# The role of carbon capture, storage and utilization in the global energy system: long-term optimization and decarbonation of the industry

Lucas Desport, MINES ParisTech, 06.76.69.12.22, lucas.desport@mines-paristech.fr
Sandrine Selosse, MINES ParisTech, , sandrine.selosse@mines-paristech.fr

## Overview

Because of the concern and awareness raised by climate change and global warming, most of the countries have engaged their energy transition. In order to mitigate these phenomena, different pathways exist and are already incorporated into the economic system. The pillars are energy efficiency enhancement, renewable energies utilization and a behavior change of the consumers. Those necessary and unescapable pathways can reduce human greenhouse gas (GHG) emissions. Recurrently, carbon capture and storage (CCS) technologies appear as an additional option to achieve carbon neutrality. In this context, the purpose of this study is to explore the value that CCS can bring to the world energy system and the environment. In particular, we aim at focusing on the decarbonation of industry by capturing, storing and using carbon dioxide (CCUS) as a merchant product in a circular economy. Practically, a long-term optimization with an integrated assessment model (IAM) named TIAM highlights technico-economic optimal pathways to respect the Paris Agreement using CCS and CCUS technologies in the world energy mix and industry. The added-value stands in the analysis of the realistic nature of those optimal pathways in terms of costs, policies, technologies and regional variability.

## Methods

Those past years, numerous studies about CCS and CCUS emerged as the interest for it grows. This is illustrated by the number of articles published since the beginning of the century (Figure 1). These removal technologies are currently analyzed and studied under various aspects such as costs [1], technical methods [2], acceptability [3], resources potentials [4] or regional variability [5]. But the possibility of utilizing carbon dioxide with CCUS technologies has raised interest more recently, hence the smaller number of studies compared to CCS.

In order to study the deployment of various CCUS technologies for the next decades and over a long-term optimization, it is first required to well know and understand their differences and specificities regarding the aspects cited before. Thus, summarizing the findings about the utilization of $CO_2$ is an important primary step and it needs to be done all along the study. It allows both a rigorous implementation of each technology in the IAM and key information for the assessment of the output solutions.

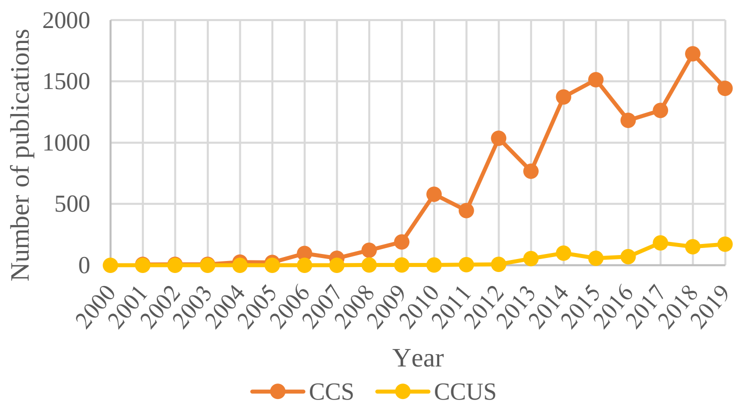


*Figure 1. Number of articles about CCS and CCUS published per year [Source: ScienceDirect]*

This analysis is developed with TIAM-FR, the French version of the TIMES Integrated Assessment Model, a linear programming TIMES family model developed under the IEA's Energy Technology Systems Analysis Program (ETSAP) [6]. More precisely, TIMES is a generator of partial equilibrium techno-economic models representing the energy system of geographical areas. Thus, TIAM-FR is the bottom-up TIMES model representing the world energy system. For each area and time period determined by the modeler, it depicts the world energy system with a detailed description of different energy forms, technologies and end-uses, thus constituting the Reference Energy System (RES). Several thousand existing and future technologies described by their economic and technological parameters are connected to the RES for all sectors in the energy system (industry, commercial, agriculture, transports, etc.). Those last ones are also characterized by their energy carriers, energy services, materials and GHG emissions. Driven by end-use demand, the model aims at supplying energy services at minimum global cost by simultaneously choosing the best investments and operations to apply to the energy system, dealing with numbers of environmental and technical constraints.

In addition, via the dual solution, in other words the "shadow price" of each commodity of the RES (fuels, materials, energy services, emissions), the marginal costs of environmental measures such as GHG reduction targets can be discussed. The interest of this type of model is the opportunity they offer to explore the possible energy futures in the long term based on scenarios, *i.e.* consistent assumptions on the trajectories of the determinants of the system.
The enrichment of the various CCUS technologies into the model proposes new optimal pathways to reduce $CO_2$ emissions and decarbonize the industry at lower costs. The 2°C and 1.5°C mitigation ambitions are studied. Although debatable, the enhanced oil (resp. gas) recovery (EOR resp. EGR) is already commercialized but other $CO_2$ use technology pathways are currently in development such as thermochemical $CO_2$ conversion, electrochemical and photochemical $CO_2$ conversion, carbonation and cement uses of $CO_2$ and biological $CO_2$ uses [7]. Once again, the primary study is used to discuss the feasibility and realistic nature of the optimal pathways.

## Results

The purpose of this study is to find optimal pathways to allow the research, development and the commercial deployment of CCUS through industry portfolio business. The results shed light on the most pertinent investments the global energy system should consider in terms of technology but also on the geographical areas, the intensity and the time and periods along the 21$^{th}$ century. To assess the results, we focus on indicators such as avoided emissions, the structure of the system, costs and investments. Especially for cement industry, iron and steel industries, refineries and hydrogen industries, the results provide an optimum distribution of $CO_2$ between the use into the processes, the selling or the storage assuming incentives and discount rates for the storing. Finally, the study ensures important information on the main factors, parameters and assumptions that must be considered carefully regarding their influencing role on the results. This will be achieved with a sensitivity analysis on important drivers such as incentives rates and costs and efficiency of capture, transport and storage.

## Conclusions

This work provides the enrichment of a tool that will bring enlightenments and recommendations on the ways to master our GHG emissions within the global energy system in order to mitigate climate change below the 2°C target at the 2100 horizon. To do so, the study focuses on the decarbonation of the industry by synthesizing all the findings in the utilization of carbon dioxide and incorporating them into a TIMES integrated assessment model. Assessment of the subsequent infrastructure needs and costs is achieved by a sensitivity and feasibility analysis and to evaluate the realistic nature of various scenarios.

## References


[1] L. Irlam, « Global costs of carbon capture and storage », Global CCS Institute, 16 pages, 2017.
[2] M. Bui *et al.*, « Carbon capture and storage (CCS): the way forward », *Energy Environ. Sci.*, vol. 11, n° 5, p. 1062-1176, 2018, doi: 10.1039/C7EE02342A.
[3] S. Shackley, D. Reiner, P. Upham, H. de Coninck, G. Sigurthorsson et J. Anderson, « The acceptability of $CO_2$ capture and storage (CCS) in Europe: An assessment of the key determining factors: Part 2. The social acceptability of CCS and the wider impacts and repercussions of its implementation », *International Journal of Greenhouse Gas Control*, vol. 3, p. 344-356, may 2009.
[4] S. Selosse, « Bioenergy with carbon capture and storage: how carbon storage and biomass resources potentials can impact the development of the BECCS », in *Bioenergy with Carbon Capture and Storage*, Elsevier, p. 237-256, 2019.
[5] J. Kearns, G. Teleztke, J. Palmer, H, Thomann, H. Kheshgi, Y-H Henry Chen, S. Paltsev et H. Herzog, « Developing a consistent database for regional geologic $CO_2$ storage capacity worldwide », Energy Procedia, vol 114, p. 4697-4709, 2017.
[6] R. Loulou et M. Labriet. « ETSAP-TIAM: the TIMES integrated assessment model Part I: Model structure. Computational Management Science », Special issue "Managing Energy and the Environment", p. 7-40, 2008.
[7] National Petroleum Council. "Meeting the Dual Challenge : A Roadmap to At-Scale Deployment of Carbon Capture Use and Storage", vol 3, chapter 9 : $CO_2$ use, 49 pages, 2019.