Demonstrating sustainable value creation from industrial CO_2 by its thermophilic microbial conversion into acetone

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D6.13 – AURA CCU HUB ROADMAP AND PRELIMINARY INVESTMENT PLAN

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Responsible Author(s)	Angélique JALLAIS		
Contributor(s)	Angélique JALLAIS, Chérif MORCOS		
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LIST OF ABBREVIATIONS

Abbreviation	Description
ADEME	Agence de la transition écologique
AURA	Auvergne Rhône-Alpes
CBAM	Carbon Border Adjustment Mechanism
CCfD	Contracts for Difference
CCU	Carbon Capture and Utilization
CCS	Carbon Capture and Storage
CCUS	Carbon Capture, Utilization, and Storage
CCU HUB	A CCU hub takes carbon dioxide from several different emitters, transports and utilize it to produce new products, using common infrastructure
CEF	Connecting Europe Facility
CSF-NSE	Strategic Committee – New Energetic Systems
DACC	Direct Air Carbon Capture
DECLYC	DECarboner LYon vallée de la Chimie
EUAs	Emission allowances
EU ETS	European Union Emission Trading System
GHG	GreenHouse Gaz
GPID	Grands Projets Industriels de Décarbonation 2024
IPCC	Intergovernmental Panel on Climate Change
NZIA	Net-Zero Industry Act
PCI	Projects of Common Interest
PEPR	Priority Research Programmes and Equipment
PtG	Power-To-Gas
PtL	Power-to-Liquid
PtX	Power-to-X
SME	Small and Medium-Sized Enterprises
SNBC	French government National Low-Carbon Strategy
TRL	Technology Readiness Levels
ZIBAC	Zones Industrielles Bas Carbone

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FOREWORD

AXELERA is a French cluster that supports chemical and environmental companies, as well as research centers, in their innovation processes and business development. By the end of 2023, it has approximately 400 members. Regarding the PYROCO$_2$ project, AXELERA is involved in Task 6.3, titled "Derisking and Market Readiness in 4 Emerging CCU Hubs for Replication."

The present deliverable “AURA CCU Hub Roadmap and preliminary Investment Plan” aims to elaborate the roadmap for the emergence of a CCU hub in AURA region. This document is related to the deliverable D6.12 detailing the “Replication strategy: process and tools for facilitating the emergence of local CCU hubs” and the deliverable D6.14 “Toolbox for the facilitation of emergence of CCU hubs”. These deliverables aim to create a straightforward and comprehensible methodology, assisting European clusters in systematically and efficiently establishing their CCU Hubs. By doing so, they facilitate the growth of CCU projects, ultimately contributing to the reduction of CO_2 emissions.

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1. CONTEXT

To achieve climate neutrality by 2050, there must be a swift transition towards adopting innovative, climate-friendly solutions that can stimulate growth in the European market. Newly emerging methods such as Carbon Capture, Utilization, and Storage (CCUS) hold significant promises for reducing carbon emissions in the chemical industry, while also enabling value creation from carbon emissions.

The PYROCO$_2$ project aims to showcase the scalability and economic feasibility of Carbon Capture and Utilization (CCU) to produce environmentally beneficial acetone from industrial CO_2 and hydrogen generated from renewable electricity. Central to this technology is an energy-efficient microbial bioprocess, projected to reduce CO_2 emissions by 17 million tons by 2050. The acetone produced through the PYROCO$_2$ process is envisioned as a versatile platform for catalyzing the synthesis of various chemicals, synthetic fuels, and recyclable polymer materials from CO_2. This initiative aims to establish a repertoire of viable business models and pre-established processes for replication and commercialization.

1.1 ABOUT CCUS

Carbon Capture, Utilization, and Storage refers to a set of technologies aimed at capturing carbon dioxide (CO_2) emissions, typically from industrial sites:

- To inject and store CO_2 in suitable geological formations, thus preventing it from being released into the atmosphere.
- To use it as a resource in the production of goods.

These technologies are essential for decarbonizing activities where no low-carbon alternatives exist in the medium term. This is especially true for many industrial emissions directly linked to the processes used (cement production, lime production, chemical industries, metallurgy, etc.), which cannot be reduced simply by transitioning away from fossil fuels.

At both global and European levels, CCUS is recognized as a crucial tool for achieving carbon neutrality. According to the Intergovernmental Panel on Climate Change (IPCC), Carbon Capture and Storage (CCS) is seen as a credible solution for reducing emissions from large industrial or energy systems reliant on fossil fuels. This assessment is based on scenarios that lead to net-zero CO_2 emissions globally, a key condition for stabilizing global warming. The IPCC also notes that the current deployment of CCUS technologies is significantly behind the pace required to meet the goal of limiting warming to below 2°C[1]. The International Energy Agency estimates that CCUS could contribute to about a 10% reduction in global greenhouse gas emissions by 2050. Furthermore, the importance of CCUS in combating climate change was solidified during the COP28 summit in Dubai in December 2023.

[1] Haut Conseil pour le Climat, Avis sur la stratégie de capture du carbone, son utilisation et son stockage – Novembre 2023

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In Europe, the "Net-Zero Industry Act" (NZIA) identifies CCUS as a strategic pillar for reaching carbon neutrality by 2050, alongside hydrogen, renewable energy, and nuclear power. The framework outlines the development of an annual CO_2 storage capacity of 50 million tons within the European Union by 2030, with mandatory contributions from hydrocarbon producers to help meet these goals.

Additionally, on February 6, 2024, the European Commission released the first version of its industrial carbon management strategy[2]. This strategy focuses on increasing storage capacity, expanding transportation networks, and leveraging existing financial instruments to support the development of CCUS projects, aligned with the target of achieving climate neutrality by 2050. The European Commission projects CO_2 capture volumes could reach 280 million tons by 2040 and 450 million tons by 2050. These targets include negative emissions, emissions reductions, and CO_2 utilization.

A brief description of the different building blocks of a CCUS value chain is given in the following paragraphs.

1.1.1 Carbon Capture

Various carbon capture technologies can be used across a range of processes that emit carbon dioxide, including power generation, cement production, iron and steel manufacturing, waste-to-energy facilities, low-carbon hydrogen production, and various industrial processes. The extraction of CO_2 from these processes can be achieved through chemical or physical methods, as well as through selective membranes for physical separation.

When CO_2 is separated from a source that includes biogenic origins and is then stored permanently, carbon dioxide removal (CDR) is achieved (such as Bio-CCS/BECCS, Waste-to-Energy with CCS, etc.). Another emerging CDR technology is Direct Air Capture (DAC), where CO_2 is extracted directly from the atmosphere. Various other capture methods, including absorption by liquid solvents, adsorption by solid sorbents, oxycombustion, membranes, solid looping, low-temperature separation, among others, have been tested at pilot scale in numerous national and European research initiatives. Among these, absorption by liquid solvents stands out as the most developed and commercially available technology at large scale.

1.1.2 Carbon storage

Secure and enduring storage of CO_2 is accomplished through deep underground repositories, utilizing natural mechanisms akin to those responsible for the trapping of oil and gas over millions of years. Geological formations such as oil and gas fields and deep saline aquifers exhibit similar characteristics required for CO_2 storage: a permeable rock layer to contain the CO_2 and upper layers of impermeable cap rock that seal the underlying porous layer, effectively trapping the CO_2. The European Directive concerning the geological storage of CO_2 establishes a regulatory framework enabling storage operators to validate the permanent and safe storage of CO_2 deep underground. Numerous projects worldwide have demonstrated the safety, technical feasibility, and cost-effectiveness of CO_2 storage, with the Norwegian Sleipner project standing out

[2] EUR-Lex 52024DC0062

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as one of the longest-running initiatives globally. Presently, a range of European storage sites are being assessed and developed, forming a pipeline of storage locations that will facilitate the establishment of initial CO_2 capture and transportation networks. Nevertheless, a greater number of storage sites will be required across various regions to enable Europe to attain its climate mitigation objectives.

1.1.3 CO_2 Transportation

CO_2 transportation primarily relies on pipelines, although alternative modes such as shipping, rail, or road transport are becoming increasingly significant. Establishing a shared CO_2 transport infrastructure to link industrial clusters with storage sites is pivotal for realizing economies of scale at regional, national, and European levels. To achieve decarbonization goals throughout the EU, it will also be essential to expand the implementation of CCS and CCU technologies to encompass small and stranded emitters that may not have direct access to pipeline transportation networks. The transition from individual point-to-point solutions to the establishment of hubs and clusters, where CO_2 infrastructure is utilized collectively by various emitters, is crucial for the advancement of CO_2 networks.

1.1.4 CO_2 Utilization

Utilization involves employing captured CO_2 in industrial processes or products. CCU technologies play a crucial role in producing everyday items derived from CO_2, including building materials, synthetic fuels, chemicals, plastics, and for horticultural purposes. By doing so, CCU has the potential to supplant existing products, reduce dependence on fossil fuels, and facilitate the transition to a carbon circular economy. Similar to other environmental technologies, conducting full lifecycle analyses is essential to ascertain the climate benefits of each CCU application, and such analyses are increasingly becoming available in certain areas. The commercialization of CCU technologies is in its nascent stages, with numerous ongoing and planned projects expected to reach industrial scale within the next five years.

1.2 FOCUS ON CCU

1.2.1 Valorisation of CO_2 for decarbonizing Air and Sea transports

CO_2 can be used in the production of molecules that serve as the base for fuels in the maritime and aviation sectors. At the European level, the FuelEU Maritime and ReFuelEU Aviation regulations set targets for incorporating sustainable alternative fuels in these industries. Additionally, the Renewable Energy Directive establishes goals for renewable energy use across the entire transport sector. The amount of CO_2 utilized for these purposes will depend on the evolving economic balance, but the decarbonization needs of air and maritime transport are likely to stimulate the development of a production sector in France.

However, caution is necessary to ensure these efforts align with climate goals. The production of e-fuels is associated with significant electricity consumption, projected to require over 100 TWh of electricity by 2050. Most of this will be for the hydrogen production required, with a smaller portion tied to CO_2 capture. Moreover, the CO_2 used in e-fuel synthesis is re-released during fuel consumption. Therefore, the French government aims to prioritize the use of biogenic CO_2 and CO_2 removed from the air for e-fuel production (with the latter to be deployed later). Ultimately, other CO_2 sources will be phased out for these purposes.

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1.2.2 CO_2 as a feedstock for chemical production

CO_2 can also be used as a raw material to produce various intermediate chemicals, such as ethylene, propylene, and methanol. These intermediates can then be converted into more complex products essential to the petrochemical industry. In the long term, these products could potentially replace current petrochemical-based materials. However, they will require significant support in terms of research, development, and industrial scaling, given the currently high costs associated with these processes, as well as their energy and water consumption.

1.2.3 CO_2 long-term sequestration in materials

CO_2 can be utilized and sustainably sequestered within materials, where it is considered to be trapped over an extended period. This process is often referred to as the "sequestering use" of CO_2, with one notable example being the carbonation of concrete.

1.2.4 Direct injection of CO_2 into products

The direct use of CO_2 is already established in various industrial processes, where it serves as an input for applications such as solvents and paint stripping, as well as in greenhouses and the food industry. However, the French market, currently around 800 ktCO_2 per year, remains relatively small and does not effectively contribute to decarbonization, as the CO_2 is typically released back into the atmosphere.

1.3 GENERAL CONCEPT OF A HUB

The local industrial landscape of a CCU hub would include factories emitting CO_2, some of which can potentially purify it for further catalytic conversion. Regional factories may utilize derivatives of CO_2 produced, e.g., by the PYROCO_2 demonstrator or a derived full-scale production plant, while others could adopt the project's catalytic solutions or feed on their residues (e.g. cell mass). Additionally, local factories might employ CO_2 for non-competitive processes like mineralization. The area also would feature existing and emerging capacity for green H_2 production, crucial for many CO_2 applications. These hubs should serve as pivotal points for either gathering CO_2 from multiple sources or distributing it to various clusters. At a storage hub, CO_2 collected from different sources is commonly injected. Hubs may be situated either at the capture point or the storage point of a pipeline serving multiple users, or potentially at both ends of the storage system.

Hubs serve as strategies to encourage the utilization of communal facilities and streamline the expansion of CCUS initiatives. One primary benefit is cost efficiency, where involved parties can lessen initial infrastructure expenses by tapping into the advantages of linking economical industrial sources with storage locations. Moreover, by sharing infrastructure, both investment and operational costs can be dispersed, resulting in a considerable reduction in the cost per unit of CO_2 transported. This reduction in costs helps mitigate entry barriers for CCS/CCU/S projects. The second advantage lies in ensuring stable operational activities.

1.4 HUBS IN ACTION

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Nationally Determined Contributions are voluntary commitments made under the Paris Agreement to combat climate change. They outline emissions reduction goals for 2030 along with strategies to achieve them. Up to now, 21 Countries, including the European Union as a single entity, have incorporated CCUS as a specific tool for decarbonization within their NDCs.

Figure 1 shows geographical points with detailed listing of the CCUS hubs worldwide, currently in development or established. The majority of these hubs will be established near industrial conglomerates where the sources of emissions are in proximity, such as the East Coast Cluster or the Junggar Basin in China. However, some will be dispersed geographically, amassing emission sources via pipelines or ships, like the Northern Lights project in Norway and a range of forthcoming hubs in the Asia-Pacific area.

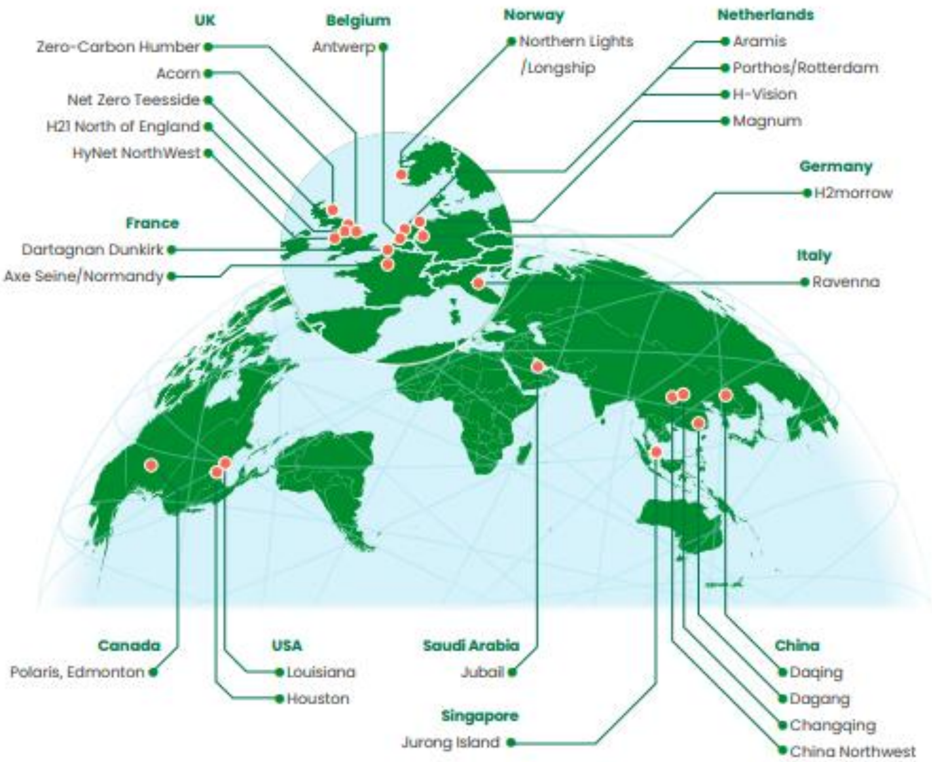

Figure 1 : Geographical points of CCUS hubs worldwide.

There are several factors that drive the development of a CCUS hub, as an example, the Norwegian hub Northern Lights, which is the most advanced hub benefits from these factors:

- There is a strong belief in the existence and usability of carbon storage, thanks to prior work on CCUS and the participation of companies with expertise in subsurface and transportation. The Northern Lights/Longship project in Norway is a prime example of this. It has capitalized on the lessons learned from over two decades of experience in storing carbon dioxide under the North Sea. This extensive experience has not only proven the feasibility of carbon storage but also contributed to the refinement of techniques and strategies, enhancing the efficiency and effectiveness of CCUS operations.

- Support at both the national and regional levels is crucial to encourage the substantial, high-risk capital investments that are initially needed. This backing can help mitigate the risks associated with these investments and pave the way for advancements in sectors such as renewable energy, infrastructure, and technology.
- The comprehension of the value proposition of CCUS hubs by a consortium of stakeholders engaged in knowledge creation and advocacy is crucial. This understanding aids in streamlining the process and fostering a more expansive ecosystem. These stakeholders play a pivotal role in promoting the benefits of hubs, thereby encouraging more widespread acceptance and implementation. Their efforts can help overcome barriers, drive policy changes, and facilitate the growth of this vital technology. For instance, in Norway, both the government and industry have gleaned valuable lessons from unsuccessful attempts to establish CCUS facilities in the 1990s. These experiences have fostered a productive collaboration between the two entities, demonstrating the importance of learning from past failures to drive future success. This collaborative approach has been instrumental in advancing CCUS technology and its implementation.

The North-CCU-Hub, comprising over 20 partners from diverse sectors such as steel, chemistry, energy, dredging, logistics, as well as knowledge institutes, and local/regional governmental agencies (including city, province, port authority, and innovation clusters), is a collaborative effort aimed at developing a CCU strategy for the North Sea Port region spanning Belgium and the Netherlands. The primary objective of this consortium is to establish sustainable value chains based on CCU principles, fostering a local green economy through industrial symbiosis. Their inaugural endeavor, the North-C-Methanol project, seeks to produce 46,000 tonnes of green methanol for local consumption. This will be achieved through the synthesis of local CO_2 and green hydrogen, generated by renewable energy sources in a newly constructed 65 MW electrolyser plant. Furthermore, by-products such as oxygen and heat will be locally utilized. Looking ahead, the North-CCU-Hub intends to expand the North-C-Methanol project, enhancing capacities and broadening the range of products offered.

1.5 CHALLENGES IDENTIFIED

As we delve into the realm of CCUS hubs in Europe, it’s crucial to acknowledge the inherent challenges, complexities, and drawbacks. These hubs, while promising, are not without their hurdles. From technical and financial obstacles to regulatory and public acceptance issues, the path to successful CCUS implementation is fraught with challenges:

- Technical Challenges: CCUS technology is still in its developmental stages and faces several technical challenges. These include the efficiency and scalability of capture technologies, the transportation of captured carbon, and the long-term storage and monitoring of sequestered carbon.

- High Initial Costs: The initial investment required for CCUS technology is substantial. Building the necessary infrastructure for capture, transport, and storage is capital-intensive, which can be a significant barrier to entry.
- Regulatory and Legal Issues: There are numerous regulatory and legal issues to navigate, including ownership rights for stored carbon and liability for any leaks that may occur. These issues need to be clearly addressed to provide certainty for investors. Also, aspects related to the utilization of captured CO_2 are not yet fully covered by legislation. Regulations for certain CCU-derived products (synthetic fuels, building materials) are under development.
- Public Acceptance: Public acceptance of CCUS technology is mixed. While some see it as a necessary tool in the fight against climate change, others have concerns about the potential risks, such as leaks from storage sites.
- Increasing Energy Prices: Rising energy costs could pose a potential challenge considering the high energy demand of CCUS technology. Thus, this issue extends beyond CCUS and similarly impacts other sectors, including AI, heavy industry electrification, and battery production, where energy efficiency is crucial for controlling costs and maintaining competitiveness.
- Market Conditions: Without a strong market for captured carbon or a high price on carbon emissions, there may be limited economic incentive for companies to invest in CCUS technology.
- Geographical Limitations: Not all regions are suitable for carbon storage. Suitable geology is required, and some populated areas may be unsuitable due to the potential risks involved.

In conclusion, while CCUS hubs hold great promise for reducing greenhouse gas emissions, they also face significant challenges. Overcoming these will require concerted effort from policymakers, industry, and society at large. It's a complex issue, but with the right approach, these challenges can be addressed, paving the way for a more sustainable future.

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2. POLICIES AND LEGISLATIONS

In 2024, the policies and legislation regarding carbon capture and utilization as well as carbon capture and storage are evolving rapidly at both the European and French levels. As seen previously, these technologies are seen as crucial to achieving the carbon neutrality goals set for 2050 by both the European Union and France.

2.1 EUROPE

Several European regulations have already been introduced concerning CCUS. For instance, the European Union's Emissions Trading System already allows for the use of carbon storage. More recently, the European Commission has proposed the Net Zero Industry Act, which recognizes CCUS as one of the key technologies necessary to meet Europe's climate ambitions. Additionally, the Commission has outlined a carbon management strategy for industry, providing guidance on the actions it plans to take in the coming years on this front.

2.1.1 Europe Emissions Trading System (EU-ETS)

The EU Emissions Trading System (EU ETS) was implemented on January 1, 2005. It was the first major carbon market in the world and was established as a key component of the European Union's strategy to reduce greenhouse gas emissions and combat climate change. The EU Emissions Trading System is a cap-and-trade system designed to reduce greenhouse gas emissions in the European Union, relaying on:

- Cap Setting: A limit is set on the total amount of greenhouse gases that can be emitted by all participating installations. This cap is reduced over time to decrease overall emissions.
- Allocation of Allowances: Emission allowances (EUAs) are distributed to companies either through free allocation or auctioning. Each allowance allows the holder to emit one metric ton of CO_2 equivalent.
- Monitoring and Reporting: Companies must monitor and report their emissions accurately. This ensures transparency and compliance with the regulations.
- Trading: Companies can buy and sell allowances in a carbon market. If a company reduces its emissions below its allocated amount, it can sell its surplus allowances to others that are exceeding their limits.
- Compliance: At the end of each compliance period (usually annually), companies must surrender enough allowances to cover their emissions. If they fail to do so, they face significant financial penalties.
- Market Dynamics: The market for EUAs fluctuates based on supply and demand. Factors influencing this include changes in regulatory frameworks, technological advancements, and market sentiment regarding climate policies.

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Under the EU Emissions Trading System, captured CO_2 intended for utilization is treated as emitted at the industrial site. Consequently, companies do not receive any exemptions from the obligation to surrender carbon quotas if they choose to utilize the captured CO_2. The benefit of emission reductions is allocated to the sector that utilizes the product manufactured from the captured CO_2. For what is referred to as "sequestering" carbon capture and utilization, the EU-ETS directive stipulates that the emission reduction achieved through the utilization of CO_2 is only effective for the industrial entity if the CO_2 is transferred from the emitting facility to another site, where it is "chemically bound in a permanent manner to a product, ensuring it does not enter the atmosphere under normal usage conditions." A delegated act is currently being developed at the European level to clarify this aspect, expected to be published in the third quarter of 2024.

The anticipated review of the EU-ETS framework in 2026 may lead to updates in the accounting framework for CCU, particularly for products with a medium lifespan (several decades), while avoiding double counting. The European Commission has already mentioned potential modifications to these incentives in its communication regarding the strategy for industrial carbon management, and France will advocate for such changes.

2.1.2 Regulatory Framework for CCUS

Europe has already implemented various regulations that oversee CCU and CCS activities, in particular:

- Directive on the Geological Storage of CO_2 (2009/31/EC)[3]: This directive sets the rules for CO_2 capture, transport, and storage in the EU, particularly for safe geological storage. It imposes strict rules on site assessments, long-term monitoring, and liability in case of CO_2 leakage.
- Trans-European Energy Networks Regulation[4]: CCS is considered a priority for energy infrastructure. The regulation helps identify and support Projects of Common Interest (PCI), which are essential for the transport and storage of CO_2.
- EU Taxonomy for Sustainable Activities[5]: In 2024, CCS projects and certain CCU projects are eligible for green financing under the EU taxonomy. The taxonomy is a classification system that defines criteria for economic activities that are aligned with a net zero trajectory by 2050 and the broader environmental goals other than climate. It helps direct investments to the economic activities most needed for the transition, in line with the European Green Deal objectives.

2.1.3 The European Green Deal

The European Green Deal was proposed by the European Commission on December 11, 2019. It aims to make Europe the first climate-neutral continent by 2050 and includes various initiatives and regulations to address climate change and promote sustainability across different sectors. The deal encompasses a wide range of

3 EU-Lex 2009/31/EC
4 EU-Lex 32022R0869
5 EU taxonomy navigator

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policies and actions, with ongoing developments and implementation steps taking place since its announcement. CCU and CCS technologies play a key role in this strategy, particularly to decarbonize industries that are hard to electrify (cement, steel, chemicals).

2.1.4 Carbon Border Adjustment Mechanism (CBAM)

The Carbon Border Adjustment Mechanism (CBAM)[6] is a proposed regulatory framework by the European Union aimed at addressing carbon leakage and ensuring that European industries remain competitive while pursuing climate goals. CBAM is designed to level the playing field between EU producers, who must comply with strict carbon emissions regulations, and foreign producers from countries with less stringent climate policies. The mechanism aims to prevent carbon leakage, which occurs when companies relocate production to countries with lower environmental standards. Under CBAM, importers of certain goods (such as steel, cement, and electricity) into the EU will be required to pay a carbon adjustment fee. This fee is calculated based on the carbon content of the imported goods, effectively aligning the costs of carbon emissions for both EU and non-EU producers.

CBAM is being implemented gradually. The European Commission proposed the mechanism in July 2021, and the regulation is expected to come into full effect by 2026. It will initially cover a limited number of sectors and gradually expand its scope. Importers will need to report the emissions associated with their products, and they may be required to buy carbon certificates corresponding to the emissions linked to their goods. The revenue generated from CBAM is intended to support the EU's climate initiatives. The mechanism has raised concerns and discussions internationally, as it could affect trade relations and global supply chains. The EU aims to encourage other countries to adopt more ambitious climate policies while protecting its own industries. Overall, CBAM is a key component of the EU's strategy to achieve climate neutrality by 2050 and to ensure that the transition to a low-carbon economy is fair and equitable for European industries.

2.1.5 Fit for 55

"Fit for 55" is a comprehensive package of legislative proposals introduced by the European Commission in July 2021 as part of the EU's climate strategy. The main goal of this initiative is to help the EU achieve its target of reducing greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. The package includes various measures aimed at promoting sustainability and ensuring that the EU is on track to reach its long-term climate goals, particularly the goal of becoming climate-neutral by 2050.

2.2 FRANCE

2.2.1 National Low-Carbon Strategy (SNBC)

Introduced by the Energy Transition Law for Green Growth, the National Low-Carbon Strategy (SNBC) is France's roadmap for combating climate change. It provides guidelines for implementing the transition to a low-carbon, circular, and sustainable economy across all sectors. It outlines a pathway for reducing

[6] EC Website - CBAM

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greenhouse gas emissions until 2050 and sets short- and medium-term goals: the carbon budgets. It has two main ambitions: achieving carbon neutrality by 2050 and reducing the carbon footprint of French consumption.

First adopted in 2015, the SNBC was revised in 2018-2019 with the aim of achieving carbon neutrality by 2050 (a more ambitious target compared to the first SNBC, which aimed for a Factor 4 reduction, meaning a 75% reduction in GHG emissions by 2050 compared to 1990). This revised SNBC draft was subject to public consultation from January 20 to February 19, 2020. The new version of the SNBC and the carbon budgets for the periods 2019-2023, 2024-2028, and 2029-2033 were adopted by decree on April 21, 2020.

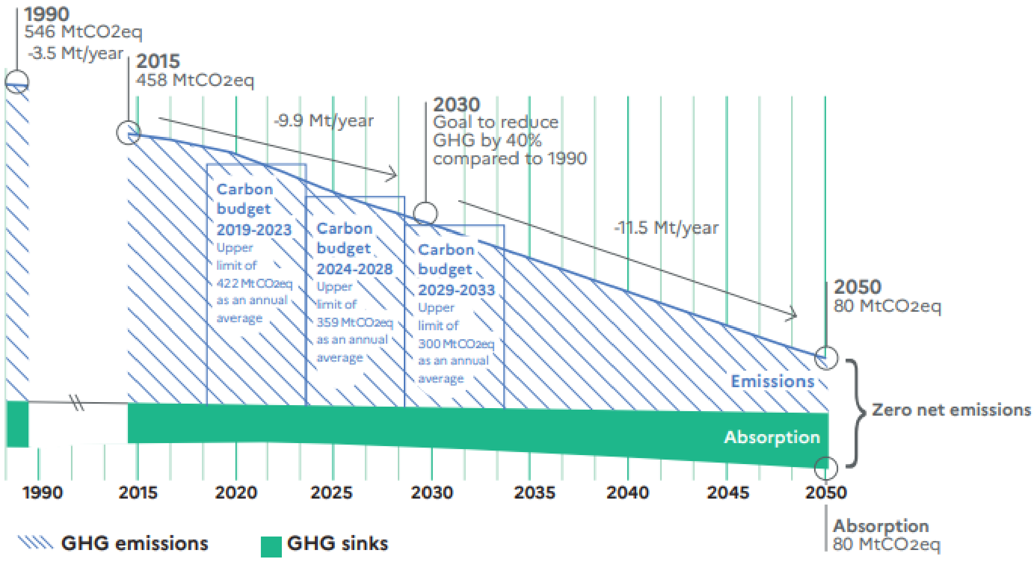

Figure 2: Evolution of GHG emissions on French territory between 1990 and 2050 in MtCO2eq. (CITEPA 2018 inventory and revised SNBC scenario)

To comply with the European environmental ambition, France has established a new target in its National Low-Carbon Strategy 2 (SNBC 2) to reduce industrial GHG emissions by 35% by 2030 compared to 2015 levels, and by 81% by 2050. These targets will be raised to align with the "Fit for 55", as specified in the National Integrated Energy and Climate Plan submitted by France to the European Commission in November 2023. This preparatory document for SNBC 3 indicates a target of a 46% reduction in industrial GHG emissions between 2015 and 2030.

2.2.2 Contracts for Difference (CCfD)

The SNBC proposes a support regime via Contracts for Difference (CCfD), which are a policy mechanism used to promote low-carbon technologies by guaranteeing a stable revenue stream for projects that reduce carbon emissions. These contracts will bolster decarbonization projects, including carbon capture and sequestration initiatives identified through the 50-site exercise. CCfDs are designed to encourage the deployment of low-carbon industrial projects, such as renewable energy or low-emission manufacturing technologies, by reducing the risks related to fluctuating carbon prices. The objective is to bridge the gap

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between high-carbon and low-carbon alternatives by offering financial incentives that make green projects more competitive.

In practical terms, the French government sets a fixed "strike price" for the carbon emissions reductions achieved by the project. This strike price represents the cost of reducing a ton of CO_2 equivalent. If the carbon price in the EU ETS (Emissions Trading System) or another carbon market is lower than the strike price, the government compensates the difference to the project developers. If the market carbon price exceeds the strike price, the project developer pays the government the difference. This mechanism guarantees revenue stability for the project and makes the economics of decarbonization projects more predictable. It encourages companies to invest in technologies like CCU, CCS), hydrogen production, and energy efficiency measures.

2.2.3 CCUS deployment trajectory[7]

France plans a phased deployment of CCUS, with initial focus on major industrial zones such as Dunkerque, Le Havre, and Fos-sur-Mer. Subsequent areas include Lacq/Southwest and Loire Estuary, followed by the Grand-Est region. The industrial emissions are strongly concentrated around these major hubs, which facilitates a regional approach to the decarbonization of industries. The distribution of emissions across these industrial clusters presents several advantages for the deployment of CCUS technologies, particularly in terms of infrastructure sharing and synergies among companies. Sites with a maritime front, such as Fos-sur-Mer, Dunkirk, Le Havre, and Saint-Nazaire, offer strategic opportunities for exporting captured CO_2 to underwater storage sites, such as saline aquifers or depleted oil and gas fields. In more inland areas, such as the Paris Basin, the Southwest, and the Grand Est, onshore storage could represent an alternative solution, especially in suitable geological formations. Moreover, the development of a large-scale CO_2 transport network, connecting several emitting sites to storage locations, could be considered in the long term, particularly if captured volumes increase sufficiently to justify investment in such infrastructure.

The deployment strategy is based on three phases:

- Phase 1 (2024-2030): The development of at least two CCUS hubs would enable the capture of 4 to 8 MtCO2 per year by 2030. The support mechanism for the deep decarbonization of industry (see 3.2.2) should lead to the emergence of between two and four hubs in the industrial-port areas of Dunkirk, Fos-sur-Mer and the Rhône axis, Le Havre, and Saint-Nazaire. These areas are particularly suitable for initial deployments due to their high concentration of large industrial emitting sites, operators of shared infrastructures (such as existing liquefaction terminals, pipelines, etc.), and maritime transport options to CO_2 storage locations mainly located in the North Sea and the Mediterranean. Considering a deployment timeframe of 3 to 5 years for CCUS chains following the investment decision, at least two hubs could be established by 2030, with the first hub potentially operational as early as 2028. The volumes of CO_2 captured per cluster range from 1.5 to 4 MtCO2 per

[7] État des lieux et perspectives de déploiement du CCUS en France – Juillet 2024

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year, allowing for the possibility, with the development of two to four CO_2 hubs, to capture 4 to 8 MtCO2 per year by 2030.

- Phase 2 (2030-2040): The development of sovereign storage and regulatory changes would enable the capture of between 12 to 20 MtCO2 per year by 2040. The revision of the EU ETS, scheduled for 2026, could accompany several major changes, including the development of an incentive framework for negative emissions resulting from the capture of biogenic emissions. Moreover, it is expected that sovereign storage, particularly onshore, will develop in France after 2030, which will (i) unlock certain industrial areas far from foreign storage, such as the Paris Basin, the Mediterranean, or the Pyrenean foothills, and (ii) reduce CCS costs. The development of new CO_2 hubs and the scaling up of existing hubs through a gradual extension of transport infrastructures in the form of CO_2 valleys would enable the capture of CO_2 volumes ranging from 12 to 20 MtCO2 per year.
- Phase 3 (2040-2050): The quantities of captured CO_2 could reach 30 to 50 Mt per year. The goal of capturing CO_2 by 2050 is more uncertain, but the ambition to capture 30 to 50 MtCO2 per year seems realistic in light of the political objective of carbon neutrality. These volumes could be achieved by considering:
    - A national and European CO_2 infrastructure network that allows for the connection of isolated emitters, particularly linking waste incineration facilities and district heating plants in major urban areas close to CO_2 valleys.
    - The development of negative emissions through the capture of CO_2 from bioenergy or directly removed from the air.
    - The establishment of new industrial sites, particularly in the biorefining sector.
    - Achieving deep decarbonization of the largest sites, in accordance with the mutual commitments of emitting industries and the state within the framework of Ecological Transition Contracts.

These numbers are initial estimates, which could evolve with the final orientations of the SNBC, particularly the assumption regarding direct air carbon capture, which is derived from the European Commission's estimates in its communication on industrial carbon management (in the range of 100-150 MtCO2 at the European level by 2050).

3. FUNDING OPPORTUNITIES

In this section, we will explore the various funding opportunities that are pivotal to the advancement of a CCUS hub and projects. Funding is a crucial aspect of CCUS projects, as it enables the necessary research, development, scale-up, and deployment of these technologies.

3.1 EUROPE

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The European Union is committed to achieving climate neutrality by 2050, and CCUS plays a pivotal role in this endeavor. To support investment in CCUS research and deployment, the EU has established several funding programs.

3.1.1 Innovation Fund

The Innovation Fund is a major European funding program aimed at supporting the demonstration of innovative technologies that help reduce greenhouse gas emissions, particularly in industries that are difficult to decarbonize. It focuses on projects that have the potential to drive the EU toward its climate neutrality goals by 2050, supporting sectors such as renewable energy, energy storage, and carbon capture and utilization or carbon capture and storage.

One of the key features of the Innovation Fund is its emphasis on scalability. It aims to fund large-scale projects that are not only technologically advanced but also commercially viable, capable of being replicated across the EU or beyond. This ensures that projects receiving support can have a wide-reaching impact, helping industries transition to more sustainable models. The fund is financed by revenues from the EU Emissions Trading System, meaning it operates within the broader context of the EU's climate policy framework. Eligible projects must demonstrate significant reductions in emissions compared to traditional technologies and should be able to prove their potential for long-term sustainability, whether through reducing costs, increasing efficiency, or offering new ways to reduce carbon output.

What makes the Innovation Fund particularly attractive to businesses and industries is its focus on risk-sharing. It provides grants that cover up to 60% of additional costs related to innovation, thereby de-risking investments in emerging technologies. This makes it a key mechanism for accelerating the deployment of technologies that might otherwise face financial hurdles in the initial stages.

Additionally, the Innovation Fund is not limited to any specific sector but rather encourages cross-sector collaboration, supporting projects in energy, heavy industries, and even agriculture. The evaluation criteria for funding are rigorous, with an emphasis on potential emission reductions, technical maturity, scalability, and cost efficiency. In essence, the Innovation Fund is designed to bridge the gap between the demonstration of innovative low-carbon technologies and their commercial deployment, aiming to foster a competitive and sustainable European industrial landscape capable of meeting the continent's ambitious climate objectives.

Currently, 26 CCUS projects, including three in France, have received funding from the Innovation Fund amounting to €3.3 billion. Among them, two French carbon capture and storage projects involve the deployment of a complete chain for capturing, transporting, and storing CO_2 from the French sites of Eqiom and Lhoist in the Dunkirk area, with storage in the North Sea, aiming for a reduction target of 1.5 MtCO2/year by 2030. Additionally, a project for the capture and utilization of CO_2 led by Elyse Energy, which utilizes CO_2 from a Lafarge cement plant to produce e-methanol, has also been selected.

3.1.2 Horizon Europe

Horizon Europe is the European Union's flagship research and innovation program, designed to drive scientific excellence, technological advancements, and sustainable solutions across various sectors. Running

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from 2021 to 2027, it builds on the success of its predecessor, Horizon 2020, but with an even stronger focus on addressing global challenges such as climate change, energy transition, health crises, and digital transformation. With a budget of over €95 billion, Horizon Europe represents one of the largest funding programs of its kind in the world.

At its core, Horizon Europe is structured to support breakthrough research and innovations that can transform industries and societies. It fosters collaboration across borders, bringing together research institutions, businesses, and public bodies to work on cutting-edge projects that push the frontiers of knowledge and technology. One of its key ambitions is to make Europe a global leader in science and innovation, positioning the EU as a competitive player in the race for technological leadership.

The program is organized into three main pillars. The first pillar, "Excellent Science," focuses on strengthening the EU's scientific base by supporting the work of top researchers and providing funding for frontier research, largely through the European Research Council. It also supports the development of new skills and knowledge through mobility grants like the Marie Skłodowska-Curie Actions, which encourage researchers to collaborate and share expertise across Europe and beyond.

The second pillar, "Global Challenges and European Industrial Competitiveness," is dedicated to tackling societal challenges and reinforcing industrial competitiveness. It promotes collaborative research projects that address pressing issues such as climate change, health, and food security. This pillar also emphasizes partnerships with industries to ensure that innovations are not just theoretical but can be implemented in real-world applications, helping to bridge the gap between research and market deployment.

The third pillar, "Innovative Europe," is aimed at fostering disruptive innovation and scaling up high-potential technologies and start-ups. It features the European Innovation Council, which provides financial and advisory support to startups and SMEs with groundbreaking ideas. This pillar helps businesses commercialize new technologies, particularly those that are high-risk but could have a transformative impact on markets and society.

Horizon Europe also prioritizes inclusivity, supporting the widening of participation and spreading excellence across all member states, particularly those with emerging research and innovation systems. Moreover, the program is aligned with the European Green Deal, ensuring that a significant portion of its funding is directed towards projects that can help Europe transition to a low-carbon, circular economy.

3.1.3 Connecting Europe Facility for Energy (CEF Energy)

The Connecting Europe Facility (CEF) is a crucial EU funding tool supporting the European Green Deal and advancing the Union's decarbonization goals for 2030 and 2050. It facilitates the development of sustainable, high-performance, and efficiently interconnected trans-European networks in transport, energy, and digital services. By investing in these areas, CEF helps to bridge gaps in Europe's energy, transport, and digital infrastructure. CEF brings benefits to citizens across all EU Member States by making travel more accessible and sustainable, strengthening Europe's energy security, promoting the use of renewable energy, and enhancing cross-border interactions between public administrations, businesses, and individuals.

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Beyond grants, CEF provides financial assistance to projects through innovative tools such as guarantees and project bonds. These instruments significantly amplify the impact of the EU budget, acting as catalysts to attract additional investment from both the private and public sectors.

3.2 FRANCE

With a strategic focus on CCUS, France aims to reduce greenhouse gas emissions and foster innovation. To support investment in CCUS research and deployment, France has established several funding programs.

3.2.1 France 2030

France 2030 is a strategic investment plan launched in 2021 by the French government aimed at transforming and modernizing the French economy over the next decade. It follows the post-covid investment plan "France relaunch". France 2030 involves a significant financial commitment, with an investment of around €30 billion. This funding is directed towards various sectors to stimulate innovation and growth. A significant focus of France 2030 is achieving the country's climate goals. This includes initiatives to reduce greenhouse gas emissions, enhance energy efficiency, and support the development of renewable energy sources.

3.2.1.1 iBac, DEMIBac and ZIBac initatives

France 2030 includes specific initiatives aimed at supporting small and medium-sized enterprises (SME) and enhancing innovation in key sectors. Two notable programs under this initiative are iBaC and DEMIBaC:

- The "iBaC PME" call for projects aims to support innovation by targeting SMEs. SMEs are indeed key players in providing decarbonization solutions; they offer equipment and services and are present at all levels within the industrial decarbonization sector. This call aims to finance single-partner innovation projects led by small and medium-sized enterprises (SMEs) — as defined by the European Union — with significant potential for the French economy. It allows for co-financing research, development, and innovation projects with total costs of less than €1.5 million and contributes to accelerating the development and market deployment of innovative solutions and technologies.

- The "DEMIBaC" call for projects aims to support innovation by promoting the development of technological building blocks, demonstration actions, and the adoption of low-carbon production solutions by industries. This call has two components:
  - Component 1 concerns projects for the development of innovative technological building blocks and demonstration actions, typically involving consortia made up of academic institutions and industry players offering these technologies.
  - Component 2 targets projects led by consortia consisting of one or more industrial players providing decarbonization solutions and one or more industrial players on the demand side ready to adopt these solutions.

These two calls for projects seek to provide funding for initiatives across various priorities, including the capture, storage, transport, and utilization of CO_2 through:

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- The development and implementation of efficient, competitive, and low-energy-intensity capture technologies.
- The mineralization of CO_2.
- The production of synthons and molecules of interest for industry (chemistry, etc.) or for energy.

Another France 2030 mechanism to support the territorial planning of CCUS Hubs is the ZIBac call for projects. Through this system, the government supports industrial territories in their ecological and energy transformation to enhance competitiveness and attractiveness within a framework of decarbonization and reindustrialization. Currently, four zones have been selected as winners in the first phase, located in the most emitting industrial areas, followed by six additional zones identified as being highly emitting. ZIBaC will finance numerous studies related to CCUS, focusing particularly on relevant CO_2 flows within industrial zones, infrastructure, and the reuse of infrastructures, as well as the economic viability of CCUS.

3.2.1.2 Others fundings initiatives of interest

Alongside the previously mentioned programs, there are additional project calls (some of which may have closed but could reopen) managed by ADEME, BPIFrance, or ANR:

- ANR annual generic call for projects. The ANR (Agence Nationale de la Recherche) in France regularly issues annual generic calls for research projects aimed at fostering innovation and scientific advancement across various fields. It funds academic research projects across various domains, including CCUS. It aims to encourage and support research activities within the TRL range of 1-4.
- Carb Aero “Development of a French production sector for sustainable aviation fuels”. The overarching goal of the Carb Aero program is to not only reduce greenhouse gas emissions in aviation but also to establish a competitive industrial base in France for SAF production. This is critical as the aviation sector looks to decarbonize and meet future sustainability targets.

3.2.2 Priority Research Programmes and Equipment (PEPR)

The Priority Research Programs and Equipment (Programme et Équipements Prioritaires de Recherche, PEPR) are initiatives aimed at promoting and funding research and innovation in strategic areas of importance to the country. PEPRs are designed to support high-impact research projects that address key societal and industrial challenges, including climate change, energy transition, digital transformation, health, and biodiversity. The programs provide substantial financial support, enabling researchers and institutions to develop innovative technologies and processes. This funding often targets early-stage research and development. PEPRs promote collaboration between public research institutions, universities, and private industry. They encourage the establishment of partnerships and networks to strengthen the research ecosystem. Each PEPR typically has a specific focus area or theme. The PEPRs align with national and European research priorities, contributing to France's overall research strategy and goals in areas like sustainable development and innovation.

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The PEPR named SPLEEN (Soutenir l'innovation pour développer de nouveaux procédés industriels largement décarbonés, Supporting Innovation to Develop New Industrial Processes that are Largely Decarbonized) aims to encourage and support upstream research activities, within the TRL range of 1-4, in the field of industrial decarbonization. Of the ten projects launched in 2023 with a budget of €35 million, which mobilize communities structured around these major challenges, 6 projects are related to CCUS topics.

3.2.3 Major industrial decarbonisation projects 2024 consultation (GPID2024)

The Major industrial decarbonisation projects 2024 consultation (Grands Projets Industriels de Décarbonation 2024, GPID2024) is a public initiative launched in June 2024 by the French government in partnership with the Ademe (French Environment and Energy Management Agency) and the Energy and Climate Direction and aims to gather input for a forthcoming call for projects focused on industrial decarbonization. This consultation serves as both a public consultation and an invitation to express interest for future funding opportunities. Participants must submit an application during this phase to qualify for the subsequent call for proposals. The program is designed to support large industrial decarbonization projects that exceed €20 million in public funding. This includes initiatives related to carbon capture, utilization and storage and the electrification of major industrial sites, aligning with the European carbon market. By facilitating these large-scale projects, the initiative aims to significantly contribute to France's decarbonization goals, enhancing both environmental sustainability and industrial competitiveness.

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4. EMERGENCE OF A HUB PROJECT IN THE AURA REGION

4.1 BACKGROUND

Lyon Vallée de la Chimie is a strategic area within the Lyon Metropolis, stretching from Lyon's 7th district to Givors. It hosts a leading ecosystem of innovation and industrial production, focusing on the chemistry-energy-environment and Cleantech sectors. This major industrial zone within the Lyon Metropolis is also responsible for nearly 25% of the metropolitan area's CO_2 emissions (2020 assessment). The Lyon Vallée de la Chimie territorial project, initiated in the early 2010s by the Lyon Metropolis with the creation of the Lyon Vallée de la Chimie Mission, is based on a strong partnership between industry players, municipalities, residents/workers, and the Lyon Metropolis. This partnership has been further strengthened through the "Impact Pact 2023-2030," which aims to bring together industrial players, research centers, and the Lyon Metropolis under a common ambition.

In France, the industrial sector emits 78 million tons of greenhouse gases, with 19 million tons coming from the chemical industry and 11 million tons from refining. In the AURA region specifically, industrial emissions represent 22% of GHG emissions, with 11,4 million tons. The cement-lime, refining, and chemical sectors—key players in the DECLYC project—account for two-thirds of this total.

4.2 PROGRAM DESCRIPTION

DECLYC is part of the ZIBAC call led by ADEME. It is led by the AXELERA cluster, the national cluster for the chemical industry, which brings together various partners and provides them with daily support on technological innovation challenges. The coordination is carried out in collaboration with the Vallée de la Chimie Mission of the Lyon Metropolis, which manages the area.

This project brings together 14 main CO_2-emitting industrial players in the Vallée de la Chimie, to conduct a work program over the years 2024-2025, aimed at defining a coherent decarbonization strategy for the entire region.

Figure 3: Industrial partners

DECLYC aims to accelerate the decarbonization of the Vallée de la Chimie targeting an 80% reduction in CO_2 emissions by 2050 (1.6 million tons of CO_2 per year), thus reducing its environmental footprint. Two key milestones have been set for 2030 and 2050 by the industrial partners involved in the DECLYC project regarding the reduction of CO_2 emissions within Scope 1 and 2 boundaries:

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- 40% reduction between 2015 and 2030.
- 80% reduction by 2050.

These objectives represent the overall ambition of the Vallée de la Chimie and come from both collective studies conducted within the ZIBAC framework and specific initiatives undertaken individually. In many cases, these individual projects present synergies and opportunities for pooling resources and improving efficiency across the zone, which will be considered in the cluster studies, particularly for the aggregation of needs (H2, networks). The decarbonization challenges by 2030/2050 are inherent to the nature of the activities present and include:

- Combatting climate change: the necessary decarbonization of the energy mix and the production/consumption of renewable energy.
- Water resource management.
- Optimization of resource consumption.
- Adaptation to climate change.

4.3 APPROACH

Regarding CCUS, DECLYC aims to offer a solution for reducing CO_2 emissions after all optimization levers have already been activated. The Vallée de la Chimie is characterized by diffuse sources that require a collective approach for the capture, utilization, or storage of CO_2. Among the 16 industrial partners involved in the DECLYC program, 5 are involved in the CCUS project.

Figure 4: Industrial partners involved in the CCU hub

This project seeks to explore the potential of CCUS initiatives and therefore, to initiate the development of a hub in the AURA region. To accomplish this, partners will launch a public call for tenders to select service providers who will deliver a comprehensive and phased assessment of the total CO_2 storage and utilization capacity of the Vallée de la Chimie facilities. To support this approach, several monitoring indicators will be used:

- Volume of CO_2 stored (biogenic and non-biogenic) and volume of CO_2 utilized (biogenic and non-biogenic).
- Balance of CO_2 emissions (scope 1/2/3).
- Energy consumption and efficiency.

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Each service provider must ensure that the local environment is considered in their analysis. For instance, regarding CCUS, they should assess whether there are other significant emitters beyond those involved in the project, and similarly for utilization, explore whether there are other potential interactions or synergies. The starting point of the project is the current situation. The study will project developments up to 2050 with relevant intermediate milestones to be defined (at a minimum, 2030, but typically with timeframes of 5 to 10 years).

4.4 BUDGET

DECLYC has a budget of 1.9 million euros, co-financed equally by industrial partners and a government grant. This budget is divided into eight themes, with 200,000 euros dedicated solely to the CCUS project. It is important to keep in mind that DECLYC focuses on conducting preliminary studies rather than making investments.

4.5 SCHEDULE

This project was submitted in May 2023 and was officially notified by ADEME to the coordinator, the AXELERA association, in December 2023. The next steps are:

- 2024-11 – Closing of the CCU/S public call for tenders
- 2025-01 – Sorting, scoring and selection of applications
- 2025-02 – Start of the CCU/S studies
- 2026-09 – End of the work programm

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5. METHODOLOGY FOR THE EMERGENCE OF A CCU HUB

To ensure the progress of each study, a monitoring committee should be established. Its objective is to meet monthly, providing an opportunity for partners to discuss any challenges encountered, successes achieved, regulatory developments, and other relevant updates. Each service provider is required to submit a final deliverable at the conclusion of their assigned study. The results would then be reviewed by the monitoring committee, which then should identify priorities among the proposed solutions.

The chosen methodology for the CCU DECLYC project is based on four main tasks that could form the basis of any replication project for CCU hubs, in France or in Europe.

5.1 STEP 1: ASSESS THE FATAL CO_2 FLOWS FROM INDUSTRIAL PLAYERS IN THE TARGETED REGION

Assessing the fatal CO_2 flows from industrial players in the targeted region is crucial for understanding the environmental impact of local industries and identifying opportunities for carbon reduction strategies. This assessment involves quantifying the amount of CO_2 emissions produced by key industrial sectors, including manufacturing, energy production, and chemical processing. By analyzing these emissions, stakeholders can pinpoint the major sources of CO_2 and evaluate their contribution to the overall carbon footprint of the region. Furthermore, this assessment can help in identifying patterns and trends in emissions over time, enabling the development of targeted policies and initiatives aimed at mitigating carbon emissions. Engaging with local industries and collecting comprehensive data will also facilitate the exploration of potential collaborations for carbon capture, utilization, and storage projects, which can effectively reduce the fatal CO_2 flows. Ultimately, a thorough assessment not only informs regulatory frameworks but also supports the transition towards a more sustainable industrial landscape in the region.

5.2 STEP 2: IDENTIFY THE BEST OPPORTUNITIES FOR CO_2 TRANSFORMATION FOR LOCAL STAKEHOLDERS

- Study the CCU Market: Analyze the CCU market (e-fuels, e-chemicals, mineralization, algae, e-CH_4, etc.) considering the regulatory framework for CCU (biogenic and non-biogenic, ETS and non-ETS, RED III). Identify potential molecules while considering market opportunities in the Vallée de la Chimie.

- Conduct a Comparative Analysis: Perform a comparative analysis of CCU valorization pathways for each partner (Life Cycle Assessment, technological maturity, infrastructure needs, identification of potential technologies for each company). This should take into account the evolving quantity of CO_2 that can be utilized or stored based on ongoing and future projects for industrial sites in the project and the AURA region.

- Define the E-Molecule of Interest: Identify the e-molecule of interest within the regional context, taking into consideration the market study, available technologies, willingness to pay, specific characteristics of each company, potential synergies, and upcoming projects.

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- Analyze the Use of Green/Decarbonized/Low-Carbon Hydrogen: Assess the potential cost synergies among industrial players regarding CO_2 emissions volumes, necessary infrastructure, risks, land requirements, and oxygen valorization. This includes an analysis of hydrogen produced on-site (local) versus externally (regional).
- Estimate Infrastructure Costs: Provide an estimation of costs related to infrastructure, necessary land, CAPEX, required equipment, additional costs, and OPEX (including utility balances, primarily electricity, and materials). This should also analyze the potential for shared infrastructures among companies for the production of e-molecules.

5.3 STEP 3: EVALUATE THE INFRASTRUCTURE AND TRANSPORTATION NEEDS FOR CO_2 RELATED TO CCU/S PROJECTS

For this part, CO_2 transport infrastructures include pipelines, barges on waterways and freight on railways. In principle, road transport is excluded.

- Identify, characterize, and map existing infrastructures that can be (re)used:
  - Collect data on potentially (re)usable infrastructures for CO_2 transport, differentiating between local, national, and European scales (literature review and interviews).
  - Detail the characteristics of these infrastructures (e.g., for pipelines: diameter, length, products transported so far, maximum regulatory pressure, etc.).
  - Specify the suitable states of CO_2 (liquid, gaseous, dense) for each alternative and scenario.
  - Determine the CO_2 transport capacities of these infrastructures based on their characteristics.
  - Provide estimates of CAPEX for reconditioning (pipelines) and the cost of CO_2 per ton transported (pipeline, river, and rail).
  - Identify limitations (regulatory, technical, economic, etc.) for each infrastructure and detail alternatives, including new infrastructures.
  - Geographically represent these infrastructures, identify major CO_2 emitters, potential CO_2 users including funders of this task, and publicly announced potential underground CO_2 storage sites.
- Define and map new CO_2 transport infrastructures:
  - Identify new infrastructure alternatives assuming existing infrastructures cannot be (re)used, clearly defining the purposes (U and/or S).

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  - Propose necessary new infrastructures to connect emitters and users to existing or new infrastructures based on identified scenarios (volumes of CO_2 involved, timelines, and purposes U or S).
  - Detail the characteristics of these infrastructures and specify the suitable state of CO_2.
  - Provide estimates of CAPEX/OPEX for the infrastructures to be developed according to the scenarios, along with a cost per ton of CO_2 transported.
  - Identify limitations (regulatory, technical, economic, timelines for completion, etc.) for each identified infrastructure.
  - Geographically represent these infrastructures, complementing the previously mentioned map.
- Regarding the electricity Infrastructure:
  - Identify the electrical infrastructure needs for CCUS projects.
  - Develop a detailed plan for implementing the necessary electrical infrastructure.

5.4 STEP 4: DEVELOP SUITABLE ECONOMIC MODELS FOR CCU/S PROJECTS

The objective of this task would be to compile data from the two previous ones, along with input data provided by partners, to propose one or more economic models aimed at maximizing the reduction and valorization of CO_2 emissions, either by pooling separation/capture/valorization techniques or by individualizing these processes. These models would be tailored to the characteristics of the region and will be essential for constructing the most appropriate roadmap. They must include environmental, regulatory, economic, and social considerations, as well as the opportunities and needs of the territory.

- Define the selected scenarios based on the previous studies, data from industries, and regulatory context analysis. Detail the assumptions made.
- Propose economic models tailored to each company involved in the lot, taking into account the chosen e-molecules.
- Conduct a prefeasibility analysis considering possible scenarios for CO_2 storage.
- Evaluate the potential benefits of a "CO_2 Hub" around the Vallée de la Chimie to receive CO_2 from current and future emitters.
- Analyze the life cycle, carbon footprint, and timeline for implementing the projects.
- Assess the possibility of collaboration for hydrogen production both on-site and off-site.

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Conduct a regulatory analysis of CO_2 capture and its impacts on projects (including biogenic and non-biogenic CO_2, ETS market, etc.) applicable to industries, taking into account various regulations (ETS market, carbon border adjustment mechanism, industrial carbon taxes, and regional, national, and European subsidies) to facilitate the implementation of a CCU/S process. Analyze the regulatory risks related to "Fit for 55" in the short, medium, and long term. Evaluate the impacts of implementation permits for a CCU/S process in the industrial zone. Through this analysis, the goal is to determine the impact of different solutions for companies: Who benefits from the decarbonizing effect? What are the regulatory and economic incentives for various technologies, and what reporting is required?

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CONCLUSION

In conclusion, this document aims to outline a clear and actionable methodology designed to assist European industrial clusters in establishing their CCU hubs systematically and effectively. By examining the context of CCUS, the relevant policies and legislation in Europe, and the available funding opportunities, we tried to lay the groundwork for replicating this model across Europe. The proposed methodology serves as a comprehensive guide that not only highlights best practices but also addresses the unique challenges faced by emerging hubs.

The replication methodology, toolbox, and this roadmap will serve as valuable resources for clusters and innovation support agencies throughout Europe in developing additional CCU hubs. In short future, AXELERA will collaborate closely with other clusters in Europe, providing mentoring and forming partnerships to assist them in their CCU hub development. The specific locations of these three European regions are currently being determined.

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