas, the cryogenic carbon capture process greatly benefits from high CO_2 concentrations in the treated flue gas such as in the case for cement production. The cryogenic separation process may also be coupled with pressure swing adsorption, membrane separation or oxyfuel to increase the CO_2 concentration prior to the cryogenic separation.

Cryogenic carbon capture has several advantages including high capture rate of above 95%, high CO_2 purity, and, relatively, energy requirements are potentially low compared to other carbon capture technologies. Cryogenic carbon capture is a tail-end technology that only requires access to sufficient power and cooling, and a low energy penalty can be ensured with heat integration. However, it also has challenges, such as high capital costs associated with the cryogenic equipment and has limited references in large-scale application.

Hot potassium carbonate (HPC) carbon capture

The HPC solution reacts with CO_2 in the flue gas, forming potassium bicarbonate ($KHCO_3$) when water is present. The HPC process is an example of a chemical absorption process for carbon capture. The chemical absorption process includes an absorption column and a regeneration column. The flow diagram, excluding the regeneration vessel, is illustrated in Figure 3.

HPC offers high CO_2 capture efficiency (removal rates typically exceeding 90%), low thermal energy requirements, and can handle fluctuating CO_2 concentrations and flow rates in industrial flue gases. The potassium carbonate solution has lower affinity towards CO_2 compared to other solvents and therefore requires an elevated partial pressure of CO_2 in the absorber column. The elevated partial pressure of CO_2 is obtained by compression of the flue gas to obtain a CO_2 partial pressure of approximately 1 bar. The compression of the flue gas requires electrical energy, however a lot of the thermal energy needed in the desorption process can be recuperated from the compression step as shown in Figure 3.

The HPC process benefits from the high CO_2 concentrations in the flue gas from cement production. Considering a typical CO_2 concentration of 20%, the flue gas must undergo compression to only 5 bar compared to 7 – 8 bar for solid fuel combustion plants such as biomass or waste-to-energy facilities. Further, HPC does not need much steam, which cement plants do not have. The HPC is therefore a good fit for carbon capture from cement plants.

However, challenges associated with hot potassium carbonate carbon capture include the corrosive nature of potassium carbonate solutions, reduced reaction speed over time, and the need for efficient heat integration and solvent regeneration to minimise energy consumption and operating costs. Ongoing research and development efforts focus on addressing these challenges and improving the overall performance and cost-effectiveness of the technology. The maturity of the technology is the main drawback, as the flue gas compression has not been displayed or confirmed/verified for post-combustion applications.

Optimisation of the amine-based carbon capture process

Amine-based carbon capture is widely used and offers several advantages such as high CO_2 capture, scalability making it suitable for large-scale applications, and compatibility with existing industrial infrastructure, easing retrofitting to existing plants. However, challenges associated with amine-based carbon capture include a high energy consumption for solvent regeneration, solvent degradation, and potential corrosion issues. Efforts continue to focus on reducing the energy requirements of the process, especially reboiler duty, and improving the solvent resistance towards degradation.

One approach to improve amine-based carbon capture is to use alternative amines or blends of amines. The traditional amines include monoethanolamine (MEA), diethanolamine (DEA), and methyldiethanolamine (MDEA). In recent times, amine blends have been developed such as AMP-PZ (CESAR1) and AMP-DMSO. Furthermore, there are advanced supplier designed amines commercially available: MHI (KS-1™, KS-21™), OASE®blue, ACC™ S21 & S26, APBS-CDRMax®, CANSOLV DC-103, or Econamine FG PlusSM. The development of these new amine solvents has resulted in 10 – 20% lower energy consumption, more stable solvents, and less make-up/reclaiming needed. However, these new solvents are more expensive and careful emission control may be required depending on flue gas NOx levels, and the temperature and pressure in the absorber column.

Another approach to reduce the energy requirement of the carbon capture process is internal carbon capture improvements. There are various approaches for optimising the flow diagram of carbon capture. Some improvements include absorber intercooling (AIC), lean vapour compression (LVC), or mechanical recompression systems (MVR). A flow diagram of the amine-based carbon capture with AIC and LVC is illustrated in Figure 4. By using AIC, the solvent can absorb more CO_2, consequently reducing the reboiler duty. The LVC configuration flashes the hot regenerated solvent from the reboiler to provide additional stripping steam. This reduces the amount of necessary reboiler duty, but it comes at the expense of compressor power costs.

Amine-based carbon capture at cement plants faces different challenges such as the availability of steam, and the cleaning and cooling of the flue gas to make it suitable for carbon capture. The need for steam can be reduced by optimisation of the heat integration and by implementation of heat pumps and steam fans. The amine-based carbon capture can thereby be considered with varying complexity. Different cases of the amine-based carbon capture process are shown in Figure 5, where the expected reduction in the reboiler duty is included.

To supply the carbon capture plant with heat, waste heat can be recovered from both calciner flue gas and clinker cooler gas through large waste heat recovery (WHR) units, also called boiler units. WHR allows for some steam production to be used directly in the carbon capture reboiler. It can also be used to upgrade hot water with heat pumps and steam fans to provide a significant amount of steam for the reboiler. The potential energy available in a standard cement kiln process allows for approximately 30 – 40% of the energy needed to be delivered as steam, and 40 – 100% of the energy needed to be delivered as hot water. By optimisation of the amine-based carbon capture process and using WHR, it is thereby almost possible to cover the heat demand for the amine-based carbon capture facility without investing in a dedicated steam producing system.

Figure 5. Optimisation of amine-based carbon capture.

Carbon capture in the cement industry

According to IEA, the cement sector is the third-largest industrial energy consumer and the second-largest industrial CO_2 emitter globally. To get on track with the Net Zero Scenario, emissions from cement production must fall by an average of 3% annually by 2030. Carbon capture is crucial for the cement industry as it offers a pathway to mitigate the significant GHG emissions associated with its production. Currently, there are many projects working on improving ways to capture carbon emissions from the cement industry. Some methods, like cryogenic and membrane technologies, are being developed, but they have not been tested on the scale needed for cement production yet. Oxyfuel technology is also receiving a lot of attention, although it requires a larger interaction with the main process than post-combustion technologies. Finally, there are also other carbon capture technologies only focusing on the calcination part of cement production, which may become feasible.

There are various technologies available for carbon capture and some may see implementation on a large-scale in the future, but the carbon capture technology with the most large-scale references is currently the amine-based capture technology. This technology is commercially available, can be retrofitted to an existing cement plant, and there are various options for heat integration to reduce the operating costs of the technology. By adopting carbon capture and through the continued innovation of emissions reduction technologies, the cement industry can make significant strides towards decarbonisation and sustainable production of cement. ■

About the authors

Burcin Temel Mckenna, Head of Department, is Global Head of Carbon Capture at Ramboll serving optimal customer outcomes for system integration in CCUS projects within Waste-to-Energy, Cement and Biomass.

Christian Riber, Business Development Manager, has been leading more than 35 CCS projects for the past seven years and has profound knowledge of the entire CCS value chain.

Jimmy Andersen, Lead Carbon Capture Consultant, has more than 10 years of experience in the power plant industry and has comprehensive knowledge of operation and optimisation of the carbon capture process.

Jens Kristian Jorsboe, Consultant, has more than five years of experience within carbon capture technologies and a strong background in process modelling and optimisation.

Project Development

Ramboll typically acts as the technical advisor, owner’s engineer or EPCM Engineer. We have developed in-depth knowledge of processes, technologies, suppliers, and facility operation as well as strong in-house expertise in contractual and financial matters.

Ramboll's project execution model for successful development and implementation of CCUS projects

	Project development			Implementation			
Project Lifecycle	**Feasibility**	**Outline Design** (Front end engineering design)	**Basic Design** (Procurement)	**Detailed Design** (Design review & coordination)	**Manufacturing/Construction** (Inspections)	**Test & Commissioning** (Inspections)	**Operation**
Technical and commercial services	• Technical and economic feasibility • CO_2 flowrate and biogenic/fossil predictions • Existing operations profile • CO_2 quality requirements • Technology assessments • Initial performance estimates • Establish high-level scope • Site selection • Preliminary layout • Indicative budget & time scheduling • M&E balances and process calculations • PFDs/concept diagrams	• Further mature technical concept and scope including relevant documentation such as PFDs, equipment lists, line lists etc. • Assessment of utilities and interfaces • Final site selection • Further layout development • Procurement strategy / DOW • Start and permitting • Risk assessment • Update budget & time scheduling	• Selection of procurement strategy. • Contractor FEED studies • Develop procurement documentation (technical and commercial conditions) • Conduct procurement • Finalized planning and permitting, Obtain permits • Review Risk assessment • Update budget & time scheduling	• Contractors detailed design of plant • Detailed design review • Review Risk assessment • Update budget & time scheduling	• Contractors' manufacturing of equipment • Inspections of cold/hot commissioning, performance tests, safety procedure, trial operation period • Transportation of equipment to site • Site preparation • Mechanical and Civil Construction • Review Risk assessment • Update budget & time scheduling	• Cold/Hot commissioning • Performance tests • Safety procedures • Trial operation period • Review Risk assessment • Update budget & time scheduling	• Closing of snagging lists • Review of Guarantee Tests • Inspections during Defect Notification • Performance monitoring • Final Take Over Protocol • Inspection during revision stops • Contract Management • Progress reports
Goal	Establish an understanding of viability of the project	Establish sound basis for launching the Basic Design	Establish sound basis for launching the project and ensure implementation contract	Ensure that plant is designed in accordance with contract	Ensure that plant is built in accordance with contract	Ensure that plant is in stable operation in accordance with contract	Closing of contract
Duration	4-6 Months	6-10 months	8-12 months	6-8 months	20-26 months	8-10 months	
Aace Capex Estimate	Class 4 (-30% / +50%)	Class 4 (-25% / +30%)	Class 3 (-15% / +20%)	Class 2 (-10% / +15%)	Class 2 (-10% / +10%)	Class 1 (-5% / +7%)	

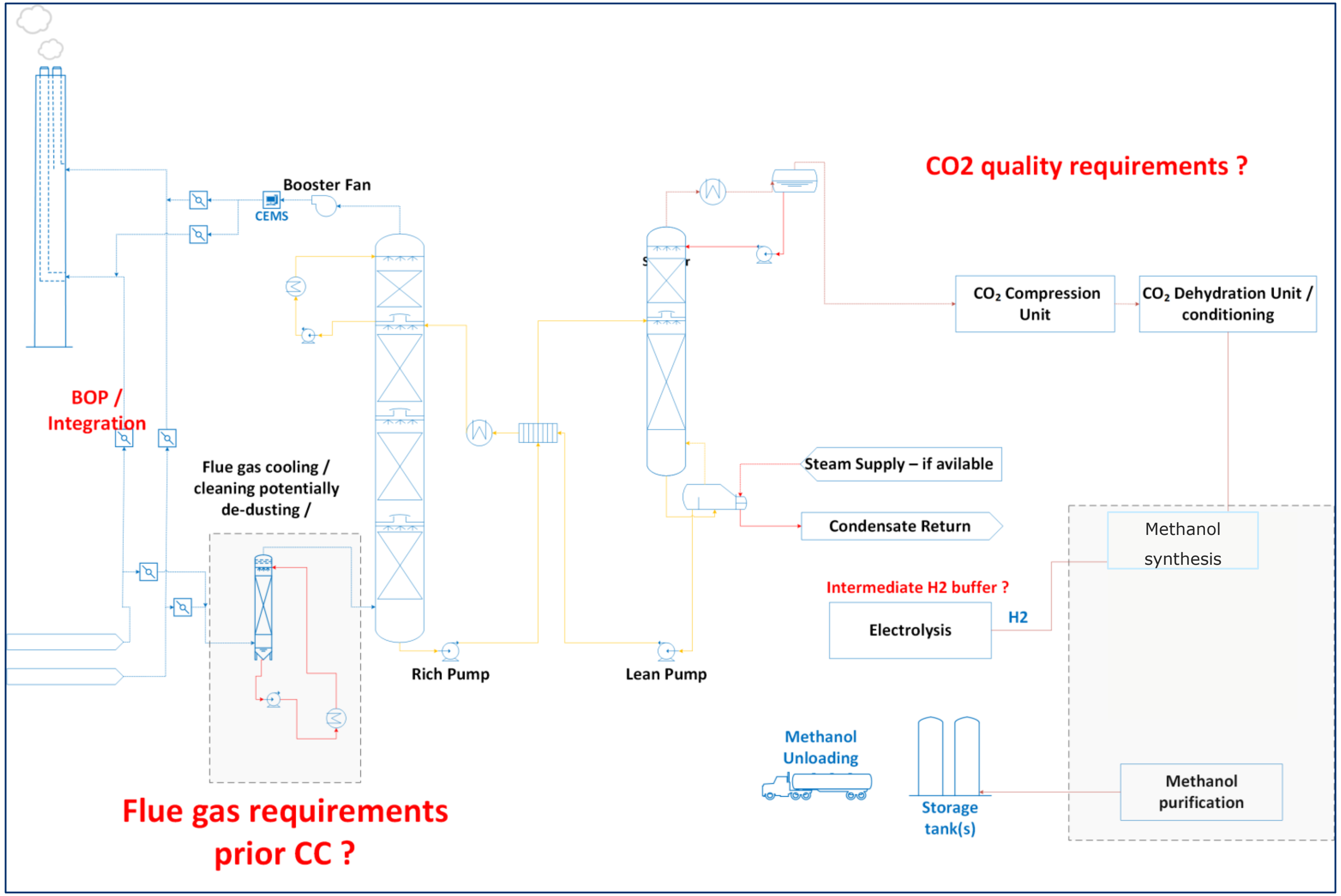
Note: The simplified project lifecycle presents a non-exhaustive list of services

Procurement models – how to ensure competitive tension for key suppliers / contractors ? EPC or EPCm?

Choice of CC technology ?

Project execution model ?

Technology provider is often not an EPC.

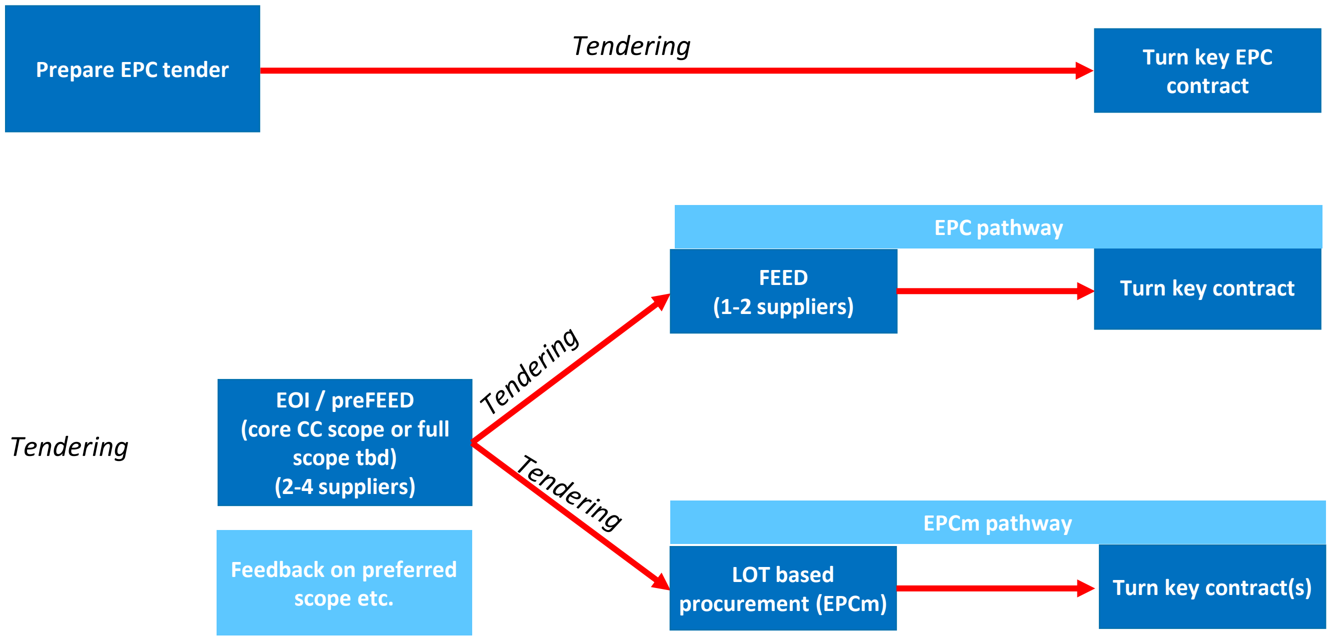


<u>Larger scope packages to be considered:</u>

- *Flue gas conditioning (and potentially reheating)*
- *Core CO_2 capture incl. emission measurement*
- *CO_2 conditioning (if needed)*
- *H_2 production plant*
- *Water purification plant*
- *Electrical project*
- *Methanol plant*
- *Steam generation package (if needed)*
- *Waste-water treatment*
- *Cooling package for waste heat*
- *Integration works*

Procurement models – how to ensure competitive tension for key suppliers / contractors ? EPC or EPCm ?

CO_2 capture technology choice (& risk)



Prepare EPC tender

Tendering

Turn key EPC contract

EPC pathway

FEED (1-2 suppliers)

Turn key contract

Tendering

EOI / preFEED (core CC scope or full scope tbd) (2-4 suppliers)

Tendering

Tendering

Feedback on preferred scope etc.

EPCm pathway

LOT based procurement (EPCm)

Turn key contract(s)

What is the risk appetite?
Is EPC a project financing requirement?
Is fixed price obtainable?
Risk wrapping comes at a cost

Paid pre-engineering probably needed to obtain fixed price proposals

Higher risk profile with many sub-contracts
Lower risk in getting performance and price guarantees

O&M risk?

Client-1

State of project (Jan 2024)

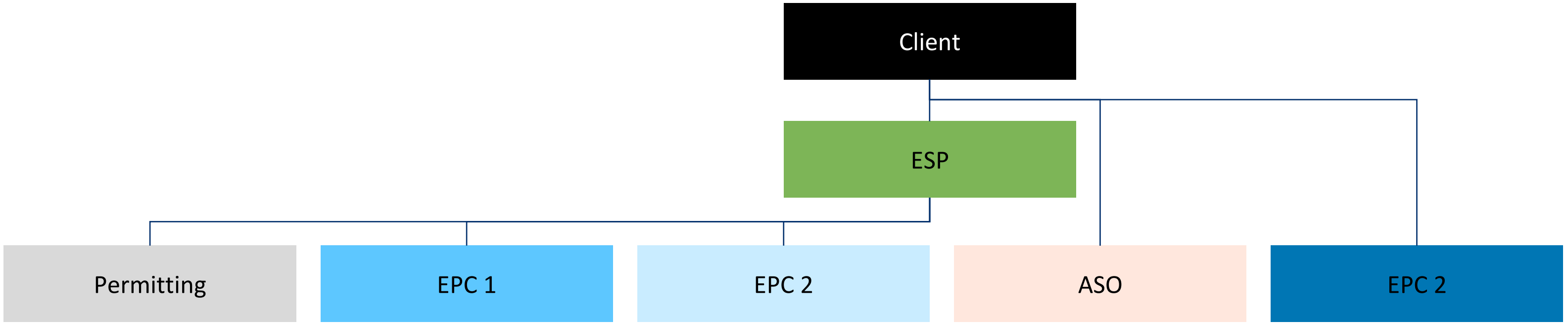
	Design basis / Pre-Feasibilty	Concept design / Feasibility	Basic design / Tender	FEED / Procurement	Detailed design / Construction	Commissioning
Contract manager			ESP	ESP	ESP	ESP
Civil	ESP	ESP	ESP	EPC 2	EPC 2	EPC 2
Integration / BOP	ESP	ESP	ESP	ASO[1]	ASO[1]	ASO[1]
Carbon Capture	EPC 1	ESP	ESP	EPC 1[3]	EPC 1	EPC 1
CO_2 handling	ESP	ESP	ESP	EPC 1[3]	EPC 1	EPC 1
3D model (plant)	ESP	ESP	ESP	ESP[2]	ESP[2]	ESP[2]
CO_2 export (Train)	ESP	ESP	ESP	EPC 1[3]	EPC 1	EPC 1
Power plant new line	ESP	ESP	ESP	EPC2	EPC2	EPC2
Permitting			ESP	ESP	ESP	ESP

[1] Several smaller contracts

[2] Integration of all 3D models, clash control, space management

[3] Competition between 2 Suppliers, closed in this phase

Legend
ESP *Engineering Service Provider (on behalf of owner)*
EPC 1-4 *Individual EPC Suppliers of engineering, procurement and construction*
ASO *Asset Owner and Operator*



Client

ESP

Permitting

EPC 1

EPC 2

ASO

EPC 2

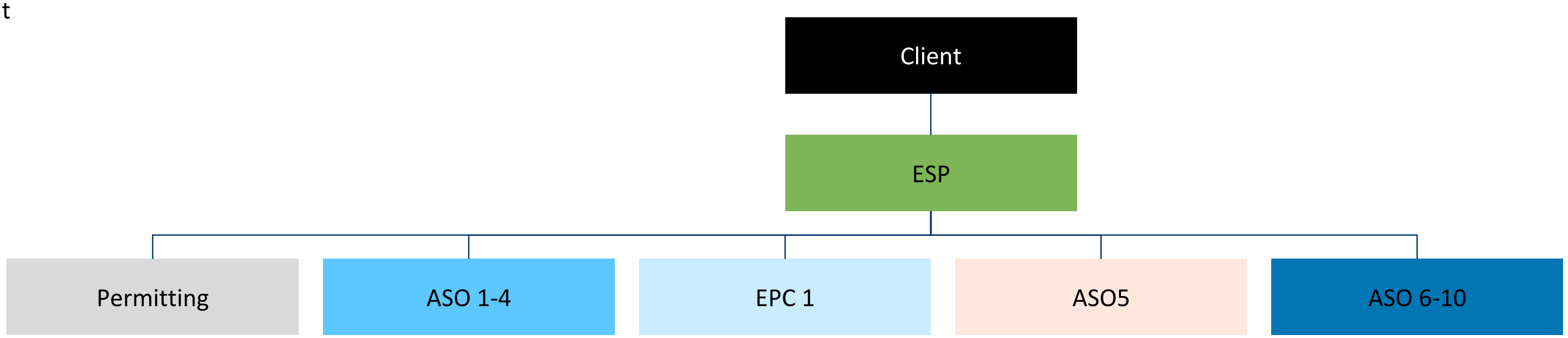
Client-2

State of project (mid 2024)

	Design basis / Pre-Feasibilty	Concept design / Feasibility	Basic design / Tender	FEED / Procurement	Detailed design / Construction	Commissioning
Contract manager			ESP	ESP	ESP	ESP
Civil	ESP	ESP	ESP	ESP	ASO 1-4	ASO 1-4
Integration / BOP	ESP	ESP	ESP	ESP[1]	ASO6-10	ASO6-10
Carbon Capture	ESP	ESP	ESP	EPC 1	EPC 1	EPC 1
CO_2 handling	ESP	ESP	ESP	EPC 1	EPC 1	EPC 1
3D model (plant)	ESP	ESP	ESP	ESP[2]	ESP[2]	ESP[2]
CO_2 export (Truck/Harbour)	ESP	ESP	ESP	EPC 1	EPC 1	EPC 1
Power plant modific.	ESP	ESP	ESP	ESP	ASO5	ASO5

[1] Several smaller contracts

[2] Integration of all 3D models, clash control, space management



Legend
***ESP** Engineering Service Provider (on behalf of owner)*
***EPC 1-4** Individual EPC Suppliers of engineering, procurement and construction*

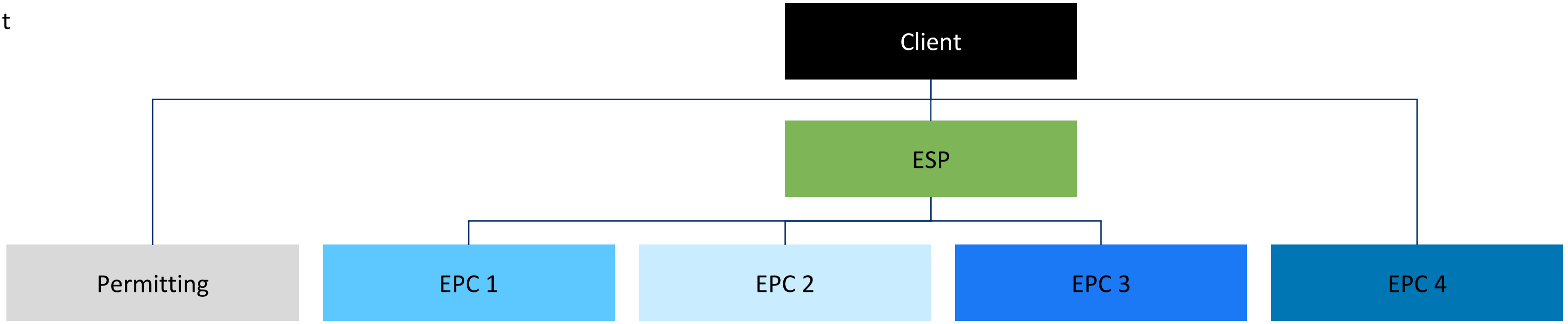
Client-3

State of project (end 2023)

	Design basis / Pre-Feasibilty	Concept design / Feasibilty	Basic design / Tender	FEED / Procurement	Detailed design / Construction	Commissioning
Contract manager			ESP	ESP	ESP	ESP
Civil	ESP	ESP	ESP	EPC 2	EPC 2	EPC 2
Integration / BOP	ESP	ESP	ESP[1]	ESP[1]	ESP[1]	ESP[1]
Carbon Capture	EPC 1	ESP	ESP	EPC 1[3]	EPC 1	EPC 1
CO_2 handling	ESP	ESP	ESP	EPC 1[3]	EPC 1	EPC 1
3D model (plant)	ESP	ESP	ESP	ESP[2]	ESP[2]	ESP[2]
CO_2 export (Harbor)	ESP	ESP	ESP	EPC 3	EPC 3	EPC 3
Existing plant modific.	EPC4	EPC4	EPC4	EPC4	EPC4	EPC4

[1] Several smaller contracts
[2] Integration of all 3D models, clash control, space management
[3] Competition between 2-3 Suppliers, closed in this phase

Legend
ESP *Engineering Service Provider (on behalf of owner)*
EPC 1-4 *Individual EPC Suppliers of engineering, procurement and construction*



Four models for cooperation and support

Support

Direct support in one or more engineering disciplines, e.g.

- process
- permitting
- risk assessment
- procurement

Provide a specific scope

E.g. all Risk & Safety scope, such as

- HAZID/HAZOP workshops
- Quantitative Risk Assessment
- Functional Safety

3rd party review

Review by experienced Ramboll expert of e.g.
layout, plan,engineering design, cost estimate, procurement strategy, tender documents.

FEED / OE service

for all project following through from early phases to managing the construction phase.

- Engineering
- Procurement
- Construction supervision

Regulatory requirements | Legal advisory | Environmental permitting | Financial & Commercial advice | Sustainability expertise
We continuously advise policymakers and industrial clients in all stages of the CCUS value chain.


Christian Riber


Jasmine Nordenström


Jesper Andersen


Lasse Tobiasen


Maje Müllenborn


Stella Bücker

Thank you!

RAMBOLL


Burçin Temel Mckenna
btma@ramboll.com