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Carbon Capture and Utilization: CO_2 as an Asset?
Recovery and Reuse of CO_2 from Power and Industry Sectors

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ABSTRACT

The implementation of Carbon Capture, Utilization and Storage (CCUS) technologies in the Energy and Industrial sectors was one of the various strategies, indicated by the International Energy Agency (IEA) at the beginning of this decade to invert the trend of increasing CO_2 emissions, together with the development of renewables and increase of energy efficiency. Although Research and Development efforts have been going on intensively in the last decade, the development of CCUS technologies is still far below the objectives fixed. Technical, economical, political and social issues related to CCUS are reviewed in this paper, together with an analysis of the main utilization strategies and ongoing projects in the world, and of the Italian situation.

1. INTRODUCTION

Carbon capture, utilization and storage, or CCUS, is an important emissions reduction strategy that can be applied across the energy system as well as in industry. Figure 1, adapted from the IEA website, indicated what is the actual trend of CO_2 emissions (in particular those related to energy production) and where we would need to go according to the sustainable development scenario (SDS).

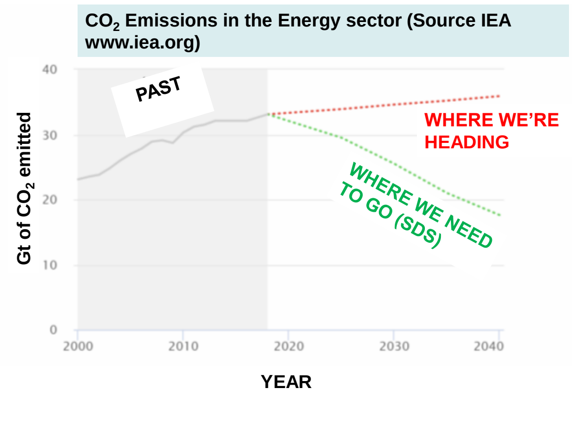

Figure 1. Energy-related CO_2 emissions (www.iea.org)

CCUS approaches involve the capture of CO_2 from fuel combustion or industrial processes, the compression and transport via ship or pipeline, and its use or storage underground in geological sites. CCUS paths are the only ones giving the possibility of actual reduction of current CO_2 levels ("negative emissions"), if the CO_2 is captured at the end of a bio-based processes, or directly from the atmosphere [1].

The current level of CO_2 captured from power and industrial facilities each year equals 35Mtonnes.

The present contribution aims at illustrating the potentialities of CCUS, the role of CCUS in CO_2 emission reductions envisaged by the IEA, and illustrating briefly the situation of the current world projects about CCUS. The contribution, on the other hand, does not aim at giving the technical details about the technologies involved in CCUS. The majority of the information contained in this contribution is public property as it comes from the International Energy Agency (IEA) as well as public research projects websites.

2. CO_2 CAPTURE IN THE CTS AND CURRENT SCENARIO

In the Clean Technology Scenario (CTS), envisaged by the IEA to meet the Paris Agreement targets, CCUS technologies must contribute to 13% of the emissions reductions needed by 2060. In other words, CCUS is the 3rd contribution, after energy efficiency (39%) and use of renewables (36%). About 49% are captured from the power sector, 25% from industrial processes and 27% from processes [1].

In the CTS, 30% of the CO_2 captured are from biomass, creating negative emissions, and 93% is stored underground, while the rest is re-used in industrial processes [1].

2.1 CO_2 capture from power production

The CCUS implementation in the energy sector was one of the strategies envisaged by IEA at the beginning of the decade to tackle the reduction of CO_2 emissions, together with renewables. In Table 1, however, it can be seen that the current status of CCUS is not on track. In the power production sector, current CCUS projects have an overall capture capacity of 2.4 $MtCO_2$ per year, while the sustainable development goals (SDS) aim at capturing 350 $MtCO_2$ per year by 2030 [1].

Table 1. Energy sector decarbonization strategies envisaged by IEA at the beginning of this decade, and current status with respect to what foreseen [1]

Low carbon energy production Strategy	Current status
Renewable power	More efforts needed
Hydropower	More efforts needed
Solar PV	On track
Bioenergy	On track
Onshore wind	More efforts needed
Offshore wind	More efforts needed
Geothermal	Not on track
Concentrating solar power	Not on track
Ocean	Not on track
Nuclear	More efforts needed
Natural gas fired power production	More efforts needed
CCUS applied to power production	Not on track

The largest CCUS projects in the world in the power sector are the one in Petra Nova (Texas, 2017), which is a retrofit post-combustion system on a coal-fired power plant and captures 1.4 $MtCO_2$. The CO_2 is used in Enhanced Oil Recovery (EOR), to extract oil that is otherwise not recoverable. [1]

Another important projects is the one named Boundary Dam (Canada, 2014), capturing 1 $MtCO_2$/year, sold to an oil company for EOR. [1]

The most relevant CCUS projects involving newer technologies are the NET Power project, 2018, a 50-MW energy plant that employs Allam cycle technology, where CO_2 is the working fluid of an oxyfuel, supercritical CO_2 power cycle. The Drax's bioenergy project in the UK is an example of "Carbon-negative" solution, as it captures CO_2 from a power plant fueled by biomass [1].

In 2019, the U.S. Department of Energy (DOE) has announced $110M for CCUS projects. DOE has selected nine projects to receive $55.4 million in federal funding for cost-shared R&D. The selected projects will support FEED studies for commercial-scale carbon capture systems. Most of such projects involve Retrofitting Fossil Fuelled Power plants, while one project deals with membrane-based capture technology [2].

2.2 CO_2 capture projects from Industry

Industry processes that cannot be electrified must reduce emission through increased energetic efficiency, innovation and carbon capture. Industry emits about one-quarter of the total CO_2 emissions. About 30% of such emissions are required to produce high temperature heat, that is mostly obtained by burning fossil fuels. A big portion of emissions is then related to process industry reactions, which cannot be avoided by using alternative fuels. However, in those cases, such as in the production of ammonia, where a relatively pure CO_2 stream is produced, the implementation of CCUS is rather easy. In the IEA Clean Technology Scenario, 20% of the emissions reduction are to be achieved with CCUS, mostly in the cement, steel and chemical sectors [1].

The total number of industry-related CCUS projects was equal to 16 at the end of 2018, while 6 are under development in Europe, three of which are related to low carbon hydrogen production. The deployment of CCUS in industry is still much below the SDS levels (28 $MtCO_2$ versus 400 $MtCO_2$ per year). Policy measures, like public procurement, incentives, tax credits and research funding are needed [1].

The most important projects currently in place are the one in Jilin, China, that captures 0.6 $MtCO_2$ /year for EOR from a natural gas processing plant. A second one in Abu Dhabi recycles 0.8 $MtCO_2$ /year in the iron and steel sector. Finally, the bio-CCUS project in Illinois, USA, capturing 1 $MtCO_2$ /year in a corn ethanol plant [1].

3. CO_2 UTILIZATION

The use of CO_2 in the development of products and services is a valid way for mitigating climate change, developing new technologies and supporting a circular economy. The interest is demonstrated by private funding for CO_2 use start-ups in the US, reaching nearly USD 1 billion.

Around 230 Mt/y of CO_2 are currently used in the world: -) 130 Mt CO_2 in urea manufacturing for fertilizers; -) 70-80 Mt for enhanced oil recovery. Other applications are food and beverage production, metal fabrication, cooling, fire suppression and agriculture [1].

Global consumption of CO_2 is expected to grow steadily in the coming years, especially for EOR and on-site urea production.

3.1 CO_2 in Enhanced Oil Recovery (EOR)

Enhanced Oil Recovery – or EOR – is a process aimed at increasing the amount of oil that can be recovered from an oil reservoir, by injecting a substance into an existing oil well to increase pressure and reduce the viscosity of the oil. Enhanced oil recovery increases the oil recovery by up to 15%. The injection of compressed CO_2 that expands in a reservoir lowers the oil viscosity and improve the flow rate, as CO_2 is a solvent. CO_2 EOR operations traditionally focused on optimizing oil production, while they can result in effective storage.

3.2 CO_2 to fuels

CO_2 could be an important raw material for products that require carbon, such as many chemicals and fuels, in the presence of hydrogen. However, the production of CO_2-based fuels and chemicals is energy-intensive and requires large amounts of hydrogen, so that production costs are currently much higher than for their fossil counterparts. Commercial production is possible in markets where cheap renewable energy and CO_2 are available. CO_2-derived polymers could be produced at lower cost than their fossil analogs, but the market is still small [1].

3.3 CO_2 to chemicals

The carbon (and oxygen) in CO_2 can be used to replace fossil fuels in the production of chemicals and polymers. The most mature technology is the one converting CO_2 to methanol and methane, not to mention that methanol can be later converted into other components useful for making plastics.

Polymer production with CO_2 requires a lower energy than other conversion routes, and can be competitive in the market, due to the relatively low energy required and the polymer high value [1].

3.4 CO_2 to building materials

CO_2 can be used in the production of building materials to replace water in concrete, or as a raw material in its constituents. These applications involve the reaction of CO_2 with calcium or magnesium to form low-energy carbonate molecules. CO_2-cured concrete is one of the most mature and promising applications of CO_2 use. It is less energy-demanding to react CO_2 with minerals or waste streams to form carbonates for building materials [1].

Alternatively, the production of building materials from waste and CO_2 can also be competitive as it avoids the cost associated with conventional waste disposal. The CO_2 used in building materials is permanently stored in the product, and provides larger emissions reductions than products that eventually release CO_2 to the atmosphere, such as fuels and chemicals [1].

3.5 Crop yield boosting with CO_2

CO_2 can be used to enhance yields of biological processes, such as algae production and crop cultivation in greenhouses. The application of CO_2 with heat in industrial greenhouses can increase yields by 30%. The leader Country in this technology is the Netherlands, with an annual use between 5 and 6 $MtCO_2$ [1]. The use of captured CO_2 could ensure climate benefits.

4. CO_2 TRANSPORT

It is evident that, in places such as the US and Canada where an existing infrastructure for CO_2 transportation exists, used traditionally in EOR, the implementation of CCUS is readily achievable. The development of CO_2 transport and storage networks for industrial CCUS hubs can reduce unit costs through economies of scale and facilitate investment in CO_2 capture facilities [1].

The Norwegian project Northern Lights [3] is an example of full-scale CCS project. The project, funded by the Norwegian Government, includes capture of CO_2 from industrial capture sources in the Oslo-fjord region (cement and waste-to-energy) and shipping of liquid CO_2 to an onshore terminal on the west coast. From there, the liquified CO_2 will be transported by pipeline to an offshore storage location subsea in the North Sea, for permanent storage.

It is important to speed up the development of CCUS "hubs" in industrial areas with shared transport and storage infrastructure, to reduce costs of CCUS implementation.

5. CO_2 STORAGE

CO_2 use cannot replace CO_2 storage in reaching the high emissions reductions needed to meet Paris Agreement targets. Obviously, CO_2 use may turn into a more attractive option where the potentiality of CO_2 storage is limited, but it would not reach similar levels of deployment. Moreover, CO_2 used is not the same as CO_2 avoided, because it does not guarantee to reduce emissions, and the exact estimation of benefits for climate requires a complicated life-cycle assessment. For sure, the use of CO_2 is beneficial for climate where the application is cheap, uses low-carbon energy, and contributes to form durable products [1].

The IEA Clean Technology Scenario (CTS) foresees that 107 $GtCO_2$ must be permanently stored by 2060 to meet the emission reductions goals. If a smaller amount of CO_2 is stored, additional measures will be required in order to achieve the target emissions reductions, such as using technologies that are in an early stage of development [1].

6. CCUS POLICIES

Countries like Canada, China, Japan, the Netherlands, Saudi Arabia, UK, US have implemented a CCUS policy [1].

In the US, the 45Q tax credit provides a tax credit for each ton of CO_2 sequestered or utilized. The credit corresponds to $35/ton for CO_2 used in enhanced oil recovery or another application, and $50/ton for permanent geologic storage, the difference corresponding to the value of CO_2 recycled on the market.

Ensuring investment in CCUS, during the early phase of commercialization, will require policy support. Moving from single CCUS facilities to a network of facilities and infrastructures could significantly increase efficiencies and reduce costs of CCUS implementation.

In the UK, where they adopt a target of net-zero emissions by 2050, the Climate Change Committee recognised that "CCS is a necessity, not an option", and commented that the early measures to meet global demand for low-carbon materials and technologies could give UK a competitive advantage.

7. ITALIAN SITUATION

There are several CCUS projects, funded by the EU framework, for instance. led by Italian Universities or research centers.

As far as the CO_2 capture is concerned, the most important projects led by Italian entities are ENOS, NANOMEMC^2, CLEANKER.

The ENOS project, led by OGS Trieste, is devoted at enabling onshore CO_2 storage in Europe with a comprehensive site characterization, monitoring and involvement of the local communities. ENOS strives to enhance the development of CO_2 storage onshore, close to CO_2 emission points. Several field pilots in various geological settings are studied in detail and best practices that stakeholders can rely on produced. ENOS wants to demonstrate that CO_2 storage is safe and environmentally sound and increase the confidence of stakeholders and the public in CCS as a viable mitigation option [4].

The DICAM department of the University of Bologna coordinated the NANOMEMC^2 project that developed high efficient nanomembranes for CO_2 capture. (2016-2019).

In particular, the NANOMEMC^2 project aims to overcome the current limitation of membrane capture technology by focusing on the development of innovative CO_2 selective membranes with high flux and selectivity suitable for application to both pre and post-combustion capture processes. Hydrogen selective (for pre-combustion) and CO_2 selective membranes (for both pre and post combustion) were developed for industrial deployment of carbon capture membrane technologies. The project involved industrial partners such as BP, Colacem and Fujifilm as well as many startups (Figure 2) [5].

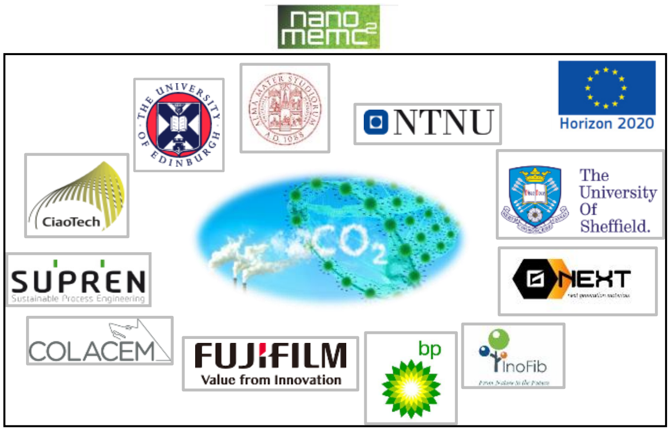

Figure 2. The consortium of the H2020 NANOMEMC^2 project for capture of CO_2 with membranes, coordinated by DICAM UNIBO (www.nanomemc2.eu)

The LEAP consortium based in Piacenza is leading the CLEANKER project, aimed at reducing the emissions in the cement industry by using the calcium looping capture technique. The core activity of the project is the design, construction and operation of a CaL demonstration system in the cement plant operated by Buzzi Unicem sited in Vernasca (Piacenza, Italy) [6].

The Sotacarbo Clean Energy research center [7] is also a main National driver of initiatives in the whole CCUS chain, such as in the ECCSEL European shared research infrastructure facility [8] and through the CCS Summer School organized every year in Carbonia for PhD students [9]. Furthermore, the Center contributes to the storage research studies with the Sulcis storage project [10].

ENEA is also part of the ECCSEL research network and partner of the most important CCUS projects in Europe.

The above mentioned ones are just some examples of the Italian excellence and leading positions in the research in CCUS. Support to projects to develop technologies that make CO_2 capture economically viable is required.

8. CONCLUSIONS

The deployment of CCUS in the CTS requires a rapid scale-up from today's levels, with only around 33 million tonnes of CO_2 (Mt CO_2) currently captured each year [1].

Innovation for CCUS, especially in power generation, needs to achieve cost reductions, improve the efficiency of CO_2 capture, and expand the collection of available CCUS technologies.

Support to projects to develop technologies that make CO_2 capture economically viable is required.

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