Zero emissions platform

CCU – carbon capture and utilisation

European Technology Platform for Zero Emission Fossil Fuel Power Plants

Key messages

General
The application of CCU could offer two important benefits: first of all the uptake of CO_2 and to a certain degree the reduction of CO_2 emission into the atmosphere and, second, a significant economic value to a CCS project. For the shorter term the largest potential in Europe is offshore EOR, mainly in Eastern Europe (where this process is already being applied) and the North Sea. On the longer term other large CO_2 uptake potential might come available from emerging technologies, subject to their development.

Role
The re-use of CO_2, Carbon Capture and Utilisation (CCU), as either a solvent, working fluid or as a source of carbon, can become an enabler for CCS deployment and vice versa. As such, the reuse of CO_2 cleverly integrated with permanent CO_2 storage options enables the opportunity to develop a common CO_2 infrastructure, increase the demand of CO_2, provide system flexibility by demand response of CCU applications and provide a reliable CO_2 source for emerging CCU technologies with smaller CO_2 off- take levels.

Impact
The use of LCA for assessing the potential environmental impacts of CCU remains a key aspect, especially for mitigation pathways that aimed to decrease climate change as they target to reduce the net amount of CO_2 emitted into the atmosphere. Given the increase complexity of CCU systems (multi-product systems with displacement of current products) is important that assumptions, data and results are provided in a harmonized and transparent way. On the shorter term CO_2-EOR is a proven technology increasing oil recovery and simultaneously storing CO_2 permanently in the subsurface and for the longer term, emerging alternative CCU options with large CO_2 uptake potential might be available, such as renewable methanol or formic acid production with baseload renewable energy generation technologies.

Next steps
It is imperative that action is needed to exploit and accelerate the full potential of CCU and CCS:

- Increase the CO_2 uptake potential of all promising emerging CCU technologies and incorporate CCS and CCU in Horizon 2020 as an enabling technology for Europe.
- Actively pursue the development of CCU technologies by national and EU funding schemes.
- Develop business models and define realistic CCU and CCS scenarios potential clusters throughout Europe.
- Improve the understanding of the potential of different CCU technologies as CO_2 mitigation option.
- Develop LCA guidelines for CCU that facilitate comparison among studies by providing harmonized and transparent framework for reporting.
- Conduct CO_2-source to CO_2-use spatial mapping, linked to CCS cluster developments.
- Design tailor-made incentive schemes at national and EU level to kick-start early projects.

Rationale

The Intergovernmental Panel on Climate Change (IPCC) recently announced that radical changes in the energy, industry and transport sectors are required to achieve a moderate temperature rise of 2 °C instead of an increase between 2.7 °C and 4.8 °C as compared to pre-industrial levels. To achieve this, deep cuts in CO_2 emissions over the coming decades are required. Carbon Capture and Storage (CCS) represents a potentially important abatement option for achieving the 2 °C climate target. However, commercial scale CCS developments are lagging behind. Therefore, the EU needs an appealing approach for CCS that provides improved solutions with respect to cost, performance, operational flexibility and re-use of CO_2.

The re-use of CO_2, Carbon Capture and Utilisation (CCU), as either a solvent, working fluid or as a source of carbon, can become an enabler for CCS deployment and vice versa. CCU applies to a range of applications that utilise CO_2 either as part of a conversion process, for the fabrication or synthesis of new products (e.g. methanol, urea, polymers), or in non-conversion processes, where CO_2 is used as a solvent (e.g., for enhanced oil recovery, CO_2-EOR). CO_2-EOR is a proven technology increasing oil recovery and simultaneously storing CO_2 permanently in the subsurface. Commercial CCU propositions such as mineralization and CO_2-EOR can make a significant contribution to climate change abatement by providing long term CO_2 storage and also providing an economic drive for CO_2 capture and network development. Other CCU propositions, although involving smaller quantities of CO_2, and without long term storage potential, can also provide economic drivers for CO_2 carbon capture, especially in locations where access to storage sites is limited. Commercial CCU can also be part of resource efficiency and circular economy strategies that look at the valorisation and use of waste streams . The assessment of such future options for CO_2 re-use requires a careful comparison against alternative scenarios involving similar clean processes that do not use CO_2 (IPCC SR on CCS, 2005) [6].

This paper aims to provide an overview of the different CCU options, technology maturity, and their potential to reduce CO_2 emissions in an EU context.

Contents

1 CCU status overview

The EU energy policy has identified research priorities for CCS and CCU:

✓ An Energy Union research priority – COM(2015)80:

«A forward-looking approach to CCS and CCU for the power and industrial sectors will be critical to reaching the 2050 climate objectives in a cost-effective way»

✓ A SET-plan Action priority – C(2015)6317:

«*Step up R&I activities on the application of CCS and commercial viability of CCU*»

✓ An Integrated Roadmap theme- JRC93056 / 2014

«Enabling carbon capture, CO_2 utilisation and storage technologies...»

✓ SCCS CO2-EOR Joint Industry Project - CO_2 storage and Enhanced Oil Recovery in the North Sea: securing a low-carbon future for the UK- (2015) – ISBN: 978-0-9927483-2-6.

«This CO_2-EOR route achieves two desirable objectives. A business demand is created, driving sequential construction of CO_2 capture, which develops learning and reduces costs of CO_2 supply, enabling cheaper low-carbon electricity »

These documents point out the key issues for CCU:

- How competitive are the emerging technologies?
- What is the technology maturity of the emerging options?
- What are the climate change mitigation credentials of different technologies?
- How large is their potential in reducing CO_2 emissions?

As discussed previously, with the exception of mineralisation and CO_2-EOR, for a substantial number of CCU options CO_2 will be released back into the atmosphere. In case of a (hydrocarbon) fuel that will happen relatively quickly. If the CO_2 is used for producing e.g. a polymer, CO_2 will be released at the end of the lifetime of the final product (e.g., when the product is incinerated). The potential impact of this “temporal storage” on climate change should be quantified in LCA methodologies. It should be noted that debate on the significance of temporal storage in terms of climate change is still on-going and robust conclusions are yet to be drafted.

As a second point, the utilization of CO_2 could displace the use of fossil fuels. This displacement may result in a lower carbon footprint for a product. However, it is still not clear how large this impact can be. Recent reports show that although the development of commercial CCU propositions is expected to support the development of carbon capture and storage (CCS), accelerating deployment of CCS will enable large scale commercial CCU project such as CO_2-EOR to take place. It is worth noting that the use of captured CO_2 as the solvent for EOR operations will facilitate the production of more fossil fuels with a lower carbon footprint[7], which can displace not produced marginal oil produced with higher intensity extraction methods. However, study of the carbon accounting balance of CO2 produced and CO2 stored, shows that CO2-EOR continues to enable “green” low-carbon electricity produced by CCS and where alternative carbon accounting, including the emissions of the oil produced, results in lower well to wheels intensities than alternative routes[8].

The current World market size of CO_2 utilization is approximately 126 Mtpa [3].

✓ Solvents	66 Mtpa
✓ Feedstocks	36 Mtpa
✓ Energy	14 Mtpa
✓ Working fluid	10 Mtpa

Figure 1 illustrates the main CO_2 utilisation options including emerging options, based on a categorisation approach developed by the US DoE.

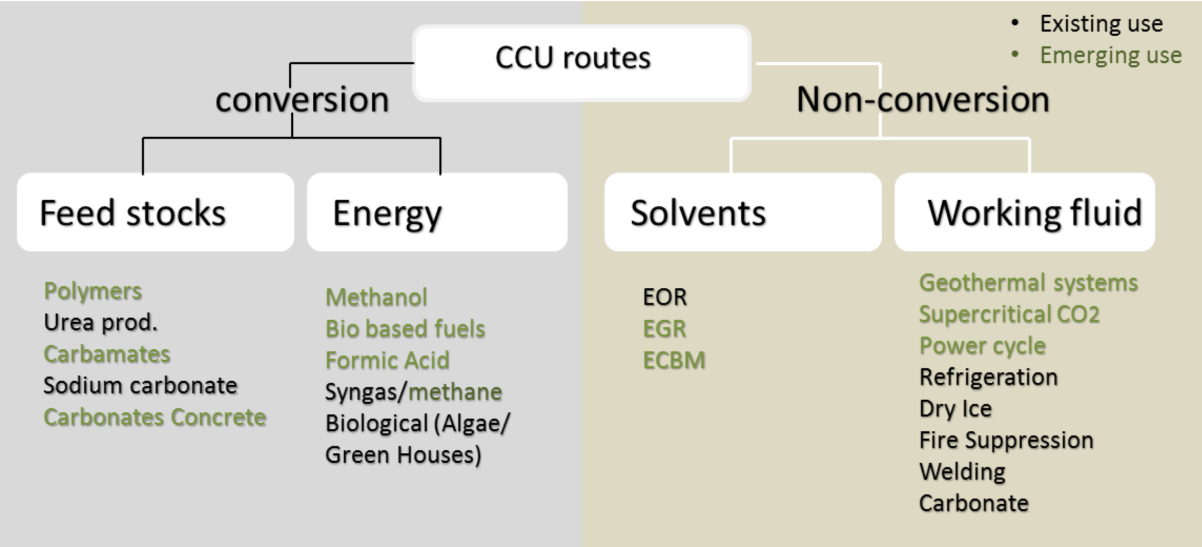

Figure 1: CCU routes (source: US DoE).

In the case of CO_2 conversion categories, it must be noted that almost all conversion processes require the input of energy. Figure 2 provides a schematic overview of the increase of energy needed in relation to the functional level of CO_2, for the different CO_2 conversion technologies. With new, emerging technologies CCU can replace conventional processes. An important prerequisite is the availability of low cost renewable energy in order to result in a carbon uptake and be commercially competitive.

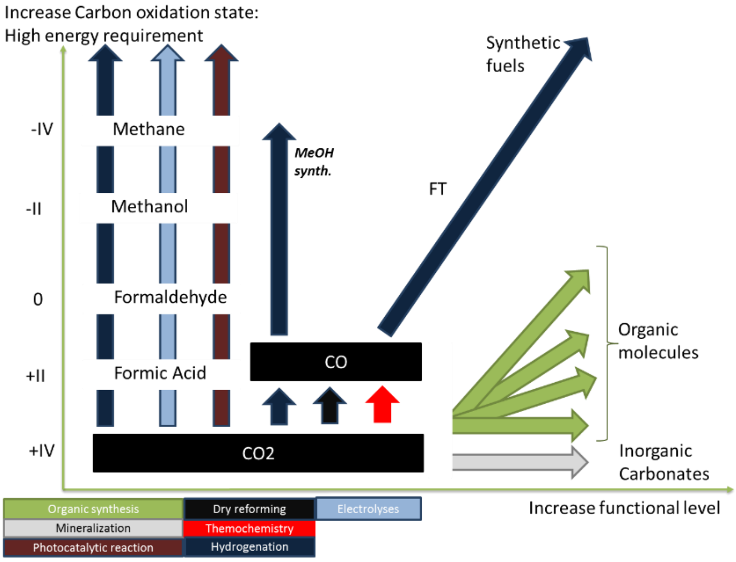

Figure 2: Schematic overview of energy requirement for CO_2 conversion (source: ENEA 2015)[2].

Several opportunities and challenges for the four main CCU routes can be identified.

Feedstock: Urea production is a strong growing market, hampered by access to reasonably priced CO_2 [3]. Therefore on the short term it is estimated that there is a need for 50 – 500 kt/yr range of capture plants[3]. Emerging use of CO_2 in carbonation of alkaline waste in concrete materials is another option, however it has a limited market potential due to scaling up limits imposed by CO_2 absorbed per tonne (max 400 kg/tonne of steel slags), the alkali supply, the material properties for construction applications and use of the carbonated product [3]. Other emerging opportunities are mineralisation such as concrete curing or enhanced weathering. Another emerging use of CO_2 is as feedstock for polymers, which is moving fast into pilot plant demonstration phase.

Energy: The main limiting factor of this route relates to the availability of renewable and low cost energy. Most proposed options require H_2 and, for obtaining positive carbon credentials, the energy required for the CO_2 conversion must be from a carbon-neutral or low-carbon source. CO_2 use for energy carriers (e.g., methanol, formic acid) can partially replace fossil fuels by recycled carbon and therefore could have a lower CO_2-footprint in comparison to conventional fuel production processes based on fossil fuel. From a climate perspective, the captured CO_2 is converted into an energy carrier and thus the CO_2 will ultimately be released into the atmosphere. In order to develop business cases in the short term incentive systems are needed. These incentive systems will help technology development and thereby bring down future cost for the use of these technologies.

Solvents: EOR development is hampered by, among others, access to CO_2. Large volumes are required subject to reservoir characteristics in the range of 500 ktpa up to 4Mtpa. New emerging use could take place in the areas of enhanced gas recovery (EGR) and enhanced coal bed methane recovery (ECBM). Currently CO_2 EOR is an established technology in onshore US, predominantly using CO_2 from natural sources. A recent development is CO_2-EOR in the Lula field, offshore Brazil. There is a global potential for CO_2 EOR.

Working fluid: The use of CO_2 as working fluid is considered to have low impact, mainly niche applications, competing with cheaper fossil fuels. Several technologies are emerging that make direct use of CO_2 for example in dry cleaning and car air conditioning systems. In these applications CO_2 can replace other raw materials or harmful chemicals.

2 Storage, fossil fuel displacement and uptake potential

The uptake potential of existing and emerging CCU technologies is illustrated in Figure 3; the numbers are based on [1].

Displacement of fossil fuel

There are several ways in which CCU could result in displacement of fossil fuels. A relatively simple one is using CO_2 in greenhouses where it displaces burned NG for the production of the CO_2 in greenhouses applications. This option is already applied at a relatively large scale in the Netherlands. A more complex case is the displacement of fossil fuel is by fuels that are produced from captured CO_2 and H_2 with a neutral carbon-footprint (when produced using renewable energy). The CO_2 originated from fuel combustion will however be re-emitted from a large number of distributed sources, e.g., car engines, making unlikely the possibility to re-capture it and store. This is where low cost carbon dioxide capture at (industrial) point sources can help in developing the business case for power to gas and power to liquid. Besides, these options could reduce the amount of fossil fuels going into the economy and leading to significant CO_2 emission reductions.

For example, the conventional production of Formic Acid (FA) requires 2.2 tonne CO_2 emitted per tonne FA [2], while direct CO_2 reduction has been reported with a negative CO_2 footprint as it is fixing 0.6 tonne CO_2 per tonne FA. Note that whether a positive net impact will be obtained depends on the carbon footprint of the process/product that will be displaced. See also Figure 4[1].

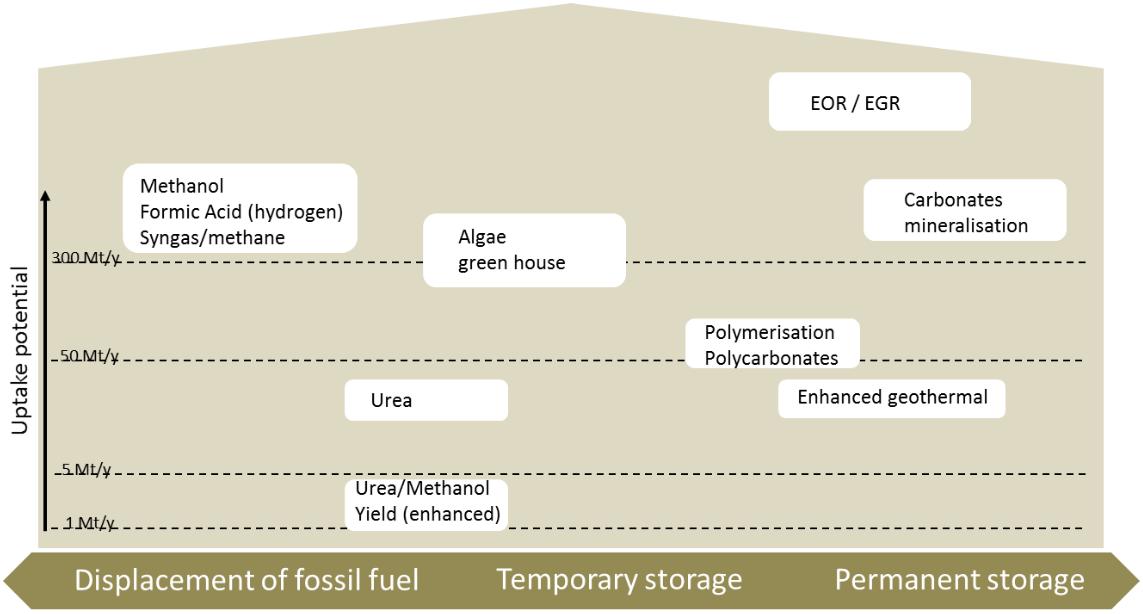

Figure 3: Storage, fossil fuel displacement and uptake potential (long term). Source: [1]

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[1] The displacement of fossil fuel through CCU with renewable energy should be compared in all its merits with the functional alternative applying BECCS and offsetting the ‘hard to capture’ fossil fuel emissions for example in air traffic and heavy-duty transport.

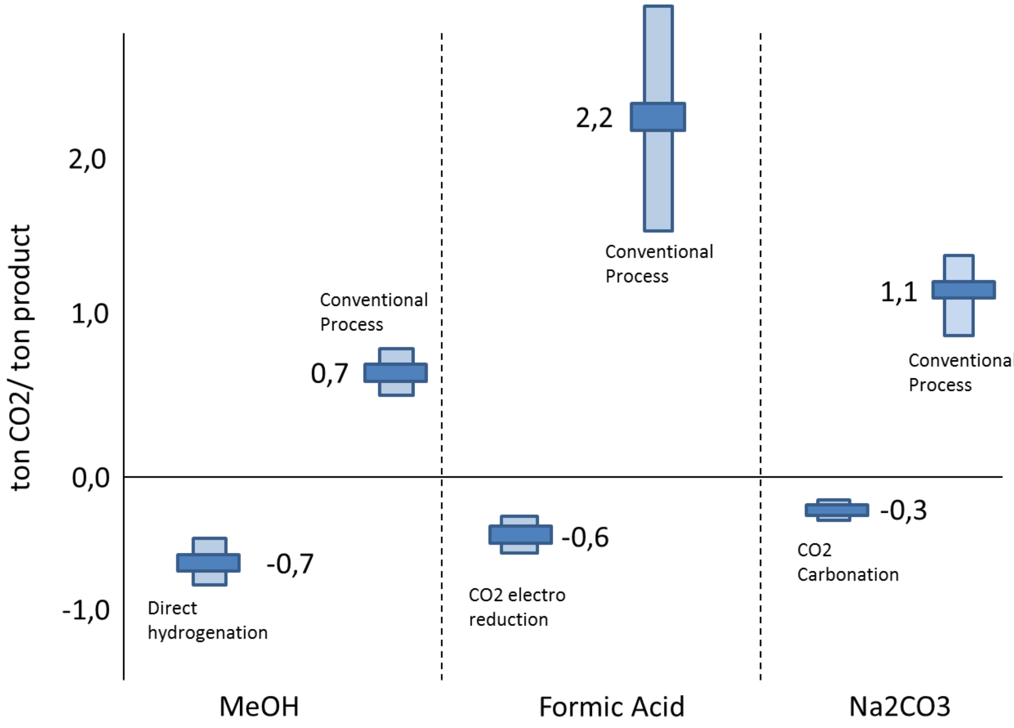


Figure 4: CO_2 foot print of CCU options (Source ENEA 2015) [2].

Temporal storage

The temporal storage of CO_2 relates mainly to its use as feedstock or a working fluid. In most cases CO_2 will be released into the atmosphere after end of life. Typical use of CO_2 as a feedstock can be found in the production of urea, fertilizer or products like polymers. The impact on CO_2 emission reduction is expected to be low as CO_2 avoided highly dependents of the market size, which for these products is orders of magnitude lower than for fuels and therefore it is expected that although they may have a lower carbon footprint, their contribution in terms of climate change target is limited.
Note: Using captured CO_2 and hydrogen made from renewable energy to produce fuels is also a form of temporal storage and can replace fossil fuels.

Permanent storage

Permanent storage options are mainly focused on using CO_2 as the solvent for EOR, and the emerging technologies of carbonation and mineralization feedstock options, coming from industrial sources generating mineral residues sufficiently reactive with CO_2. For climate change, these emerging options provide the long-term storage needed but their very limited scale limits their global mitigation potential. Technologies for large scale industrial mineral carbonation (using natural occurring minerals) remain at very low TRL as the reactions involved are very slow. Therefore, questions remain related to the size of the market for mineral carbonation options, and how much CO_2 can be stored to make significant contributions to CO_2 mitigation targets. Off shore CO_2-EOR is a proven technology as has been demonstrated in two technically similar projects that have been commercially successful offshore in the North Sea since 1998 and 2002. These projects inject miscible methane gas, as a means to produce additional oil. This gives high confidence that CO_2-EOR is achievable in Central North Sea oilfields. The economic viability of CO_2-EOR with current oil prices remains a key issue for developing business cases. A recent study shows that CO_2-EOR can be economic if the CO_2 is provided to EOR projects at near zero transfer price, and if fiscal incentive structures are introduced that are similar to existing brownfield and cluster allowances[8].

3 Life cycle assessment

There is an increasing number of studies looking at the life cycle environmental performance for a number of CCU options, particularly mineralisation, power to fuels, production of chemicals, EOR and biodiesel from algae. Typical indicators that are studied are global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), photochemical ozone creation potential (POCP), and ozone depletion potential (ODP), though most studies focus on GWP. A state of the art review is provided by Cuéllar-Franca & Azapagic [4]. Note that the results of the life cycle assessments (LCA) are highly dependent on assumptions, system boundaries and the choice of the products and processes CCU will be displacing. As a consequence, contradictory results and large ranges can be found when comparing studies. A typical example of this are LCA assessments of Microalgae refineries (which use CO2 as feedstock) to produce biodiesel. [4] compares nine studies with a total of 19 cases. The process was compared with production of fossil diesel. The GWP varied between a 78% reduction and 530% increase. For the GWP, these large differences are largely due to the method assumed for disposal of waste. Landfilling seems to be the worst option, while a study with electricity generation from incineration produces the most promising result.

The use of LCA for assessing the potential environmental impacts of CCU remains a key aspect, especially for mitigation pathways that aimed to decrease climate change as they target to reduce the net amount of CO2 emitted into the atmosphere. Given the increase complexity of CCU systems (multi-product systems with displacement of current products) is important that assumptions, data and results are provided in a harmonized and transparent way. It is expected that as additional processes are developed, further LCA studies will appear in the literature. This could allow drafting more robust insights. Nevertheless, as happens with other technologies, the benefits and impacts will depend on how individual process chains are set up.

4 Technology TRL classification

Figure 5 illustrates a technology maturity curve for CO_2 technologies. EOR is a mature technology, which fulfils potentially a crucial role as an enabler for large uptake volumes of CO_2 and thus CCS. The use of CO_2 to boost urea or methanol production reached already commercial status whereas others are at the theoretical and research phase, or are at the pilot/demonstration phase, and need further development to reach commercial status. For example, the direct electrochemical reduction of CO_2 from bio-based feedstocks is currently available only at low TRL numbers. Therefore, significant research efforts are still required, before these technologies will have impact.

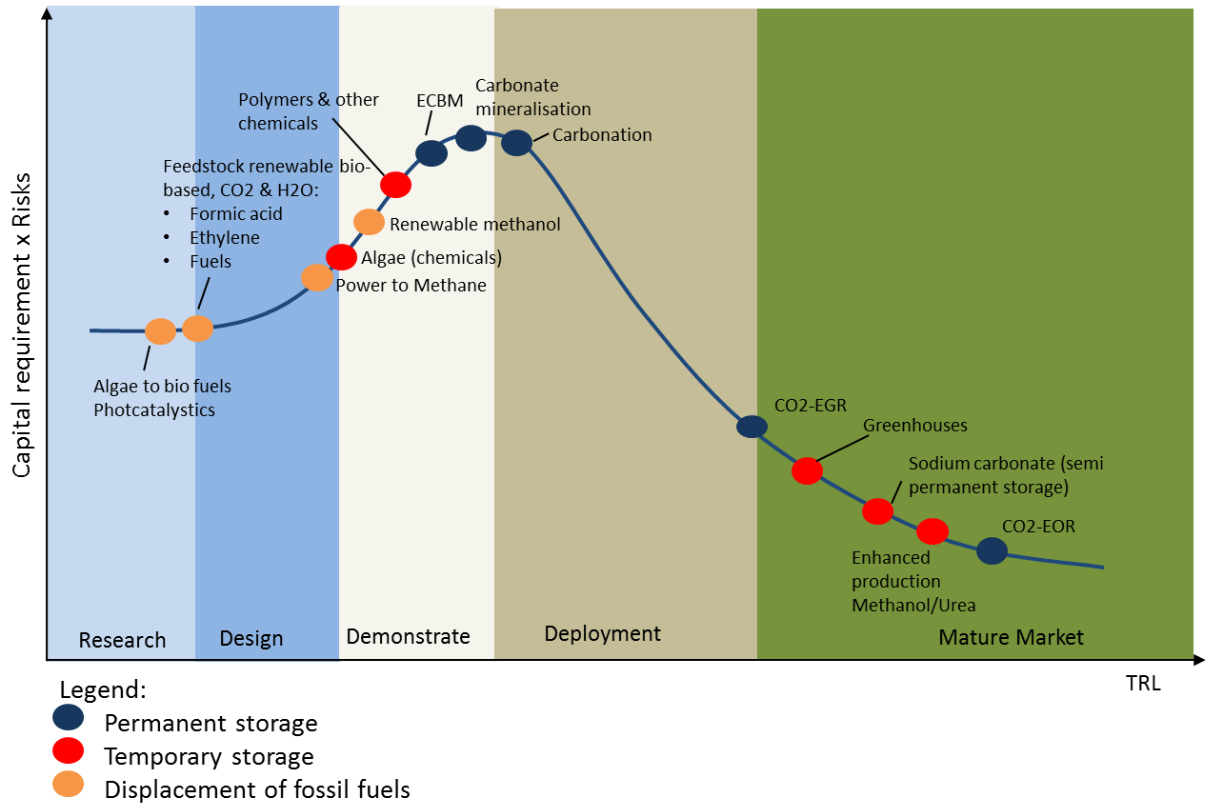


Figure 5: Technology maturity curve of CCU options (status: 2015).

5 CCU as an enabler – stepping stone for CCS

The current mature technologies for CCU that have a large CO_2 uptake potential are EOR and, if it is proven to be an economically viable process, EGR. CO_2-EOR can maximise and extend the life of the hydrocarbon production assets, and permanently lock-up part of the CO_2 used in geological formations. On the longer term, emerging alternative options with large uptake potential might be available, such as renewable methanol or formic acid production with baseload renewable energy generation technologies. Although the impact of these market uses of CO_2 on climate change mitigation may be minor, they may be a crucial stepping stone on the short term for CCS deployment. Figure 6 illustrates the future CO_2 uptake potential of CCU.

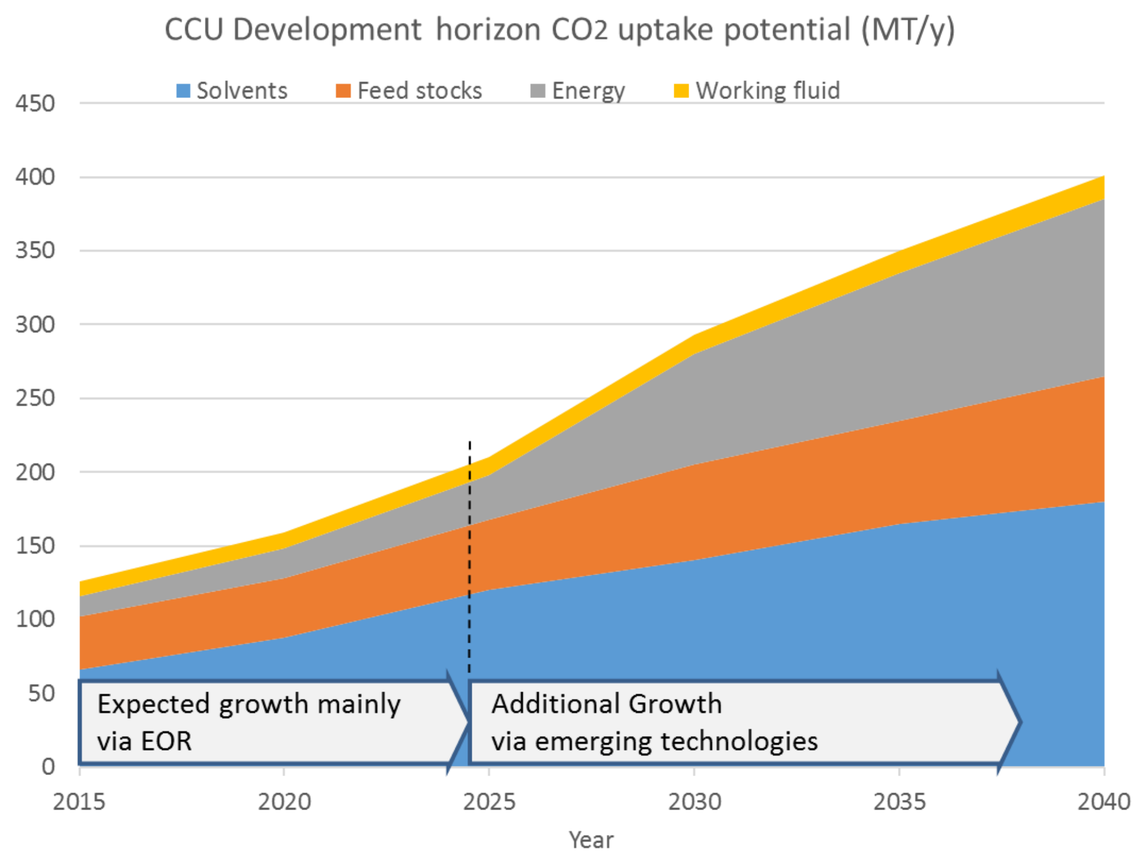


Figure 6: CCU development and future CO_2 uptake potential (team estimation).

For CCU as an enabler for CCS, system integration will be a crucial aspect to be considered, because :

- Multiple users might benefit from a common CO_2 infrastructure for storage and utilisation;
- Increase of CO_2 demand;
- System flexibility will be increased, by demand response of CCU applications, facilitating base load off-take for EOR and storage;
- Emerging CCU technologies will benefit from a reliable supply chain of CO_2, the emerging CCU technologies will have different flow rates and in most cases the uptake volume is lower than cost–effective capture technologies produce.

6 Summary and recommendations

The application of CCU could offer two important benefits: first of all the uptake of CO_2 and to a certain degree the reduction of CO_2 emission into the atmosphere and, second, a significant economic value to a CCS project. For the shorter term the largest potential in Europe is offshore EOR, mainly in Eastern Europe (where this process is already being applied) and the North Sea. On the longer term other large CO_2 uptake potential might come available from emerging technologies, subject to their development.

The reuse of CO_2 cleverly integrated with permanent CO_2 storage options enables the opportunity to develop a common CO_2 infrastructure, increase the demand of CO_2, provide system flexibility by demand response of CCU applications and provide a reliable CO_2 source for emerging CCU technologies with smaller CO_2 off-take levels.

Urgent action is therefore needed to exploit and accelerate the full potential of CCU and CCS:

- Increase the CO_2 uptake potential of all promising emerging CCU technologies and incorporate CCS and CCU in Horizon 2020 as an enabling technology for Europe.
- Actively pursue the development of CCU technologies by national and EU funding schemes.
- Develop business models and define realistic CCU and CCS scenarios potential clusters throughout Europe.
- Improve the understanding of the potential of different CCU technologies as CO_2 mitigation option.
- Develop LCA guidelines for CCU that facilitate comparison among studies by providing harmonized and transparent framework for reporting.
- Conduct CO_2-source to CO_2-use spatial mapping, linked to CCS cluster developments.
- Design tailor-made incentive schemes at national and EU level to kick-start early projects.

7 Demo Case(s)

OCAP, greenhouses CO_2

OCAP is a CO_2 network for the Dutch greenhouses. This CO_2 is produced at Shell during the production of H_2 in an oil gasifier, and during the production of bio-ethanol at Abengoa in Europoort Rotterdam. OCAP supplies this CO_2 via a pipeline with an extensive distribution network (see figure below). This enables greenhouses to save about 115 million cubic metres of natural gas a year, which would otherwise be used in the greenhouses to produce the CO_2. The greenhouses annual CO_2 emissions are reduced by about 205 ktpa [5].

OCAP CO_2 infrastructure

Sunfire, Power to X Using Reversible SOC technology:

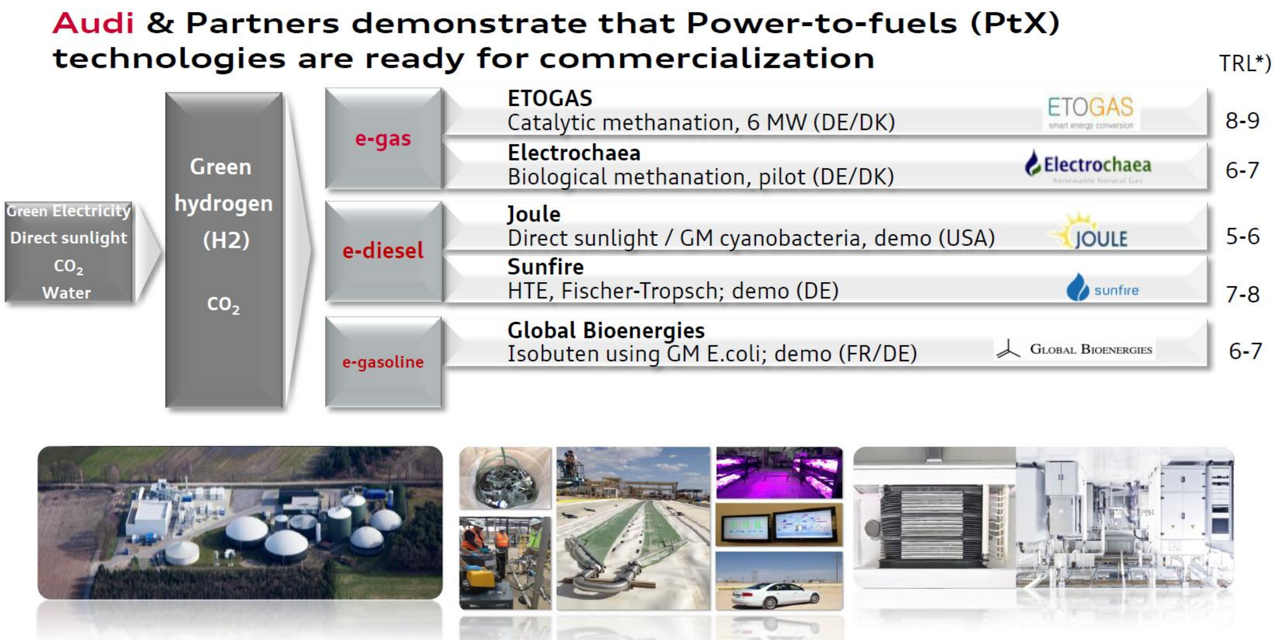
Sunfire is a manufacturer and developer of a SOC technology called Reversible Solid Oxide Cell (rSOC). The technology produces Syngas from H_2O, CO_2, electricity and heat. See picture of Sunfire Fuel 1 pilot plant in Dresden.

+ SOFC and SOEC in **one single device**
+ High efficiency SO technology ($\eta_{elFuelCell}$ ca.50%; $\eta_{elElectrolysis}$ ca.92%)
+ More economically advantageous than traditional one-way electrolysers
+ System's connection to different energy sec enables flexible ratio of storage and supply

TECHNICAL SPECIFICATION

+ Electrical power input/output:	10 – 1000 kW
+ High performance flexibility:	1% - 100% in 15mins
+ Electrical efficiency:	76 - 92% SOEC 50% SOFC
+ Operational mode:	24/7 possible
+ Low maintenance:	no moving parts

Sunfire already has some first customer orders from Boeing/Gazprom and has had positive support from Audi, to produce synthetic fuels using FT technology.



Audi CCU demonstration projects

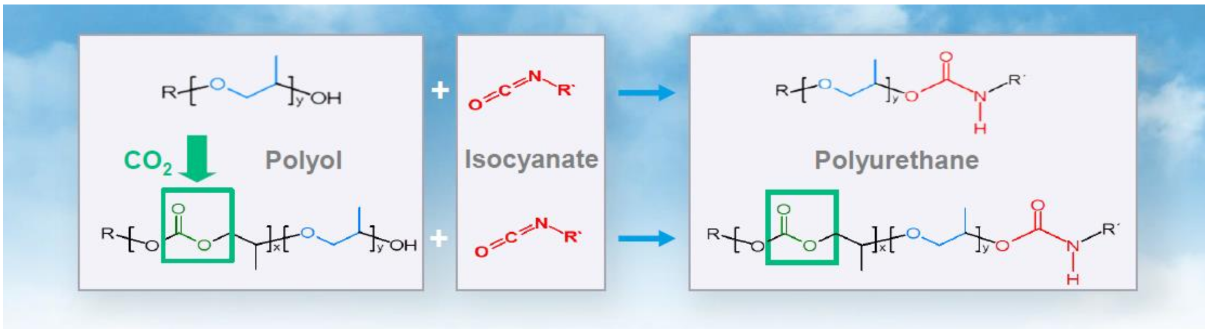
Covestro - Bayer, CO_2 Feedstock for high performance Polyurethane Plastics:

Covestro (formerly Bayer MaterialScience) developed a production technology that converts polyols into foams, using CO_2-based polyethers. As such the CO_2 is chemically fixed inside the polyurethane backbone for the lifetime of the foam.

Covestro is investing €15 million in the construction of a production line at its Dormagen site, which will use CO_2 from a RWE plant to produce a precursor for premium polyurethane foam. The line will have an annual production capacity of 5,000 metric tonnes.

The objective of this project, so called "Dream Production", is to launch the first CO_2-based polyols on the market starting in 2016. Processors of polyols and polyurethanes have already expressed considerable interest.

Using CO_2 as a building block enables a reduction in the amount of the petroleum-based raw material propylene oxide, which polyols are normally made entirely from. The CO_2 balance of the new process is far better than that of the conventional production method. First products for end customers are mattresses.



Source Covestro (2015)

DSM, Novel renewable coating resins based on LimoneneOxide and CO_2

DSM is developing together with TU Eindhoven new coatings using CO_2 as a feedstock. The first results are promising and delivered new fundamental insights such as crosslinking reactions using thiolene chemistry. Research is ongoing see: [http://www.fp7-refine.eu/.](http://www.fp7-refine.eu/)

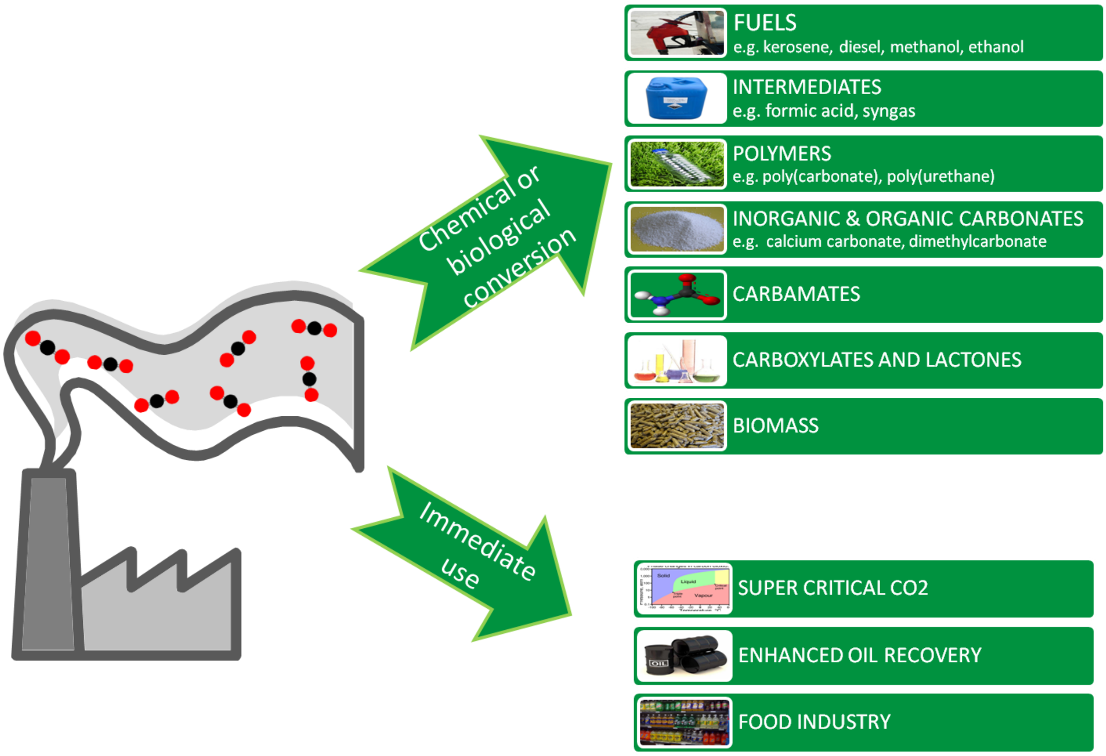
VITO, Carbonation (building materials from waste streams)

Vito demonstrated successfully carbonation technology for the concrete industry. Together with Recmix, VITO investigated the option of creating building materials with finely ground steel slag and CO_2. The study resulted in a process that converts steel slags into artificial calcareous sandstone via its reaction with CO_2. See http://www.carbstoneinnovation.be/nl/.

CO2Chem, is a Carbon Dioxide Utilisation Network

CO2Chem brings together academics, industrialists and policy makers over a wide range of disciplines to consider the utilisation of carbon dioxide as a single carbon chemical feedstock for the production of value added products.

The primary objective is to develop science and engineering strategies to tackle CO_2 capture and re-use over a 20-40 year time frame and to identify funding streams to address their implementation. Bayer has launched a pilot plant in Leverkusen which uses carbon dioxide for the production of plastics with the help of a new catalyst.



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Annex I: Members of the ZEP Temporary Working Group CCU

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