Université Grenoble Alpes

Cross Disciplinary Project (CDP) - 2022

Project Acronym	CO2Challenge
Project Title	CO_2 valorization: a scientific and societal challenge
PIs of the project & laboratories	Carole Duboc, Thomas Reverdy, Véronique Blandin, Vincent Artero CERAG, DCM, GAEL, G-SCOP, ISTerre, LCBM, LEPMI, LiPhy, LITEN, LPCV, MEM, PACTE, SyMMES

Project description

I- Project context

One of the most important challenges facing our society today is the reduction of the concentration in the atmosphere of carbon dioxide (CO_2), the main greenhouse gas that influences the climate by contributing to global warming. CO_2 emissions are both of natural and anthropogenic origin, the latter being the result of human activities, mainly related to the agricultural, industrial sector, transportation and housing. CO_2 plays a special role in the carbon cycle because it is its most oxidized form and a near-inert compound. Human activities based almost exclusively on oxidation/combustion emit too much CO_2 for ecosystems to absorb, thus unbalancing the carbon cycle and causing an inexorable increase in atmospheric CO_2 concentration.

Three leverages are currently in place to contain, or even reduce, the concentration of CO_2 in the atmosphere: (i) reduction of CO_2 emissions, (ii) CO_2 capture and permanent storage (CCS), and (iii) capture and reuse of CO_2 through its chemical transformation to close the carbon cycle. It is on this last leverage, i.e., carbon capture and utilization (CCU), that our project focuses. CO2Challenge aims to develop disruptive technologies that will enable large-scale applications, while ensuring their positive impact on the environment and has also the advantage of creating a virtuous circle through the principles of the circular economy, with positive effects on global growth and development.

I.1- Scientific, technological and methodological questions, socio-economic issues

The valorization of carbon dioxide (CCU strategy) consists in considering CO_2 as a raw material that can be captured and used to synthesize a number of products (fuels, commodity chemicals, industrial chemical building blocks…). This approach should thus reduce the carbon footprint for industrial or energy processes. However, the CO_2 molecule is a very stable molecule, difficult to capture, activate and transform. Indeed, separating CO_2 from other gases, breaking it down or binding it to any other supports requires a lot of energy!

Capturing CO_2 is expensive in terms of energy. It is more cost-effective to capture it at point sources (large carbon-based energy plants, highly CO_2-emitting industries, etc.) than to extract it from the air because its low concentration (around 400 parts per million) makes the process expensive. Different technologies are currently developed, including absorption, adsorption, chemical looping, membrane gas separation or gas hydration. But they all suffer from high energy costs and therefore an unsatisfactory environmental impact.

Lack of available technologies for industrial CO_2 transformation. Currently, the CCU approach is not commercially available, as the technology is simply not available, at scale, anywhere in the world. While the CCS approach is already available on an industrial level, it has been developed in a climate of urgency with short-term solutions. However, CCU represents a longer-term, more sustainable strategy and contributes to the political commitment to develop an industrial sector based on the circular economy.

Lack of shared sociotechnical and economic vision. For the valorization of CO_2 to support circular and climate neutral economy, it is essential to define guidelines enabling a common understanding of how to assess the environmental impacts of CCU technologies to design an appropriate policy framework, to evaluate proposals, to avoid utilization of non-relevant indicators, and to define risk-sharing measures to develop appropriate funding for technology development along the value chains (at all TRL: technology readiness levels).

How CO2Challenge will contribute to find solutions to these issues.

Capturing CO_2. Taking advantage of the expertise of different CO2Challenge research teams, we want to develop innovative concepts based on the CO_2 adsorption properties of nanoporous materials and aqueous foams, and on bioinspired approaches with the use of carbonic anhydrase mimics. A further step will be accomplished by combining these assemblies with catalytic CO_2 conversion systems to produce demonstration prototypes, capable of producing fuels or commodity chemicals.

Transforming CO_2. Grenoble is recognized as a national and international leader in the field of bio-inspired chemistry, in particular for the development of catalysts and metal-based molecular materials designed to reduce CO_2 by photo- or electrochemical processes. CO2Challenge thus proposes to design and optimize catalytic systems with low energy costs, high selectivity, and low environmental impact. In addition, we aim at overcoming scientific and technological bottlenecks in the scale-up of the most mature technologies for CO_2 utilization developed in UGA laboratories in order to produce demonstration prototypes.

Evaluating the environmental impact. The aim of the project is to develop technologies which would capture atmospheric CO_2, but it is essential to verify that the life cycle encompassing these technologies actually imply a reduction in CO_2 concentrations! For example, if the manufacturing of the said technologies emits more greenhouse gases than they will capture − which can be verified thanks to a Life Cycle Assessment (LCA) − this would mean that they are not efficient enough and should therefore be improved or discarded before their industrialization. An impact of this project for the Grenoble community will be gain competence in this area, which will give us a competitive advantage in the necessary development of this type of technology.

Debating sociotechnical and economic visions. One of the main challenges of this multidisciplinary project is also to propose deliberation processes allowing to share knowledge and uncertainties on the benefits and impacts of these technologies (integrated in complex socio-technical systems) and to involve the various parties concerned in the decisions of technological and industrial policies. The research will be able to highlight the difficulties and biases in these deliberation processes, in particular in the formulation of scenarios and in the identification of economic and environmental impacts.

Grenoble is already a place where the issue of reducing atmospheric CO_2 concentration is central to many research laboratories. Promising results at different technology readiness levels (TRLs between 2 and 6) have already been obtained thanks to numerous sources of funding at local (IDEx, LabEx, etc.), national (ANE, CNRS, CEA, etc.) and even European (ERC, international ANR, etc.) levels, and industrial contracts are underway with TOTAL, GRDF and Engie. The running projects represent a funding of around 8 620 k€, and other projects are currently being evaluated for a total amount of 1 400 k€.

I.2- Objectives

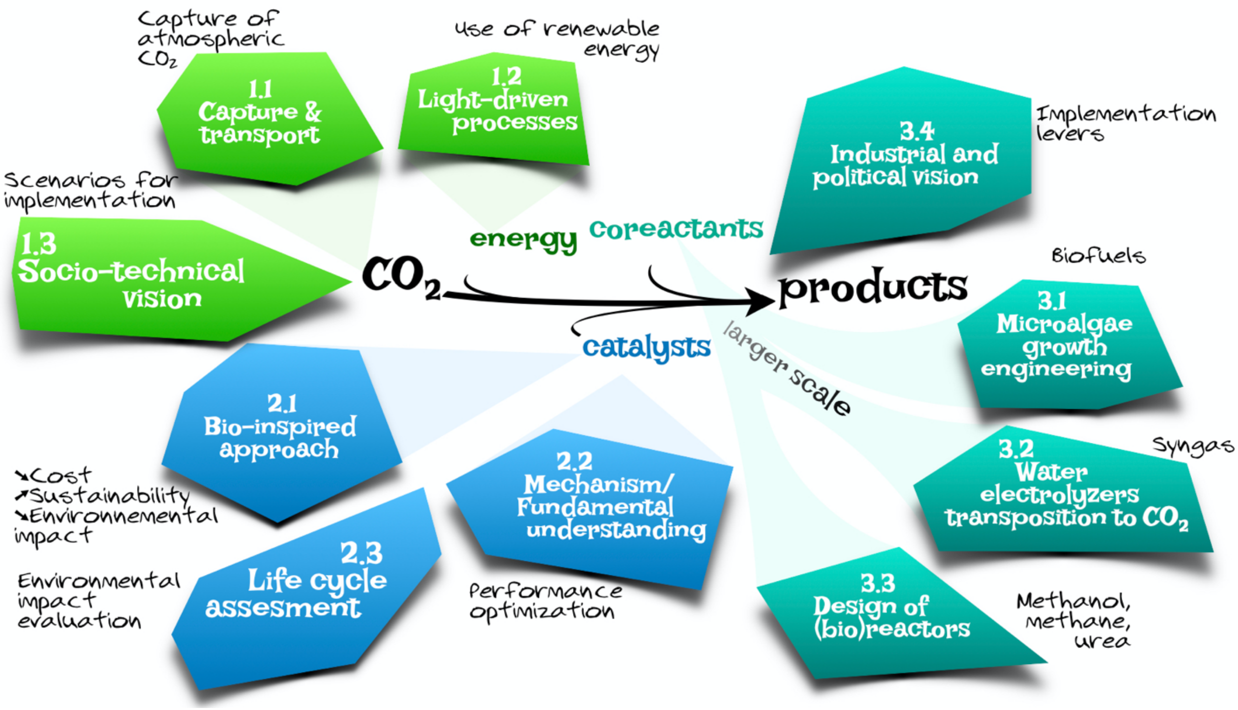
More specifically, the main objectives of CO2Challenge are

- exploitation of bacteria and microalgae for the production of biofuels and bio-sourced molecules,
- use of natural and artificial enzymes for CO or syngas production, methanation and carbonation reactions,
- elaboration and optimization of innovative materials for the photo/electro catalytic reduction of CO_2,
- development of high temperature electrolysers,
- socio-economic study to orient the experimental research projects and to make a technical-economic comparison of the various technologies,
- understanding of the societal debate on CCU technology,
- contribution on the definition of the public policy of CCU development.

I.3- Strategy

I.3.a- Multidisciplinary aspect. We believe that the interdisciplinary approach we have chosen, ranging from biology, chemistry, physics, engineering, socio-economic and socio-technological sciences to humanities and social sciences, is fundamental in addressing this societal challenge. CO2Challenge goes far beyond the development of new technologies with limited environmental impacts on the basis of prospective life-cycle analysis, since it also aims to analyze how the desirability and credibility of these technologies will be constructed through socio-technical discourse, define how industries can integrate political, regulatory and economic uncertainties into their strategy and try to reduce them by contributing to public policy making. Convinced of the benefits of an interdisciplinary approach and with this vision in mind, we have chosen to integrate the social sciences and engineering sciences in each of our work packages that differ from their levels of maturity of the technologies. Indeed, it is from this synergy that real disruptive and viable solutions from both technical and socio-political points of view will emerge.

I.3.b- Methodology. To achieve the ambitious objectives of CO2Challenge, 4 well-defined work packages will be implemented. The first three are dedicated to the scientific aspect, while the fourth is related to the management and organization of the project. In the first work package, we will focus on proofs of concept for disruptive technologies combining CO_2 capture and conversion based on the use of renewable energies that will fit into a realistic socio-technical vision for the implementation of the technologies at large-scale. The second work package will aim at setting up innovative strategies for the transformation of CO_2 into chemicals of interest, based on bio-inspired catalysts containing earth-abundant, cheap and non-toxic metals, with optimal performance, and adapted to photo- or electro-catalytic devices with minimal environmental impact, evaluated through life cycle assessment at an early-stage of their development. Finally, the third work package will consider the scientific and technological bottlenecks that should be overcome in the scale-up of near-mature technologies based on microalgae or bacteria able to produce biofuels or on CO_2 (co-)electrolysers, and identify public policies that can be leveraged to implement the CCU technologies, thereby contributing to the overall societal benefit.



Scheme 1. Illustration of the proposed methodology to achieve the scientific objectives of CO2Challenge

Finally, the last work package will focus on the follow-up of the scientific project, and will guarantee the implementation of the training program and of the dissemination and valorization of the results. A central part of this effort will be to initiate and strengthen international collaborations as well as collaborations with industry.

I.3.c- A multi-disciplinary consortium. The consortium of CO2Challenge brings together more than 70 scientists (researchers, faculty members, engineers, PhD students & postdocs) from 13 laboratories, corresponding to 6 research departments of the UGA (CBS, PEM, PAGE, SHS, PSS, CEA-DRT). The expertise of the members (Table 1) covering disciplines spanning from biology, chemistry, physics, engineering, socio-economic, to socio-technological, human and social sciences will ensure the implementation of this cross-disciplinary project and the achievement of its ambitious objectives.

Table 1: Skills and competences gathered in the CO2Challenge consortium

Organic synthesis	Coordination chemistry, transition metal ions
Photochemistry (including photocatalyse & photoelectrode)	(Bio)electrocatalysis, homogeneous & heterogeneous catalysis
Photovoltaic, organic dyes	Theoretical chemistry
Mechanism (in situ & operando characterization)	Characterization (advanced spectroscopic techniques and microscopy)
Nanomaterials and renewable materials	(Artificial) metalloenzymes
Methanogens (production of methane), lipid metabolism (biofuels), photosynthetic CO_2 assimilation (algae)	CO_2 valorization (CO_2 insertion chemistry, free radical synthesis, cascade reactions)
High temperature electrolysers	Molecular & surface chemistry
CO_2 capture (porous liquids & materials, molecule separation, fluid mechanics)	Energy-climate prospective, life cycle assessment
Sociotechnical imaginaries & transition	Constructive technology assessment,
Social practices of valuation	Industrial policy & energy policy,
Climate change policy	Regulation, planning,
Market-structure & competition	Industrial engineering (dynamic modelling, upscaling)

II- Quality of the project

II.1- Novelty in the problems addressed

By bringing together several disciplines ranging from chemical and biological sciences to socio-economic and management sciences via human and social sciences, CO2Challenge must contribute to collectively meeting the environmental, energy and economic challenges related to CO_2 emissions and transform society by reconciling the economic, social and environmental impact of human activities.

Chemically converting CO_2 is a real challenge, which the CO2Challenge aims to meet by proposing innovative solutions based on the know-how and expertise that the UGA possesses within its laboratories. The CO2Challenge must thus lead to breakthrough solutions thanks to a shared vision of scientists with diverse expertise but with the same objective, adapted to the constraints of the industrial world by relying on socio-economic studies, and relevant to the expectations of society in terms of CO_2 emission mitigation and environmental limitations.

Besides prototyping near-mature technologies in WP3 such as photobioreactors for biodiesel production, CO_2 (co)electrolysis for syngas production and (bio)methanation using green hydrogen, we aim in WP1 at investigating disruptive concepts for combined CO_2 capture and catalytic conversion and to power this process with light, thereby reproducing the natural photosynthetic systems. While artificial photosynthesis is an active field since several decades (Grenoble is a key international player in this area and organized the International Solar Fuel Conference in 2021), it has so far mainly focused on hydrogen production through water splitting. On the other hand, technological solution for CO_2 utilization usually relies on pure CO_2 feeds that require either purification steps (for flue gas issued from point sources) or capture from the air (requiring a large amount of energy for recovery after adsorption). The innovative concept here is to take benefit of the expertise in the physics of CO_2 adsorption in nanoporous materials and innovative aqueous foams and to combine it with bioinspired approaches for CO_2 capture (carbonic anhydrase mimics) and (photo/electro)conversion (molecular and hybrid photo(electro)catalytic systems) and generate novel proof of concept prototypes such as continuous flow catalytic (photo/electro) reactors for CO_2 capture and production of fuels (e.g. methane, ethanol…) or chemicals (e.g formic acid, ethylene …).

In contemporary debates on the climate change mitigation, CO_2 capture technologies are facing many controversies that weaken the commitment to a subsidy policy. They are accused of slowing down efforts to change production and consumption practices, of displacing emissions, of increasing energy consumption... It is consequently necessary to identify the dynamics of mobilization around the sociotechnical assessment of these technologies.

In parallel we will investigate how technologies will be used, accepted or rejected by the market and the different companies and how public intervention can facilitate their emergence. Going further, we will study how ecological planning must take into account the emergence and existence of technologies (from basic research to near-mature technologies) by coordinating environmental policy, industrial policy, public orders, and the strategies of public companies. This planning would have to be consistent with the environment impact predicted in WP2 and the institutional and political context analyzed in WP3.

The bio-inspired approach proposed in WP2 for the design of highly performant catalytic systems towards the transformation of CO_2 is particularly ambitious since our objective is to find alternatives to the current industrial processes that are often based on noble, rare and sometimes toxic elements and operate under harsh conditions of temperature and pressure. We also aim to go beyond the production of C1 products, that are generally targeted in the literature, to more complex organic molecules, by elaborating cascade catalytic processes that will be relying on the most promising achievements of the local teams.

Environmental impact assessments with LCA are generally conducted on existing products or processes. In the case of new technologies, they are usually performed on pilot installations or adapting processes. IN the case of new technologies, attempts to assess their environmental impacts in the early stages of their development are reported, and are either based on expert judgement or based on process simulations. Actually, each result found in the literature is specific to one special case: there has been no generic nor sectoral method to do so. In this project we propose, to use the diversity of processes studied for the common purpose of decarbonation, in order to create a model which would enable to assess, at the early stages of a project, the environmental impacts of its developments at industrial scale. Besides, coupling this prospective LCA model with a consequential approach would enable to estimate the decarbonation potential of the diffusion of the technologies developed in CO2Challenge at industrial scale, in regards to greenhouse gases emission and other environmental impacts reduction goals. Thus, CO2Challenge would contribute to improve the assessment of the environmental impacts of novel technologies based on “lab” data during their development and to switch from a relativistic LCA approach (does the studied technology do better than the existing ones?) towards an absolute approach (will the studied technology contribute to do enough?).

In the implementation of new technologies carried out in WP3, the scale-up is a challenging part that cannot be underestimated. Especially, with higher volumes to be transformed, a better compactness of the installation is expected (e.g. a higher concentration in the (bio)reactor), which requires to investigate and optimize energy and mass transfers through process design and engineering. In the case of microalgae-based transformations, a challenge not yet overcome by the scientific community worldwide is a change in the developmental behavior of the living organisms when more densely stored.

In contrast to the scale-up challenges encountered with the microalgae-based transformations or (bio)methanation reactions, CO2Challenge chose another angle with CO_2 (co-)electrolysis. We will take advantage of the technical developments already performed on water electrolysers and of the experience gained during their scale-up, and transpose the setup of these electrolyser cells to CO_2 (co-)electrolysis. The adaptation will rely on the cathode structure tuning.

Current climate change policy in Europe is mainly based on a generic instrument: the EU emissions trading system (EU ETS). CO_2 capture could benefit from the strengthening of this instrument (carbon price). But this economic mechanism of integration of environmental externalities, which is desirable in principle, could also have indirect economic effects that could weaken the political legitimacy of the EU ETS and encourage additional corrections, through quota distribution and cost compensations. The modeling of the different effects of existing instruments on industrial transformation is still in progress in economics. Considering the existing political debates on EU ETS, there is an urgency for a better understanding of the political dynamics of appropriation, contestation and adjustment of economic instruments of climate policy.

II.2- Soundness of the proposed methodology

Table 2. Description of the WPs 1-3

WP1. Disruptive combined CO_2 capture and conversion technologies using renewable energies: proof of concept and ecological planning
WP leaders: Jean-Philippe Nicolai & Vincent Artero
Laboratories: DCM, LCBM, GAEL, LiPhy, LITEN, LPCV, PACTE, SyMMES,
Objectives. - Establish a proof of concept for novel technologies for combined capture and catalytic conversion of CO_2 into fuels or commodity chemicals and using renewable (solar, wind…) energy input - Develop an ecological planning for the large-scale implementation of such innovative technologies, as well as more mature ones in relationship with their environmental impact (WP2) and the scenarios envisaged in WP3.
Task 1.1. Combined capture and catalytic conversion. Innovative fluid CO_2 sorbents will be developed and characterized for further implementation in continuous flow catalytic (photo/electro)reactors. In particular, aqueous foams incorporating mimics of carbonic anhydrase enzymes should be able to efficiently capture CO_2 from dilute sources and to transport it to immobilized catalysts for conversion into fuels (methane, alcohols…) or chemicals (e.g., formic acid to be used in WP3). The aim is to produce a proof-of-concept continuous flow millifluidic catalytic reactor and to characterize it (physico-chemical models for CO_2 capture, energy conversion efficiency, net carbo balance) as input for WP2. **Tasks 1.2. Light-driven processes**. We will here focus on driving the catalytic processes from Task 1.1 (or WP2) using sunlight with the ultimate goal of mimicking photosynthesis. Here we will (i) develop photocatalytic systems combining novel molecular dyes or semi-conductor nanocrystals with catalysts from WP2, (ii) immobilize them onto active materials and (iii) implement them into catalytic photoreactors to be combined with outputs from Task 1.1 to produce a full prototype for light-driven CO_2 capture and conversion. **Task 1.3. Sociotechnical and economic vision**. The contribution of the economics in CO2Challenge will be to design an ecological planning that takes into account both the emergence of technologies and the mechanisms necessary for their promotion. We will study the different obstacles that can be encountered in the development and implementation of technologies. In particular, we are interested in the degree of market concentration and the strategies of the different companies involved. Moreover, cross-talks between technology developers, sociologists and economists will allow shaping the most suitable policy for the implementation of these innovative technologies (and the more mature ones from WP3) and to articulate such technological implementation with the scenarios envisaged in WP3. We also propose to identify the socio-technical imaginary of CO_2 atmospheric capture, the anticipations (positives or negatives) associated with these different strategies for combating climate change. We will analyze how uncertainties about their environmental performance and their direct and indirect impacts can be debated in the context of controversies, how desirability and credibility of this technologies are constructed through sociotechnical discourse.
Foreseen industrial partners. GRDF, Total Energy, Engie, **UGA's technical platforms.** ICMG
Scientific (co)-funded PhD/postdoc packs. - Implementation of phot(electro)catalytic devices (co-funded with Arcane; LCBM/DCM/SYMMES) - Chemical CO_2 capture coupled with its catalytic conversion (co-funded with Lanef; LiPhy+IRIG) - Development of socio-technical scenarios (PACTE, GAEL)

WP2. Toward innovative CO_2 transformation strategies combining high performance with low environmental impact
WP leaders: Damien Evrard & Carole Duboc
Laboratories: DCM, LCBM, G-SCOP, ISTerre, SyMMES, MEM,
Objectives. - Develop catalytic systems based on earth-abundant, cheap and non-toxic metals, able to transform CO_2 into C1 and beyond C1 products of interest, selective, efficient and robust (inputs for WP3) that can be adapted in devices with minimal environmental impact.

- Develop industrial models based on the state-of-the-art catalytic systems developed at Grenoble (WP2) to carry out prospective life cycle assessment (LCA) for an evaluation of their environmental impacts (inputs for WP1).
- Establish a roadmap for higher performance and lower environmental impact of CCU technologies.

Task 2.1. Bio-inspired systems. One strategy will be to develop innovant electro- or/and photo- catalytic systems to activate CO_2 and transform it into selective products of interest based on a bio-inspired approach, i.e., on the use of synthetic models, metalloenzymes or hybrid assemblies. In all these systems, CO_2 is activated and transformed at a metallic center composed of non-noble and non-toxic metals, and their performance in terms of efficiency, selectivity and robustness will be assessed under homogeneous or/and heterogeneous catalytic conditions and under mild temperature and pressure (inputs to Task 2.3). To go beyond the production of C1-products, cascade chemical processes will also be implemented.
Tasks 2.2. Optimization of the performance. With the aim of enhancing the efficiency, selectivity, and stability of the catalytic systems, the full understanding of the catalytic mechanism and degradation process(es) will be investigated to design in a rational way their next generation (inputs to Task 2.1). To do this, we will use several complementary approaches: (i) in operando investigation based on different spectroscopic or spectrometric techniques, (ii) trapping and characterization of short-life species to identify intermediate species, and (iii) quantum chemistry based on different methodologies including dynamic ones, to predict full mechanisms.
Task 2.3. Life cycle engineering. To perform a thorough analysis of the environmental impacts of new technological approaches, the standardized LCA methodology is the most advanced tool because it is based on a global and multi-criteria evaluation. However, to have a concrete impact, LCA must be carried out as early as possible to have a real impact on development decisions and lead to a system that best meets regulations and political and social expectations. In this WP, we will target our latest breakthroughs in CCU technologies to provide data for LCA, so that the developed processes can be upscaled, assessed and optimized (inputs to WP1 and Task 2.1) based on this analysis and industrial engineering methods.

Foreseen industrial partners. GRDF, Total Energy, Engie
UGA's technical platforms. GRICAD, ICMG

Scientific (co)-funded PhD/postdoc packs.
- Development of bio-inspired, enzymatic and hybrid catalytic systems (co-funded with Eur-CBH; LCBM/DCM/SYMMES)
- Mechanistic investigation & in operando characterization (co-funded with CEA/International; MEM, SyMMES, DCM/LCBM)
- Implementation of LCA methodologies (G-SCOP)

WP3. Near-mature technologies & leverages for implementation

WP leaders: Véronique Blandin & Thomas Reverdy

Laboratories: CERAG, GAEL, LCBM, LEPMI, LITEN, PACTE, PCV

Objectives. - Overcome scientific and technological bottlenecks in the scale-up of the most mature technologies for CO_2 utilization in order to produce demonstration prototypes.
- Establish a comprehensive view of the different public policies in favor of CO_2 mitigation and the articulation thereof.

Task 3.1 Microalgae as biofuel providers. Using formic acid and solar energy, strains of microalgae are able to capture atmospheric CO_2 and accumulate it in the form of energy rich molecules, especially lipids — biofuel direct precursors, with a promising yield. We will investigate the scale-up of these photosynthetic cell factories from fundamental considerations (influence of the growth medium concentration on the development behavior of microalgae) as well as engineering considerations, such as energy saving (distribution of the solar energy between photosynthesis and utilities for the production) and (continuous) extraction of products of interest. Reports from previous attempts in the development of microalgae-based technologies will also contribute to Tasks 1.3 and 3.3 as first-hand examples.
Task 3.2. CO_2 (co-)electrolysis. Several technologies for water electrolysis into hydrogen and oxygen, using low-carbon electricity, are at an advanced stage of development, with the high temperature solid oxide electrolyser cell (HT SOEC) technology being at the prototype demonstration level. We will investigate the transposition of the above technologies to the electrolysis of CO_2, or its co-electrolysis (H_2O/CO_2 stream), for the production of CO or syngas. This will require several adjustments, facilitated by the cells modular

structure. Especially, structure-activity relationship data will be gathered for the fine tuning of the cathode in order to avoid coke formation.

Task 3.3. Water electrolysis downstream transformations. Hydrogen issued from water (photo)-electrolysis can react with CO_2 or CO to give methane or methanol, or could help produce urea in the presence of nitrogen. (Bio)reactors designed to accommodate such (bio)catalyzed reactions will be developed.

Task 3.4. Industrial strategy and public policy. Economic sociology could examine the institutional and political conditions of a public support for the large-scale development of these technologies. Different kind of policy are overlapping: targeted economic support for research and development of CO_2 capture technologies, support for renewable energy, and general environmental policy for CO_2 emission mitigation as European ETS. This task will investigate the articulation of the different public policies and question the strategy of industrial actors investing in these technologies or integrating them into their carbon-emitting facilities. The aim is to understand how industrial actors integrate political, regulatory and economic uncertainties into their strategy and try to reduce them by contributing to the definition of public policies. It could be relevant to investigate how carbon accounting should be implemented by industrial firms and to investigate the link between technologies and the energy mix.

Foreseen industrial partners. Total, Genvia (potential partners: Vicat, Air Liquide), Engie
UGA's technical platforms. LIPANG, PFNC

Scientific (co)-funded PhD/postdoc packs.
- Implementation of a technological pilot based on microalgae (co-funded with Gral; PCV)
- Development of a high temperature electrolyser (co-funded with Cemam/International; LITEN, LEPMI)
- Investigation of the articulation between the public policies and the industrial sector (PACTE, GAEL)

II.3- Conception and practice of interdisciplinarity

Our interdisciplinary approach will allow a sharing of knowledge to optimize the catalysts, processes and devices targeted through cross interactions, a more relevant orientation of projects in accordance with the expectations of the industrial world and society. The current consortium makes it possible to take up the challenges and should allow an optimal synergy between all the actors.

Conception. The expertise of the researchers involved in the consortium is remarkably diverse (Table 1), and the research projects they are currently developing are not all directly related to the CO_2 issue. However, by sharing know-how, it will be possible to exploit all this knowledge, in a synergetic manner, to come up with breakthrough solutions, with an enhanced impact with respect to individual or monodisciplinary research project.

Practice. Such an objective requires a better understanding of each other (who does what and how). It will therefore be necessary to promote exchanges between researchers so that everyone can define their needs but also generate new ideas through the discovery of unknown disciplines. From the kick-off, very didactic presentations will be selected to present the different disciplinary fields and their link with the project, followed by discussions between experts and non-experts to enable everyone to position themselves within the consortium and thus define how best to interact. Besides, the monthly seminars will be a meeting place with a strong pedagogical vocation through the presentation of the projects developed within CO2Challenge. During the scientific days and final conference, a specific tutorial-type intervention will be planned to help the researchers to exchange ideas on with themes that will be chosen according to requests and needs.

Other targeted training will be organized. For example, we have already pointed out during the submission process that there is a strong need to train researchers (permanent and non-permanent) in LCA as it becomes an essential tool for the development of technologies that must respect environmental policy.

II.4- Excellence of the consortium

This consortium is distinguished by its interdisciplinarity nature and combines both internationally recognized scientists and promising young researchers covering the whole range of knowledge required for an optimal development of the project and to achieve the ambitious objectives set. Beyond the purely scientific aspects, the consortium brings together dynamic members who share a vision. We must contribute to the visibility of Grenoble as an international research, innovation and training center and we are convinced of the importance of being a team with different expertise both scientifically and professionally to tackle such a challenge.

Many of our members also have strong responsibilities within our institutions in Grenoble and beyond, whether in teaching, research, development or management of European (ERC, ITN, …) or PIA projects (labex, EUR). Thus, it will foster a distinctive dynamic by bringing together these differences.

The researchers involved in this consortium already have a strong international visibility with numerous collaborations with European partners (past, current and under evaluation projects: COST, ITN/DN (MSCA), Twinning, ANR-DFG/Switzerland/Japan) and also at an international level (international IDEX with Japan, USA, Canada, ...). These scientific collaborations have also led to the establishment of ERASMUS agreements between several universities (Gröningen, Belgrade, etc.).

The consortium beyond its recognized expertise in its respective fields and more globally the site of Grenoble will benefit from the visibility given by the structuring of this project on CO_2 valorization at the local, national and international level. This will give the consortium the collaborations and recognition necessary to go on to larger tenders.

Scientific positioning of the consortium. CO2Challenge brings together 71 researchers from 13 laboratories, expert in various disciplines ranging from biology, chemistry, physics, engineering, socio-economic and socio-technological sciences to humanities and social sciences. Recognition of the research developed in the laboratories can be estimated by the number of publications (more than 200 in last 10 years in domains related to this project) published in journals of high impact factors (including Nature, Nature Chem., J. Am. Chem. Soc., …) and also by number of grants already obtained (see paragraph IV.3.B).

Methodological positioning of the consortium. The consortium of CO2Challenge is composed of a minority by researchers currently working in a specific field with CO_2 in focus. Its strength is to gather experts in diverse and complementary fields in order to find original solutions and to make chains of competences from design to the conception of devices that are viable and adapted to the expectations of environmental regulations and the industrial sector. The contribution of the socio-economic component of the project will be a key added value to better understand the market related to the CO_2 industry, to optimize the use of governmental instruments, and to improve the links between academic research, industry and society.

The methodological positioning of the consortium is well illustrated in Scheme 1 showing how the three scientific WPs are interconnected and based on a multidisciplinary approach. CO2Challenge will mobilize all these skills to work in synergy in order to tackle the problem as a whole: from atmospheric CO_2 to the large-scale production of biofuels and commodity chemicals, using technologies with highest performance and lowest environmental impact and an implementation strategy taking into account the expectations of all stakeholders.

II.5- Anchoring in the scientific strategy of the UGA

Data used : Strategic plan : https://www.univ-grenoble-alpes.fr/universite/ambition-et-strategie/, youtube popularized simplified version subtitles in English: https://www.youtube.com/watch?v=xFauhvon3a0. Ambition and research strategy : https://www.univ-grenoble-alpes.fr/recherche/ambition-et-strategie-de-recherche/l-ambition-et-la-strategie-de-recherche/

UGA's research strategy is rooted in the University's strategic plan. Thus, our shared commitments in research are aimed at solving, with the pioneering spirit of the region, the most pressing challenges of our time: 1- Sustainable planet and societies; 2- Health, well-being and technology; 3- Understanding and supporting innovation: culture, technology, organizations; 4- Digital technology at the service of humanity and society.

CO2Challenge is fully and clearly in line with topics 1 and 3. Indeed, CO2Challenge aims to reduce the adverse effects of CO2 emissions linked to human activities with the clear objective of a more sustainable society using a multidisciplinary vision that is reflected in each of its WP.

Beyond the thematic adequacy with these topics, our project is in phase with the global ambitions of our university. Our project will nurture the interdisciplinary needed for an efficient innovation, will strengthen the links with the local industrial sector and our international academic partners. The CO2Challenge will also give students and staff the opportunity to develop their creativity and their expertise beyond their core activities. They will also benefit from the networks necessary for their professional careers.

III- Impact of the project

III.1- Contribution to the response to the major social issue addressed by CO2Challenge

Reducing the concentration of CO_2 in the atmosphere is an emergency, a challenge that our society must meet. Contributing to the energy and ecological transition is the major objective of CO2Challenge. This project will provide concrete solutions that will not only limit the increase of CO_2 concentration in the atmosphere by transforming CO_2 into (bio)fuels or high value-added products, but will also pave the way for the long-term storage of renewable energies, a prerequisite for a complete energy transition.

CO2Challenge will address these issues along 4 main lines:

Development of new processes. We will specifically target new approaches to integrate the capture of CO_2 from dilute or point sources with its catalytic conversion. Such an integrated process is already at play in photosynthetic organisms and CO2Challenge will fund research to enhance the productivity of microalgae for lipid production. In parallel, we will design bioinspired systems for combined CO_2 capture and conversion, through the combination of CO_2 sorbents, mimics of the enzymes responsible for CO_2 capture and catalysts for CO_2 conversion. We will also integrate these two processes in a photo(electro)catalytic reactor in order to drive them in a fully sustainable way. These new processes will come in addition to more mature technologies (such as e-fuels and chemicals) and help building a socio-technical vision of a carbon neutral world by 2050.

***Catalysts and materials development*.** Today, a key challenge in CO_2 transformation is the lack of selectivity of most available catalysts that are generally found as inorganic nanoparticles. By contrast, enzymes hold great promise: First, they are exclusively based on Earth-abundant elements, which offers cost-effectiveness and possible worldwide upscaling of bioinspired materials. Second, enzymes use only a handful of metal atoms while nanoparticles expose ~ 10% of their atoms at their surface, thus wasting 90% of the metal loading as inactive atoms. Third, enzymes are highly selective and, fourth, they operate under mild temperature and pressure conditions and in aqueous media, which are assets en route to them being considered green and safe. In CO2Challenge, we will be inspired by such natural systems for designing alternative catalytic materials with the aim to meet the specifications of targeted technological applications and verify the ecological impact of such systems through a systematic assessment of their life cycle and cost.

***Chemical engineering*.** To promote the above new processes and materials to the level of new technologies, we will integrate them into complete systems such as bioreactors, photo(bio)reactors or electrolysis cells and optimize these systems in terms of mass and heat transport or light management. To get reliable data, we will implement a constant monitoring of their function and we will develop coupled systems, for example photobioreactors with microalgae growing thanks to formate produced via electrolysis of CO_2 or biomethanation using solar hydrogen. Such efforts in chemical engineering will help strengthening the techno-economical assessment of CCU technologies.

***Piloting of the ecological transition*.** To ensure the success of the ecological transition, it is necessary to integrate into the design of climate and industrial policies a very precise knowledge of the different CO_2 capture technologies, but also to identify all the obstacles to the deployment of technologies and the implementation of policies. The multidisciplinary approach of CO2Challenge is well designed to become a powerful tool contributing to the piloting of the ecological transition. Moreover, the inclusion of stakeholders in the construction and implementation of new technologies and policies to mitigate climate change is an essential condition for success. Finally, outreach and diffusion activities of the CO2Challenge will help in creating public awareness of the issues related to the increase of the atmospheric concentration of CO_2 in creating a sustainable future

III.2- Measures to maximize expected outcomes and impacts

***III.2.a- Dissemination of scientific and methodological results to the academic world*.** The results arising from the CO2Challenge will be disseminated at the highest level, both during the project and after its completion. Dissemination will be accomplished by presenting the results by the researchers and students (Master II, PhD students) at national and international conferences, by publishing results in international peer-reviewed, high impact scientific journals, according to the rules of open science, and by implementing the open data management plan. All scientific publications will be made available Open Access and links to all publications will be available on the CO2Challenge's website. Further dissemination activities highlighting the overall activities of the project will be explored through discussion that includes all the stakeholders, including students, in order to use means adapted to researchers of different generations and fields.

III.2.b- Exploitation of the research results*.* Valorization of key scientific results will be encouraged. Depending on the nature of the innovations and their potential application appropriate protection policy will be decided through the filing of patents or supported and developed within the framework of a CIFRE thesis, for instance. These actions will be achieved through the support of Floralis, or other institutions such as the CEA or CNRS valo cell.

Depending on the TRL of the project, the project leaders will also turn to the IDEX (IRGA valo/TRL3) or the SATT linksium (TRL4) to request financial support in order to develop industrial processes, which in this field most often require a strong partnership with an industrial company.

III.2.c- Communication activities towards the society*.* Communication to the general public and politicians will also be an important issue of the project. We will make society aware of the CO_2 problem thanks to a website dedicated to CO2Challenge which will not only present the project but will also be a relay towards the citizen to explain the problem by centralizing documents (report, publications, film, presentations) adapted to all ages. The permanent members of the consortium, doctoral students and master students will participate in local actions (science festivals, GEPhyX, high school students' day, ...). Moreover, the consortium members are used to popularize their results in the general (newspaper les Echos, science et vie junior, la recherche, the conversation, ...), scientific (newsletter of the CEA, CNRS, chemical news, ...) and local press (newsletters / sections highlights of the websites of local institutions, UGA, laboratories, EUR, labex). We will also be keen to provide forums for debate between scientists/society/decision-makers in a convivial way (Pint of Science, Tribulations Savantes) or in an institutional way by proposing debates in collaboration with Sciences Po Grenoble or in the framework of the European networks of which Grenoble is a member (Unite!, Aurora).

III.3- Contribution to the visibility of UGA in a national and international context

III.3.a- Interaction with the PEPR decarbonation. The work program of CO2Challenge is relevant to two national acceleration Priority Research Program and Equipment (PEPR) and one exploratory PEPR, all three currently under final evaluation:

The first one is the acceleration program on bio-sourced products, white biotechnologies and durable fuels which should contain a focus on biofuel production with microalgae. The second one is the acceleration program on industrial decarbonization, that will include a targeted program on e-fuels and solar fuels, in which two UGA teams are involved. Finally, artificial photosynthesis is one focus of the LUMA exploratory PEPR but the focus of this project is more on harnessing light-matter interactions than on the promotion of catalysis and CO_2 conversion.

A few teams from UGA are involved in the two PEPR projects. Funded research is related to WP1 (1 project on CO_2 photoreduction) and WP3 (1 project on CO_2 electroreduction, 2 projects on biomethanation/ bioelectromethanation and 1 project on biofuel production using micro-algae) but this only funds a low fraction of the teams active in this field of research in Grenoble and, to the best of our knowledge, the Grenoble teams are not involved in the work program of these two PEPR targeting the coupling of carbon capture and catalytic transformation and the development of prototypes to gain data for life cycle assessment. More importantly, the socio-technical and socio-economic studies planed in these two projects will mainly focus on their major work packages (electrification, biomass valorization...) : Within Axis 1 of the Industry decarbonation PEPR about new prediction and monitoring tools, the G-SCOP lab will contribute to the research of data analytics methods for diagnosis and real-time control of continuous chemical processes in order to identify the main contributors to greenhouse gases emissions and propose solutions to decarbonate the process while ensuring the production activities. This research will be carried out using AI for decision-making, system controls and life cycle assessment, to propose a framework for the management of industrial systems with a view to decarbonization. Furthermore, researches of the Life Cycle Assessment method itself will be focused specifically on dynamic decarbonation strategies drafting, thus not much on the new CCU technologies that will be fostered in CO2Challenge.

CO2Challenge will therefore allow an effective structuration of the local community across disciplines and, importantly, include and fund more teams and researchers from UGA. Our objective is to increase the visibility of the Grenoble community to the national level. In that prospect, the few teams already identified in the above two PEPR projects will act as ambassadors to promote the research carried out at UGA and help the other researchers from UGA to establish connection with the French community.

CO2Challenge is committed to ensuring that the same project cannot be financed by both the CDP and any of the PEPR or other funding source (ANR, EU, industry…), but proposes to target funding that allows for synergy between these different funding sources.

III.3.b-Initiation and strengthening international collaboration*.* Researchers of CO2Challenge have already developed many international collaborations with several countries over the world with projects related to the scientific question addressed by CO2Challenge (past, current and under evaluation projects: COST, ITN/DN (MSCA), Twinning, ANR-DFG/Switzerland/Japan, international IDEX with Japan, USA, Canada, etc.). The UGA is a strong supporter of the Sunergy initiative aiming at promoting solar energy as a driver for the establishment of a circular economy and the production of fuels and chemicals from abundant molecules from the biosphere, among them CO_2 will be the source of carbon. To strengthen these collaborations and initiate new ones, CO2Challenge will propose “short-term mission packs” (see budget Table 5) that will financially cover short-term missions for CO2Challenge researchers to travel to a foreign team (outside France) to develop a scientific project or to acquire a complementary training.

Scientific days and a final conference will be organized during which international speakers will be invited. In addition, the CO2Challenge members will be encouraged to use part of their financial support (through functioning accompanying PhD & master II packs or scientific tickets) to participate in international conferences. All these actions should help to initiate international collaborations.

III.3.c- Benefits for UGA students*.* CO2Challenge will contribute to training within the UGA along the following main lines: raise awareness, inform on training courses, provide complementary courses, develop skills.

Conferences or panel discussions will be organized for undergraduates to give them an overview of the issues regarding the CO_2 cycle, existing technical possibilities that could contribute to a carbon neutral scenario and their economic impact. This course format could be part of an interdisciplinary unit dealing with the socio-ecological transitions. We will take advantage of CO2Challenge multidisciplinary team to identify all the courses adapted for future technicians and executives to take up the challenges industry and society must face in regard to CO_2 emissions mitigation. The corresponding knowledge and skills fit within a wider educational framework for mastering the ins and outs of new technologies favoring the energy transition, and we propose a joint effort with the ongoing work on H_2 related courses for the dissemination of the collected information towards students and potential recruiters. This inventory work will also allow identify lacks, if any, or synergies between disciplinary fields that would give students a key added value, and we then would contribute to the design and implementation of these new courses. Training sessions meeting specific expectations of local or national industrial players will also be designed (Air Liquide has already shown interest). A training session devoted to Life Cycle Assessment will be organized for CO2Challenge participants and will be mandatory for PhD students. Interdisciplinary summer schools will be proposed for Master II and PhD students within the CO2Challenge program and beyond, that will include a creative workshop in which they will express hard skills and develop soft skills. Looking further ahead, it will be possible, thanks to the strengthened relationship with industrial players, to bring together multidisciplinary teams of students to work on industrial projects in place of a classical internship, or during their doctorate within the “label REI” program.

III.4. Potential for wide use and mutualisation of the tools and methodologies developed, if necessary in connection with the UGA's technological platforms.

Within the project, several UGA’s technological platforms will be used as indicated in the description of the scientific WPs (Table 2). Besides, the members of CO2Challenge undertake to make available to the scientific community all the methodologies and tools that may be developed. We will also establish a data management plan (DMP) that will ensure that the FAIR principles are respected: the data should be findable, accessible, inoperable and reusable.

IV- Project implementation, including budget justification

IV.1- Project Management, Organization & Governance

The coordination of the project will be censured by the project coordinator (Carole Duboc), who will be the direct link with the UGA (IDEX), and will monitor the progress of the project on a regular basis (research and budget), and a project manager (to be recruited, half time), who will provide assistance in all financial and administrative aspects, in the organization of all management, training and scientific events and animate the communication cell. In her work, she will be accompanied by the co-leaders of the project: Vincent Artero, Véronique Blandin and Thomas Reverdy. Together, they guarantee a representation of the different ambitions of the project in terms of education, research, valorization, interdisciplinarity, internationalization and link with the socio-economic partners.

The steering board will be composed of the co-leaders of the project and of one representative of each laboratory involved in the project and will impulse shared visions and take **decisions**. It will meet twice a year (or upon request). It will examine the reports and recommendations of the scientific council and provide directives to the executive board to ensure that all objectives will be met. The steering board will be responsible for monitoring the project and evaluating the quality of the research activities. It will approve and control the execution of all strategic activities of the network and will be responsible for monitoring the budget.

The executive board will be composed of all WP leaders and chaired by the project coordinator. It will meet every two months. Its role will be **to implement actions to follow the directives of the steering board**, including the communication and formation aspects with the support of the project manager.

The scientific council will be composed of representatives of the different stakeholders: the project coordinator, 3 representatives of each WP, 3 international experts, 6 representatives of IDEX scientific instances (CBS, PAGE, PEM, PSS, SHS, and CEA-DRT), and 2 industrial representatives. The steering board will be in charge of the list, which may evolve during the course of the project. The scientific council will meet twice a year and will **prepare reports with recommendations for the steering board**. It will be a place for discussions to make the project evolve, to find collective solutions to the research problems encountered, to consider the international and scientific positioning of the project.

The proposed organization of the governance and the high experience of the executive board's members in interdisciplinary and multi-partner project management (ITN/DN, COST, ANR -PRC and PRI) will lead to an optimal progress and risk management of the project (with a reorientation of certain projects if necessary).

Table 3. Description of WP4

WP 4. Management & Organization
WP leader: Carole Duboc
Laboratories: all teams of the consortium
Objectives. **-** Ensure that the progress of the scientific objectives and activities of CO2Challenge are in line with the planned schedule and comply with the budget. - Ensure the impact of the CO2Challenge scientific project will have an impact on the scientific community, raise awareness among the general public of CO_2-related issues and possible solutions, initiate and strengthen collaborations with the non-academic sector and international partners, and stimulate lasting relations between them. - Ensure that all actions planned to promote the multidisciplinary aspects of the project will be organized to initiate interdisciplinary collaborations, raise the researchers' and the next generation's awareness of the importance of a cross-sectoral approach to better meet the current and future societal challenges, and train the CO2Challenge participants to other disciplines than their expertise to enable them to find the most appropriate strategies to develop their own research.

Task 4.1. Project coordination. Prepare tracking tools for the project (including a Gantt chart). Ensure the smooth running of the scientific project. Ensure the organization of all project meetings. Monitor and update project risks and advise on actions as needed. Prepare and check the progress of the data management plan and its implementation. Ensure the communication between the different CO2Challenge committees and boards.
Tasks 4.2. Calls for funding. Define, organize and follow all the procedures for the project calls (PhD/postdoc packs, Scientific tickets, International short-term mission tickets, Master II packs.
Task 4.3. Dissemination & valorization plan. Monitor the implementation of the dissemination & valorization plan described in section III.2 and propose adaptations if needed. Implement the website that will report on all actions of the project in a lively style (regularly updated), including the presentation of the consortium & objectives, kick-off, recruitment, workshops, public events, main achievements, publications, participation to conferences.
Task 4.4. Organization of scientific events for all publics. Ensure that all planned scientific and training events (conference, scientific days, summer schools, …) will be organized, especially with the active participation of the young researchers. Other events will be encouraged to raise among all types of non-scientific audiences, from very young children to the elderly, awareness of the issues associated with the increased atmospheric level of CO_2 and of possible solutions. Project members will be encouraged to publish articles in the non-specialized (online) press/media (the conversation, national newspapers, local newsletters).
Task 4.5. Collaborations with the non-academic sector and international collaborations. Enhance the relation between the academic and non-academic sectors through the involvement of the industrial partners to the Scientific council (discussion & advices) and organization of events where industry meets academy. Ensure sustainable collaboration with international partners and initiate novel collaborations.
Task 4.6 Multidisciplinary actions. Organization of (i) interdisciplinary summer schools (in relation with the EUR-CBH) for master II and PhD students, (ii) training sessions that will answer specific demands from the academic and industrial sectors (including in-company training), including LCA training, (iii) monthly seminars during which CO2Challenge participants will be invited to explain in a pedagogic way their project, and (iv) trimestrial meetings (half day) where PhDs, postdocs and master II students will be invited to present their results in front of all the CO2Challenge participants.

Table 4. Timetable of the non-scientific activities

	2022	2023			2024			2025		
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
Organization										
Website online & updated										
Data management plan & implementation										
Training events						SS		TS/I	SS	
Conferences	KO			SD	IW		SD	IW		FC

KO: kick-off, FC: final conference, SD: scientific days, SS: summer schools, IW: industrial workshops, TS/I: specific training session towards industrials.

IV.2. CO2Challenge and beyond: networking and key UGA partners

IV.2.a- Non-academic sector. Researchers from the project are already privileged partners of several companies, including GENVIA (electrolyser project), and Total Energy (joint research team within the LPCV, microalgae project). Furthermore, through the Arcane component, strong contacts have been made with Air Liquide, in particular the local branch, which wishes to develop specific collaborations with the Grenoble laboratories in order to develop joint research projects, including projects linked to the CO_2 valorization. Air Liquide also has high expectations in terms of professional training adapted to their staff with regard to the changes in expertise that will accompany the industrial renewal.

To broaden the number of contacts beyond these identified connections, we will use one of CO2Challenge strengths: its ability to network. CO2Challenge participants would interview their contacts (industrial players, non-profit organizations, local governments) to gather information on their needs and expectations regarding CO_2-related issues so that we could propose collaborations based on UGA expertise in research and in the design of training sessions. Industrial workshops will be organized to promote CO2Challenge field of action, and a speed dating session will be included to prompt direct interactions.

As a complement to this proactive approach, we will work in tandem with UGA representatives that are entry points for industrial companies or local governments.

IV.2.b- Articulations with trans-laboratory bodies and other UGA structures.* Strong interactions with different local partners have been initiated during the preparation of this project and we have received solid supports. The LabEx Cemam and Lanef, the EUR-CBH together with its components Arcane and Gral have accepted to co-fund PhD packs (one each of them, see below paragraph IV-3.1 budget). They are also interested in co-organizing scientific and training events.

We will naturally ask for the support of the different UGA services, including the "DGD Recherche, Innovation et Valorisation" (to accompany researchers who want to valorize their innovations), "DGD Formation" (to develop continuous training adapted to the industrial partners) and "DGD Développement international et territorial" (to initiate and strengthen international collaborations). Our project being in line with the strategic axes set for the UGA social and environmental responsibility, we will also work with the "RSE team".

Within the context of valorization, we will be interacting with Floralis, the CEA and CNRS valo cells, and the SATT linksium, local actors, with whom particular interactions have already been created with different CO2Challenge researchers and also through other actors such as LabEx and EUR.

IV.3- Budget

IV.3.a- Description of the budget. The budget proposes to cover the expense of **3 PhD packs of 120 k€** including the full salary for 3 years PhD (or 24 months postdoc) and operating costs, **6 co-funded PhD packs of 70 k€** including the 18 months of PhD salary and operating costs, that will be equally divided into each WP (1 funded + 2 co-funded). The research projects will be also financially supported through **12 scientific tickets of 15 k€** for operating costs, equipment costs or salary and **10 master II packs of 5 k€** to cover the gratification of the student and operating costs. The permanents and non-permanents will be also assisted to initiate or strengthen international collaborations through **10 short-term mission packs of 3 k€.** The rest of the budget will be allocated **for 25 k€ per year for the training and communication actions** (schools, scientific days, public events, …) and for **25 k€ for the running of the project** (website, committees, salary of a half-time project manager).

Table 5. Budget

	9 PhD packs	12 Scientific tickets	10 Master II packs	10 Inter. missions	Training & Comm.	Management	Total
Salaries	600 k€					60 k€	660 k€
Functioning	180 k€	180 k€	50 k€	30 k€	75 k€	25 k€	540 k€
Total	780 k€	180 k€	50 k€	30 k€	75 k€	85 k€	1 200 k€

For the PhD packs, all topics relevant to carbon capture and utilization will be open in 2022 for calls for proposals (i.e., the 6 co-funded PhD projects on topics already identified in the three WPs, beginning of the thesis autumn 2023). Regarding the scientific tickets for joint research projects, 2 open calls in 2023 and 2024 are planned since the budget should be used within 2 years. For the master II packs, 3 open calls (every year) will be organized. International short-term mission packs will be allocated on a case-by-case basis throughout the project.

IV.3.b- Co-funding. CO2Challenge has already obtained support of different local instances to co-fund specific actions:

- 6 co-funded PhD packs: the EUR-CBH and its Arcane and Gral components will co-fund 3 packs (each of them one), the labex Lanef and Cemam, 2 others, and 1 pack will be open for an international collaboration. The different scientific teams involved in CO2Challenge are engaged in many international collaborations and are attracted by such opportunity. **This represents 300 k€ of co-funding.**

- PhD and postdoc students funded by other means coming from academic resources including ANR, EUR-CBH, local labex, CEA, MRENT grant, …, but also from industrial supports though CIFRE grants will contribute to the achievement of the CO2Challenge project. At this stage, it is difficult to estimate the corresponding co-funding (**8 620 k€ of co-funding based on the running projects**), but from the 27 funded projects, 19 include salaries for PhDs /postdocs.

-Training: the training events will be organized in consultation with local and national instances and will therefore benefit from additional financial support (CNRS for thematic schools, EUR-CBH for transdisciplinary summer schools, as examples), but also from industrial support when specific training courses are organized for particular industrial demands. **This represents a co-funding of about 20 k€.**

Energy-related issues (development of new non-fossil fuels, (bio)fuels, syngas) and environmental issues (reduction of CO_2 concentration in the atmosphere) are at the heart of PIA4's preoccupations. Thus, the local structuring of all the actors in this field at the UGA level through a translational approach, combined with a strong interaction with the industrial sector will be a strong asset to meet the challenges of the PIA4. As explain above several projects are likely to be funded by the acceleration PEPR on industry decarbonisation, bio-sourced products and possibly Light-Matter interactions, which represent a **co-funding of about 0.5 to 1 M€ o**ver the 3-year duration of CO2Challenge.

IV.4- Feasibility, risk management

Since the **CO2Challenge research project** involves challenging cutting-edge inter-disciplinary techniques and methodological developments, it may be confronted with technical problems, scientific issues or delay of output. Fallback solutions will be chosen on a case-by-case basis depending on the nature of the difficulty encountered. The executive board (WP leaders), which will meet every two months, will specifically monitor and reassess the risks identified in this proposal, will be responsible in highlighting the unexpected risks and will propose, together with the scientific council, mitigation measures, to be voted by the steering board.

Table 6. Description of identified risks and proposed solutions.

Risks (High-Medium-Low)	Solutions
WP1. Disruptive combined CO_2 capture and conversion technologies using renewable energies: proof of concept and ecological planning	
Issue to link CO_2 storage and utilization (low)	The targeted millifluidic catalytic reactor will be based on a promising CO_2 storage strategy and on efficient catalytic systems to transform CO_2, thus overcoming the most problematic issues.
Lack of coordination between the different teams that could slow down the development of ecological planning (low)	The development of ecological planning requires the transfer of information and results from other teams. Regular meetings and presentations will be organized to facilitate these exchanges.
WP2. Toward innovative CO_2 transformation strategies combining high performance with low environmental impact	
Issues to enhance the robustness of the catalysts (medium).	Several strategies are envisaged, including the heterogenization of the most promising catalysts, a field in which the consortium has experts who have developed several approaches, and the understanding of the degradation mechanism, an original approach which will make it possible to identify the key factors to be played on.
Late availability of lab data of technologies under development for LCA (low).	Creation of a database of existing data among members of WP1 and WP3 early in the project to identify the gaps to be filled and target the most relevant case studies.

WP3. Near-mature technologies & leverages for implementation	
Issue to develop of CO_2 (co)-electrolysers (low)	The design of CO_2 (co)-electrolysers being based on mature technologies conceived for water electrolysis into H_2 and O_2 and implemented by consortium members, their transposition to CO_2 should not cause major problems.
Lack of interaction with the economic actors, other interested parties and policy makers, in order to understand economic and political issues. (medium)	CO2Challenge participants will share their network of contacts involved in public policy debates.
WP4. Management & Organization	
Lack of interaction between the different academic partners/teams (medium)	Monthly interdisciplinary seminars, and trimestrial meetings where PhDs, postdocs and master II students will present their results in front of all the CO2Challenge participants should prevent this situation & additional actions will be implemented if necessary.
Lack of interaction between the academic and industrial partners (low)	There are already several official partnerships with companies and the consortium is used to managing this type of collaboration with the support of the "valorization services", including that of the UGA. Specific actions are also planned to strengthen these links and develop new ones.

IV.5- Commitment to the evaluation of the carbon trajectory over the duration of the project

Finally, we will not limit ourselves to developing research related to environmental and energy issues, but we are committed to having an environmentally friendly policy in our decisions for the organization of events and meetings, and to raising awareness of the consortium on these issues throughout the project.