Carbon capture, storage and use

Preface

Claude Mandil, Former Executive Director, International Energy Agency (IEA)

Introduction

Dominique Auverlot, CGDD, and **Richard Lavergne**, CGE

Achieving global climate goals (1.5°C) would be socially and economically unacceptable without the use of CCUS and other GGR (Greenhouse Gas Removal)

Net zero commitments drive global momentum for CCUS

Mary Burce Warlick, Deputy Executive Director, International Energy Agency (IEA)

A net-zero energy system requires a profound transformation in the way we produce and use energy. This can only be achieved with a broad suite of technologies. Carbon capture, utilisation and storage (CCUS) is the only group of technologies that contributes both to directly reducing emissions in key sectors and to removing CO_2 to balance emissions that are challenging to avoid – a critical part of "net" zero goals.

Over the years, CCUS deployment and investment has lagged behind other clean energy technologies. However, new investment incentives and strengthened climate goals are building a renewed momentum behind CCUS. In 2021, over 100 CCUS projects have been announced in over a dozen countries.

In order to translate ambition into action, governments and industry can build on this global momentum in four key areas: create favourable investment conditions; coordinate and underwrite industrial hubs and shared infrastructure; encourage CO_2 storage development; and boost innovation.

State of the art of CCS and CCUS: description, cost, constraints

Pierre-Franck Chevet, François Kalaydjian and **Guy Maisonnier**, IFP Énergies nouvelles (IFPEN)

CCUS – CO_2 capture and transport, followed by storage or use – is a mature technology option, which is included in most scenarios aimed at limiting global warming to 1.5°C. CO_2 capture can be operated on existing or future power plants or industrial units, thus allowing the decarbonization of cement, iron, steel or chemical production. CCUS also paves the way for low-cost, low-carbon hydrogen production. By combining it with bioenergy (BECCS) or implementing it directly into the air (DACCS), CO_2 capture can result in negative emissions that offset unavoidable or technically difficult to reduce emissions. In terms of recovery of captured CO_2, the production of synthetic fuels seems to be the most promising solution to meet the needs of the aviation sector. However, the deployment of these different options will depend on their societal acceptability, the reduction of the corresponding costs, and the public support aimed at valorizing the reduction of CO_2 emissions.

Global overview of CO_2 storage potential

Isabelle Czernichowski-Lauriol, Delegate for research and public policy support at BRGM, President Emeritus of the CO_2GeoNet association and member of the Board of Directors of the French CO_2 Club, and **Christophe Poinssot**, Deputy Director General and Scientific Director of BRGM

Since the 2005 IPCC Special Report on CO_2 Capture and Storage, which indicated a global storage potential in geological formations of at least 2000 $GtCO_2$, various methodologies for estimating storage capacities have been proposed. Many countries have estimated their CO_2 storage potential, based on volumetric calculations, and about ten of them have developed atlases presenting their CO_2 storage potential. For a number of potential storage sites, more precise estimates of storage capacity have been made, based on dynamic simulations of CO_2 injection into the storage reservoir. Despite the high uncertainties related to the limited data available on the deep subsurface and the natural heterogeneity of the geological formations, the estimated global storage capacities are much higher than the storage needs to combat climate change.

The development of UK CCUS strategy and current plans for large-scale deployment of this technology

Jon Gibbins, UK CCS Research Centre, University of Sheffield, and **Mathieu Lucquiaud**, University of Edinburgh

For over 20 years, carbon capture utilisation and storage (CCUS) has been recognised as a useful tool to help reduce UK national emissions. Over this period the target reduction in greenhouse gas emission rates for 2050 has increased, from 60% to 100%, i.e. net zero. This has led to change in the role envisaged for CCUS, from initially just cutting emissions on coal power plants by around 50%, to the point where capture and secure sequestration of all fossil CO_2 emissions is required, either directly at source or indirectly via carbon dioxide removal from the air (CDR). Additional CDR, either through the use of biomass energy with carbon capture and storage (BECCS) or direct air carbon capture and storage (DACCS), will also be required to compensate for other UK greenhouse gas emissions. Potentially over 100 $MtCO_2$/yr of CCUS is needed by 2050. Current UK plans are to establish four CCUS clusters by 2030, capturing and storing a minimum of 10 $MtCO_2$/yr from industry, power, hydrogen production and, potentially, CDR. The UK has a large amount of secure storage capacity for CO_2 in geological formations a kilometre or more below the sea bed in the North Sea and the Irish Sea.

State of the art of CCUS and other RMM processes

CCUS and Coal – Are there still development opportunities for coal plants?

Sylvie Cornot-Gandolphe, president of SCG Consulting

More and more governments have committed to reach net zero carbon emissions by 2050. They are moving away from coal and accelerating the build-up of renewable energies. In this context, what is the development of CCUS on coal-fired power plants? The article answers this question by first explaining the reasons for the failure of the first wave of CCUS projects in the 2000s, which mainly focused on capturing emissions from coal-fired power plants. Then, it examines the application of CCUS on coal-fired power plants in the context of the renewed interest in CCUS since 2018. CCUS policies and projects in three key countries (the United States, China and India) are studied. This analysis shows that CCUS remains essential in Asia for decarbonizing the electricity mix, still largely dominated by coal, but its contribution requires a carbon price signal and research efforts to reduce the costs of CO_2 capture. CCUS contribution may be reduced by the early closure of coal-fired power plants, their repositioning, and advances in disruptive technologies.

CCS projects underway at TotalEnergies

David Nevicato, Head of business development and partnerships for the CCS (Carbon Capture and Storage) division at TotalEnergies

TotalEnergies' CCS first actions are focused on Europe with a strong traction enabling to scale up CCS at an industrial scale. Business development will continue in other parts of the world in line with the growing wave of projects where our European expertise could serve the necessary adaptations. TotalEnergies has expanded its efforts in this domain via several major North Sea projects, such as Northern Lights in Norway, the first worldwide commercial CCS chain, Antwerp@C in Belgium, one of the main CO_2 hubs in Europe, the Aramis and Azur projects in the Netherlands, respectively CO_2 storage in depleted gas fields and blue hydrogen in a refinery, and finally Net Zero Teesside and the Northern Endurance Partnership in the UK, respectively CO_2 capture coupled with gas fired power generation and CO_2 storage, in a deep saline aquifer, in the U.K. offshore.

ExxonMobil: Carbon capture is critical to attaining society's emission-reduction goals

Joe Blommaert, President, ExxonMobil Low Carbon Solutions

Few challenges are more important than meeting the world's growing demand for energy while reducing environmental impacts, including the risks of climate change. ExxonMobil believes carbon capture and storage is an essential technology to help meet this dual challenge, because it is one of the few proven technologies that could enable some sectors to decarbonize, such as manufacturing and heavy industry.

ExxonMobil has more than 30 years of experience with CCS technology, including the design, construction and safe operation of carbon capture and storage facilities around the world. Additional opportunities are under evaluation, and they all have the potential to move forward with current technologies, provided stable, supportive policies and regulatory frameworks are established.

The opportunities offered by the CCUS to decarbonize French industry

Benoît Legait, Honorary Engineer General of Mines

In industry, CO_2 capture and storage is mainly of interest to the steel and cement industries, and allows "negative" emissions for carbon dioxide from biomass combustion. In 2050, about 15 Mt CO_2eq should be captured and stored, provided that several obstacles are removed. The use of CO_2 seems especially promising for crop growth and ethanol production: it still requires increased R&D efforts.

The potential of geological storage of CO_2 by mineralization

Sylvain Delerce, Graduate engineer from AgroParis-Tech, et **Éric H. Oelkers**, Director of research at the CNRS

Since the mid-2000s, researchers have been actively working on carbon storage through mineralization with a major milestone reached in 2016 with the results of the European CarbFix project in Iceland. Since then, this technology has been deployed at an industrial level on the Hellisheiði geothermal power plant and combined with direct air CO_2 capture (DAC in English). In this paper, we explore the mechanisms of mineralization to assess its potential in the fight against climate change. The history of the CarbFix project allows us to highlight the viability of this method and show that it is ready for large-scale deployment.

No decarbonization of the aviation sector without CO_2 capture and storage

Dominique Vignon, Member of the French Academy of Technologies

Greenhouse gas emissions (GHG) from aviation are increasing by 7% per year. In September 2021, IATA, the industry's organization, announced that it was aiming for "zero net emissions" by 2050.

In addition to better control of traffic growth, the reduction of emissions will essentially mobilize fuels that can be directly substituted to kerosen, the SAFs (synthetic/sustainable aviation fuels), the potential of hydrogen being limited until 2050. However, SAFs have a marginal carbon content and their availability is not sufficient to cover all traffic.

It is therefore estimated that aviation will need to use carbon sinks from the 2020s, which are expected to reach 1.5 Gt of CO_2 per year by 2050. The certification of sequestered emissions is tricky, and an organization independent of the industry must be set up.

The storage of French emissions to reach the net zero emissions target exceeds the objectives of the SNBC.

Social acceptability of CO_2 capture, transport, use and storage technologies: a task of adjusting the technical project and the stakeholders

Jonas Pigeon, Doctor in spatial planning

Carbon Capture, Transport, Utilization and Storage (CCUS) technologies can rapidly reduce greenhouse gas emissions from the industrial sector without fundamentally changing the socio-economic model. Although the various components of this technical device have been used for a long time in industry, it remains underdeveloped. According to sector experts, one of the limiting factors in the development of CCUS is the lack of social acceptance. In this article, we will first recall the conceptual and epistemological issues of the notion of social acceptance. Based on these theoretical materials, we will then analyze different cases of CCUS technology development. This analysis will finally allow us to identify the fundamental issues of the social acceptance of these technologies.

The development of negative emissions

Carbon storage in soils

Claire Chenu, UMR Ecosys, Université Paris-Saclay, INRAE, AgroParisTech, **Jean-Luc Chotte**, UMR Eco&Sols, IRD, CIRAD, INRAE, Université de Montpellier, SupAgro Montpellier, et **Paul Luu**, Executive Secretariat of the International "4 by 1000" Initiative

Soils globally represent a major stock of carbon, approximately 2400 Gt of C, as soil organic matter. While a small loss of this stock would have disastrous consequences for the climate, a small increase could help mitigate climate change. This article presents the characteristics of this storage, the soil management options that can protect and increase the existing soil organic C stocks, the performance of these options, as well as the many associated benefits in terms of soil fertility and therefore food security, adaptation to climate change and ecosystem services, but also the barriers to implementation and associated risks. Even though C storage in soils is a low-cost negative emission technology, as widely promoted by the international "4 per 1000" initiative, incentives are truly needed to enable its implementation.

Direct Air Capture (DAC) in Germany: resource implications of a possible rollout in 2045

Simon Block, Research assistant in the Division of Future Energy and Industry Systems at the Wuppertal Institute for Climate, Environment and Energy, and **Peter Viebahn,** Head of the Research Unit Sectors and Technologies within the Division of Future Energy and Industry Systems at the Wuppertal Institute for Climate, Environment and Energy

Direct Air Capture (DAC) is increasingly being discussed as a possibility to limit climate change. In this study, a possible rollout of the DAC technology at German coastal areas is analysed based on an existing climate neutrality scenario. For the year 2045 the resulting costs as well as land, water and energy consumption are examined. It is concluded that a realization of the DAC technology in Germany might be possible from a technical point of view. However, there is a high demand for land and energy. Since a rollout is needed to start in 20 years at the latest, the required discussion and evaluation should be initiated as quickly as possible.

Geoengineering - Perspectives, limits and risks

Ilarion Pavel, Ingénieur en chef des Mines – CGE

Geoengineering refers to technologies aiming at controlling the Earth's climate, in order to fight the Earth' global warming caused by human activities, in particular by the emission of greenhouse gases. They can be divided into two classes: management of solar radiation and extraction of atmospheric CO_2. The article reviews these various technologies and analyzes their limitations and risks.

Geoengineering and solar radiation management

Anni Määttänen, Sorbonne université, UVSQ Université Paris-Saclay, CNRS

Solar geoengineering aims at cooling the climate by decreasing the solar radiation entering the climate system through changing the reflectivity (albedo) of the Earth. To achieve this, it has been suggested to increase the albedo of clouds, paint surfaces white or inject reflecting particles into the stratosphere. Research on these topics is active and is based mainly on numerical modelling studies. The possible deployment of these methods raises questions on their technological feasibility, side effects, uncertainties, governance and ethics. This article presents a review of the solar radiation management methods.

Issue editors :
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