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"Carbon4PUR - Turning industrial waste gases (mixed CO/CO_2 streams) into intermediates for polyurethane plastics for rigid foams/building insulation and coatings"

Research and Innovation Action

Topic: [SPIRE-08-2017] Carbon dioxide utilisation to produce added value chemicals

Deliverable 7.2:
Study including replication potentials and preferred sites for industrial symbiosis

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11.	Grand Port Maritime de Marseille	MFPA	France
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Acronyms and Definitions

Acronym	Defined as
CCU	Carbon Capture and Utilisation
CEF	Connecting Europe Facility
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EO	Ethylene Oxide
GDP	Gross Domestic Product
PO	Propylene Oxide
PUR	Polyurethane
RFCS	Research Fund for Coal and Steel
RIS3	Research and Innovation Smart Specialisation Strategies
RIM	Regional Innovation Monitor tool of the European Commission
SAT	European Self-Assessment Tool
TEA	Techno-Economic Assessment
TRL	Technology Readiness Level

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1. The Carbon4PUR project

Carbon4PUR aims at turning industrial waste gases (byproduct exhaust gas streams and flue gas streams of steel industry / mixed carbon monoxide (CO) / carbon dioxide (CO_2) / CO/CO_2 streams) into intermediates for polyurethane plastics for rigid foams/building insulation and coatings.

The industrially driven, multidisciplinary consortium is developing a novel process based on direct chemical flue gas mixture conversion, avoiding expensive physical separation, thus substantially reducing the carbon footprint, and also contributing to high monetary savings. The interdisciplinary consortium consists of 14 partners from seven European countries (Germany, France, Belgium, The Netherlands, Greece, Switzerland and United Kingdom) and across sectors: four industries (Covestro Deutschland AG – short: COV, Recticel N.V. – short: Recticel, Viomichania Ritinon Megaron Anastasios Fanis Anonymos Etairia – short: Megara, ArcelorMittal – short: AMMR), five universities (Universiteit Gent – short: UGent, Universiteit Leiden – short: UL, Technische Universität Berlin – short: TUB, Rheinisch-westfälische technische Hochschule Aachen – short: RWTH, Imperial College of Science Technology and Medicine – short: ICL), one association (Dechema Gesellschaft fuer chemische Technik und Biotechnologie e.V. – short: Dechema), one research organization (Commissariat à l'énergie atomique et aux énergies alternatives – short: CEA), two service providers (PNO Consultants BV – short: PNO, South Pole Carbon Asset Management Ltd. – short: SPG) and the Grand Port Maritime de Marseille-Fos (short: MFPA).

Both the consortium and the work are organized along the full value chain starting with the provision and conditioning of industrial emissions from a steel (AMMR, UGent) to a chemical company (COV) in line with the concept of industrial symbiosis exemplarily at Marseille Fos, going through the transformation into chemical building blocks (CEA, RWTH and COV), which both will be further transformed into polymer intermediates (RWTH, COV) and flow into desired sustainable polyurethane applications of rigid foams and coatings (Recticel, Megara). Life Cycle Assessment (LCA) and technology evaluation will be done (UL, RWTH, TUB, SPG) and replication strategies to transfer the technology to other applications will be elaborated (Dechema, PNO, ICL).

The distinctive feature of the developed process is avoiding resource-intense separation of the gas components before the synthesis, and developing a chemo-catalytic process to deal directly with the gas mixture instead. The challenge and innovation is coming up with an adjustable process in terms of on-purpose and demand tailor-made production of required products, taking into account all variables at the same time: the available flue gases characteristic from the steel plant, material and process parameters, and the market requirements for the end product, thus flexibly involving the whole value chain with best results and possibly lower the prices.

2. Objectives and Overview

Deliverable 7.2 aims to help project developers, potential investors, regional development agencies and interested CCU international stakeholders to explore the possibilities to replicate the Carbon4PUR symbioses concept in other parts of Europe.

The rationale is for the readers to use the mapping and visualisation tool (described in Deliverable 7.1) and apply hard criteria, mainly related to physical potential in terms of feedstock and potential demand for CCU outputs. Users are guided to either produce and evaluate their own scenarios where demand and supply in material terms coincide or to examine the results of scenarios produced with proprietary research and internal expert consultation within the Carbon4PUR project. All of this considers already emission volumes, concentration and purity levels of CO and CO_2 mixed sources.

After the identification of sites with physical potential, users are guided to consider semi-hard criteria for successful projects; first, strategic, financial and institutional support for industrial symbiosis in general and, second, strategic, financial and institutional support for low carbon technologies including CCU. At the same time section 3.3 provides guidance and references for sources of financial and organisational support at European level.

Soft criteria, discussed in section 3.4, refer to the acceptance by consumers as well as industrial users of both infrastructure and products. The purpose of the section is to inform readers about some preliminary results of research into acceptance and highlight the need to evaluate in further detail, and probably at local level, the drivers of acceptance and the findings of the forthcoming study on this subject within the Carbon4PUR project.

3. Methodology

3.1 Introduction and definitions

Exploring the potential of a new technology is a complex undertaking and multiple parameters must be assessed. Even though a technology may provide advantages in terms of, e.g., environmental impact, its timely implementation may be hampered by a number of aspects, which may not be conceived at first sight.

For example, even though a technological development reaches a ready-to-deploy technology readiness level (TRL), the local regulations or the public perception and acceptance may be not optimal. A current example is the hampered expansion of capacity of wind energy in Germany.

The following study will describe a methodology to assess the total potential of locations for the replication of the Carbon4PUR technology and raise awareness about potential pitfalls and obstacles, which may be encountered during the replication process.

The methodology is based on the following steps:

a) Define the technology/process, which needs to be deployed or replicated,
b) Define requirements/preconditions which are mandatory to run the process,
c) Locate potential sites based on the definitions,
d) Assess regional conditions, e.g., relevant policies and regulations, access to funding, technical infrastructure and support institutions, and
e) Assess the non-technical and non-regulatory parameters, which may turn out to be hindering or limiting the successful deployment.

Step a) is intrinsically clear for the Carbon4PUR project. The Carbon4PUR project aims to develop a new technology to produce CO-based polyols, which shall be used subsequently to produce polyurethanes that are more sustainable compared to the current ones. As CO always coincides with CO_2 as mixed waste gas stream, also the production of CO_2-based polyols is considered. Therefore, the potential production capacity of both products will be highlighted in the following results section.

The requirements in step b) are what we herein call "**hard criteria**". Such hard criteria are mostly quantitative and form the base layer in the assessment process. They mostly refer to physical assets, preconditions and infrastructure. For the Carbon4PUR process these criteria are summarized and discussed in the following section 3.2.

The location of potential sites (step c) is performed by applying these hard criteria. To get a broader view, the quantitative thresholds for these preconditions have been varied. Thus, four scenarios have been elaborated. For the selection of the locations, the public online mapping tool developed by the Carbon4PUR consortium has been used.[1] The functionalities of the mapping tool, including the data sources, the assumptions and a walkthrough have been reported in our deliverable D7.1 "Mapping of CO_2/CO (CO/CO_2) mixed and pure sources in Europe", which is publicly available at the Carbon4PUR website.[2,3] Since its first publication, the mapping tool has been further developed to meet the specific need for this study. These changes include but are not limited to:

- The addition of the European steel mills,
- The addition of two buttons to select the on-site availability of ethylene oxide (EO) and propylene oxide (PO) independently,
- The addition of two buttons to visualise the ethylene and propylene pipelines, independently, and
- The removal of some minor bugs.

Step d) of the methodology comprises a desk research and assessment of what we herein call "**semi-hard criteria**". Such semi-hard criteria are enablers and descriptors, which usually show a low volatility and are still quantitative to some extent. These are for example policies and regulations, funding schemes or workforce availability.

Step e) within the methodology is the most challenging, as these non-technical and non-regulatory parameters are hard to quantify. This is what we will herein call the "**soft criteria**". Soft criteria can be both enablers and obstacles. These criteria are hard to quantify in an exhaustive way as they can be quite granular and differentiated on different levels (e.g., regional, educational and demographic). Further, they exhibit the highest volatility compared to hard and semi-hard criteria. The most prominent examples for such criteria are social acceptance and the public perception.

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1 https://carbon4pur.github.io/mapping/

2 https://www.carbon4pur.eu/wp-content/uploads/2019/09/D-7.1-Mapping-of-CO2-CO-mixed-and-pure-sources-in-Europe.pdf

3 https://www.carbon4pur.eu

3.2 Hard criteria and assumptions

The first step in the assessment process is the identification of possible locations based on the demands of the technology, which shall be deployed. Therefore, it is necessary to define decisive to the inclusion/exclusion of a location and to draw scenarios. For the specific case of Carbon4PUR, the consortium has identified five hard criteria (Table 1Table). By slight variation of the quantitative thresholds, we present three scenarios. Details are described in the specific sections.

Table 1: *Hard criteria as agreed upon by the Carbon4PUR consortium*

Precondition	Quantitative Threshold
Ethylene oxide (EO) availability	Yes/No (boolean)
Propylene oxide (PO) availability	Yes/No (boolean)
CO availability	kt/a (number)
CO source in proximity to EO / PO source	km (number)
CO source must be a steel manufacturer	Yes/No (boolean)

In the best case, ethylene oxide and propylene oxide are both available on-site, as these chemicals are prerequisites for the envisaged polyol production (criteria 1 and 2). However, at small scale these oxides could also be transported to the production site. In the worst case, a new facility for the oxidation of ethylene/propylene must be constructed. This case would require at least the vicinity to a pipeline transporting these olefins or to a refinery to produce them.

Besides the availability the oxides, CO and CO_2 waste gas streams are mandatory for the production of the envisaged CO- and CO_2-based polyols (criterion 3). Thus, it becomes possible to exclude sites based on the envisaged annual polyol production capacity. Further, we assume that the remaining weight fraction is provided by the ethylene oxide for CO-based polyols and by propylene oxide for CO_2-based polyols and that the raw material conversion and product selectivity are both 100%.

Finally, at least one of the raw material streams, i.e., ethylene oxide, propylene oxide, CO and CO_2, must be transported to the polyol production plant. Therefore, the fourth criterion has been introduced. The construction of one kilometre of pipeline is estimated to cost about € 1 million.

The fifth precondition, i.e., a steel manufacturer as CO source has been introduced, since the gas purification pathways developed within Carbon4PUR are aimed at the purification of steel mill exhaust gases. However, the Carbon4PUR polyol production technology can utilize CO independent of its source, given that a minimum purity is achieved. Therefore, this criterion can be regarded as semi-hard with respect to the polyol production technology but as hard with respect to the gas purification technology.

3.3 Semi-hard criteria

While hard criteria, presented in the previous section 3.2 are used for initial identification of promising sites, semi-hard and soft criteria are used for further assessment. As enablers that are not physical pre-conditions or assets, semi-hard criteria provide the support that can make the difference between further development or interruption of projects by providing the right incentives to operate.

Semi-hard criteria take the form of policy support and other enabling factors along the stages of the innovation cycle. The two main semi-hard criteria are, first, strategic, financial and institutional support for industrial symbiosis in general and, second, strategic, financial and institutional support for low carbon technologies. These can be broken down more specifically into the following components, which are also included in the European Self-Assessment Tool (SAT)[4] originally created to help regions determine their readiness level for investment in sustainable chemical production:

- Access to finance,
- Skilled workforce, technical expertise, training capabilities,
- Existence of support institutions,
- Strength and availability of regional markets,
- Entrepreneurship, and
- Public support policies.

The hard inclusion/exclusion criteria described in the previous section 3.2 and dealing with infrastructure and feedstock availability help identify sites where upscaling and replication of the Carbon4PUR concept is possible in material terms. The criteria listed above, in alignment with the European Sustainable Chemicals Support Service[5] are briefly outlined in this section

[4] https://ec.europa.eu/growth/tools-databases/escss_en
[5] http://suschem.org/newsroom/six-model-regions-show-way-to-a-sustainable-eu-chemical-industry

to help project developers evaluate the readiness level of identified sites to bring about the Carbon4PUR industrial symbiosis concept.

1. **Access to finance**. This criterion defines the current situation in accessing private and public funds and other investment mechanisms. It examines the conditions that create an environment where innovations can evolve, reach the market and become widely used.

2. **Skilled workforce, technical expertise, training**. This criterion evaluates the availability of capable workforce suitable for industrial development of CCU. Statistics of skilled workforce, availability of schools, and training programs for skilled and non-skilled profiles are considered.

3. **Existence of support institutions**. This criterion is related to organisations such as universities, testing and certification bodies, and research institutions that could build and transfer know-how and offer technical assistance to project developers.

4. **Strength and availability of regional markets.** This criterion evaluates framework conditions such as existence of stakeholders, potential clients for the uptake of CCU-derived products, and institutions facilitating networking.

5. **Entrepreneurship.** This refers to the availability of support to existing and new businesses such as incubators, industrial parks, information campaigns for the exploitation of regional feedstock for sustainable chemicals production, match making events, business plan drafting services

6. **Public Support Policies**. This refers to the stability (favourable to investments in general) and flexibility (to adapt to new symbioses) of the regulatory environment. Relevant information relates to the regulatory framework for facilitating the creation of new businesses and to regional policies for the development and channeling of entrepreneurial talent and for increasing the effectiveness of entrepreneurs.

3.3.1 Enablers for Research and Development

Support for research and development can cover technology improvement for both capture and, due to lower technology readiness levels, conversion processes. However, given that relevant EU regulations often do not address specific substances, e.g. CO- or CO_2-derived intermediate substances or products, they are also not addressed individually in this work.

Equally, there are policies that can be useful in different stages of the innovation cycle and we present them under this section as well as sections 3.3.2 and 3.3.3. Figure 1 shows the relevance of EU funding sources according to stages of the innovation cycle.

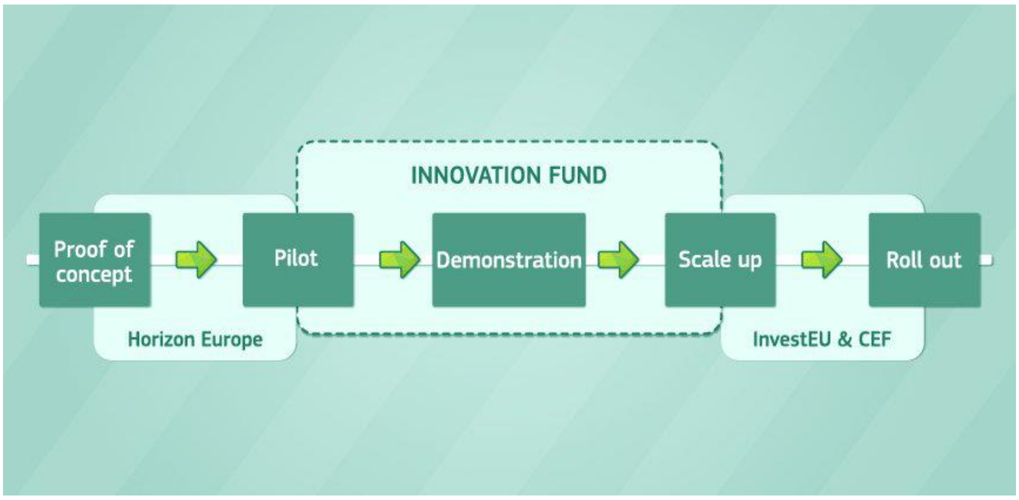

Figure 1: *European funding sources across the innovation cycle (Source: European Commission EU Innovation Fund [6])*

The main support instruments for Research and Development (R&D) that are available at European level include the following.

Horizon 2020 and Horizon Europe

Horizon 2020 is the framework programme for funding EU innovation projects. Within its "Societal Challenges" and "Industrial Leadership" pillars, there are various mechanisms aimed at funding R&D, pilot and demonstration projects. Due to its objective of fostering cross-border co-operation, Horizon 2020 projects typically required involvement of at least three independent legal entities, each established in a different Member State or Associated Country. Projects so far supported under Horizon 2020 have been aiming at either:

a) Establishing new knowledge or exploring the feasibility of a new or improved technology, and have been termed Research and Innovation Actions, or

[6] https://ec.europa.eu/clima/policies/innovation-fund_en

b) Producing plans or designs for new, altered or improved products, processes or services, including prototyping, piloting, large-scale product validation and market replication, and have been termed Innovation Actions.

Previously, the 2018-2020 Horizon 2020 work programme for secure, clean and efficient energy made particular reference to addressing scientific and technological challenges related to Carbon Capture and Utilisation (CCU). In particular it has so far targeted the following activities (Porteron et al. 2019):

- Reducing energy consumption and carbon footprint,
- Low-cost, low-carbon electricity supply,
- Alternative fuels and mobile energy sources, and
- Market uptake of energy innovation.

Horizon Prize for CO_2 Reuse

Horizon 2020 funds the Horizon Prize for CO_2 Reuse, which has been established to reward innovative products utilising CO_2 that could significantly reduce the atmospheric emissions of CO_2 when deployed at a commercial scale. The prize aims to mobilise private Research and Innovation investment, attract non-traditional stakeholders, create new partnerships and incentivise researchers and innovators to enhance efforts to abate CO_2 emissions.[7]

Horizon Europe

Horizon Europe is the successor programme of Horizon 2020.[8] It is partly still performing a strategic planning process and will focus on its global challenges and European industrial competitiveness pillar. The result of the process will deliver a multiannual strategic plan to prepare the calls for proposal for the first four years. Horizon Europe will be based on mission-oriented innovation policy and it is foreseen that its missions will:

- Be clearly framed: targeted, measurable and time-bound;
- Establish impact-driven but realistic goals;
- Link activities across different disciplines and different types of research and innovation;
- Drive systemic change and transform landscapes rather than fix individual problems;
- Make it easier for citizens to understand the value of investments in research and innovation.

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[7] https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/prizes/horizon-prizes/co2-reuse-prize_en

[8] https://ec.europa.eu/info/horizon-europe-next-research-and-innovation-framework-programme_en#proposal

3.3.2 Enablers for Piloting and Demonstration

Support for demonstration can include assistance with piloting or building demonstration facilities or case studies for validation and scale-up. In more advanced stages support can be used to demonstrate connectivity and symbiosis projects or demonstration of the attributes of the resulting products.

EU Innovation Fund for low carbon technologies

The EU Innovation Fund has been established to offer financial support according to the risk profiles of projects deemed to have sufficient potential and will mainly assist technology only partly at R&D stage. The fund is highly relevant for demonstration and deployment stages and was designed to incorporate lessons from the NER 300 programme. For instance, it considers that either selecting immature projects or providing support too late in the project lifespan in an inflexible way can lead to a low success rate (ETIP SNET, 2019). Moreover, it is important that most elements of projects financed by the fund are at advanced technology readiness levels, so that the fund can help in raising competitiveness to reach the market.

The aim of the fund is to attract additional public and private funds. It will work in synergy with InvestEU (see section 3.3.3) and other EU programmes on research and innovation for low-carbon technologies. The first call for proposals will take place in June 2020. The Industry Association CO_2 Value Europe can provide information to its members in preparing for the call (Dallemagne, 2019). The budget of the fund is expected to be € 1 to 1.5 billion and can offer a co-financing rate of up to 60% of “additional costs” (Duwe et al. 2018).

A stated aim of the fund is geographical and sectoral balance. It will finance projects with substantial emissions reduction potential in key sectors and can provide up to 40% of the grant based on pre-defined milestones before the project is fully up and running (DG Climate Action, n/d) (Figure 2). The rationale is to improve flexibility of support following the cash flow of each project (ETIP SNET, 2019).

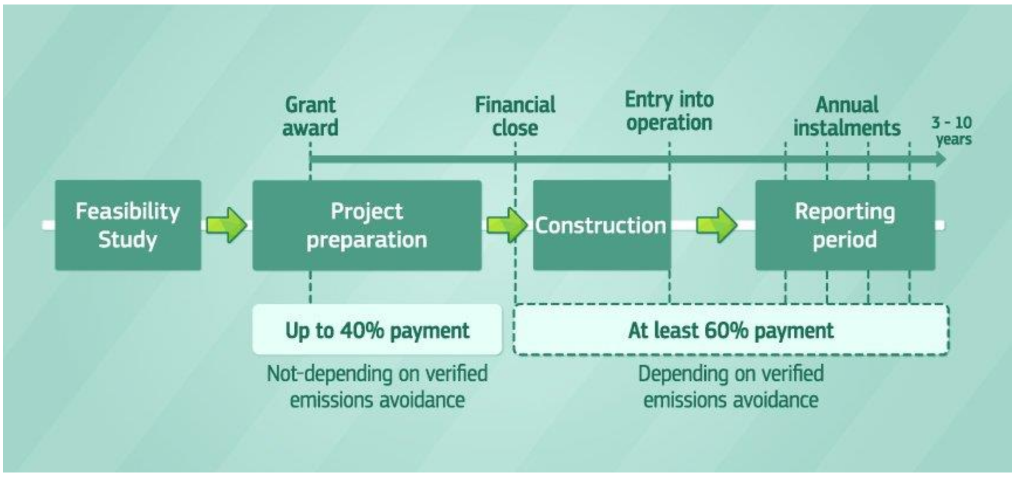

Figure 2: *Distribution of grant financing in the EU Innovation Fund (Source: DG Climate Action, n/d)*

The selection criteria of the fund are (DG Climate Action, n/d):

- Effectiveness of greenhouse gas emissions avoidance,
- Degree of innovation,
- Project viability and maturity,
- Scalability, and
- Cost efficiency (cost per unit of performance).

Research and Innovation Smart Specialisation Strategies (RIS3) Platform

The Commission has created the S3 Platform to provide advice to regions on the design and implementation of their Smart Specialisation Strategy and its aims are to: [9]

- Provide guidance material and good practice examples,
- Inform strategy formation and policy-making,
- Facilitate peer-reviews and mutual learning,
- Support access to relevant data, and
- Train policy-makers.

The platform has set up additional resources such as dedicated thematic platforms, guidance with design and implementation of strategies[10] and other support such as assistance with entrepreneurial discovery processes.

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9 https://s3platform.jrc.ec.europa.eu/

10 https://s3platform.jrc.ec.europa.eu/s3-guide

InnovFin Energy Demo Project

One of the conditions is that technologies shall be at pre-commercial level or early commercialisation stages but should be sufficiently mature for demonstration at the proposed commercial scale (technologies validated and demonstrated through previous testing) with reasonable prospects of successful demonstration. Projects should also have replicability potential and convincing market prospects for future cost reductions. Although manufacturing plants and services do not necessarily need to comply with this requirement.[11]

Cohesion Fund

The Cohesion Fund is aimed at Member States whose Gross National Income per capita is less than 90% of the EU average. It aims to reduce economic and social disparities and to promote sustainable development. For the 2014-2020 periode, the Cohesion Fund focused on Bulgaria, Croatia, Cyprus, the Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia and Slovenia.[12]

The Cohesion Fund allocates a total of € 63.4 billion to activities under the categories of (i) Trans-European transport networks and (ii) Environment. Under the latter category, the Cohesion Fund can also support projects related to energy as long as they clearly benefit the environment in terms of energy efficiency, use of renewable energy or improvement of transport.

LIFE Climate Action

The LIFE Climate Action sub-programme has the objective of incentivising transitional change to a climate resilient economy. In the context of the Climate Change Mitigation theme, co-finance grants are made available for best practice, pilot and demonstration projects contributing to the reduction of greenhouse gas emissions. Provided that the projects ensure net carbon emission reductions, the available funding may therefore, in principle, contribute to various components and needs of CCU projects, such as renewable energy provision, CO_2 emissions accounting, and introduction of CCU to industrial processes (Porteron et al., 2019).

[11] https://www.eib.org/en/products/blending/innovfin/products/energy-demo-projects.htm
[12] https://ec.europa.eu/regional_policy/en/funding/cohesion-fund/

For the period 2014-2020, the Climate Action sub-programme provided € 864 million in co-financing and eligible purposes are "pilot projects" and "demonstration projects".[13]

Research Fund for Coal and Steel

The Research Fund for Coal and Steel (RFCS) is funded by the European Coal and Steel Community. The RFCS supports research, pilot and demonstration projects in coal and steel sectors outside of projects funded by the EU's Framework Programmes.[14] It provides around € 40 million annually to universities, research centres and private companies to fund projects covering, production processes, application, utilisation and conversion of resources, reducing CO_2 emissions from coal use and steel production.[15]

European Structural and Investment Funds (ESI Funds)

Amongst the ESI Funds only the Cohesion Fund (described above) and the European Regional Development Fund (ERDF) are relevant for CCU. The ERDF is managed under the shared management mode,[16] and specific eligibility criteria and selection process depend on each region's operational programme and investment priorities agreed in concertation with the European Commission's Directorate-General for Regional Development (Porteron et al., 2019). However, ESI Funds target public bodies rather than the private sector. Any funding of CCU activities in industry must therefore adhere to regional aid guidelines.

ESI Funds are driven by 11 investment priorities, also known as thematic objectives, of which numbers 1, 4, 6 and 7 are most relevant to CCU projects: 1. strengthening research, technological development and innovation; 4. supporting the shift towards a low-carbon economy in all sectors; 6. preserving and protecting the environment and promoting resource efficiency; and 7. promoting sustainable transport and removing bottlenecks in key network infrastructure (Porteron et al., 2019).

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13 https://ec.europa.eu/clima/policies/budget/life_en

14 Council Decision 2008/376/EC on the adoption of the Research Programme of the Research Fund for Coal and Steel and on the multiannual technical guidelines for this programme

15 https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/research-fund-coal-and-steel-rfcs_en

16 https://ec.europa.eu/info/funding-tenders/how-eu-funding-works/management-eu-funding_en#differentmanagementmodes

3.3.3 Checklist of local regulatory factors

There are three areas of industrial regulations that can prevent or foster the construction of piloting, demonstration or commercial scale plants, which can vary by Member State or by in-country region. Project developers are advised to consider all available opportunities for support in conjunction with these three aspects before and during a location due diligence:

- Rules and regulations for transport of chemical substances within industrial parks as well as on public ground (road or rail),
- Regional and local health and safety regulations specific to the sectors that will be involved in the symbiosis,
- Regional and local planning permissions, industrial operations permitting procedures and similar regulations for building chemical processing or transport infrastructure such as pipelines and handling facilities.

The last point has been decisive in recent industrial attempts to build CCU infrastructure, namely for transporting CO. A recent example is the Covestro (erstwhile Bayer AG) pipeline, which was completed in 2009 and has been subject to public opposition. Apart from the general public, organisations such as the fire department in a local area have led to permitting disputes.[17]

Public opposition from densely populated areas along the pipeline trajectory criticise the toxicity hazard potentially affecting thousands of local residents. Arguments include the hazard of CO as odourless and only marginally lighter than air, which complicates its control and monitoring.[18] It is worth noting how these arguments arise despite methodological control measures of Covestro (Bayer AG). For instance, there are pressure monitoring systems as well as CO detection equipment along the pipeline. Furthermore, there are measures to monitor potential leakage by performing a mass balance between injected and delivered gas as well as an additional monitoring system of pipeline pressure fluctuation.

Further, regulations and restrictions dealing with CO_2 will inevitably also affect the use and transport of CO as these gases will coincide. The transport of CO_2 is strictly regulated within Europe and the cross-border transport is forbidden, as CO_2 is regarded as waste. On 11th October 2019, this regulation has been slightly softened by the approval of a Resolution

[17] https://de.wikipedia.org/wiki/CO-Pipeline_der_Bayer_AG#Aktuelle_Situation
[18] https://web.archive.org/web/20130221150127/http://www.contra-pipeline.de/was-wir-wollen

for Provisional Application of the 2009 CCS Export Amendment to the London Protocol.[19] Therein, it has been agreed that countries can now legally export and import CO_2 for offshore geological storage. Although, geological storage is a CCS solution and does not fall within the scope of the Carbon4PUR project, this example shows how regulations may hinder the the uptake of CCU technologies and how long amendments to such regulations may take.

3.3.4 Enablers for deployment and uptake of CCU/Carbon4PUR

Policy support to promote the deployment of symbiosis projects and the use of CO_2 are generally applicable across Europe. Instruments to provide financial support for technology uptake are likely to be modulated at regional, national and subnational level. A further deployment stage consideration for project developers is the ability to cover the adjustment costs (e.g. partial dismantling and rebuilding) in terms of finances and time of forgone revenues when retrofitting existing industrial plants. Plans should reflect whether these will be covered internally by the business case and its planned revenues or whether support will be available.

InvestEU

The InvestEU programme brings together under one roof the multitude of EU financial instruments currently available to support investment in the EU, making EU funding for investment projects in Europe simpler, more efficient and more flexible.[20] Its fund will mobilise public and private investment through an EU budget guarantee of € 38 billion that will back the investment projects of financial partners such as the European Investment Bank Group and others, and increase their risk-bearing capacity.[21]

InvestEU will run between 2021 and 2027 and aims to trigger at least € 650 billion in additional investment. The InvestEU Fund will support four policy areas: sustainable infrastructure; research, innovation and digitisation; small and medium-sized businesses; and social investment and skills. InvestEU will aim to react to market changes and policy priorities that change over time. Its advisory hub will provide technical support and assistance to help

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19 "Positive Result on the London Protocol's CCS Export Amendment", IEA GHG, https://ieaghg.org/ccs-resources/blog/positive-result-on-the-london-protocol-s-ccs-export-amendment, 22.10.2019

20 https://ec.europa.eu/commission/presscorner/detail/en/MEMO_19_2135

21 https://europa.eu/investeu/home_en

with the preparation, development, structuring and implementation of projects, including capacity building.

Connecting Europe Facility

The Connecting Europe Facility (CEF) is engineered to address two groups of factors behind the investment gap in the energy sector, namely, the need to invest in the upgrade of aging energy infrastructure and the need to assist necessary infrastructural projects that under the broader policy landscape would still not be commercially viable. Financial instruments such as grants attracting new classes of investors and mitigating certain risks will help project promoters to access the necessary financing part of the construction costs to fill the gaps of commercial viability of projects that are relevant for Europe.[22]

The 2020 CEF Energy call for proposals will make € 880 million available to finance projects of common interest in the energy sector, namely in electricity, gas, smart grids and cross-border carbon dioxide network infrastructure.[23]

The Circular Carbon Network

Two of the services the network offers are particularly valuable to project developers. First, community building, whereby it is aiming to consolidate a more connected, global community to accelerate the growth of the CCU sector. Second, it offers a deal hub, where it gathers and shares actionable investment, commercialization, and collaboration leads.[24]

CO_2 Value Europe

The European industry association for CCU, CO_2 Value Europe, works on the three main priorities of collective intelligence of CO_2 capture and conversion technologies; up-scaling and demo projects; and awareness and advocacy.[25] The association convenes several targeted working groups on:

- CO_2 capture & conversion intelligence,
- Research & Development,

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22 https://ec.europa.eu/inea/connecting-europe-facility/cef-energy
23 https://ec.europa.eu/inea/connecting-europe-facility/cef-energy/calls
24 https://circularcarbon.org/about/
25 http://pr.euractiv.com/pr/co2-value-europe-new-association-dedicated-utilisation-co2-161247

- Transversal pilot/demo projects,
- Advocacy and stakeholder relations,
- CCU standardization,
- Market development,
- PR – external communication.

Regional Innovation Monitor Plus

The Regional Innovation Monitor (RIM) is a public tool for sharing intelligence on innovation policies in some 181 regions across 19 EU Member States. It provides detailed information on regional innovation policies in Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, the Netherlands, Poland, Portugal, Romania, Slovakia, Spain and Sweden.

The platform includes an online 'inventory' of regional innovation policy measures, policy documents and organisations. Information and analysis of policy documents, governance structures, and existing innovation policy measures is gathered at the Nomenclature of Territorial Units for Statistics (NUTS) 1 and 2 levels. Where relevant, information is provided on innovation policy initiatives at sub-regional level and on inter- and/or intra-regional cooperation.[26]

3.3.5 Two example regions

Using the Regional Innovation Monitor we have identified a summary of relevant semi-hard criteria or enablers for the regions of Flanders and Provence-Alpes-Côte d'Azur to deepen the insights on the regions identified during the hard criteria filtering.

Flanders

Flanders is the Belgian region with the greatest industrial rate, it covers 44.5% of Belgium's territory and provides 59.2% of the national gross domestic product (GDP). According to the regional innovation scoreboard 2019, Flanders is ranked as a strong innovator with increasing innovation performance. In relation the R&D effort, Flanders ranks even higher than the Netherlands, France and the EU average. Its business R&D expenditures are

[26] https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/content/regional-innovation-monitor-rim-plus

mainly done in the chemical and pharmaceutical sectors. Specifically, the petrochemical industry together with the ICTs delivers products that remain top export commodities, accounting for more than 22.9% of the total value of Flemish merchandise export.

'Advanced manufacturing' has been a topic of policy and research attention for years, it has recently received an additional boost as part of the reliance activities for the province of Limburg which led to a loss of more than 10.000 high-level industry jobs in a small region. A number of already existing and new initiatives was bundled in the set-up of a Strategic Research Centre for Advanced Manufacturing (Strategisch Onderzoekscentrum Maakindustrie), called Flanders Make.

In 2014 the region’s government published a policy called “Flanders in transition” presenting several sciences, technology and innovation priorities, including sustainable chemistry, specialized manufacturing solutions, industrial design and creative industries, smart resource management. The Policy Note 2014-2019 on employment, economy, science and innovation draws up the plan to make Flanders one of the top five regions in Europe in terms of employment (76%) and R&D expenditure (3%). In relation to policy realization, several agencies exist to support companies in relation to R&D, innovation and entrepreneurship VLAIO, a merger of former agencies IWT (Innovation Agency), financial support guarantees and loans (Entrepreneurship Agency) and internationalisation support and FDI (FIT: Flanders Investment & Trade).

Provence-Alpes-Côte d'Azur

South Region is the fourth contributor to the national GDP, represented 7% of the total annual French GDP, in 2017. It is ranked as a strong innovator, its innovation performance has been increasing over time and its public expenditure on R&D accounts for 113% and 121% of the national and European performances respectively, based on the regional innovation scoreboard 2019.

For supporting growth, employment and boosting the attractiveness of the area, the South Region has launched eight sector programmes, one of which is particularly dedicated to advanced manufacturing: developing tomorrow's industrial models. The regional industrial policies are further supported by the national council for industry (Conseil National de l’Industrie), and the fund for innovation and industry (Fonds pour l’Innovation et l’Industrie) of € 10 billion supports innovation in the industry, aiming to develop disruptive innovation products or processes.

In order innovation to be reinforced, the South Region's regional council coordinates and facilitates the liaison between stakeholders of the South Region innovation ecosystem, including some competitiveness clusters, such as CAPENERGIES (focused on the ecological and energy transition) and the Economic Development Agency of the South region (risingSUD) that aims to help regional companies expand, develop international markets for regional companies and generate investment opportunities across the South Region.

3.4 Soft criteria

Important soft criteria for development of projects are, first, the public perception of CCU in general as well as perceptions about infrastructure and specific products; second, the acceptance of other stakeholders including policy makers, local authorities and intermediate users. Considering these two factors is decisive in creating the dynamics of a market pull. Whilst CCU technologies have partly reached the commercialisation stage, the CCU community has so far focused mainly on aspects of technical feasibility with less emphasis on the role of consumers and public acceptance (Arning and Ziefle, 2017). The approval of the general public of CCU products is essential, since CO_2, as important greenhouse gas, is negatively viewed (Van Heek et al., 2017). As with other technologies, not only the inherent attributes of the technology, but also a lack of knowledge and familiarity and a feeling of not being well informed can add to a negative perception (van Heek et al., 2017).

Based on research so far, perceptions of CCU are complex phenomena that vary depending on individual characteristics, context and framing through media coverage or otherwise. Results show that the general perception of CCU products ranges from support and cautious acceptance to rejection and appropriate communication strategies are needed, especially for laypeople, since public knowledge of CCU is at a very low level (Arning and Ziefle, 2017). For instance, most misconceptions about CCU products are linked to negative, albeit not scientifically supported, associations such as exposure to toxic CO_2.

Studies with a more market-oriented approach, i.e. focusing on potential customer perceptions of mattresses and plastics made using CO_2, finds that risks are generally seen as low (Arning et al., 2017; Van Heek et al., 2017). Here the perceived risks differ slightly, with 'perceived health complaints' and 'disposal conditions' being categorised as main barriers for CCU (van Heek et al., 2017). However, participants raised doubts about the technical feasibility of the technologies as well as the long-term environmental benefits. Two arguments when scrutinising possible investments in CO_2 utilisation are that they could detract from investment in other low-carbon technologies (such as renewables) or conflict with broader sustainability goals, so that CO_2 utilisation is seen by some as being predicated on the continued use of fossil fuels (Jones et al., 2016).

Furthermore, confusion or co-mingling with CCS technologies might cause negative attitudes towards CCU (Bruhn et al., 2016). Co-mingling can be due to the similarity of the terms or to the technical commonalities and can be observed in the media as well as in policy related discourses (Olfe-Kräutlein et al., 2016). Based on current knowledge, it can be expected that implementation of CCU might face acceptance problems due to co-mingling with CCS. Therefore, CCU should be clearly distinguished from CCS when communicating with stakeholders and the general public alike.

In addition, concrete ecological effects must be evaluated for each individual technology and market segment and communicated accordingly. And finally, a realistic presentation of the possibilities is necessary, in particular, regarding the potential and limitations for CCU to mitigate negative climate and environmental effects in the most diverse and imaginable scenarios.

Project developers should consider the significance of public acceptance as a driver for the Carbon4PUR replication and acceleration. Carbon4PUR will explore the perception and acceptance of insulation boards as CO/CO_2-Carbon4PUR product, in relevant stakeholder groups in order to get insights into the societal readiness towards a CO/CO_2-derived product case and communicative requirements for a market introduction. RWTH will act as the main leader of this task delivering the $PACO_2$ - Perception, acceptance and communication concepts for a CO/CO_2-derived product in Carbon4PUR report, due September 2020.

4. Scenarios and Results

4.1 Scenario 1 – The sweet spot meeting all set criteria

In scenario 1 all the hard criteria must be fully met, i.e., all the epoxides production must be in a maximum distance of 10 km to the CO source and the annual production capacity shall be at least 50 kt/a (Table 2Table).

Table 2: *Hard criteria as agreed upon by the Carbon4PUR consortium*

Precondition	Quantitative Threshold
Ethylene oxide (EO) availability	yes
Propylene oxide (PO) availability	yes
CO availability	≥ 13.5 kt/a CO for 50 kt/a polyol
CO source in proximity to EO / PO source	Max. 10 km distance
CO source must be a steel manufacturer	No

With this set of criteria, the Carbon4PUR online mapping tool resulted in exactly 1 feasible location, i.e., the Port of Marseille (Figure 3Figure). Within the radius of 10 km, the CO emissions amount 76 kt/a of which the main portion (75 kt/a) originates from ArcelorMittal FOS. With this amount of CO, the achievable CO-based polyol production is more than 275 kt/a. The polyol plant of Covestro France SNC is located directly in the area of the port enabling the envisaged industrial symbiosis. Table 3 provides a more detailed view on the available gas emissions broke down by the company and gives the potential plant capacity for both CO- and CO_2-based polyols according to the assumptions made in the introduction.

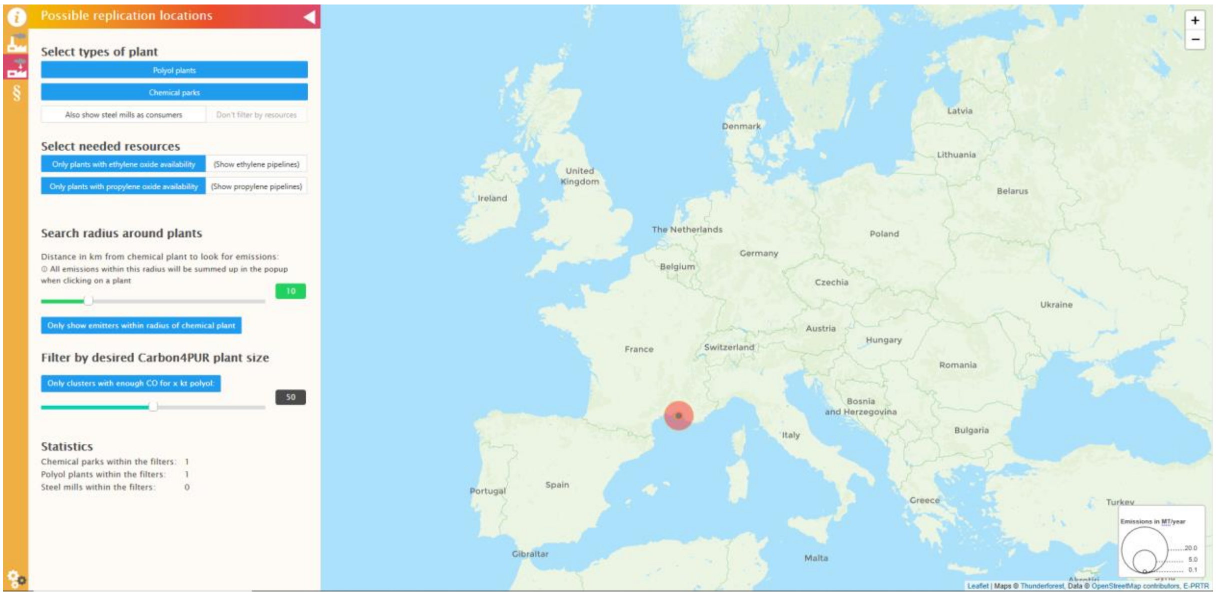

Figure 3: *Potential locations for the replication of the Carbon4PUR technology after applying the criteria summarized in Table 2. The Port of Marseille is the only location meeting all the criteria.*

Table 3: *Explicit emitters located at the Port of Marseille FOS*

Emitter	Category	CO availability	Potential CO-based polyol capacity	CO_2 availability	Potential CO_2-based polyol capacity
ArcelorMittal FOS	Iron, Steel, Ferro-Alloys	74.8 kt/a	277 kt/a	7,930 kt/a	56,643 kt/a
Asco Industries Usine de FOS	Iron, Steel, Ferro-Alloys	1 kt/a	3.7 kt/a	0 kt/a	
CYCOFOS	Production of Electricity	0 kt/a	0 kt/a	538 kt/a	3,842 kt/a
Total		75.8 kt/a	281 kt/a	8,468 kt/a	60,485 kt/a

The CO emissions in this scenario are solely from steel manufacturing. Thus, even though the fifth criterion was not considered in the filter settings, it is implicitly met and the gas purification technology developed within Carbon4PUR can be applied without further alteration development. Anyhow, Table 3 also shows non-CO emitters for the sake of completeness and because these emissions may be used for the production of CO_2-based polyols.

4.2 Scenario 2 – Pilot plant at an existing polyol plant or chemical park

This scenario basically uses the same hard criteria as scenario 1, besides the fact that the annual polyol production capacity has been lowered to roughly 10% of the initial 50 kt/a (Table 4). The main idea behind this procedure is that the E-PRTR database reflects the gas emissions to the atmosphere. CO, which is internally converted, e.g., oxidized, within the plant is not listed. Expert opinions state that the CO amount actually available is about 10 to 15 times higher than the value provided to the E-PRTR. Therefore, we assume that a demonstration plant with an annual production capacity in the range of 50 kt/a and more is actually feasible, assuming the criteria from Table 4Table . In the following examples the amount of polyol production is based on the E-PRTR database and could be multiplied by a factor of 10 to 15.

Table 4: *Hard criteria for scenario 2: The polyol production capacity has been decreased to 4 kt/a in the online mapping tool*

Precondition	Quantitative Threshold
Ethylene oxide (EO) availability	yes
Propylene oxide (PO) availability	yes
CO availability	≥ 1.08 kt/a CO for 4 kt/a polyol
CO source in proximity to EO / PO source	Max. 10 km distance
CO source must be a steel manufacturer	No

Thus, a total of five potential locations could be identified as feasible for the construction of a Carbon4PUR polyol pilot plant (Figure 4). These locations are in the vicinity of:

a) **Rotterdam** (the Port of Rotterdam, the Huntsman Holland B.V. polyol plant and the Shell Netherland Chemie B.V. polyol plant) (Table 5),
b) **Antwerp** (the Port of Antwerp, the INEOS Antwerp Site and the Covestro N.V. Antwerp polyol plant) (Table 6),
c) **Terneuzen** (the DOW Benelux Polyol Plant) (Table 7),
d) **Puertollano** (the Repsol Quimica S.A. polyol plant) (Table 8) and
e) **Marseille** (the Port of Marseille FOS and the Covestro France SNC polyol plant) (Table 3, section 4.1).

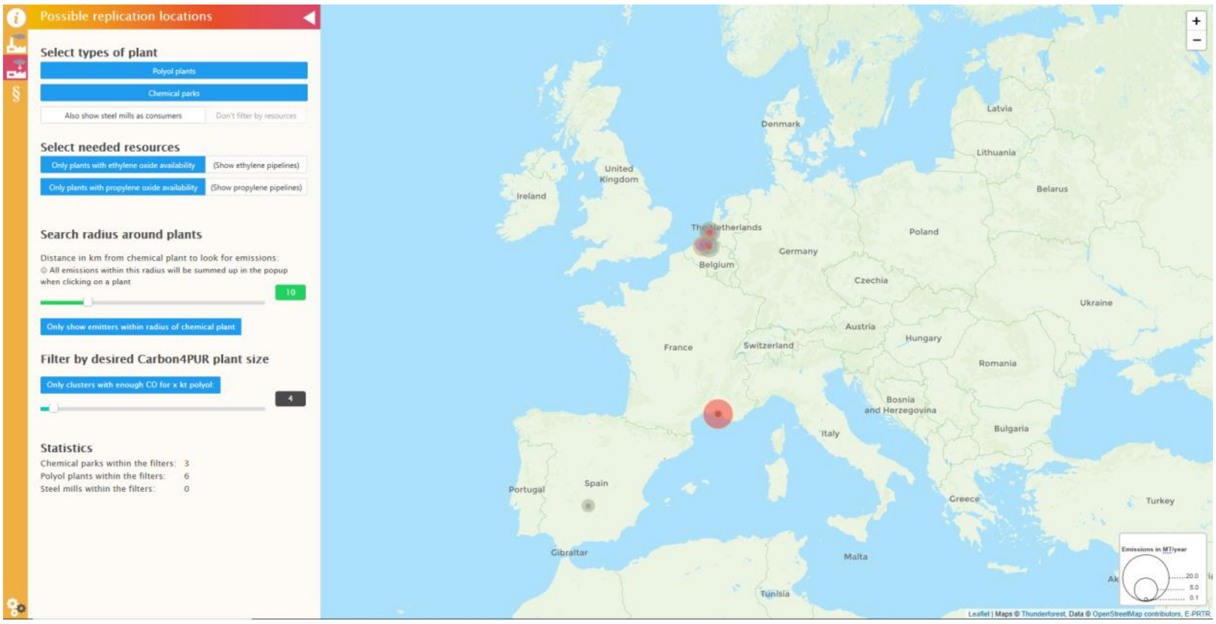

Figure 4: *Potential locations for the replication of the Carbon4PUR technology after applying the criteria summarized in Table 5.*

Emitters and polyol plants in the region of Rotterdam

The emitters in the vicinity of Rotterdam are listed in Table 5. There are exactly two sites emitting both CO and CO_2, i.e., the Esso Nederland BV refinery and the Shell Nederland refinery. Other eight sites emit only CO_2 and are listed for completeness. The total CO-based polyol capacity is 5.5 kt/a and the total CO_2-based polyol capacity is between 65 kt/a and 68 kt/a, depending on the fact, that that the Gunvor Petroleum Rotterdam B.V. refinery and the E.ON Warmte Station Galileistraat electricity plant are solely in the 10 km catchment area of the Huntsman Holland B.V. polyol plant and the Shell Netherland Chemie B.V. polyol plant, respectively.

Table 5: *Explicit emitters in the region of Rotterdam and their CO/CO_2 emissions*

Emitter	Category	CO availability	Potential CO-based polyol capacity	CO_2 availability	Potential CO_2-based polyol capacity
Shell Nederland Raffinaderij BV	Manufacture of refined petroleum products	0.9 kt/a	3.3 kt/a	3,830 kt/a	27,357 kt/a
Esso Nederland BV (Raffinaderij Rotterdam)	Manufacture of refined petroleum products	0.6 kt/a	2.2 kt/a	2,540 kt/a	18,143 kt/a
Air Liquide Pergen VOF	Production of electricity	0 kt/a	0 kt/a	1,170 kt/a	8,357 kt/a
Rijnmond Power Plant	Production of electricity	0 kt/a	0 kt/a	521 kt/a	3,721 kt/a
Maasstroom Energie CV	Production of electricity	0 kt/a	0 kt/a	425 kt/a	3,035 kt/a
Eurogen CV	Production of electricity	0 kt/a	0 kt/a	241 kt/a	1,721 kt/a
Cabot BV	Manufacture of other inorganic basic chemicals	0 kt/a	0 kt/a	240 kt/a	1,714 kt/a
Enecal Energy VOF	Production of Electricity	0 kt/a	0 kt/a	140 kt/a	1,000 kt/a
Gunvor Petroleum Rotterdam B.V. (GPR)*	Manufacture of refined petroleum products	0 kt/a	0 kt/a	435 kt/a	3,107 kt/a
E.ON Warmte Station Galileistraat**	Production of Electricity	0 kt/a	0 kt/a	105 kt/a	750 kt/a
Total		1.5 kt/a	5.5 kt/a	9,647 kt/a	68,907 kt/a

* solely in the catchment area of the Huntsman Holland B.V. polyol plant

** solely in the catchment area of the Shell Netherland Chemie B.V. polyol plant

Emitters and polyol plants in the region of Antwerp

The emitters in the vicinity of Antwerp are listed in Table 6. There are exactly two sites emitting both CO and CO_2, i.e., the TOTAL refinery and the ESSO refinery. Other five sites emit only CO_2 and are listed for completeness. The total CO-based polyol capacity is 4.9 kt/a and the total CO_2-based polyol capacity is slightly above 53 kt/a. All CO and CO_2 emitters are located in the 10 km catchment area the Covestro N.V. polyol plant.

Table 6: *Explicit emitters in the region of Antwerp and their CO/CO_2 emissions*

Emitter	Category	CO availability	Potential CO-based polyol capacity	CO_2 availability	Potential CO_2-based polyol capacity
TOTAL RAFFINADERIJ ANTWERPEN	Manufacture of refined petroleum products	0.7 kt/a	2.7 kt/a	3,680 kt/a	26,286 kt/a
ESSO RAFFINADERIJ	Manufacture of refined petroleum products	0.6 kt/a	2.2 kt/a	1,880 kt/a	13,429 kt/a
ZANDVLIET POWER - TERREIN BASF*	Production of electricity	0 kt/a	0 kt/a	696 kt/a	4,971 kt/a
INDEPENDENT BELGIAN REFINERY*	Manufacture of refined petroleum products	0 kt/a	0 kt/a	423 kt/a	3,021 kt/a
ELECTRABEL WKK LANXESS (BAYER)*	Production of electricity	0 kt/a	0 kt/a	186 kt/a	1,329 kt/a
ESSENT ENERGIE BELGIE**	Production of electricity	0 kt/a	0 kt/a	426 kt/a	3,042 kt/a
ELECTRABEL SITE LANXESS RUBBER**	Production of electricity	0 kt/a	0 kt/a	195 kt/a	1,393 kt/a
Total		1.3 kt/a	4.9 kt/a	7,486 kt/a	53,471 kt/a

* located at the INEOS Antwerp Site chemical park
** located at the Port of Antwerp chemical park

Emitters and polyol plants in the region of Terneuzen

The emitters in the vicinity of Terneuzen are listed in Table 7. There is exactly one site emitting both CO and CO_2, i.e., the YARA Sluiskil BV facility. Another one site emits only CO_2 and is listed for completeness. The total CO-based polyol capacity is 4.4 kt/a and the total CO_2-based polyol capacity is slightly above 35 kt/a. Both emitters are located in the 10 km catchment area the DOW Benelux N.V. polyol plant which is located at the Valuepark Terneuzen.

Table 7: *Explicit emitters at the Valuepark Terneuzen and their CO/CO_2 emissions*

Emitter	Category	CO availability	Potential CO-based polyol capacity	CO_2 availability	Potential CO_2-based polyol capacity
YARA Sluiskil BV	Manufacture of fertilisers and nitrogen compounds	1.2 kt/a	2.7 kt/a	3,580 kt/a	25,571 kt/a
ELSTA B.V.	Production of electricity	0 kt/a	0 kt/a	1,360 kt/a	9,714 kt/a
Total		1.2 kt/a	2.7 kt/a	4,940 kt/a	35,286 kt/a

Emitters and polyol plants in the region of Puertollano

The emitters in the vicinity of Puertollano are listed in Table 8Table . There is exactly one site emitting both CO and CO_2, i.e., the Repsol Petroleo S.A. refinery. Another one site emits only CO_2 and is listed for completeness. The total CO-based polyol capacity is 5.7 kt/a and the total CO_2-based polyol capacity is slightly below 15 kt/a. Both emitters are located in the 10 km catchment area the Repsol Quimica S.A. polyol plant.

Table 8: *Explicit emitters in the region of Puertollano and their CO/CO_2 emissions*

Emitter	Category	CO availability	Potential CO-based polyol capacity	CO_2 availability	Potential CO_2-based polyol capacity
REPSOL PETROLEO S.A.	Manufacture of refined petroleum products	1.5 kt/a	5.5 kt/a	1,570 kt/a	11,214 kt/a
FERTIBERIA	Manufacture of fertilisers and nitrogen compounds	0 kt/a	0 kt/a	445 kt/a	3,179 kt/a
Total		1.5 kt/a	5.5 kt/a	7,486 kt/a	14,393 kt/a

4.3 Scenario 3 – Stand-alone Carbon4PUR polyol plant located at a steel mill

In scenario 3 the ethylene oxide and propylene oxide availabilities have been set as non-mandatory preconditions. Neither is it compulsory that the envisaged Carbon4PUR polyol plant shall be located in an existing chemical park or polyol production site but rather at a steel manufacturing site. Consequently, this means that the needed epoxides (ethylene oxide and propylene oxide) have to be synthesised at the respective steel manufacturing site. Although this is a strong drawback, as not only the polyol plant but also the olefin-to-epoxide oxidation plant must be constructed, it may turn out to be reasonable from both an economical and an environmental perspective. The rationale behind this is that iron and steel manufacturing produce almost 75% of the European CO emissions. Thus, the highest positive impact can be achieved at these sites. However, for the feasibility of the scenario it is necessary to have an olefin (ethylene or propylene) source in certain vicinity. The olefin source can be either an existing pipeline or a refinery within an existing chemical park. The threshold for the distance between the steel manufacturing site and the olefin source has been set to 30 km. To estimate the distance between the steel mill and the chemical plant, the radius control in the mapping tool has been changed in such a way that the shown circles overlap slightly. The distance is twice the value of the radius of the circles. The preconditions and the applied thresholds are summarized in Table 9.

Table 9: *Hard criteria for scenario 3 (consider that the olefin availability has been added as a precondition)*

Precondition	Quantitative Threshold
Epoxide availability	No
Olefin availability	Yes
CO availability	≥ 13.5 kt/a CO for 50 kt/a polyol
CO source in proximity to olefin source	Max. 30 km distance
CO source must be a steel manufacturer	Yes

With this set of criteria four locations could be identified as shown in Figure 5Figure . These locations are:

a) The **Port of Marseille** in France,
b) The region of **Ghent/Terneuzen** in Belgium,

c) The region of **Duisburg/Essen** in Germany, where several steel mills and chemical parks are aggregated,

d) The region of **Amsterdam** in the Netherlands and

e) The region of **Hall** in the UK.

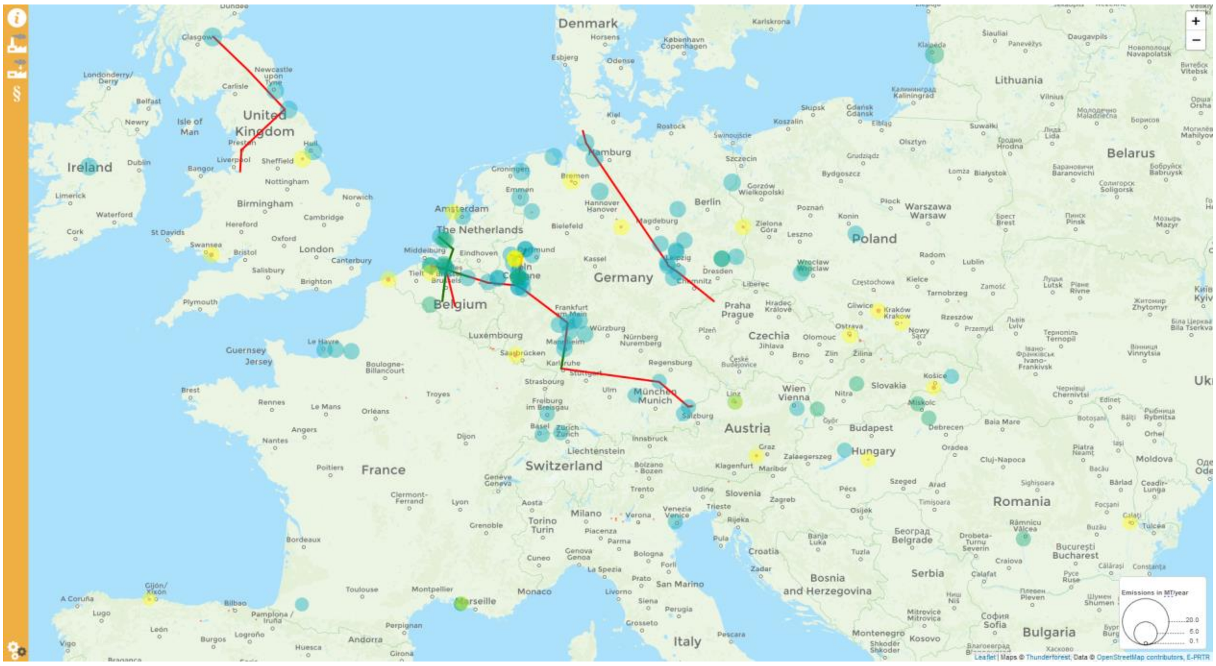

***Figure 5:** Potential locations for the replication of the Carbon4PUR technology after applying the criteria summarized in Table 9.*

Steel mills at the Port of Marseille

The steel manufacturing plant at the Port of Marseille is the ArcelorMittal FOS site. This result coincides with the scenario 1, indicating the availability of the needed epoxides. Consequently, the establishment of an olefin-to-epoxide oxidation facility is not necessary. More detailed data about the polyol production capacity can be found in Table 3.

Steel mills in the Ghent/Terneuzen region

In the region of Ghent/Terneuzen only one steel manufacturing plant, i.e., the ArcelorMittal Belgium - Ghent, can be found. It can provide a potential CO-based polyol production capacity of about 350 kt/a (Table 10). The nearest olefin source is located at the Valuepark Terneuzen at about 18 km distance. Furthermore, the DOW Benelux N.V. polyol plant located in the Valuepark Terneuzen provides availability of the needed epoxides. Consequently, the establishment of an olefin-to-epoxide oxidation facility is not necessary.

Table 10: *Steel mills in the Ghent/Terneuzen region and their CO/CO_2 emissions*

Steel Mills	CO emissions	Potential CO-based polyol capacity	CO_2 emissions	Potential CO_2-based polyol capacity
ARCELORMITTAL BELGIUM - GHENT	94.2 kt/a	349 kt/a	4.110 kt/a	29,357 kt/a
Total	94.2 kt/a	349 kt/a	4.110 kt/a	29,357 kt/a

Steel mills in the Duisburg/Essen region

There are five steel manufacturing sites in the region of Duisburg/Essen with a total potential production capacity of CO-based polyols of more than 1,150 kt/a (Table 11Table). Almost 60% of this potential production capacity is due to the Hüttenwerke Krupp Mannesmann GmbH, which is located at a distance of about 20 km from the nearest ethylene pipeline (to its east) and about 10 km to the nearest propylene pipeline (to its north). Thus, a total of about 30 km of transport pipeline would be needed to connect to steel mill to the existing network.

Another 35% of the potential production capacity can be allocated to the emissions of the thyssenkrupp Steel Europe AG Werk Schwelgern, which is located at a distance of about 5 km from the nearest ethylene pipeline (to its north) and about 3 km to the nearest propylene pipeline (to its east). Thus, a total of about 8 km of transport pipeline would be needed to connect to steel mill to the existing olefin pipeline network. In turn, an olefin-to-epoxide oxidation facility is necessary to convert the olefins to epoxides.

Table 11: *Steel mills in the Duisburg/Essen region and their CO/CO_2 emissions*

Steel Mills	CO emissions	Potential CO-based polyol capacity	CO_2 emissions	Potential CO_2-based polyol capacity
Hüttenwerke Krupp Mannesmann GmbH	185.0 kt/a	685 kt/a	5,130 kt/a	36,643 kt/a
thyssenkrupp Steel Europe AG Werk Schwelgern	117.0 kt/a	433 kt/a	4,690 kt/a	33,500 kt/a
thyssenkrupp Steel Europe AG Werk Beeckerwerth	7.3 kt/a	27 kt/a	889 kt/a	6,350 kt/a
thyssenkrupp Steel Europe AG Werk Hamborn	4.4 kt/a	16 kt/a	1,320 kt/a	9,428 kt/a
thyssenkrupp Steel Europe AG Werk Bruckhausen	3.9 kt/a	14 kt/a	516 kt/a	3,686 kt/a
ArcelorMittal Ruhrort GmbH Werk Ruhrort	0.6 kt/a	2 kt/a	258 kt/a	1,843 kt/a
Total	318 kt/a	1,177 kt/a	12,803 kt/a	91,450 kt/a

Steel mills in the Amsterdam region

In the region of Amsterdam only one steel manufacturing plant, i.e., the Tata Steel IJmuiden BV, can be found. It can provide a potential CO-based polyol production capacity of more than 180 kt/a (Table 12). The nearest olefin source is located at the Port of Amsterdam at about 25 km distance. Again, an olefin-to-epoxide oxidation facility is necessary to convert the olefins to epoxides.

Table 12: *Steel mills in the Amsterdam region and their CO/CO_2 emissions*

Steel Mills	CO emissions	Potential CO-based polyol capacity	CO_2 emissions	Potential CO_2-based polyol capacity
Tata Steel IJmuiden BV	50.8 kt/a	188 kt/a	6,930 kt/a	49,500 kt/a
Total	50.8 kt/a	188 kt/a	6,930 kt/a	49,500 kt/a

Steel mills in the Hall region

In the region of Hall only one steel manufacturing plant, i.e., the Scunthorpe Integrated Iron and Steel Works, can be found. It can provide a potential CO-based polyol production capacity of about 250 kt/a (Table 13). The nearest olefin source is located at Saltend Chemicals Parks at about 32 km distance. Again, an olefin-to-epoxide oxidation facility is necessary to convert the olefins to epoxides.

Table 13: *Steel mills in the Hall region and their CO/CO_2 emissions*

Steel Mills	CO emissions	Potential CO-based polyol capacity	CO_2 emissions	Potential CO_2-based polyol capacity
Scunthorpe Integrated Iron And Steel Works	68.0 kt/a	252 kt/a	4,960 kt/a	35,429 kt/a
Total	68.0 kt/a	252 kt/a	4,960 kt/a	35,429 kt/a

5. Conclusion

This deliverable helps potential stakeholders go through the second step of the project development process. After using the mapping and visualisation tool, developers can:

- Use the hard criteria explained in this work to refine their region selection,
- Consider the semi-hard criteria to further qualify the viability of their projects on a regional basis by combining European and local support mechanisms with the hindering or supporting regulations, and
- Refer to the soft criteria outlined to build a better understanding or their regional context in physical and societal terms.

Working through the hard criteria that would produce the main conditions for replication, we elaborated three scenarios for illustration and evaluation.

Scenario 1

Scenario 1 describes the ideal 'sweet spot' with respect to the need of the deployment of the Carbon4PUR technology. It meets all preconditions and thresholds as set by the Carbon4PUR consortium. Gas purification procedures developed for steel mill exhaust gases within Carbon4PUR can be applied, since the emissions are from the ArcelorMittal steel mill. The nominal annual polyol production capacity at the Port of Marseille is 277 kt/a.

However, this scenario with the threshold set for the given preconditions identifies the Port of Marseille-Fos as the only feasible location. Since this appears unrealistic and detrimental regarding a broader replication, the hard criteria have been slightly loosened to allow the assessment of other locations. The following scenarios 2 and 3 build on these loosened thresholds.

Scenario 2

In scenario 2, the total annual production capacity was reduced to 4-5 kt/a of CO-based polyol. This approach was chosen because the emitted CO amount represents only a small portion of the actually available amount, while the main portion of the generated CO is burned to CO_2 in order to use the generated heat of combustion. Thus, we can expect an internal, unreported CO availability that is 10 to15 times higher than the data in the E-PRTR. Consequently, the initially desired annual polyol production capacity appears to be achievable. However, a shortcoming in this scenario is that none of the CO emitters are steel manufacturers. Therefore, the purification process may need some adaption.

Five locations, including Marseille (scenario 1), were identified. Besides the Port of Marseille, the most attractive location in this scenario is the Port of Antwerp, since the polyol plant is a Covestro site. The nominal annual polyol production capacity at the Antwerp site is 4.9 kt/a. Taking the aforementioned consideration about internal CO availability into account, a realistic annual polyol production capacity of 49-73.5 kt/a can be estimated.

If technology licensing or a similar cooperation will be agreed upon, then also the other three locations, i.e., Puertollano (Repsol polyol plant), Rotterdam (Huntsman polyol plant and Shell polyol plant) and Terneuzen (DOW Benelux polyol plant), are feasible.

Interestingly, the region of Terneuzen has the lowest production potential for both CO- and CO_2-based polyols within this scenario with a nominal annual polyol production of 2.7 kt/a. However, in scenario 3, where the selection criteria have been changed, it is observed that the Terneuzen region is basically as attractive as the Port of Marseille.

Scenario 3

For scenario 3, the selection was made in view of the fact, that the Carbon4PUR polyol production shall be constructed as an add-on to a steel mill, i.e., the place where the CO/CO_2 waste gases emerge. Thus, the transport of these gases can be avoided. On the other hand the epoxide availability was set as non-mandatory. However, at least an olefin source (chemical site or olefin pipeline) had to be near the steel mill. The distance between the CO source and the olefin source was allowed to be up to 30 km. With these inclusion criteria, five European regions have been identified to be feasible replication sites. These regions are:

- The Port of Marseille, which has already been identified in scenario 1 and 2. This location is for sure the most attractive option from the point of view of the Carbon4PUR project partners, as all considerations and studies are focussed on this location, where the industrial partners are co-located. The nominal annual polyol production capacity can be more than 5-fold (277 kt/a) compared to the intended capacity. Both CO/CO_2 gas streams and the needed epoxides are available and there is no need to construct an olefin-to-epoxide oxidation plant.

- The ArcelorMittal steel mill in the region of Zeeland (Terneuzen/Gent) has a nominal annual polyol production capacity, which is about 25% higher than the ArcelorMittal FOS steel mill at the Port of Marseille. However the distance to the next epoxide source, i.e., DOW Benelux N.V., is about 18 km.
- The Duisburg/Essen region has the highest nominal annual polyol production capacity of 685 kt/a and 433 kt/a with emissions from Hüttenwerke Krupp Mannesmann GmbH and thyssenkrupp Steel Europe AG Werk Schwelgern, respectively. However, the epoxides are only available at a distance of about 45 km, where the Covestro Deutschland AG polyol plant is located. On the other hand, olefins would be available at shorter distance (5-20 km) from the nearby pipelines. However, this would require the construction of an olefin-to-epoxide oxidation plant.
- The regions of Amsterdam and Hall are ranked at the lowest within this scenario, as the distance between CO and olefin source are 25 km and 32 km, respectively. As there are no epoxide sources in the near vicinity, the construction of an olefin-to-epoxide oxidation plant would be necessary.

Scenarios 2 and 3 are hard to rank against each other. On the one hand, scenario 2 has selected only sites where the epoxides are already available. Thus, the construction of an olefin-to-epoxide oxidation plant can be avoided keeping the investment costs at a lower level. On the other hand, scenario 3, where the Carbon4PUR polyol production site shall be constructed at a steel mill, shows the enormous potential towards polyol production capacities, which are 35 to 135 times higher than in scenario 2. The drawback, however, is the highly increased capital expenditures, in some cases, due to the need of several kilometres of olefin pipeline and the necessity to construct an olefin oxidation plant. The final decision must be made using a techno-economic analysis to assess the breakeven point and the payback period of each project. Therefore, the gas treatment and purification methods must be considered as well as a cost evaluation for epoxide transport and storage versus the transport of the exhaust gases CO and CO_2. Further, the operational costs for the infrastructure maintenance must be taken into account.

Further, comparing scenario 2 and 3 we conclude that it is worth considering to allow a higher distance (20-30 km) between the CO/CO_2 source and the epoxide/olefin source, as we could show that the Terneuzen region is unattractive within scenario 2 (10 km catchment area, potential capacity = 4.4 kt/a), wheras in scenario 3 it becomes highly attractive (20 km catchment area, potential capacity = 350 kt/a).

Further considerations

This document describes a first selection of attractive locations for the replication of the Carbon4PUR technology. However, besides the technical preconditions which must be met, a number of other factors will influence the final choice of a location for the replication. A critical issue is the transport infrastructure. Questions to be answered for each and every location are for example, if local authorities will allow the transport of CO and CO_2 near to populated areas, i.e., outside of chemical parks, or what the best polyols transport method would be. Such health and safety regulations and policies must be thoroughly assessed as these could otherwise produce significant hidden costs or hinder the project from obtaining an operating permission.

Further, the final choice will be strongly influenced by the semi-hard criteria, which can act as enabler for the deployment. These include mainly funding and tenders at regional, national and European level. Semi-hard criteria have been highlighted and sources of support to achieve a good outcome in fulfilling them have been described in section 3.3. Based on scenario work using hard criteria to identify locations with material potential, we provided a summary of results from the exemplary regions of Flanders and Provence-Alpes-Côte d'Azur using the Regional Innovation Monitor of the European Commission to illustrate characteristics such as the availability of business coordination institutions.

Project developers should consider the significance of public acceptance as a driver for the Carbon4PUR replication and acceleration. Carbon4PUR will explore the perception and acceptance of insulation boards as CO/CO_2-Carbon4PUR product, in relevant stakeholder groups in order to get insights into the societal readiness towards a CO/CO_2-derived product case and communicative requirements for a market introduction. RWTH will act as the main leader of this task delivering the $PACO_2$ - Perception, acceptance and communication concepts for a CO/CO_2-derived product in Carbon4PUR report, due September 2020.

By combining the application of the hard criteria according to project needs, detailed exploration of the support sources indicated, using the Regional Innovation Monitor for the identified regions, and by considering the findings of the forthcoming $PACO_2$ study, developers and investors will be in a good position to start their due diligence in a highly targeted way only in the most promising locations for replication.

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