The Business Side of Innovative CO_2 Utilisation

Report 2015 for the wider public

listed deliverable in project

- “Rapid Prototyping” as Report 02
- “Incubation and Business Modelling” as Report 3

Version 1

Introduction

This report aims at giving an overview of CO_2 utilisation to a broad audience. Some of the relevant outcomes from the enCO$_2$re programme will be shown within the context of current discussions in the spectrum of CO_2 utilisation. These discussions have recently been sparked by the Paris climate change negotiations and the G7 summit 2015 that define novel strategies on emissions reduction and on the 'decarbonisation' of the world economy.

enCO$_2$re

The 'enabling CO_2 re-utilisation' (enCO$_2$re) programme is part of Climate-KIC's Sustainable Production Systems theme funded by the European Institute of Innovation and Technology (EIT). The enCO$_2$re programme connects academia, start-ups, and industry and facilitates research and development in Europe. The goal is to enable the utilisation of CO_2 as feedstock for industrial value chains and thereby building a circular economy.

What is CO_2 utilisation?

The term CO_2 utilisation describes a technology that consumes CO_2 to provide services or produce products with the objective of an economic benefit. In many cases the step of capturing of CO_2 is included in the definition, which is why CO_2 utilisation is also referred to as "carbon capture and utilization" (CCU) in analogue to the frequently used term carbon capture and storage (CCS). The difference between the two concepts is that in CCS the carbon dioxide is stored underground while in CCU it is utilised in the economy.

CO_2 utilisation as defined above can occur either through chemical pathways (with resulting products being fuels, base chemicals or polymers) or in non-chemical pathways (CO_2 as resource extracting agent, as solvent or in beverages). However within the literature this definition is under debate. While a first group of authors includes chemical pathways only such as (Mikkelsen, 2009; Styring, 2011; Huan, Tan, 2014; Ravanchi, Sahebdelfar, 2014; Styring, 2014) a second group includes both - chemical and non-chemical - methods in their definitions such as (Song, 2006; Plasseraud, 2010; Hunt et al., 2010; Quadrelli et al., 2011; Bhanage, Arai, 2014; Kucksheinrich, 2015).

The extended definition also counts enhanced oil recovery (EOR) technology as a form of CO_2 utilisation – a technology which is heavily debated for its ambivalence of large potential versus its environmental impact. EOR however is already under commercial-scale operation in the USA (Gozalpour, 2005) and no other novel and non-chemical option was identified in the literature. Since this report focusses on novel CO_2 utilisation options, only chemical CO_2 utilisation will be discussed in the following.

Contributions and limits of CO_2 utilisation

The impact of CO_2 utilisation is in the following explored from two perspectives: emissions reduction and resource efficiency.

CO_2 utilisation can reduce emissions through two major effects: first - *directly* - through consuming CO_2 and thereby avoiding its release in the atmosphere and second - *indirectly* - through substituting emission intensive inputs. While it was shown that the indirect effect can have a larger impact than the direct one, its quantification requires substantial simulation efforts and is subject to ongoing and future research (von der Assen, Bardow, 2014).

Today, the authors of (Styring et al., 2014) estimate that around 164 million tonnes of CO_2 are directly consumed in industrial processes per year – mainly by the production of urea. However, the overall potential is estimated to be around 23 times larger, totalling 3.7 billion tonnes per year. Now how is this related to global emissions? Worldwide around 37 billion tonnes of CO_2 were emitted in 2010 (Mikkelsen et al., 2010; Parsons Brinckerhoff, 2011). This makes clear that even if the technical potential of CO_2 utilisation could be exploited to the fullest extent, its emissions reduction potential would reach only ten percent of today's global emissions. CO_2 utilisation can therefore not be the only technology for emissions reduction, but must be accompanied by other strategies such as energy efficiency (see Figure 1).

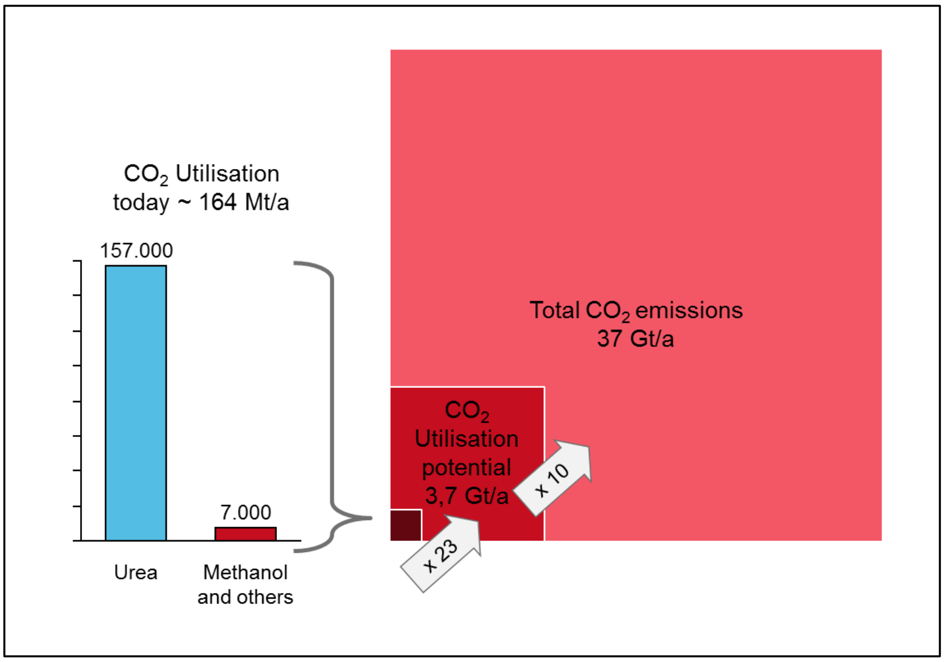


Figure 1 – CO_2 utilisation comparing today's use, technical potential and total emissions

Emission reduction promoting institutions such as the Global CCS Institute or the Zero Emissions Platform consider CO_2 utilisation to be a 'door opener' that leads the way for the commercialisation of CO_2 capture and transport innovations. This means that the technologies of CO_2 utilisation could drive the implementation of CCS with its much larger emissions reduction potentials in the long term.

Recently a new perspective on CO_2 utilisation has emerged: seeing it as a resource efficiency technology tackling the challenges of resource depletion and security. If CO_2 could be fed back into the economic system as an 'econogenic' carbon source, less geogenic (fossil) or biogenic carbon resources need to be consumed, very much in line with the circular economy concept.

Industrial processes such as oil refining, aluminium processing or cement production can be regarded as are large-scale suppliers of CO_2, or as econogenic sources of carbon. The CO_2 emissions of such processes are large enough to cover the total carbon dioxide supply for CO_2 utilisation technologies even in an optimistic long term scenario. Carbon dioxide supply from power plants based on fossil fuels will not be necessary for large-scale CO_2 utilisation (Naims et al., 2015; Naims et al. n.d.).

One promising scenario is to convert the econogenic carbon with the help of renewable energies into synthetic fuels especially in times of over supply (Varone, Ferrari, 2015; Sternberg, Bardow 2015; Klankermayer, Leitner, 2015). These fuels can then be consumed by the chemical industry or within the transport sector and thereby substituting geogenic fuels as well as complementing biogenic fuels. Other scenarios include the production of chemicals and materials.

Through the carbon feedback loop less geogenic (fossil) resources become necessary, resulting in a more efficient use. This concept of an additional carbon source seems to be well suited for regions that are short on oil resources, but highly industrialised such as the European Union or Chinas East coast.

CO_2 utilisation technology

Comparing different technologies

In many publications different CO_2 utilisation concepts are compared to one another, for example to highlight the progress to prior publications or to justify the decision for a certain technology. The comparison factors can be clustered into four fields:

- **economic indicators** such as value added or revenue,
- **environmental indicators** such as global warming potential,
- **social indicators** such as technology acceptance,
- **chemical data** such as yield or energy balance

A recent literature study by the authors of this report that will be published in 2016 showed that the comparison of CO_2 utilisation technologies is challenging, especially because most publications focus on one indicator field only, rarely in all three. However assessment cannot be limited to environmental or economic terms, but an analysis in all three pillars of sustainability is necessary to identify potential trade-offs. Additionally chemical data is often lacking that would be necessary to compare the different technologies. In general a need for an overall assessment method for CO_2 utilisation technologies can be identified, especially for the early stage technologies where no common simulation method or software exists.

One commonly used indicator for the state of development is the “Technology Readiness Level” (TRL) scale that was originally developed by NASA. The TRL concept has been adapted for the evaluation of research and development projects within the European Commission’s funding scheme Horizon 2020. The EC-TRL scale consists of 9 stages from “basic principles observed” to “system proven in operational environment”. For better understanding the terms were refined by the European Association of Research and Technology Organisations (EARTO, 2014).

Technology pathways

The state of research and development in CO_2 utilisation varies largely depending on the specific technology. To outline the state of CO_2 utilisation the refined TRL terms of EARTO were used and combined with research from (Hendriks et al., 2013) (see Figure 2).

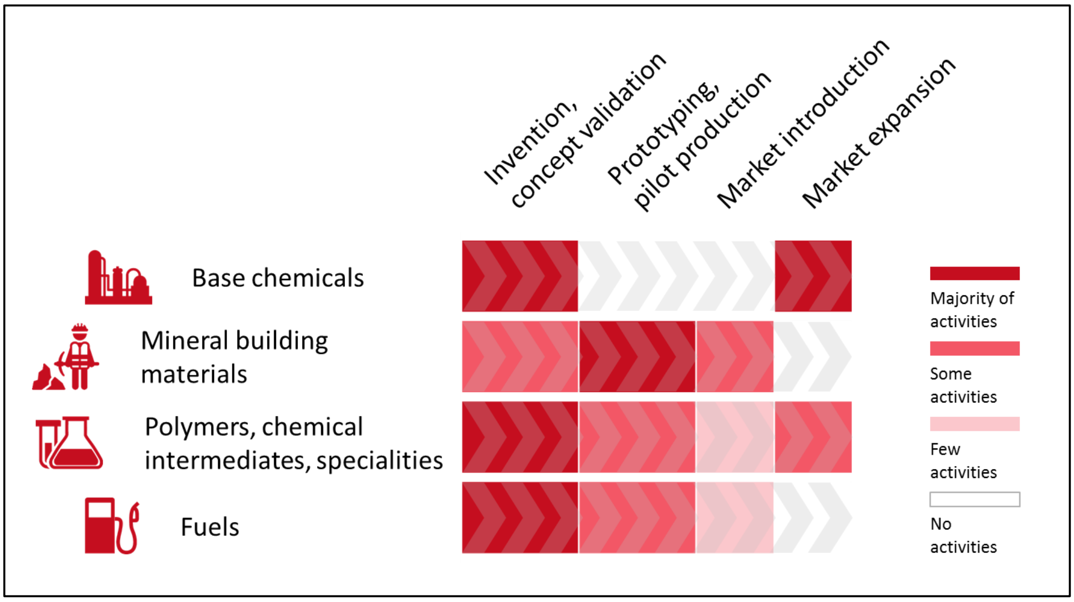


Figure 2 - State of CO_2 utilisation technologies (Zimmermann et al., 2015; Hendriks et al., 2013; EARTO, 2014)

Research through inventions and concept validation is happening in all fields of CO_2 utilisation. For example the yield boosting technology for the production of the base chemical urea is the only technology that reached mass market application but did so 15 years ago (Parsons Brinckerhoff, 2011). Mineral building materials can be considered the second most mature field, with a current focus in prototypes and pilots. For example Lafarge Holcim ran pilots on CO_2 based material products in 2013. Other chemical products or CO_2 based fuels can be identified as early stage with most activities in the invention and concept validation phase. Exceptions are the pilot plants by Covestro and Sunfire and the market entry of Novomer's chemical intermediate products.

Outlook on innovation in CO_2 utilisation

CO_2 utilisation has become a trending topic in recent years. A citation report from Thomson Reuter's Web of Science shows that from 2010 to 2015 the number of peer reviewed publications has grown strongly, from under 200 to over 700 per year. Articles dealing with CO_2 utilisation were cited over 15.000 times in 2015 (see Figure 3). Most articles are categorized in general engineering, however a significant number of publications is located in the fuels sector, followed by thermodynamics, chemistry and electrochemistry.

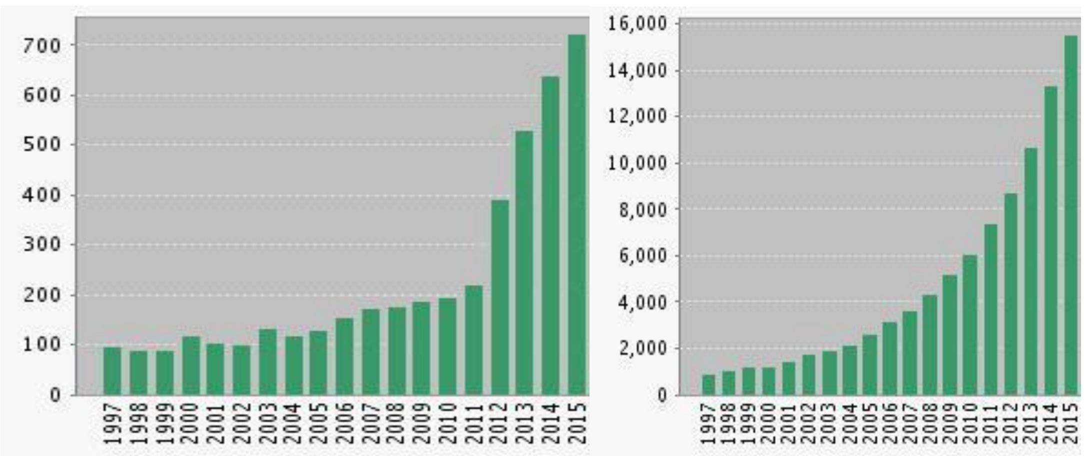
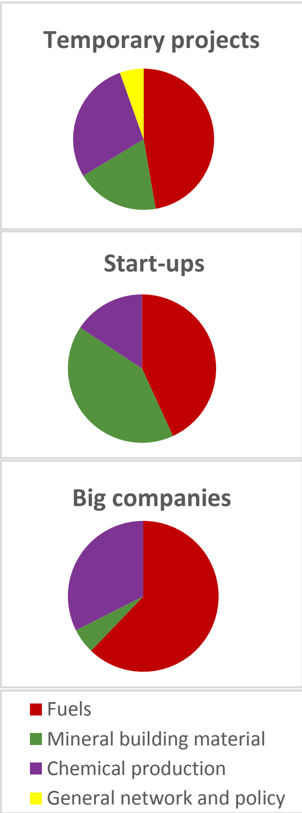


Figure 3 – Citation report from Web of Science for the search string "CO2 AND utilization", excluding medical research topics (Thomson Reuters, 2016)

It can be expected that the funding support in CO_2 utilisation as a clean technology will continue to stay strong. The Paris Agreement that was signed in 2015 includes technology and finance mechanisms with a budget of at least 100 billion USD per year that also support cleantech innovations for climate change mitigation (UNFCCC, 2015). Additionally the G7 countries agreed on the decarbonization of the world economy until 2100. Overall both declarations shape a strong future demand of low emission technologies and circular economy concepts worldwide (G7, 2015).

Project landscape of CO_2 utilisation

The landscape of activities in the area of CO_2 utilisation remains so far relatively unexplored. About 200 temporary projects, start-ups and big companies have been mapped in a joint effort with the SCOT project in a unique online database. The mapped activities depict an ideal pathway from a temporary project over a start-up towards a large established company. These three activities will be analysed closer in the following first from a technology perspective, later from a regional perspective.



In the database, more than one hundred temporary projects were listed of which around 25 are still ongoing in 2016, mainly in the EU. More than half of them focus on synthetic fuels, about a quarter on chemical production (including base chemicals as an others). Less than a quarter is either related to networking/policy or to mineral building materials. It shall be noted that the share of mineral building material projects was higher in the past than it is today. The mapped temporary projects are not solely focussed on basic research: The majority stretches to a later stage technology development and includes collaborations between academia, research and industry.

Alongside with temporary projects, start-ups are active in the domain of CO_2 utilisation. More than 50 operating start-ups were mapped. The identified start-ups set their focus either in synthetic fuel technology or mineral building materials, while only one sixth deals with chemicals production.

In contrast to start-ups, mineral building materials seem to be outsider for large companies. Large industry's main focus is set on fuels followed by chemicals production. This distribution is in line with the technology distribution of the identified temporary projects.

Most of the mapped temporary projects are located in Europe, followed by North America – two hotspots in CO_2 utilisation development (see Figure 4).

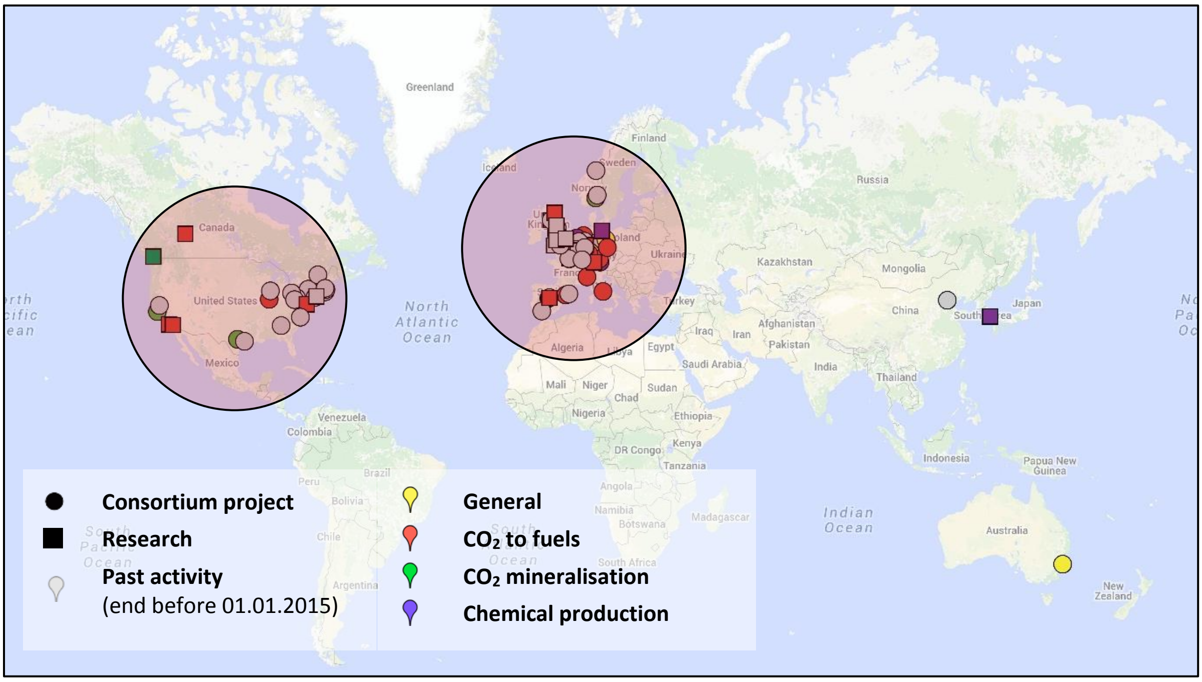


Figure 4 – CO_2 utilisation map for temporary projects

This is also true for start-ups, where both regions are equally represented. More than 30 large companies dealing with CO_2 utilisation were identified in Europe, North America and Asia. In the Middle East, Asia and Oceania only a few temporary projects could be mapped. The identification of activities in Asia remains challenging due to language and information barriers and the actual amount of activities is suspected to be a bit higher.

The purpose of such a mapping is not only to facilitate future collaborations and the exploitation of cross-sectoral synergies within the different stakeholders, but also to enable the analysis of barriers to commercialisation, so that recommendations for all relevant stakeholders of the commercialisation process can be derived.

Barriers to innovation and commercialisation

What hampers innovation? Quite a few efforts have been undertaken by scholars in the field of barrier research (Hueske, Guenther, 2015). But what are the barriers to commercialisation of CO_2 utilisation? Currently no study is dedicated to this question.

That it is why it might be worth to look into the barriers of similar technology sectors such as cleantech, green chemistry, eco-innovation or sustainability-oriented-innovation. The high capital intensity as well as regulatory constraints seem to be the recurring element in most of these areas. Demonstrators, prototypes, and pilot plants are essential to convince investors and customers via a proof of technology. These facilities are often very capital intensive. A missing access to technical expertise as well as the lack in management knowledge are also high up on the lists (CIE, 2014; Matus et al., 2007; Guenther et al., 2013; Kanda et al., 2014; Matus et al., 2007; Jay, Gerad, 2015).

An uncertainty of future benefits of ‘green’ products (Matus et al., 2007) may not only lead to a weakened marked pull (Kanda et al., 2014) but may also indicate an urge to define ‘green’, ‘clean’, ‘sustainable’, or ‘eco’ technologies (Matus et al., 2007). In line with that, ‘success’ for these technologies and how to measure it should be clarified (Jay, Gerad, 2015).

The CO_2 utilisation activity map lays the groundwork for the current commercialisation barrier analysis by the authors to find answers to the questions above. The future outcome of this study will help creating a favourable environment for start-up activities in the area of CO_2 utilisation by contributing to a dedicated business incubation process for these very start-ups.

Summary

With being both resource and climate technology CO_2 utilisation is an exciting clean technology pathway, especially for Europe and China. It was shown, that CO_2 utilisation cannot be the central emissions abatement technology, but its innovations could serve as a door opener for emissions in a much larger scale.

The current technologies can be clustered into the technology portfolios: fuels, chemicals, and mineral building materials, of which most are in the phase of R&D and rarely market ready. The fact that CO_2 utilisation is a trending topic may boost the R&D efforts further on. There are already numerous collaborative projects alongside with research, start-up and corporate activities in Europe and North America indicating a large potential for similar activities in Asia.

CO_2 utilisation technologies are difficult to compare and thus challenging to evaluate. A consistent assessment methodology is a step towards standardised indicators and criteria leading to a more profound decision making for policy makers, start-ups, investors and technology leaders. When further investigating the barriers to commercial success of CO_2 utilisation beyond more general findings such as financial and regulatory challenges, precise recommendations for action can be given and a contribution to an efficient usage of resources will be made.

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