2022-IP06

BEIS REVIEW OF NEXT GENERATION CARBON CAPTURE TECHNOLOGY FOR INDUSTRIAL, WASTE AND POWER SECTORS

BACKGROUND

AECOM and the University of Sheffield were commissioned by the Department for Business, Energy, and Industrial Strategy (BEIS) to conduct a 4-part study on the next generation carbon capture technologies for different industrial, waste and power sites. The aim of the study was to review the suitability of capture technologies to different applications with an emphasis on potential deployment at a scale of ~1,000 ton per day (tpd) of CO_2 capture by 2030

The primary deliverables of the study are:

1. A report on the next-generation carbon capture technologies
    - The aim of this study was to review technologies with the capacity to be deployed in the order of 1,000 tpd scale by 2030. Less well-developed technologies that are more likely to be deployed at scale by 2035, or later, have been reported on, but with a lower level of detail.
2. A case study of a mobile carbon capture de-risking project:
    - The objective of the case study was to develop a concept design for a nominal 100 tpd of CO_2captured in an Energy from Waste application. The demonstration plant is designed to use a solvent-based technology to operate over extended test campaigns (e.g., on the order of 10,000 hours) at representative facilities and therefore predict reclaimer, waste stream, contaminant, and make-up rates.
3. A technoeconomic methodology
    - This report defines the methodology and assumptions used in the technoeconomic analysis and benchmarking exercise conducted. The key stages within the methodology considered are:
        - Defining plant configurations
        - Data gathering
        - Modelling of scenarios
        - Summarising key outputs
        - Highlighting principal assumptions and uncertainties.

    A summary of common assumptions and associated uncertainties has been provided in the report. This summary gives an indication of where the important areas of uncertainty lie. Further commentary on uncertainty is provided in the write-up of each scenario.
4. A technoeconomic analysis
    - The technoeconomic analysis conducted compares next generation capture technologies against the benchmark technology (Monoethanolamine solvent-based postcombustion carbon capture). The study has examined several capture technologies applied to different industries, allowing comparisons between technologies and industries to be made.

REVIEW OF NEXT GENERATION TECHNOLOGIES

The next generation[1] technologies that are most likely to be deployable at around 1,000 tpd scale by 2030 are mostly amine based solvent systems that can be developed by incremental improvements. These technologies have been classified as Demonstration Stage technologies (TRL 8) in this study. Technologies that are considered more likely to be deployable at around 1,000 tpd scale by 2035 or later have been classified as Development Stage technologies (TRL 5-8). Research Stage technologies are at an earlier stage of development (TRL 1-4).

For many carbon capture projects the low-cost of emitting CO_2, and the lack of CO_2 transport and storage infrastructure, are more fundamental barriers to deployment than the availability of suitable carbon capture technology. However, with increasing concerns over human induced climate change, the commercial viability of carbon capture and storage projects is expected to improve. Cost reduction in carbon capture is important in relation to achieving large scale deployment of technologies in the sector. Both the development of new processes, and the advancement of existing systems through the various stages of commercial deployment, are important elements in allowing cost reductions to be achieved in the carbon capture sector.

Input flue gas streams to carbon capture facilities will have different physical properties and/or composition. This will give rise to different processing requirements due to factors such as pressure, temperature, contaminant species, and their concentrations. CO_2 concentration is important when considering technology selection. Thus, if a technology is applicable to one input gas stream within a certain CO_2 concentration range, it may not be applicable for another input gas stream with the same CO_2 concentration range due to differences in contaminant concentrations. A matrix of the applicability of each of the demonstration and development stage technologies to capture CO_2 from gas streams with different CO_2 concentrations is displayed in Table 1. There are two important limitations to note in relation to the classification process applied. Firstly, classification has been based primarily on input gas CO_2 concentration. The CO_2 concentrations from some industrial flue gasses are likely to change over time due to reasons such as electrification of process heating or changes to the mixture of fuels fired in combustion appliances.

[1] The term ‘next generation’ has been used to describe a variety of developing capture technologies. However, it should be noted that in the applications considered there is no established current generation of capture technology

Table 1. Technology Application Matrix, based on known projects[2]

Flue Gas CO_2 Concentration Category	Low 1-5%	Mid 5-10%	High 10-15%	Very High 15+%
Typical industrial processes where such a flue gas may be present	• CCGT • Aluminium • CHP • Glass (air/fuel furnace)	• Natural Gas Fired Boiler • Fired Heater • Oil Refining	• Oil-Fired Boiler • Coal-Fired Boiler • EfW • Biomass-Fired Boiler	• Iron & Steel Production • Cement/Lime Production • Hydrogen Production • Anaerobic Digestion
Demonstration Stage Technologies				
Mitsubishi Heavy Industry	Yellow	Yellow	Green	Yellow
Shell Cansolv	Green	Green	Green	Yellow
Fluor Econoamine FG Plus	Green	Green	Green	Yellow
Carbon Clean	Orange	Green	Green	Green
Aker Carbon Capture	Green	Green	Green	Green
Development Stage Technologies				
BASF & Linde	Orange	Orange	Green	Yellow
C-Capture	Green	Green	Green	Yellow
CO_2 Capsol	Orange	Orange	Green	Yellow
CO_2 Solutions SAIPEM	Orange	Green	Green	Yellow
Baker Hughes CAP	Green	Green	Yellow	Yellow
ION Clean Energy	Yellow	Yellow	Green	Yellow
RTI International	Orange	Yellow	Green	Yellow
Kawasaki CO_2 Capture	Orange	Orange	Green	Yellow
Svante	Orange	Green	Yellow	Yellow
TDA Research	Orange	Orange	Green	Yellow
FuelCell Energy	Yellow	Green	Green	Green
Membrane Technology and Research	Orange	Orange	Green	
Air Liquide	Orange	Orange	Orange	Green

Key	
Applicable	Green
Likely to be Applicable	Yellow
Possibly Applicable	Orange

With increasing concerns relating to rising atmospheric CO_2 levels there is a growing acceptance of the urgent need to reduce anthropogenic CO_2 emissions rapidly and substantially. This creates opportunities in relation to the development and deployment of carbon capture technologies. Some of the industry-specific opportunities common to most carbon capture projects are presented in Table 2.

[2] Department for Business, Energy, and Industrial Strategy. Next Generation Carbon Capture Technology. Technology Review, Work Package 2. 2022

Table 2: Industry Specific Opportunities and Barriers[1]

Industry	Opportunities	Barriers
Energy from waste	• Potential for net negative CO_2 emissions due to biogenic content of feedstock • Consistent high load operation • Experience of complex flue gas treatment • Improved public perception • Limited other options for residual waste treatment	• The potential impact of residual contaminant carryover from existing flue gas treatment processes. • Dispersed location of sites
CHP and gas fired power generation	• Relatively low level of contamination in flue gas • High volumes of CO_2 produced at one source	• Competing technologies for low carbon electricity generation • Possible intermittent operation • Low CO_2 concentrations
Biomass Power generation	• Potential for net negative CO_2 emissions due to biogenic content of feedstock	• Limited availability of sustainable feedstock
Cement and lime	• High volumes of CO_2 produced at one source • Limited other ways of substantially reducing CO_2 emissions • Potential to export low CO_2 product • Potential for net negative CO_2 emissions if feedstock with biogenic content is used.	• Dispersed location of sites • The potential impact of residual contaminant carryover from existing flue gas treatment processes.
Glass	• Limited other ways of substantially reducing CO_2 emissions. Particularly for large sites that cannot source enough good quality recycled glass to replace carbonate feedstock • Potential to export low CO_2 product	• Dispersed location of sites • The potential impact of residual contaminant carryover from existing flue gas treatment processes.
Oil and gas	• Experience of gas handling, including CO_2 capture technologies • Access to storage sites • High volumes of CO_2 produced at one source	• Multiple emission streams at some sites • May be perceived negatively as a way of allowing the continued use of fossil fuels
Iron, steel and non-ferrous metals	• High volumes of CO_2 produced at one source • Potential to export low CO_2 product	• Other potential decarbonisation options available
Chemicals	• Some emission streams with high CO_2 concentration (eg in fertiliser production) • Potential to export low CO_2 products • Potential to use CO_2 in product manufacture	• Different challenges for different industry subsectors. For example, intermittent operation, contamination, scale or geographic location.
Anaerobic digestion	• Potential for net negative CO_2 emissions due to biogenic content of feedstock • Relatively high CO_2 concentration in biogas • Established processes for CO_2 extraction for when biogas is upgraded to biomethane	• Relatively small scale • Dispersed location of sites
Brewing and distilling	• Potential for negative CO_2 emissions • High concentration CO_2 produced • Established CO_2 capture and sales	• Dispersed location of sites • Relatively small scale

TECHNO-ECONOMIC ANALYSIS

The technoeconomic analysis (Figure 1) conducted compares next generation capture technologies against benchmarks based on amine solvent capture technology. Amine solvents were used as the benchmark as they are the most established capture technology. Scenarios have been developed for utility scale gas power generation, energy from waste (EfW) and cement manufacture applications. These industries are likely candidates for capture technology application. In addition, they have a range of flue gas conditions and integration challenges that are representative of a wider range of industries. The results obtained should be of use to a wider range of industrial emitters. For example, the application of capture to EfW will have similarities to the application of capture to biomass power generation.

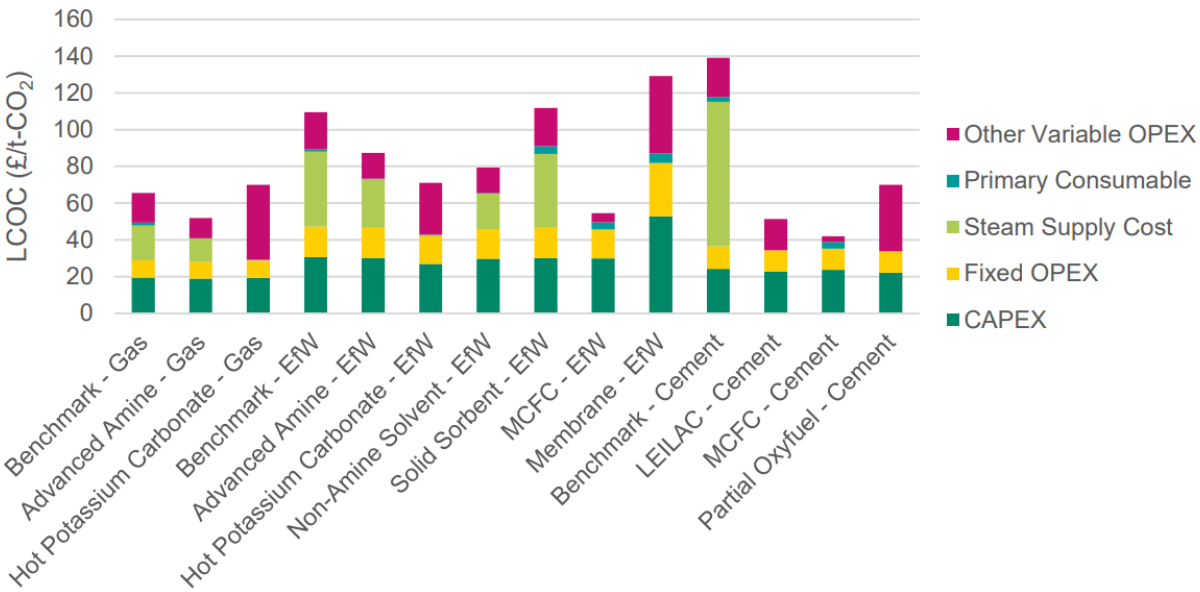

Figure 1. Levelized cost of capture (LCOC) breakdown for all scenarios

- LCOC values relate to capture only. Costs for residual CO_2 emissions and CO_2 T&S are not included.
- Capture level is 95% or greater for all scenarios other than, Hot Potassium Carbonate – Gas (90%), LEILAC – Cement (60%), Membrane – EfW (60%) and Partial oxyfuel – Cement (60%). Based on assumed CO_2 emission prices, residual emission costs and the impact on product cost will be higher where capture levels are lower.
- Capture plant scale and the assumed cost of thermal energy vary between the industry sectors analysed.
- All scenarios produce pipeline grade CO_2. For the molten carbonate fuel cell (MCFC) and membrane scenarios CO_2 is produced in liquid phase.
- The MCFC scenarios also consume natural gas and generate electricity. Therefore, LCOC values will be influenced by the economics of power generation from gas in a way that other capture technologies are not. The 'Other variable OPEX' segment in the MCFC scenarios include both a natural gas cost and a negative operating cost resulting from electricity export.
- More CO_2 is captured in the MCFC cases, relative to the other scenarios in the EfW and cement sectors, due to capture of the CO_2 from the natural gas used in addition to the CO_2 captured from the cement process, and hence LCOC is reduced commensurately.
- The Low Emissions Intensity Lime and Cement (LEILAC), and partial oxyfuel cement scenarios are process alterations that aid capture, rather than standalone capture technologies. Impacts on the cement manufacturing process may not be reflected in the LCOC values. In new build projects, capital cost reductions would be possible for these technologies as conventional equipment is replaced.
- LCOC is only one aspect of technology performance. The results must be considered in conjunction with the information provided on demonstration status, opportunities, challenges, and assumptions.

For each scenario a description of the capture technology is provided along with information on current demonstration status, technical challenges, development opportunities, capital, and operational costs, LCOC, impact of capture on product price and a summary of assumptions and uncertainties.

NEXT STEPS

1. Encourage the development of carbon capture projects in industries where it is relatively low cost and technically simple to capture the CO_2. These industries include brewing and distilling, biomethane upgrading and industrial hydrogen production. Once the appropriate

infrastructure has been developed these industries have the potential to develop low-cost CO_2 to storage projects.

2. De-risk technology through supporting the long-term testing of key components, such as solvents, sorbents, fuel cells and membrane materials under representative conditions. Performance of key components of the capture technologies is a source of uncertainty in relation to technology performance, and long-term testing would provide data to reduce levels of performance uncertainty.
3. Support the construction of mid-scale demonstration facilities (in the order of 100 tpd) can then be used to validate other aspects of plant performance including constructability, capital cost, reliability, and the performance of heat integration systems.

The outputs of the studies are intended to inform government decisions relating to the provision of innovation support funding for carbon capture, and future policy around CCUS deployment.

The full reports of the BEIS review of next generation carbon capture technology for industrial, waste and power sectors can be accessed on the UK Government website.

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