Evaluating carbon capture technology options through technology screening

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As part of its RePowerEU project, VTT has developed a model for screening and techno-economic assessment of post-combustion carbon capture technologies. By Onni Linjala, Research Scientist, VTT.

Carbon capture has been identified as a crucial complementary technology for climate change mitigation. With this several technology suppliers are competing to establish themselves as technology leaders to better secure upcoming projects in the emerging market. Despite the competition, there will be room for many types of solutions as carbon capture becomes more mainstream and suitable for variety of applications.

The broad range of options will benefit potential technology implementors as different technologies excel at different applications. As part of VTT's RePowerEU project, VTT has developed a model for screening and techno-economic assessment of post-combustion carbon capture technologies.

Most carbon capture projects have focused on capturing CO2 from stationary emission point sources of energy production and industrial processes, which can be referred to as point source capture. However, CO2 can be captured from a variety of sources like the atmosphere, oceans, or mobile applications like ships or road vehicles.

Many types of technologies have been developed for carbon capture, utilizing physical and chemical phenomena like absorption, adsorption, electrochemical potentials, selective membrane barriers, cryogenics, oxyfuel combustion, chemical looping, and various hybrid configurations (Figure 1). Furthermore, these technologies can be implemented with various capture mediums, material choices, equipment configurations, and energy integration solutions, making the portfolio of technology options even broader.

The technologies differ in terms of technological readiness, retrofittability, scalability, and operational characteristics such as energy consumption, emissions, and ability to response to dynamicity. There is no one-fits-all solution and each process has case-specific advantages and challenges, especially in point source capture where properties between different applications can vary significantly.

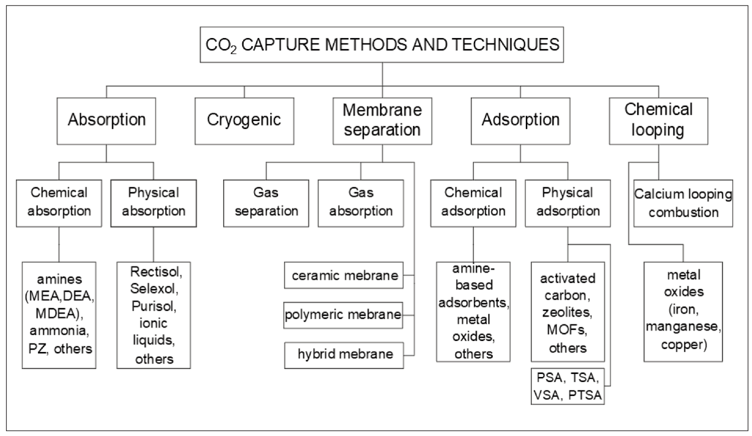

Figure 1 - Carbon capture methods and techniques (Madejski et al. 2022)

Due to several technology options and still a low number of commercial references, potential implementors are left wondering which technology would best suit their needs. Choice of optimal technology for a certain application as well as performance of the process is case-specific, being affected by the desired capture performance, characteristics of the emission source, and the operating environment. These factors are evaluated through technology screening and techno-economic assessment to identify the best technology choice for a carbon capture project.

Desired capture performance, i.e., capture efficiency and purity of the captured CO2, is a key factor for technology choice and process design. It determines how selective capture process is needed and what are the conditioning demands after capture. Selectivity refers to how well CO2 can be isolated from other compounds in the source. Generally, processes based on chemical reactions are more selective than physical reactions, but they often yield higher energy demands due to stronger bonds that take place between CO2 and the capture medium. In point source capture, capture rates of 90–95 % and purities of >99 % are typically pursued, but in some cases lower or higher performance may be desired. Optimization of the capture performance is a balance between performance and costs.

Alongside the desired capture performance, concentration and partial pressure of CO2 in the source are the primary factors to determine how selective capture process is needed. They also largely impact energy demand and capture costs that increase as CO2 concentration decreases since more work is required for the separation. Chemical absorption with liquid solvents based on amines and carbonate salts is favored in sources with low to moderate CO2 concentrations (~3-25 %) and atmospheric pressures such as combustion flue gases.

Physical solvents, solid adsorbents, membranes, and cryogenic separation are more common for sources with higher CO2 concentrations and pressures that occur, for instance, in natural gas processing. In sources with nearly pure CO2 exhaust streams, such as ethanol fermentation and biogas upgrading, removal of moisture and some impurities may be only needed.

Other source properties such as impurities, temperature, and stability of operation should be also considered to determine suitable technology choices, pre-capture conditioning needs, and heat integration opportunities. Impurities may degrade some capture mediums and materials or weaken process performance. High temperatures can also degrade some capture mediums but can provide opportunities for heat integration. Also, it should be estimated how well the technologies can response to potential dynamicity within the process like load changes and fluctuation of CO2 concentration, which may affect capture performance. Seasonal load variation should be also considered as it affects dimensioning and operational profile of the capture process.

Scale is another key factor for technology choice. Typically, the scale of a carbon capture project is reported as tonnes of annually captured CO2. Liquid solvent processes are often better scalable to large industrial processes with several hundred kilotonnes of annual CO2 emissions, whereas technologies like solid adsorbents, fuel cells and membranes are more modular and may excel at smaller scales and gain cost benefits from mass production of fixed units.

Carbon capture is often energy-intensive, making energy integration one of the most important factors regarding technology choice and process design. Energy streams available at the site (e.g., steam, electricity, low-grade heat, and cooling) affect how the process can be most cost-efficiently powered. Many capture processes have been designed to use low-pressure steam, but applications with optimized steam balances could benefit from fully electric configurations as otherwise the steam balance is affected, or new steam generation capacity would be needed.

With fully electric configurations electricity transmission capacity and dynamicity of electricity prices should be evaluated. Some applications may also have low-grade waste heat available that could at least partly power some capture processes with little impact on the energy balance. Some carbon capture processes also yield heat at recoverable levels, which could provide synergy with district heating networks or other heat demand applications. However, it also raises the question of where to direct the heat load at periods of low heat demand.

Site layout and operating environment should be also considered. In compact sites such as oil and chemical refineries there may be restrictions on size or footprint of any additional equipment and low equipment footprints may have to be prioritized. Utility demands like water and chemical use as well as emission and waste management should be also considered. Site location, readiness for logistics, and proximity of utilization applications or storage sites should be also assessed, as these factors affect logistical options and the feasibility of the value chain. As in all mechanical engineering, factors like weather conditions, humidity, and altitude should be also considered.

After technology screening, some form of techno-economic assessment (TEA) is often beneficial to estimate the economics of technologies that have been identified potential. TEA consists of outlining properties and operating profile of the CO2 source and modelling energy and mass balances of the capture processes. Furthermore, cost information is collected about the examined technologies, which are scaled and modified to fit the application in question. TEA can be performed with varying levels of detail, from simple spreadsheets to process simulations validated with experimental data. Typically, process models and TEA are detailed as the project progresses from concepts closer to full-scale.

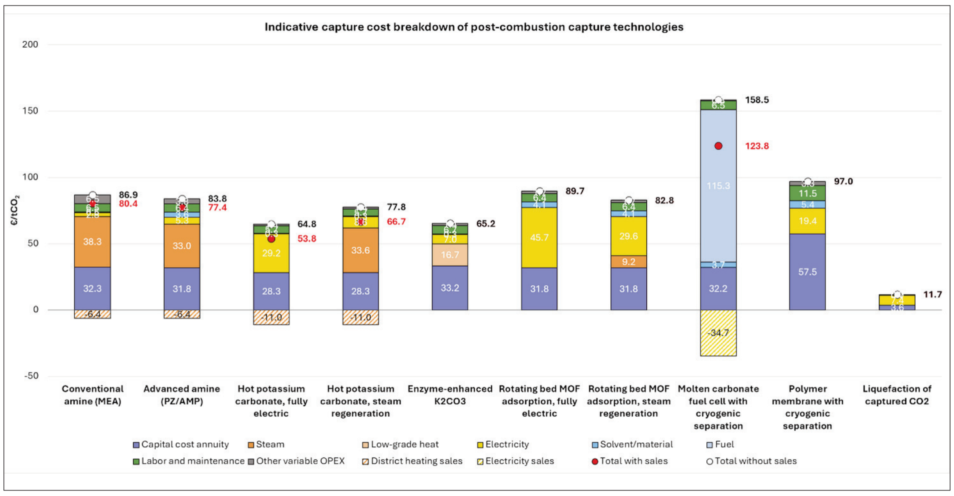

Figure 2 - Breakdown of indicative capture costs (€/tCO2) for post-combustion capture technologies calculated for a plant with 500 kt of annual CO2 emissions

As part of the RePowerEU project on CO2 supply for P2X processes, VTT has developed a calculative model for technology screening and techno-economic assessment of post-combustion carbon capture technologies. The model was constructed based on cost data collected from literature and it includes several mature and emerging capture technologies: conventional amine absorption (MEA), advanced amine absorption (PZ/AMP), hot potassium carbonate (HPC) with fully electric and steam regeneration configurations, enzyme-enhanced K2CO3 absorption, rotating-bed MOF adsorption with fully electric and steam regeneration configurations, polymer membrane separation, molten carbonate fuel cell-based capture, and liquefaction of the captured CO2.

Based on inputs regarding scale, energy prices, and investment parameters, the model calculates an indicative CO2 capture cost breakdown (€/tCO2) for each technology. Figure 2 presents an example of the results, with capture costs calculated for a plant with 500 kilotons of annual CO2 emissions. The model can be also used to conduct sensitivity analysis to identify the most influential cost factors and examine different operating scenarios.

While the tool provides valuable information about the cost structure of post-combustion capture technology options, the results are indicative, depend largely on the inputs used, and do not necessarily represent views of the technology developers and suppliers. As the operating parameters have been collected from public sources, assumptions and methodology between some of the parameters may vary. To obtain the most accurate capture cost estimates, process simulation tools validated with experiments and cost data provided by technology suppliers should be used.

In addition to post-combustion capture, VTT's RePowerEU project on CO2 supply for P2X processes has focused on integrating power-to-X technologies with direct air capture, as well as advancing the CO2 economy through development of CO2 logistics and hubs. In future work, VTT will continue to advance process simulation tools, experimental research capabilities, and novel technology concepts regarding various carbon capture value chains.

More information

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