July 2020

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Short report

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Socio-economic impact assessment of the CCU-hub implementation in the North Sea Port industrial zone

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This study was commissioned by the East Flanders Development Agency (Provinciale Ontwikkelingsmaatschappij Oost-Vlaanderen) and funded through the **Carbon2value project**: **Development and demonstration of low CARBON technologies to transform CO2 and CO streams from the steel industry into new VALUE chains** (https://www.carbon2value.be/en/) under the European Interreg 2 Seas programme and co-funded by the Province of East Flanders, BE.

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1 Introduction

1.1 CCU Hub initiative in the North Sea Port

The North Sea Port plays a major role in East Flanders' economy as well as in the Belgian economy, in terms of industrial activity and as an intermodal centre facilitating commodity flows. The port contributes to the prosperity of the region and generates a net value of €26.4 million and revenues of €106 million. The total added value of the North Sea Port is estimated at €14.5 billion.

At the same time, as one of the biggest marine and inland water transports hubs in Europe and host to one of the largest steel and chemical facilities, the port and its industrial community are high contributors to the region's overall environmental burden, including greenhouse gas emission, other air pollutants (nitrogen, sulphur, etc.), various waste streams, etc.

In an effort to reach its sustainability and climate objectives, East Flanders has been focusing on cutting industrial greenhouse gas emission in the region.

The City of Ghent, the Development Agency of East Flanders, Ghent University, Bio Base Europe Pilot Plant and North SeaPort took the initiative in 2018 to have a preliminary study carried out, to expand the port area of Ghent-Terneuzen into a hub for "Carbon Capture and Utilisation (CCU) ". Several exploratory initiatives and a pilot programme have been pursued together with local industry and other actors. The vision now is to create a viable CCU hub/cluster in the North Sea Port industrial zone, which can create new value chains, activities, and involve local, and possibly external industrial actors.

1.2 Objectives of the study

While previous assessment studies have focused primarily on technological, technical and financial aspects for the potential CCU hub, **this assignment is investigating the socio-economic aspects.**

The overall **objective** of the study is to assess the social and economic impact of the potential implementation of a CCU hub in the North Sea Port industrial zone. More specifically, the study investigates the following:

- Identification of the market opportunities for new economic activities and creation of new value chains including e-fuels, maritime and land transport, chemical and biochemical products, building materials and other.
- Envisaged socio-economic impact (both positive and negative) of developing a CCU hub on companies present in the North Sea Port industrial zone, including new economic activities, new revenues and costs, new value chains, new business models, new collaborations, new R&I activities, new markets and increased competition from others. Selected companies from other regions, potential members of the hub, as well as other non-industry actors are also covered.
- The wider/aggregated socio-economic impact on the East Flanders region in terms of competitiveness, employment, the labour market, education, collaboration, new R&I opportunities, and other spill-overs, as well as externalities in terms of economic and environmental costs.
- Socio-economic obstacles and opportunities for the realisation of an industrial cluster based on the reuse of CO/CO2 and renewable energy, including the cross-border

circumstances revolving around further development of a CCU hub in the North Sea Port industrial zone.

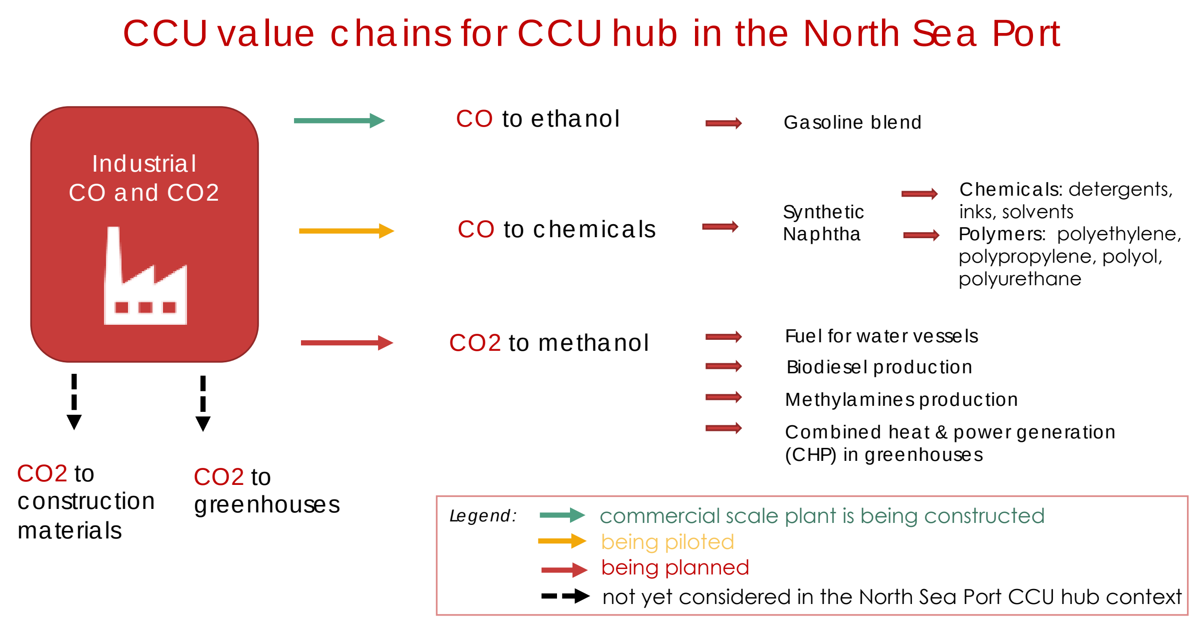
2 Scoping the study

2.1 CCU value chains covered in this study

The territorial scope of this assignment covers the industrial ecosystem in and around the North Sea Port zone which includes the areas of Ghent and Terneuzen. Moreover, in this study we also consider a wider ecosystem with potentially relevant players (industries, clusters, research, service organisations) from East Flanders, nearby Zeelandic Flanders in the Netherlands, and potentially relevant companies from neighbouring regions in Belgium.

In the context of the CCU hub in the North Sea Port, this study has analysed several CO2 and CO utilisation options that can potentially turn into value chains for the local economy. Their selection has been dictated (a) by ongoing projects working towards launching value chains in the North Sea Port area (i.e. CO to ethanol by LanzaTech, CO to synthetic naphtha and polymers by Dow, and methanol by Engie), and (b) by the availability of technologies in the national or European markets, which include CO2 based chemicals and polymers, carbonation of construction products, and CO2 enrichment of greenhouse farming, as well as additional possibilities for methanol application, such as in the production of biodiesel, synthesis of methylamines, in the combined heat and power generation modules.

Figure 2 CCU value chains covered in this study



2.2 Analytical scope – social and economic impacts

The analytical scope of this study is focused on analysing *social and economic impacts*. These impacts have been studied along several dimensions, including competitiveness, economic growth, employment, skilled human resource mobility, education, new cooperation links, and R&I opportunities.

In order to structure the analysis, the following categories of impacts have been identified:

- **Economic impacts** including:
  - Competitiveness
  - Economic cost and benefits
- **Social impacts** covering:
  - Employment generation
  - New knowledge fostering
  - New linkages creation
  - Change of image and recognition of industry
- **Technological and innovation** impact covering:
  - Technological advancement in the region, local cluster
  - Capabilities of local companies

Each CCU value chain to be established in the North Sea Port can potentially demonstrate various degrees of impact on each of the listed categories. Since this is an ex-ante impact assessment study, the measurements have been based on evidence in the practical examples of CCU value chains available elsewhere, through findings of other research and investigations including theoretical studies, as well as via consultations with stakeholders, collecting their insights and experiences.

2.3 Methodological scope

The approach to the study includes a mix of research methods including *desk research, interviews, case studies and a survey*.

Desk research helped to understand the CCU technologies and products, as well as opportunities for their application. Literature review also demonstrated that studies assessing social impact of CCU projects have been practically missing until now, something common for all the industrial symbiosis schemes. The economic viability of CCU projects has been addressed in some studies to a varying extend (e.g. in technical feasibility studies of specific projects, or in theoretical modelling studies where parameters are modified). However, the impact on the local economies of CCU projects and technologies are rarely analysed.

Interviews were one of the key instruments for collecting information from various stakeholders that directly engaged in CCU-related activities, research or actors engaged in markets that have relevance to CCU products. Interview data was used in case studies, scenario analysis, as well as the scoping of the CCU value chains for this study.

Case studies is another important sources for evidence for the present study. Real cases of the CCU projects, observations from the practices, insights and data collected during these projects provided significant input into the analysis and understanding of impacts that can potentially be created in CCU hub in the North Sea Port zone.:

Table 1 List of case studies selected and analysed for his study

	Case study	**Value chain covered**
Case 1	LanzaTech project for bioethanol production, Shougang China	CO to ethanol
Case 2	George Olah Renewable Methanol Plant, Iceland	CO2 to methanol

Case 3	ThyssenKrupp demonstration project for methanol and chemicals, Duisburg Nord Rhein Westphalia	CO2 to methanol, ammonia, other chemical
Case 4	CO2-based polyol production at Covestro	CO2 to polyol and polyurethane
Case 6	Evonik & Siemens artificial photosynthesis (electrolysis and fermentation)	CO2 to specialty chemicals
Case 6	Carbstone technology by Orbix, Belgium	CO2 to construction materials
Case 7	Organic CO_2 for Assimilation by Plants (OCAP), Netherlands	CO2 to greenhouses

3 Findings on CCU value chains

3.1 CO to ethanol

CCU-based bioethanol is an important value chain in the North Sea Port CCU hub initiative. There has been a substantial effort invested and progress achieved in setting up this value chain, the first such production facility in Europe. An EU-funded project, called Steelanol[1], combines the strength of ArcelorMittal, a major steel producer, and LanzaTech, a leading technology provider, to build and launch the new CCU facility. The commissioning and first production are expected by the end of 2020.

- Life cycle assessment of the ethanol produced via LanzaTech fermentation shows that its greenhouse gas emissions are at least 70% lower than that of conventional fossil gasoline.
- The projected cost of production of CCU-based bioethanol is said to be competitive with the lowest-cost bioethanol available today.
- At the new CCU-based bioethanol plant project, construction of the new installation will create up to 500 temporary jobs and about 30 permanent positions for operations.
- The arrival of a new ethanol producer will also boost the need for logistical, tanking, and blending services, as well some new jobs created in companies distributing/exporting transport fuel.
- Introduction of an ethanol plant will cause no losses or replacement of existing jobs locally, regionally or at the national level.

3.2 CO to chemicals and polymers

CO to chemicals and polymers is one of the value chains that has attracted strong interest in the North Sea Port industrial zone. A number of research and testing initiatives involving local players Dow, ArcelorMittal, Ghent University, as well as other international partners, have resulted in well-working solutions that can separate and clean the CO and CO2 from the industrial exhaust gases, synthetise naphtha and produce polymers (ethylene, propylene). *Steel 2Chemica*[2] and *Carbon2Value* [3] projects have have been focusing on piloting synthetic naphtha production, studying CO valorisation value chains, robustness and replication possibilities within the steel industry.

[1] http://www.steelanol.eu/en

[2] https://ispt.eu/projects/s2c/

[3] https://www.carbon2value.be/en/

- Shifting from sourcing fossil-based naphtha to CCU-based synthetic naphtha offers significant potential for locking carbon emissions from the steel industry into Dow's polymer and chemical products, one of the largest manufacturers of such products in Europe
- CO2-based polymers are still more expensive to produce and this might remain as a persisting barrier. However, as a superior quality is assured companies that will use these polymers are likely to accept higher prices as the case study of polyol demonstrated.
- An important benefit of introducing CCU-based production lines at Dow is related to creation of employment. Between 50 to 100 jobs can be created at the upstream end of the value chain that will integrate the synthetic naphtha production from blast furnace gases. In addition, a few indirect jobs could be created at the logistics, supporting facilities, and other adjacent service providers.
- A considerable impact is also envisaged in the 'greening' of existing jobs at the company in the segments where the production process does not change.
- Other benefits include strengthened the expertise and knowhow both at the research team at Dow, and also within the collaborators from the Gent university, and other organisations engaged in the pilot projects. The projects also has contributed to the positive image of the companies and the region.

3.3 CO2 to methanol

The CCU-based methanol production is actively explored in the CCU hub. It has been central in this study and a large share of interviews focused on discussing challenges around CCU-based methanol production and its market viability. The consultations have focused on upstream and downstream sections of the methanol value chains starting from CO2 capture, purification, H2 production, methanol synthesis, and its application.

- Existing in the North Sea Port biodiesel and methylamines producers can potentially be a substantial market for CCU-based methanol as they require large amounts of methanol in their production processes.
- There is a growing momentum for methanol in maritime industries due to climate issues and IOM commitments. This may create a wider market for traditional methanol, where 'green methanol' can also find customers.
- The premium price expected for CCU-based methanol can create challenges for its uptake. It is argued that the size of the premium cannot be too high to maintain business interest. Companies are less likely to go beyond 10-20% extra.
- A promising job generation potential is in the upper segments of the value chain associated with the methanol synthesis and electrolyser management. Between at the pilot and the commercial plants 25-24 and 100-180 permanent direct and indirect jobs can be created. Construction activities can also create 500-700 jobs over the 3-4 years
- On the downstream part of the value chain, job creation due to shift to CCU-based methanol has rather low potential. Substitution of inputs in biodiesel and in methylamines production does not require changes in the processes. Water vessels by switching to methanol will not need any additional staff, but may require re-training. New methanol-fuel logistics and tanking facilities will be needed, which offer some opportunities for job-creation. Similarly, in the methanol-fuelled CHP system for greenhouses, employment generation is not promising. Current CHP system suppliers are likely to adopt the new technology using existing capacities. ogistics and tanking facilities might offer some opportunities for new jobs, but the number is not going to be large.
- Development of the CCU-based methanol value chain and products will require experimental activities. This will lead to knowledge-creation that will be accumulated

locally with local stakeholders. This can potentially help these actors to capitalise on knowhow gained in other markets around the country or aboard.

3.4 CO2 mineralisation on construction materials

CO2 mineralisation is a carbon binding technology that also offers stronger qualities of constuction materials thanks to carbonation. This value chain has been included in this study as it could be very relevant in the context of the CCU hub. One of the most advanced technology providers is Orbix, a company based in Belgium which offers a new patented technology called Carbstone that converts the fine residual product from the slag, a by-product of steel production, into high-value construction materials. Thus it offers both recycling of CO2 and recycling of the process wastes. This new technique is done without adding expensive binders like cement – which is a cost-saving benefit. Such technology can be used in the production of floor tiles, roof tiles, clinkers, boarding stones, building blocks and briquettes.

If commercialised, the potential social, economic and environmental benefits of the production plant can be significant.

- The CO2 mineralisation technology has strong potential to establish symbiotic linkages that are wider than other CCU technologies because it valorises the waste stream and offers cross-benefits to the steel and construction materials industries.
- In helps to create new jobs along several phases of the value chain, including management of the slag, carbonation, manufacturing of products, CO2 and input material sourcing, as well as in support services like logistic, distribution, etc. The number of new jobs created can range from 30 to 100 direct and indirect jobs. Construction and installation of the new facility could create between 80 and 150 temporary jobs lasting a few months to a couple of years.
- There is a potential energy and resource saving impact. With the substitution of cement, it helps to reduce energy consumption. More efficient and less time-consuming processes offer further energy saving.
- The economics of the Carbstone-based production is promising thanks to is certification for the emission trading market. Carbon emissions reduced can be converted into quotas that can be sold on the European or international carbon markets .
- A production facility with this technology is likely to be constantly engaged in developing new types of products ranging from construction materials for buildings, to unique building blocks for industrial infrastructure, roads, pavements, bridges, and other public facilities. This means new research, innovation and experimentation that will help to strengthen the local knowledge and scientific base.

3.5 CO2 enrichment of plant growth in greenhouses

The benefits of CO2 enrichment of plant growth and production within the greenhouse environment are well known. CO2 plays an essential role in photosynthesis, a chemical process that uses light as a source of energy to convert CO2 and water into sugars in green plants. Through a respiration process, these sugars are used for growth by the plant. The analysed case study of OCAP has demonstrated positive outcomes:

- In terms of economic impact, the technology is beneficial for the entire sector. Harvests will be larger, and it prompts investment in bigger greenhouses.
- The application of CO2 enrichment in greenhouses can create new jobs which however will be mainly connected to secondary employment such as transport of CO2 including hauliers, CO2 compressions/liquification, IT development, etc.

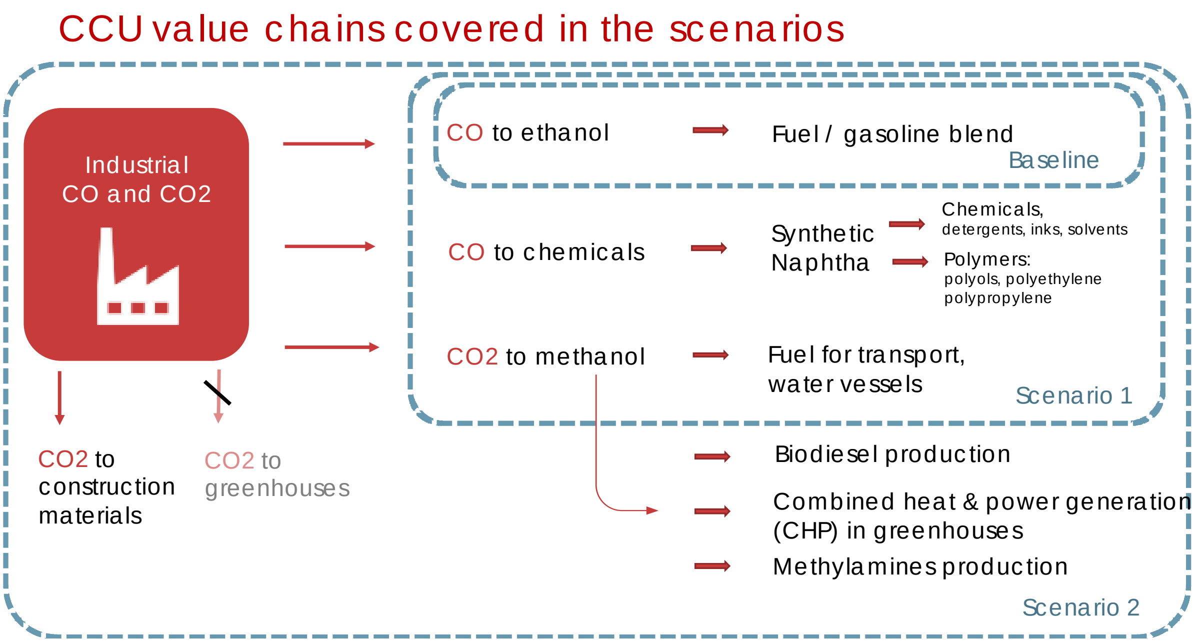
East Flanders has about 360 greenhouse companies covering over 470 hectares. Many greenhouse farms produce their own CO2 from combined heat and power (CHP) generation units. In the past decade, CHP technology has become more popular because it offers an efficient source of heat, electricity and CO2 feeds for stimulating plant growth in the greenhouses. Such a 3-in-1 solution leaves farmers little incentive to look for external sources of CO2. Nevertheless, during discussions with stakeholders from the farming community, an opportunity was identified to replace traditional fuel used in greenhouse CHP units with CCU-based methanol. The advantages of methanol is that its combustion does not produce other emissions commonly associated with the use of diesel or mazut, and the transportation and storage of methanol is simpler than, for example, natural gas. In the long run, the use of CCU-based methanol will also allow local agro-companies to demonstrate their commitment to climate change mitigation and be ready for possible emission targets and compliances that can be imposed by states.

4 Scenario analysis

Three scenarios of CCU cluster development in the North Sea Port and beyond have been tested in this study. These included the baseline scenario where the current state of play will continue, while two other scenarios are based on the various parameters and permutations of new value chains and boundaries of the CCU hub's outreach. The geographical boundaries of the scenario stay within the North Sea zone that is shared between East Flanders of Belgium and Zeelandic Flanders in The Netherlands, due to proximity of some key players involved in the CCU hub on different sides of the border.

The figure below schematically shows the scoping of each scenario and which value chains in includes, while **Fout! Verwijzingsbron niet gevonden.** below summarises the scenario profiles.

Figure 4-1 Scoping the value chains in the Scenarios for this study



In this study the following scenarios have been put forward:

Table 2: Scenario profiles

Scenario	features	Details
Baseline scenario	No additional interventions – One value chain: *CO to ethanol	'No change' (counter factual) baseline scenario captures the continuation of current developments. This scenario includes autonomous developments of the ongoing project focused on CO to ethanol value chains. LanzaTech's commercial-scale facility is under construction with a planned launch in 2021. The impact scale will be linked to this value chain.
Scenario 1	CCU hub with three value chains: *CO to ethanol *CO2 to methanol for transport fuel *CO to chemicals and polymers	This scenario covers three value chains: CO to ethanol which is at a commercialisation stage; CO2 to methanol and CO to chemicals, value chains currently being explored and tested. The CO2 to methanol project is seeking investment while the CO to chemicals and polymers pilot has been launched and will test its small-scale facility with the aim of scaling it up at the premises of DOW and ArcelorMittal. Here, assumptions include the full-scale deployment of these technologies, that they will go beyond the pilot scale. Downstream of the methanol value chain is the water transport sector.
Scenario 2	CCU hub with five value chains: *CO to ethanol *CO2 to methanol for transport fuel *CO to chemicals and polymers *CO2 to construction materials *CO2 to methanol for - biodiesel production - Methylamines production. - CHP generation in greenhouses Note: Use of CO2 to greenhouses was excluded from the secnario due to non-viability	This scenario is the most inclusive and assumes the development of a diverse mix of CCU value chains under the CCU hub. In addition to value chains considered in scenario 2, it also considers additional value chains: (1) CO2 to construction materials, (2) CO2 to methanol for biodiesel production, (3) CO2 to methanol for the chemicals market mainly to methylamines synthesis (4) CO2 to methanol for heat and electricity generators in greenhouses. The value chain of CO2 in greenhouses as a stimulant for plant growth was not found to be a viable option in the region. Alternatively, greenhouses in East Flanders foresee good opportunities for using methanol as a clean fuel for their CHP generation units.

The scale of the impact in each scenario would differ due to the technological scope and number of value chain covered in each. Each value chain considered in this study comes with its certain value in increasing social and economic benefits. It is clear that the value chains with products non-existent in the economy of the region can bring the largest value added, as there will be values created on upstream and downstream segments. Namely methanol is likely to be the most impactful value chain, but at the same time most complex in terms of technical implementation. Products that are already have their market (ethanol, chemicals/polymers, construction materials, biodiesel, methylamines) will have less challenges, but some would still need to overcome competition against traditional alternatives which in some cases cheaper. Combination of these value chains can show cumulative impact and dictate complexity and viability of each scenario.

The analysis clearly demonstrates that the positive socio-economic impact of the last scenario is the highest. However, the cost and complexity of this scenario is also the highest.

Table 3 Comparison of impact scale across scenarios

	Baseline **One Value Chain**	**Scenario 1** **Three Value Chains**	**Scenario 2** **Four Value Chains and extra downstream options**
Economic impact			
Competitiveness	+	+++	++++

	Baseline One Value Chain	Scenario 1 Three Value Chains	Scenario 2 Four Value Chains and extra downstream options
• Competitive / commercially viable new value chain	*Highly Competitive*	*Medium to High*	*Medium to High*
• Value added to local economy	*65 to 110 mln eur/year*	*110 – 160 mln eur/year*	*150 – 250 mln eur/year*
• Arrival of new companies to the regions	*Low*	*Low*	*Low*
• Increased interest from investors, new/envisaged investment flows	*Medium*	*Medium to High*	*Medium to High*
• Higher energy and resource independence	*Low*	*High*	*High*
Wider economic benefits (+) and costs (-)	**++/0**	**++/-**	**+++/-**
• New revenues, profits, savings for consumers and other companies	*Medium*	*Medium to High*	*High*
• Extra cost for consumers, negative economic externalities	*None*	*Medium*	*Medium*
Social impact			
Employment	**++**	**++++**	**+++++**
• New jobs created	*~ 23-40 permanent jobs ~ 500 temporary jobs*	*~180-325 permanent jobs ~ 1150-1250 temp. jos*	*~210-425 permanent jobs ~1200-1600 temporary jobs*
• Old jobs lost	*none*	*none*	*None*
Linkages/partnership	**++**	**++++**	**+++++**
• New partnerships created within and across industries	*in 1 VC (up to 8 partners)*	*In 3 VC (~20-25 partners)*	*In 4 VC (~up to 40 partners)*
Fostering local knowledge base	**+++**	**++++**	**+++++**
• New knowledge, better expertise	*1 VC, no diverse downstream*	*3 VC related expertise*	*4 VC – related expertise + wider downstream options*
• Knowledge spillovers	*Medium to High*	*High*	*High to very high*
• Brain gain in the region	*none or limited*	*none or limited*	*none or limited*
Image and visibility of the region	**++++**	**+++++**	**+++++**
• Positive impact/ Recognition of leadership	*Medium to high*	*High*	*High*
Innovation impact			
Technological advancement	**+++**	**+++++**	**+++++**
• Improvement of technology and process	*in 1 VC and associated technologies*	*In 3 VC and associated technologies including shared ones*	*In 4 VC, wider downstream options, and associated technologies including shared ones*
• Technological leadership	*medium*	*high*	*High*
• TRL progression	*In 1 CV TRL 8-9*	*In 3 VC TRL between 4 and 9*	*In 4 VC TRL between 4 and 9*

	Baseline One Value Chain	Scenario 1 Three Value Chains	Scenario 2 Four Value Chains and extra downstream options
• Technology transfer	*yes*	*Only in 1 VC, rest local technology development*	*Only in 1 VC, rest local technology development*
Capabilities of local companies	***0***	**++**	**+++**
• Innovation, new services by local companies	*None*	*Likely yes*	*Highly likely yes*
• Creation of start-ups, spinoffs	*No impact*	*Likely yes*	*Likely yes*
Feasibility			
Cost	*150 mnl eur*	*300 – 400 mln eur*	*400-500mln eur*
Complexity and technical challenges	*resolved*	*Attracting CO2 to methanol technology owner* *Secure renewable energy supply*	*Attracting CO2 to methanol technology owner* *Secure renewable energy supply* *Engaging construction material manufacturer*

5 Conclusions and recommendations

Promotion of large-scale industrial initiatives requires solid justification from environmental, economic and social development points of view. The CCU hub initiative that is being launched in the industrial zone of the North Sea Port is one of the most ambitious carbon capture and utilisation initiatives in Europe. Today, when economic prosperity has to be assured in conjunction with social and environmental sustainability, the big challenge is in making the right decision on actions and investment. In the context of the North Sea Port, as well as East Flanders development, this means that the CCU hub is expected to help sustain the local economy, create new jobs, foster economic and innovation linkages, while helping the local industries to reduce their carbon, as well as broader environmental footprints.

The present study has tried to analyse how much the planned ideas and piloted projects would be able fulfil the expectations put upon the CCU hub initiative. The study is forward looking and based on lessons of other CCU projects in EU and globally. Considering that the CCU practice is still new and in many cases technologies and value chains are in the R&D and piloting stage the evidenced of actual impacts and lessons from the real practice examples are still scarce. This study largely relied on the consultation with the stakeholders engaged in the CCU projects in the EU and beyond and their analysis and assessments of the impact that can be generated.

5.1 Key take aways

In the **economic impact** dimension, the key observations and conclusions are the following:

- Estimates and economic forecasts in this study have demonstrated that implementation of the value chains of CCU-based methanol, ethanol, chemicals/polymers and construction materials can result in *€150-250 million annual value added to the local economy*.
- *The competitiveness* of most of the CCU-based products under current conditions is likely to be challenged by higher production cost and therefore the higher market price. The

premium price challenge is especially highly relevant for the methanol, chemicals, polymer cases. However, some business cases are secured by creating protected markets such as in China where state guarantees procurement of all CCU-based ethanol produced in the LanzaTech plant, or with special clients who are ready to pay a premium price, such as methanol from CRI George Olah bought by gasoline and biodiesel companies in the UK, Netherlands, Sweden and Iceland, in the example where CO2-based polyol was purchased by a mattress manufacturer, Recticel.

- Current examples of projects are still small and *struggle to secure resources or energy independence* from a region or country. But this should change for the better with upscaling and larger scale production. For instance, at Dow the deployment of the CCU technologies and production of synthetic naphtha from the local steel blast furnace gases would be able to offer a significant decrease in dependency on naphtha supplies from oil refineries. Similarly, switching from traditional fuel to methanol by ships hosted by the North Sea Port would be able to decrease reliance on fossil fuel. For biodiesel producers (Cargill Bioro and Oleon-Bioediesel) and methylamines producer (Eastman-Taminco), up to 80-90% of methanol supply can be replaced by the CCU based methanol,
- There are very few commercial-scale examples of CCU. The CCU initiatives currently implemented in different parts of the world are mostly smaller in scale (i.e. R&I, pilot or demonstration projects). The small scale of these initiatives has not allowed the *emergence of new business ecosystems*. However, it is believed that larger-scale commercial production is very likely to generate impact in downstream parts of value chains where other companies will start using CCU-based materials/chemicals in their production lines, or introduce new products.
- There is an increasing *interest from private investors* in CCU-based product-oriented businesses. Most of the companies that brought the technology into the market began as start-ups and managed to attract significant investments (e.g. LanzaTech is one of the fast-growing cleantech companies, as well as CRI, and Orbix,). Regions piloting such businesses can also benefit from private investment (venture capital, etc.) if they can show an interesting and convincing business idea.

In the **social impact** dimension, the following is found:

- Estimates in this study have demonstrated that launching all viable value chains (CCU-based ethanol, methanol, chemicals/polymers, construction materials) considered in this study will result in *200 to 425 new permanent jobs* at the industrial facilities, related services, upstream and downstream segments, as well as *1200 to 1600 temporary jobs* related to construction and installation. At the same time, there is evidence that no jobs would be lost and some jobs will even be 'greened over'.
- *Fostering cross-industry linkages* is at the core of the CCU. At the minimum, bilateral links are established between CO or CO2 sources (e.g. steel company) and a partner converting the CO and CO2 into new materials (e.g. chemical company). More complex networks are being established in methanol production where, for example, a renewable energy supplier enters the network; meanwhile the local biodiesel and chemical companies, greenhouse farms or water shipping companies can enter as consumers of the CCU based methanol; and in carbonated concrete production, construction companies enter the network. Other types of companies could be specific technology providers, logistic companies, gas pipeline owners, various service providers, water and waste companies, fuel distributors, export companies, etc.
- *The image and visibility* of the region and the North Sea Port is among the other positive impacts of hosting CCU projects. In light of the increased ambitions in climate change

policies this is an important element in overall regional and national efforts towards reaching the climate targets.

Technological and innovation impact is another dimension of socio-economic impacts:

- *Technological advancement* is often reflected in the technological leadership status obtained by a region, or a company, or a CCU cluster. Many CCU projects are pilots or experimentations which allowed their technologies to progress in TRL scale. New patents are filed under many CCU initiatives. Technology transfer is another impact that has been observed in some projects (e.g. LanzaTech bringing CO to ethanol technology).
- *Fostering knowledge* in the region is seen in all CCU projects. Many of them stem from innovative initiatives that helped to strengthen the knowledge base in the region and even attract highly qualified experts. Involving local knowledge organisations has been seen in many projects where they are engaged in experimental or monitoring work.

Innovation spill-overs, such as the increased capabilities of other companies, are not always observed but can be potentially expected of the companies represented in the downstream value chain when they start adapting to new input materials and retrofitting their equipment. It was noted that often, with the regulation push towards more sustainable processes, investment is done also in overall modernisation and enlargement of facilities.

5.2 Policy recommendations

New technologies present opportunities but usually come with their own economic challenges. Green technologies are special in that the environmental sustainability mission does not always immediately translate into commercial viability.

Economic obstacles faced by CCU projects mainly concern (i) the price of the product, and (ii) high investment cost of CCU projects.

(i) High price of product

Recommendations:

Promote public procurement instruments for CCU-based products/services, e.g. public transport and shipping services can specify recycled carbon-based fuels in their green procurement products; construction of public buildings or infrastructure can specify procurement of carbonation-based construction materials.

Promote other schemes that will boost demand for CCU products and fuels, e.g. setting specifications for fuel blends, carbonation-based construction materials, recognition under the local green product labelling, etc.

Set examples to follow, e.g. public transport companies (train, water shipping) can shift to CCU-based fuel use which would create a secured market for the CCU fuel and help in further rolling out to a wider market.

(ii) High investments cost

Recommendations:

Ensure diverse EU funding schemes for upscaling and commercial projects in CCU and related technologies such as green hydrogen. Today, many CCU technologies have been developed in labs; they need incentives and direct support to move to the market.

Dedicate special support instruments for industrial symbiosis projects. It can be a purely public funding or co-funding of the new facilities, or a combination of public and private financial instruments with favourable financing conditions.

CCU technology is still emerging as a commercially viable field. Promising innovations such as growing bacterial protein from waste CO2, boosting algae farming with industrial CO2, CO2-based specialty chemicals, and numerous other examples need some maturing to scale them up and make them more efficient, ensuring high- quality and safe products, while reducing dependence on high energy and resource inputs, and developing efficient and less costly gas separation, hydrogen production and other auxiliary technologies.

Recommendations:

Encourage carbon-intensive industries that have little room to manoeuvre in cutting their carbon emissions, to invest, introduce and integrate carbon-recycling technologies that can also generate additional value in their local economies.

The EU should sustain its leadership in CCU technologies by continuously supporting technology development, commercialisation, upscaling as well as R&I in novel carbon-recycling possibilities. Technological barriers that exist now can find solutions via R&I and testing efforts. All these are needed to de-risk the required CCU development trajectories, to explore alternative processes and find economic and environmental optimisations at different scales and with different process setups.

The environmental performance of CCU technologies remains a complex and debated issue. This is because such performance could be unique to each CCU project and depend on a combination of many factors, including (i) the availability of renewable energy as a guarantee of the climate mitigation potential of CCU products that require energy for production processes, as well as (ii) lack of comprehensive LCA assessment methodology for CCU.

(i) Availability of renewable energy

Recommendations:

Policy and investment support are highly recommended in expanding renewable energy production, scaling up existing capacities and launching new renewable energy production capacities, which for CCU projects can be off-grid installations, however overall greening of the electricity grid should be the ultimate aim.

Addressing the cost of the renewable energy to encourage its competitiveness against fossil-based energy should be a priority policy objective. Wider deployment is one of the ways to cut production costs and prices (which has been seen with the wind energy deployment). Redistributing fossil fuel subsidies[1] to support renewable energy development, as well as using

(ii) Lack of a commonly recognised, comprehensive LCA assessment

Recommendations:

Development of a comprehensive LCA guideline for assessing the environmental impact of CCU projects, as well as common recognition of methodologies across Europe and possibly internationally need to be facilitated on an EU level. For CCU, it is necessary to calculate the CO2 avoided rather than the CO2 used in the process. The methodology should focus not only on climate mitigation and GHG reduction, but also cover other impacts related to ecosystems, water, land use, air, energy, materials and waste.

LCA results should become a basis for fair recognition of CCU technologies in the European Emissions Trading Scheme, in as much as they lead to a net reduction of CO2 emissions over the whole life cycle. LCA should also become a basis for demand-boosting instruments for CCU

Addressing regulatory gaps is vital because there is presently no proper framework conditions to help CCU technologies reach wider acceptance and become more competitive and commercially viable.

Recommendations:

Develop a regulatory framework that incentivises both the permanent sequestration of CO2 into, for example, polymers or construction materials by the mineralisation as well as temporary sequestration in CCU fuels. The regulatory setting should assure comprehensive LCA methodology for CCU as a precursor for other regulatory measures (addressed below), and securing an even playing field with bio-based and traditional products.

Ensure that CCU is ultimately recognised under the EU Emissions Trading Scheme in order to allow a breakthrough for CCU technologies. Namely, along with the carbon storage via mineralisation, the accrediting of GHG emissions avoided and/or carbon negative emissions should be considered under the EU-ETS.

A smart carbon-pricing system should be introduced to push CCU projects into profitable areas. Carbon taxation should be applied with a warrantee of an international level playing field – within Europe and with border-tax adjustments between the EU and the rest of the world.[1] Carbon taxation should also be sensitive to various types CCU products: e.g. carbon tax for CCU fuel could be paid by the CO2 producer, while if it is a CCU product with a longer lifetime (e.g. polymers, construction material) the carbon tax would be paid by the product user. At the same time, benchmarking against footprints of currently used (e.g. fossil-and bio-based) products should be considered in calculating carbon tax.

Ensure full implementation of the revised Renewable Energy Directive (RED II), which includes mandatory targets for CO2-based fuels, via rapid and fair adoption of the required Delegated Acts[1]. At the same time, encourage members states and regions to consider concrete strategies and plans on deployment of CCU technologies in achieving the 2030 and 2050 climate targets and the new EU Green Deal goals.

POLICY IMPLICATIONS

This study has demonstrated that the environmental, economic and social benefits of CCU technology deployments could be promising for the local economy, while their wider diffusion can offer solid input towards addressing global climate change imperatives. This study, however, also showed that there are a number of obstacles that prevent the CCU initiatives from easily and quickly penetrating current industrial and economic systems. Addressing these obstacles would need favourable framework and market conditions that can be created by carefully designed policy measures and incentives.

With the proliferation of the circular economy in the EU there are growing calls for carbon removal via re-use and storage in products. Yet, CCU is still not well understood and embraced by a wider policy and economic community and often not regarded as a promising approach for GHG reduction. There are several challenges that prevent CCU technologies from gaining wider diffusion: economic barriers related to the cost of CCU technologies and products, technological challenges requiring further improvements, testing, piloting, research and innovation, ambiguity and lack of understanding of CCU technologies' environmental performance, and policy barriers that are mainly due to uneven playing fields, lack of favourable framework conditions and limited political support.

These obstacles are interlinked and to great extent reinforce each other, which means resolving them would require a **comprehensive approach** and favourable framework and market conditions, measures and incentives.

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With the proliferation of the circular economy in the EU there are growing calls for carbon removal via re-use and storage in products[4]. Yet, CCU is still not well understood and embraced by a wider policy and economic community and often not regarded as a promising approach for GHG reduction. There are several challenges that prevent the CCU technologies to gain wider diffusion in the market:

- Economic barriers related to the cost of CCU technologies and products.
- Technological challenges requiring further improvements, testing, piloting, research and innovation.
- Ambiguity and lack of understanding of CCU technologies' environmental performance.
- Policy barriers that are mainly due to uneven playing fields, lack of favourable framework conditions and limited political support.

These obstacles are interlinked and to great extent reinforce each other, which means resolving them would require a **comprehensive approach**. Addressing these obstacles would need favourable framework and market conditions that can be created by carefully designed policy measures and incentives. A major policy signal has to come from the EU regulatory landscape where international regulatory framework also needs to be contextualised. National and regional policies are also important in setting local and national ambitions and strategies and driving the local actions.

Below are policy recommendations addressing challenges faced by CCU technologies in the EU. They have been generated based on consultation with stakeholders, lessons from the

[4] COM(2020) 98 final, A new Circular Economy Action Plan: For a cleaner and more competitive Europe, Brussels, published on 11 March 2020

analysed case studies, as well as suggested in the analytical reports on CCU reviewed in this study.

5.2.1 Recommendations addressing economic challenges

Economic challenges are faced by many new technologies arriving on the market, and especially for green technologies as often the environmental sustainability mission does not immediately translate into commercial viability. Economic obstacles faced by CCU projects are related to (i) high price of the product and (ii) high investment cost of CCU projects.

(i) Price competitiveness of the CCU products

Today, the majority of CCU products produced with captured CO/CO2 are more expensive than traditional chemical synthesis routes so it is difficult to compete with conventional products. As shown in the analysis in this study, price competitiveness remains an issue for all types of CCU products, except for the CCU-based ethanol price that is expected to be comparable to the traditional ethanol production, including the ones produces for biofuel purposes. The current low prices for fossil resources acts as an obstacle to the competitiveness of CO2-based products. High price might also block demand for CCU products, although the study has shown that there are customers ready to pay premium prices for greener products or features of the products (e.g. manufactures of mattresses from CCU polyol, selected water transporters), but those are in a minority**.** A rise in prices for fossil resources and/or increased availability of renewable energy at the lowest cost possible could support the implementation of such technologies. Without creating favourable framework conditions, regulatory support, boosting or securing market interest, it will not be possible for CCU products to continue competing with cheap fossil-based alternatives.

Recommendations:

- Promote public procurement instruments for CCU-based products/services, e.g. public transport and shipping services can specify recycled carbon-based fuels in their green procurement products; construction of public buildings or infrastructure can specify procurement of carbonation-based construction materials.
- Promote other schemes that will boost demand for CCU products and fuels, e.g. setting specifications for fuel blends, carbonation-based construction materials, recognition under the local green product labelling, etc.
- Set examples to follow, e.g. public transport companies (train, water shipping) can shift to CCU-based fuel use which would create a secured market for the CCU fuel and help in further rolling out to a wider market.
- Recognise that CO2 must have a price that induces emitters to re-use it as a resource, wherever fossil replacement technologies are becoming available. Develop mechanisms that effectively lead to a progressive increase of the price of CO2 emissions.

(ii) High investments cost

The analysis in this study shows that under the current market and policy framework conditions CCU technologies are not profitable yet. To launch any CCU technology, large investment is needed. Furthermore, many CCU technologies and support processes such as segregation of various gases existing in the flue gas mix, need more research and testing in order to reach better efficiency. Thus, direct financial support to the research, innovation, development, demonstration, pilot and commercial projects will still be needed.

Recommendations:

- Ensure diverse EU funding schemes for upscaling and commercial projects in CCU and related technologies such as green hydrogen. Today, many CCU technologies have been developed in labs; they need incentives and direct support to move to the market.
- Dedicate special support instruments for industrial symbiosis projects. It can be a purely public funding or co-funding of the new facilities, or a combination of public and private financial instruments with favourable financing conditions.

5.2.2 Recommendations addressing technological challenges

The analysis in this study has demonstrated that most of the CCU value chains have not yet reached full commercialisation. Furthermore, there is rising number of promising innovations suggested by scientists and entrepreneurs, for example growing bacterial protein from waste CO2[5], boosting algae farming with industrial CO2[6], CO2-based speciality chemicals[7], and numerous other examples[8]. Maturing these technologies will be key to scaling them up: making them more efficient; ensuring end-products are high quality and safe; reducing their dependence on high energy and resource inputs; and developing efficient and less costly gas separation, hydrogen production and other auxiliary technologies. Looking toward the future, in addition to continuing work on these technologies, research and innovation should be pursued for new routes to valorise industrial flue gases.

Recommendations:

- Encourage carbon-intensive industries that have little room to manoeuvre in cutting their carbon emissions, to invest, introduce and integrate carbon-recycling technologies that can also generate additional value in their local economies.
- The EU should sustain its leadership in CCU technologies by continuously supporting technology development, commercialisation, upscaling as well as R&I in novel carbon-recycling possibilities. Technological barriers that exist now can find solutions via R&I and testing efforts. All these are needed to de-risk the required CCU development trajectories, to explore alternative processes and find economic and environmental optimisations at different scales and with different process setups.

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[5] NovoNutrients, novonutrients.com

[6] https://www.treedom.net/en/blog/post/carbon-dioxide-is-becoming-fish-food-1876

[7] https://corporate.evonik.com/en/technical-photosynthesis-25100.html

[8] https://carbon.xprize.org/prizes/carbon,

5.2.3 *Recommendations on ensuring the environmental performance of CCU*

The environmental performance of CCU technologies remains the most complex and debated issue. This is because such performance could be unique to each CCU project and depend on a combination of many factors. These factors include (i) the availability of renewable energy as a guarantee of the climate mitigation potential of CCU products that require energy for production processes, as well as (ii) lack of comprehensive LCA assessment methodology for CCU.

(i) Availability of renewable energy

The key parameter for CCU product sustainability is its climate mitigation potential which, ideally, should be higher than for conventional products. It depends on the substitution of similar products on the market made from fossil- or bio-based feedstocks; otherwise CCU products would simply create a rebound effect with more material use and CO2 emissions. Use of renewable energy is core in defining the climate mitigation potential of all CCU products as the production process is energy intensive, and in many cases CCU chemicals and fuels are defined as power-to-X, which means they store renewable energy which would otherwise be curtailed. In the methanol production case, powering hydrogen electrolysis with wind- or solar-based electricity could help to mitigate the irregularities in production and use energy that is otherwise not consumed.

From the economic perspective, the CCU product while offering the climate mitigation potential, should also be competitive with conventional alternatives. This is mostly not the case as the analysis in this study shows. The *cost of renewable energy* is one of the major factors adding to production costs and reducing the demand for – and competitiveness of – CCU products against conventional products. Thus, access to affordable renewable energy sources is key a determinant for the commercial success of CCU product.

Recommendations:

- Policy and investment support are highly recommended in expanding renewable energy production, scaling up existing capacities and launching new renewable energy production capacities, which for CCU projects can be off-grid installations, however overall greening of the electricity grid should be the ultimate aim.
- Addressing the cost of the renewable energy to encourage its competitiveness against fossil-based energy should be a priority policy objective. Wider deployment is one of the ways to cut production costs and prices (which has been seen with the wind energy deployment). Redistributing fossil fuel subsidies[1] to support renewable energy development, as well as using carbon tax revenues for investment in clean energy production facilities, could also be part of the policy support package.

(ii) Lack of a commonly recognised, comprehensive LCA assessment

Poor understanding of the environmental benefits and associated footprints – and of the economic returns that CCU projects can generate – are barriers to their eventual development and acceptance. There could be multiple approaches for assessing environmental benefits and impacts using various sets of parameters.

The most commonly used parameter in the CCU context is greenhouse gases emissions (GHG) savings, CO2 being the most prominent. To date, there are still no reliable estimates for the total actual implementable saving of GHG emissions via CCU technologies, due to the fact that the usable emissions described do not correspond with the actual saved emissions: the emissions savings can vary greatly, depending on the employed technology (i.e. can be smaller or larger than the amount of used CO2 emissions, depending, in particular, on the energy to be spent during the process and the emissions associated with that). It is even possible that an increase in emissions will occur. Therefore, a full individual life cycle assessment is necessary to identify the environmental effects of each technology application[9].

Other parameters used in the environmental impact assessment of CCU products can include air and water pollution, energy efficiency, material efficiency, impact on ecosystems, water and land footprints, etc. These impacts, however, are scarcely addressed in CCU related LCA. Furthermore, benchmarking against the environmental footprint of alternative products is not well addressed. For example, there is an emerging debate about offering CCU fuels an even playing field with biofuel because biomass production puts more pressure on the environment due to vast land use and impacts on ecosystems, whereas fuel from CO2 recycling requires no land[10]. Therefore, the need for a comprehensive assessment is increasingly stressed.

Recommendations:

- Development of a comprehensive LCA guideline for assessing the environmental impact of CCU projects, as well as common recognition of methodologies across Europe and possibly internationally need to be facilitated on an EU level. For CCU, it is necessary to calculate the CO2 avoided rather than the CO2 used in the process. The methodology should focus not only on climate mitigation and GHG reduction, but also cover other impacts related to ecosystems, water, land use, air, energy, materials and waste.
- LCA results should become a basis for fair recognition of CCU technologies in the European Emissions Trading Scheme, in as much as they lead to a net reduction of CO2 emissions over the whole life cycle. LCA should also become a basis for demand-boosting instruments for CCU products (e.g. procurement, product certificates and labels, minimum fuel blending quotas, etc.).

5.2.4 Recommendations addressing regulatory gap

The analysis presented in the studies, as well as challenges discussed above conclude that there is no proper framework conditions that will help CCU technologies reach wider acceptance and become commercially viable. While the rhetoric of carbon recycling are generally positive in the policy discourse on circular economy, industrial symbiosis, as well as opportunities under the Renewable Energy Directive II (REDII), there are no regulatory provisions that ensure competitiveness. CCU technologies need support through a regulatory framework and a long-term policy that will systematically address the economic, technological, and environmental performance or recognition of related barriers .

CCU is not part of the ETS market, and this holds back the development of CCU technologies as industries wanting to decrease GHG emissions by using a CCU solution would not be eligible.

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[9] EC 2019, Identification and analysis of promising carbon capture and utilisation technologies, including their regulatory aspects by Ramboll, the Institute for Advanced Sustainability Studies, CESR (Centre for Environmental Systems Research at the University of Kassel, CE Delft, and IOM Law, January, 2019

[10] CORESYM 2019, CarbOn-monoxide RE-use through industrial SYMbiosis between steel and chemical industries, report prepared by Metabolic under Coresym project

From the discussion above, it is clear that part of the reason for omitting or excluding CCU in ETS is the lack of guidance on LCA. Another issue is that there is no mechanism for setting the price of CO2 (carbon market, tax, etc.).

Recommendations:

- Develop a regulatory framework that incentivises both the permanent sequestration of CO2 into, for example, polymers or construction materials by the mineralisation as well as temporary sequestration in CCU fuels. The regulatory setting should assure comprehensive LCA methodology for CCU as a precursor for other regulatory measures (addressed below), and securing an even playing field with bio-based and traditional products.
- Ensure that CCU is ultimately recognised under the EU Emissions Trading Scheme in order to allow a breakthrough for CCU technologies. Namely, along with the carbon storage via mineralisation, the accrediting of GHG emissions avoided and/or carbon negative emissions should be considered under the EU-ETS.
- A smart carbon-pricing system should be introduced to push CCU projects into profitable areas. Carbon taxation should be applied with a warrantee of an international level playing field – within Europe and with border-tax adjustments between the EU and the rest of the world.[1] Carbon taxation should also be sensitive to various types CCU products: e.g. carbon tax for CCU fuel could be paid by the CO2 producer, while if it is a CCU product with a longer lifetime (e.g. polymers, construction material) the carbon tax would be paid by the product user. At the same time, benchmarking against footprints of currently used (e.g. fossil-and bio-based) products should be considered in calculating carbon tax.
- Ensure full implementation of the revised Renewable Energy Directive (RED II), which includes mandatory targets for CO2-based fuels, via rapid and fair adoption of the required Delegated Acts[1]. At the same time, encourage members states and regions to consider concrete strategies and plans on deployment of CCU technologies in achieving the 2030 and 2050 climate targets and the new EU Green Deal goals.
- Ensure that standardisation bodies (CEN and national bodies) work hand in hand with industry in developing required standards for the new CCU industry (e.g. standards for the quality of captured CO2). Align policy and regulatory development around industrial symbiosis and CCU, such as on standards development, reporting, indicators, and for promoting CCU by building favourable framework conditions for industrial symbiosis.

CCU, from challenges to strengths

CCU is the process of capturing polluting CO and CO2 emissions and either using them directly as a carbon resource or transforming them into a new product through biological or chemical processes. CCU has the ability to transform most polluting industries, diversifying outputs and turning a liability into a strength.

Challenges:

- While the technology has already been successfully demonstrated, the efficiency of chemical processes and innovation in new pathways have to be increased. Doing so will not only increase the economic viability of CCU but will also offer alternative applications for this resource.
- If commercial success is to be achieved, funding will play a primary role in order to negotiate the economic obstacles. Collaboration between public and private organisations is an essential part of the future of CCU technology, as this will allow to overcome the current financial barriers for large-scale commercialisation.
- Considering the role of the public sector in supporting the implementation of CCU, regulations should reflect the necessity for our current society to move from fossil fuels to CO2. Ensuring conformity of legislative changes with the low-carbon agenda at each level of government will be a challenge that needs to be addressed.
- The lack of information in terms of the societal perception of CCU technology is the final issue that needs to be addressed. Diffusing knowledge on the benefits and risks of CO2-based products will go a long way to underling its potential to a wider audience.

From challenges to strengths:

- CCU has been identified as a potential driver of growth in the future EU low-carbon circular economy. CO2 is a future replacement for fossil hydrocarbons.
- CCU can facilitate the European energy transition. For example, while the transition to low-carbon energy sources is in full swing, intermittent/insecure supply continues to be a major obstacle for these renewable options. Synthetic fuels may be the solution required to address this problem, enabling a riskless and sustainable transition.
- The most straightforward benefit of CCU is the reduction of carbon emissions. Not only does the utilisations of CO and CO2 allow for long-term storage in new products, it also greatly diminishes the addition of ‘fresh’ hydrocarbons into the current economy.
- Utilisation of carbon emissions can be commercialised globally (a benchmark non-EU case is the Shaugang project in cooperation with LanzaTech).