The potential for CO_2 capture and storage in EU refineries

CCS technology has the potential for large-scale reductions in CO_2 emissions to the atmosphere—but it also presents significant challenges for the refining sector.

CO_2 capture and storage (CCS) is seen as one of the most promising routes to a major reduction in CO_2 emissions to the atmosphere. Its deployment on a large scale would make it possible to continue using fossil energy resources while meeting the challenging emission reduction targets that are widely believed to be necessary to avoid serious climatic consequences. A 2009 McKinsey report[1] states that CCS is the largest single lever for abating oil and gas emissions, if enough resources—both in terms of capital and engineering capacity—are made available.

CCS does, however, raise a number of technological, economic and legal challenges. For example, it requires capture equipment, transport infrastructure, injection and monitoring facilities—bringing high complexity and cost. Beside the extra investment costs, there will also be additional operating costs because CCS will require additional resources, especially energy. The extra expenses can only be justified if CO_2 has a sufficiently high long-term price.

Technologies to collect, separate/capture, transport and inject CO_2 into geological structures are known and have all been applied in commercial ventures. Nonetheless, the scale required for widespread application of CCS and the need to combine all steps into a seamless chain raise significant technological, practical and regulatory challenges.

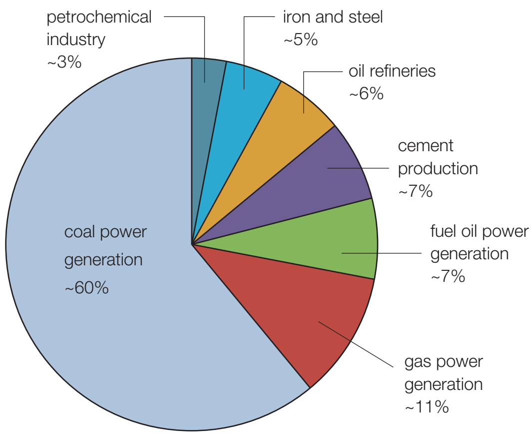
Underground storage of CO_2 over many centuries also raises specific legal issues regarding ownership and liabilities. Although governments and international institutions, particularly in Europe, are working on the development of appropriate legal frameworks, operators do not currently have a clear picture of their short- and long-term legal positions.

CONCAWE recently published a report (Report No. 7/11) which focuses on the specific challenges faced by oil refineries in Europe for the capture of the CO_2 they emit during normal operations, the availability of suitable storage sites within reasonable distances from refineries and the development of a CO_2 transport infrastructure. Information in this report is based on literature sources, particularly the comprehensive 2005 IPCC special report[2]. Some sources are already a few years old and, although technology has not evolved much over the period, estimated costs have increased significantly.

Refinery CO_2 emissions in perspective

Oil refineries require energy to convert crude oil into marketable products. In the process, they emit CO_2 by burning fuel to produce heat and power, and by producing hydrogen used for conversion processes. As shown in Figure 1, the EU refining sector currently produces approximately 6% of total European industrial CO_2, i.e. 3–4% of all anthropogenic emissions in Europe. In comparison, more than 75% of Europe's industrial CO_2 emissions come from power generation.

Figure 1 EU large stationary sources of CO_2

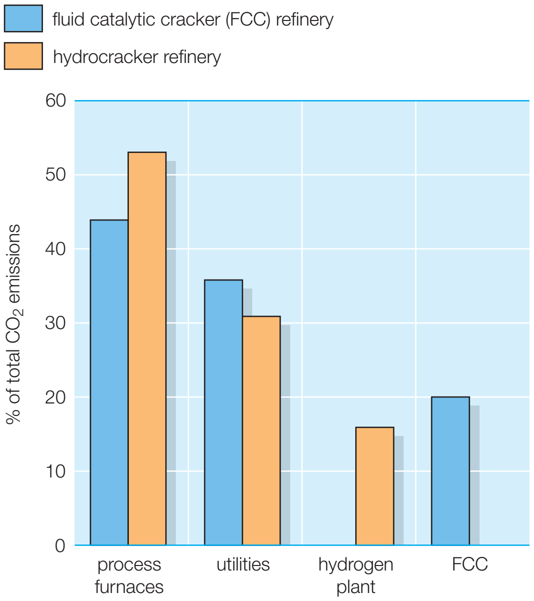


Source: IPCC SRCCS (2005)

Individual refineries are fairly large CO_2 emitters but are still, in comparison, much smaller emitters than power generation plants. Unlike these plants, refineries emit CO_2 from many dispersed and often relatively small sources, which adds a level of complexity to the capture process, particularly for post-combustion capture technologies.

[1] Dinkel, J. *et al.* (2009). *Pathways to a low-carbon economy—version 2 of the global greenhouse gas abatement cost curve*. McKinsey & Company.
[2] Metz, B. *et al.* (2005). *IPCC special report on carbon dioxide capture and storage*. Intergovernmental Panel on Climate Change, Working Group III. New York: Cambridge University Press

Figure 2 Typical distribution of CO_2 emissions by source in a complex refinery



Refinery CO_2 emissions are dominated by those from process furnaces and utilities, as shown in Figure 2. In practice, heat and power plants within refineries are the largest single sources, although a moderately complex refinery may have 20 to 30 separate process heaters often spread over a fairly large geographical area.

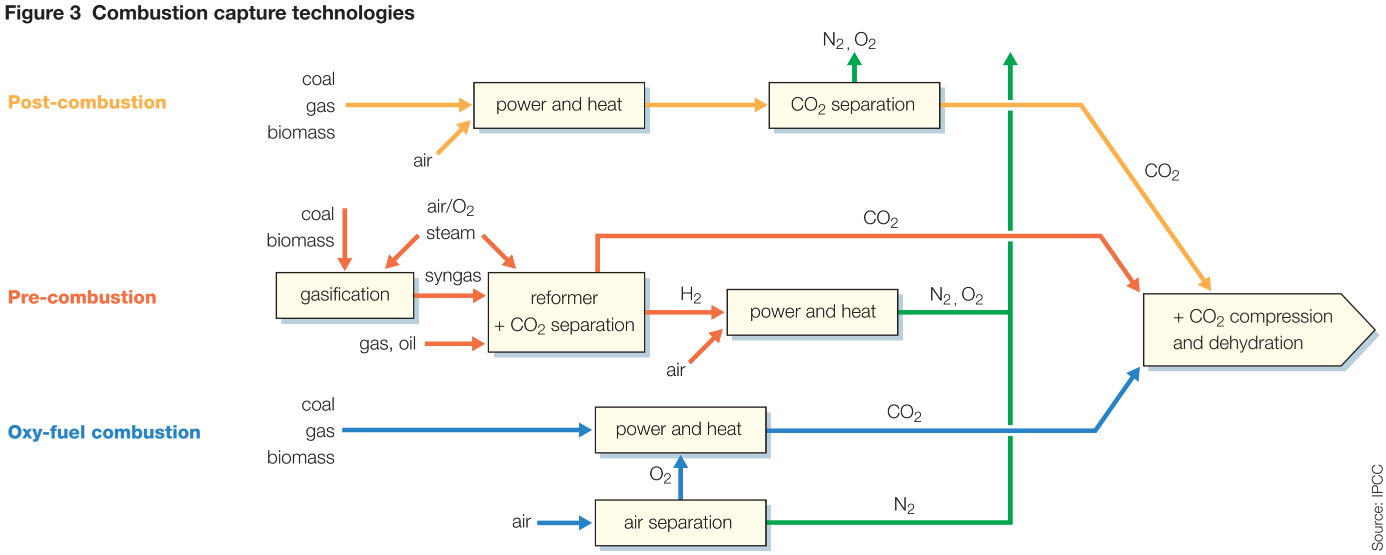
With the exception of some hydrogen plants, CO_2 is emitted in flue gases with fairly low CO_2 concentrations, typically in the order of 3–12% v/v CO_2.

Refinery CO_2 capture and associated combustion technologies

There are essentially three routes to CO_2 capture: **post-combustion**, **pre-combustion** and **oxy-fuel combustion** (Figure 3).

- **Post-combustion** capture does not change the combustor technology and captures CO_2 from large volumes of flue gases having low CO_2 concentrations. Existing chemical absorption technology can be used for the CO_2 capture but it would have to be implemented on an unprecedented scale. Impurities and contaminants commonly found in flue gases would also present new technical challenges. Post-combustion capture is costly from a capital perspective and requires a large amount of extra energy, mostly for desorbing CO_2 from the solvent, which in itself leads to extra CO_2 emissions. As a result, the total amount of CO_2 'avoided', i.e. prevented from reaching the atmosphere, will be about 30% less than the total CO_2 captured.
- **Pre-combustion** consists of partially or completely decarbonising the refinery fuel to produce two separate streams: hydrogen for combustion as an energy source and concentrated CO_2 for removal 'before combustion'. In practice, this approach consists of gasifying a heavy feedstock or converting fuel gas to a mixture of hydrogen and carbon monoxide (CO) known as syngas, followed by conversion of CO to hydrogen via the water-gas shift reaction in a reformer. Although the completely

Figure 3 Combustion capture technologies



decarbonised fuel chain is not used today, the process building blocks are already available as commercial technologies. These, however, can be complex and expensive installations. Retrofitting refinery heaters to burn pure hydrogen or hydrogen-enriched fuel gas could require extensive modifications, depending on the hydrogen concentration.

- **Oxy-fuel combustion** involves replacing the combustion air by pure oxygen, thereby eliminating nitrogen from the flue gases. This greatly increases the CO_2 concentration and reduces the flue gas volumes to be handled by the capture process. This approach has not been widely deployed in industry thus far and brings significant technological challenges. Retrofitting the large number of individual refinery process heaters to burn pure oxygen would also be complex and possibly expensive.

Whatever technology is selected, CO_2 capture would result in high cost and significant extra energy consumption and CO_2 production in a typical refinery. Adding large capture facilities with previously untested technology at the required scale could also affect the reliability of existing refinery installations. Although some of the developments in CCS for the power sector could be implemented in refineries, there is a need for demonstration projects using technology developed to address the specific challenges of refineries, such as specific impurities, lack of ground space, high reliability requirement, low retrofitting impact, energy consumption and energy integration.

Energy integration, in particular, is much easier in power plants, because they are steam and electricity producers and can easily be derated to provide the energy required for the CO_2 capture process. In refineries, which would need to install new utility plants for the additional energy demand, the need for improvement in energy consumption for CCS technology will be greater in refineries than in power plants. This will require special effort and support to be given to developing technologies that tackle this problem.

CO_2 transport

CO_2 can be transported in bulk either as a supercritical liquid in pipelines or as a refrigerated liquid in ships. There is already commercial experience with both approaches. For large quantities of CO_2 and short to medium transport distances, pipelines are the most cost-effective transport option.

Pipeline costs per tonne of CO_2 transported depend strongly on scale. The investment cost for a small-diameter pipeline dedicated to transporting about 2 Mt of CO_2 per year would be about 16 €/t CO_2. A larger diameter pipeline capable of transporting 5–10 Mt of CO_2 per year would cost about half this amount. Because of the cost and complexity of major pipeline projects, it will make economic and practical sense to build large pipelines serving several users, most probably around large single emitters such as power stations or in industrialised areas.

Quality specifications for the CO_2 streams will also need to be developed to address all potential impacts on pipeline performance including corrosion. Transport and handling of large quantities of CO_2 near populated areas could raise safety concerns and, therefore, public acceptance issues. The most significant safety risk is leakage of CO_2 from a pipeline into the atmosphere or the subsurface. High concentrations of CO_2 caused by a release to the atmosphere would pose health risks to humans and animals. Risk management techniques will be required to identify, mitigate and manage these risks in order to ensure the safety of CO_2 transport, handling and storage.

CO_2 storage

Large amounts of CO_2 can potentially be stored in various geological formations in Europe. Most of the potential CO_2 storage capacity in Europe is located offshore (68% of the total). Figure 4 shows the locations of refineries in Europe and potential onshore and offshore sedimentary basin storage sites.

Storage of CO_2 in deep saline aquifers is the most promising in terms of capacity. CO_2 can also be permanently stored in fully depleted oil and gas fields which are generally well known and documented, although storage capacity in these sites would be smaller than in aquifers.

CO_2 injection into oil and gas fields for enhanced oil/gas recovery (EOR/EGR) is a fully developed technique

Figure 4 Location of EU refineries and potential underground sites for CO_2 storage

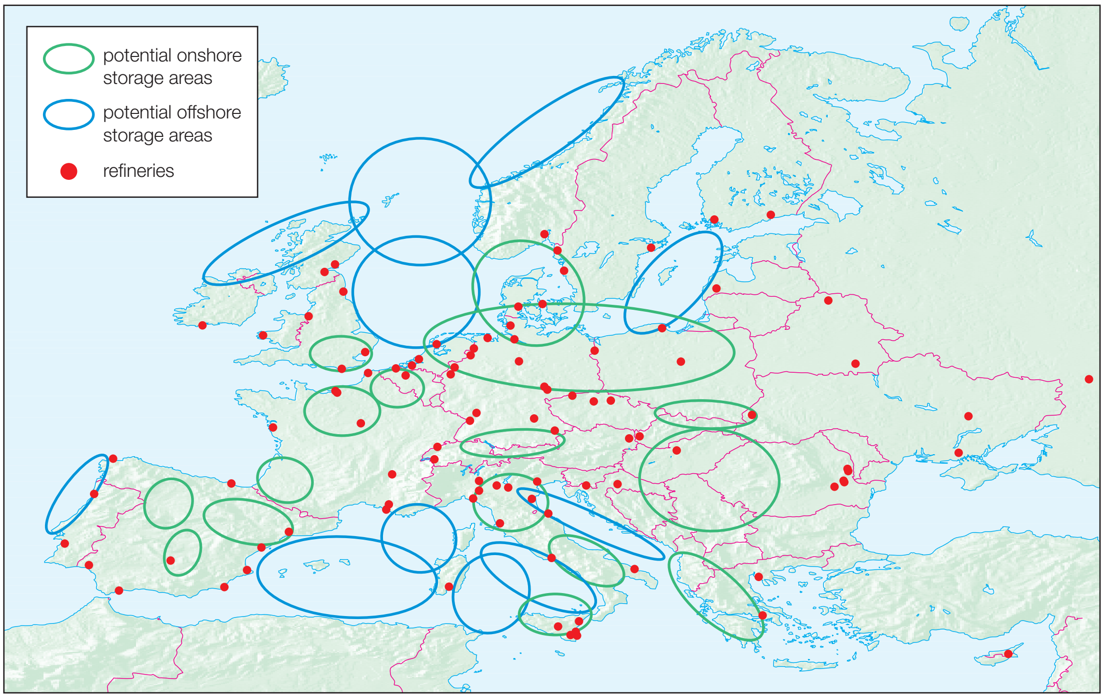


Figure 4 shows the location of EU refineries and potential sedimentary basin storage sites. The red dots represent the refineries, and the areas bounded in green and blue are the potential storage areas, onshore and offshore, respectively.

through which some CO_2 can be retained. Compared to North America, where EOR and EGR are widely practised, the use of CO_2 for EOR/EGR is not expected to be economic in Europe if the crude price is consistently lower than about 100 $/bbl.

After the CO_2 has been injected underground, the integrity of the storage sites will need to be continuously monitored using a range of techniques and protocols, many of which are already well known.

Refinery CCS costs

The cost of refinery CCS is expected to be significantly higher than the current estimates for CCS in coal-fired power plants, which range from 60–80 $ (43–57 €) per tonne of CO_2 avoided. The estimated cost of CO_2 capture, which is typically about 80% of the total, will vary widely, depending on each refinery's size, complexity and location. The cost is also highly dependent on the fraction of the total emissions to be captured, because refineries usually have a small number of large emission sources and a large number of smaller, low concentration sources.

The capture cost for the first 50% of the total CO_2 emissions from a large, complex refinery has been estimated in a report by Shell[3] at 90–120 € per tonne of CO_2 avoided (2007 basis). The cost will be considerably higher to capture the remaining 50% of CO_2 emissions. Smaller, less complex refineries would not benefit from the economy of scale and unique configuration of the refinery in the Shell study. Taking into account the costs of transport, storage and monitoring, the total CCS cost estimate for the Shell example refinery would be in the range of 132–178 € per tonne of CO_2 avoided (on a 2010 basis).

With the current lack of experience of large-scale CCS projects and therefore limited understanding of the cost implications, there are wide variations in published cost estimates. A detailed estimate of refinery CCS costs was beyond the scope of the current CONCAWE report, requiring rigorous analysis of a wide range of variables in order to place the costs in their proper context.

[3] van Straelen, J. *et al.* (2010). CO_2 capture for refineries, a practical approach. *International Journal of Greenhouse Gas Control 4, 2, 316–320.*