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A comparative study of various strategies used for the mitigation of global warming

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Abstract

The global temperature has risen yearly by a bit more than 1 degree Celsius during the industrial revolution. Many experts believe that if current greenhouse gas emissions continue, the planet will become hotter, ocean level will rise and climatic conditions will change excessively. Temperatures are expected to rise faster in the coming decades than they have in the previous 10,000 years, according to some scientists. Greenhouse gases are thought to be the most important factor causing climate change. CO_2 is by far the most important anthropogenic greenhouse gas, with concentration in the atmosphere rising by more than 80% between 1970 and 2021. About 91 percent of total CO_2 emissions from human sources come from fossil fuels. Controlling greenhouse gas emissions and preparing human settlements to withstand extreme climate change have emerged as two of our age's most daunting challenges. The purpose of this study is to discuss and compare various strategies that can be used for reducing or eliminating carbon dioxide emissions. Various CO_2 reduction approaches have been investigated, including the replacement of fossil fuels with renewable energy sources, carbon dioxide capture and storage, and carbon dioxide capture and utilization. The goal of this research is to look at several options for meeting energy needs for long-term development without causing negative climate change i.e. renewable energy sources, carbon dioxide capture and storage, carbon dioxide capture and utilization.

1. Introduction

Global warming is one of the world's most important issues, drawing the attention of scholars, policymakers, and other experts from all around the world. Climate change has increased global warming, environmental degradation, technical dilemmas and societal obstacles. The rise in global temperatures is one of the most visible and direct effect of global warming. The average worldwide temperature has risen by roughly 1 degree Celsius, according to the National Oceanic and Atmospheric Administration in the last 100 years (NOAA). Rising levels of greenhouse gas emissions are regarded to be a primary factor to such issues [1-3]. The key contributions to global climate change have been recognized as Sulphur dioxide, nitrogen dioxide, and CO_2, which has gotten a lot of attention throughout the world. The United States Environmental Protection Agency (EPA) created the Global Warming Potential (GWP) to measure greenhouse gas emissions. For a specific time period, the GWP represents how much energy will be absorbed by 1 ton of a released gas compared to 1 ton of CO_2. The greater a gas's GWP value, the more it will warm the world for the same amount of time as CO_2. The most common time period for calculating GWP is 100 years. Because CO_2 is chosen as a reference, its GWP value remains constant over time, but other greenhouse gases, such as CH_4, have GWP values of 28–36 over 100 years. Chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) have GWP values in the thousands or tens of thousands over 100 years. Although the other greenhouse gases have higher GWP values than CO_2, the net energy absorption is more for CO_2 because it stays in the atmosphere for thousands of years while the other greenhouse gases stay in the atmosphere for much shorter periods of time (emitted CH_4 stays in the atmosphere for almost a decade, emitted N_2O stays in the atmosphere for 100 years). It represents the peak global warming potential of CO_2 over thousands of years. This level of CO_2 in the atmosphere, as well as its lifetime in the atmosphere, causes significant global warming and pollution. CO_2 pollution is also a major contributor to climate change, as evidenced by the rise in ocean water levels, which has resulted in the loss of coastline and coastal wetland areas. These consequences highlight the relevance and necessity of reducing CO_2 levels in the environment. The greater a gas's GWP value, the more it will warm the world for the same amount of time as CO_2. Carbon dioxide has long been thought to be the most significant cause of climate change [4, 5], prompting scientists to look into carbon reduction and mitigation techniques.

Fig. 1 shows the percentage of gases causing the global greenhouse effect [5]. It can be seen 65% of carbon dioxide produce due to fossil fuel and industrial processes, 11% due to forestry and other land use, 16 % due to methane and 6 % due to nitrous oxide. Carbon dioxide emissions, for example, have risen from 22.15 Gt in 1990 to 36.14 Gt in 2014. Global carbon emissions from fossil fuels have risen considerably. Since 1970, CO_2 emissions have climbed by more than 90%, with fossil fuel burning and industrial activities accounting for over 78 percent of the total increase in greenhouse gas emissions between 1970 and 2011. The other largest contributors to global warming are deforestation, and other land-use changes [6, 7].

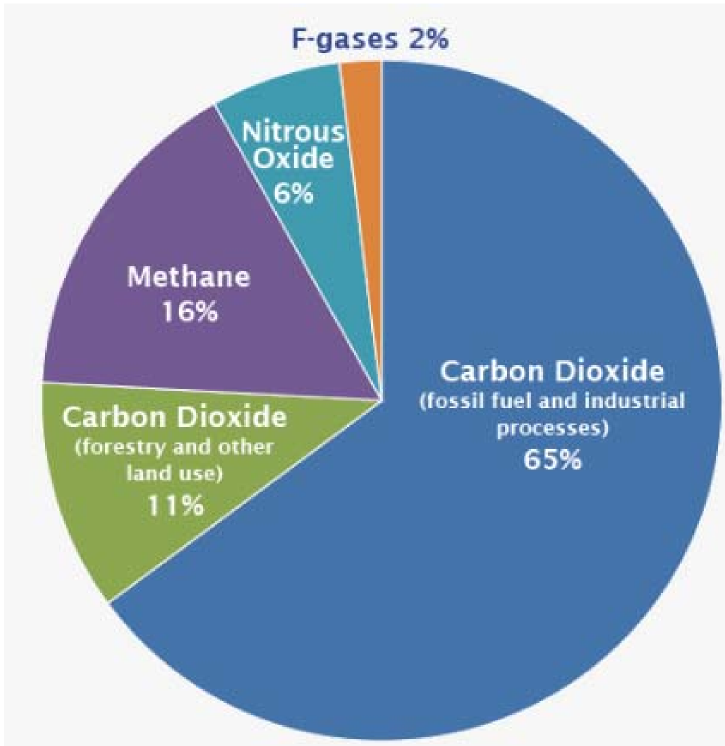

Fig. 1. Percentage of gases causing greenhouse effect [5]

According to Heede [8], 80 percent of worldwide carbon dioxide emissions are attributed to human activities in cities. Huge amount of carbon dioxide is emitted into the atmosphere due to human activities such as the combustion of fossil fuels in automobiles and the burning of fossil fuels for the generation of electricity. Construction and other heavy industries have also been identified as significant sources of CO_2. As a result, scholars around the world have been focusing their efforts on discovering carbon dioxide emission reduction schemes. As a result, monitoring carbon emissions at many stages (consumer, company, regional, and national) has become a useful asset for developing and implementing environmental policies and strategies aimed at lowering carbon emissions.

In the current study, various carbon dioxide mitigation strategies are discussed. This study is mainly focused on three strategies. The first strategy is focused on increasing the use of the renewable energy sources as a replacement for the fossil fuels. The second strategy is focused on injecting carbon dioxide into deep geological reservoirs in order to alleviate the level of carbon dioxide in the atmosphere. The third strategy is focused on converting the emitted carbon dioxide into useful products that will potentially reduce the adverse effects of the global warming.

1.1 Carbon dioxide cycle

In 1981, the first paper on carbon dioxide emission study was published, and it focused on biodegradable chemicals carbon emissions from cooling tower water [9]. Fig. 2 depicts the Carbon Cycle. Plants use carbon dioxide and sunshine to make their own food. Plants are the ones who take up the carbon. Plants that die and are buried may decay into carbon-based fossil fuels like coal and oil over thousands of years [10].

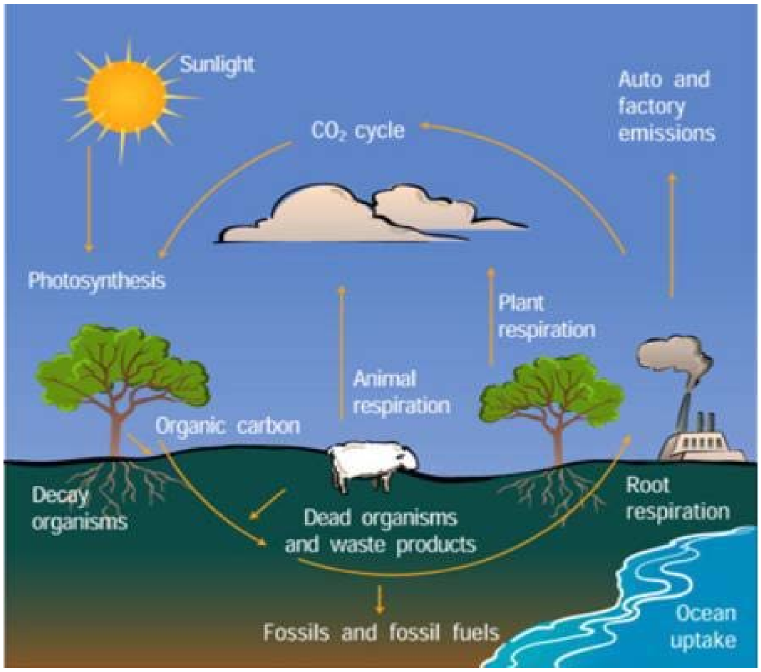

Fig. 2. Carbon Cycle [10]

When people burn fossil fuels, the majority of the carbon is released into the atmosphere as CO_2 [11]. Climate change has become a huge global problem and the most critical issue that the international community must solve in the twenty-first century as a result of rising temperatures [12]. Since carbon emissions were identified as the fundamental cause of climate change, research on global carbon emissions has exploded. China, the United States, Russia, the European Union, Japan and India are among the world's largest carbon emitters, are all concerned about rising carbon emissions [13].

1.2 Mitigating carbon dioxide emission

Researchers have focused on developing strategies to understand and mitigate the impact of carbon dioxide emissions, as the importance of sustainable development has grown in the past few decades [14]. The main strategies for lowering carbon dioxide emissions are as follows: replacing fossil fuels with renewable energy sources, carbon dioxide capture and storage and carbon dioxide capture and utilization.

1.2.1 Renewable energy as an alternative source for fossil fuels

Renewable energy resources can be helpful in meeting the global energy needs without any diverse effects on the atmosphere. Fig. 3 shows a variety of renewable energy sources [15]. Due to the excessive emission of the greenhouse gases like carbon dioxide, the level of carbon dioxide in the atmosphere has increased. In order to minimize carbon dioxide emissions, renewable energy must be provided at a competitive cost. To alleviate the effects of the environmental crisis, governments must develop and enforce energy conservation polices. Depending on their conditions and concerns, different countries may adopt different policies and legislative measures for energy transition [16-18].

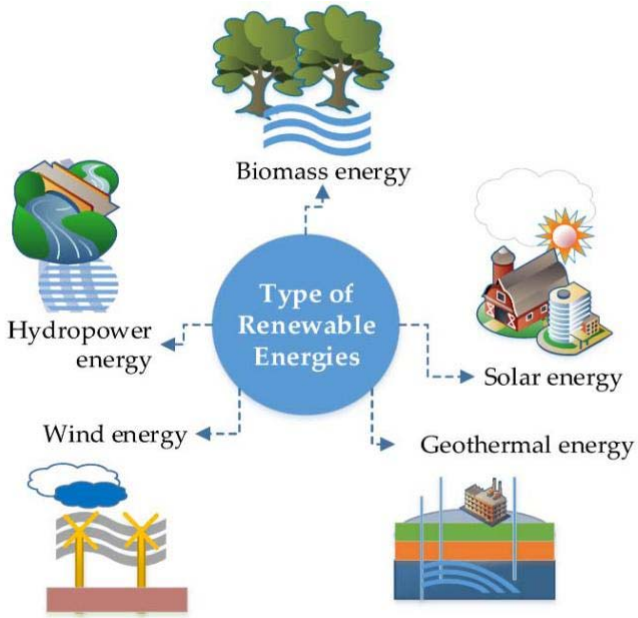

Fig. 3. Various renewable energy sources [15]

A flowchart depicting the various types of renewable energies is shown in Fig. 4. Solar energy is the most important renewable energy source. This is due to the fact that solar energy may be used directly and also indirectly it is a drive force for the various other renewable energy sources. Hydropower is a type of energy that is generated by water flow. The reason of the existence of the hydropower is the solar energy because the sun's energy evaporates water at low altitudes and then rains it from higher altitudes. The sun creates wind by causing the earth's surface to heat up in different ways. Photosynthesis, which is powered by the sun, produces biomass in plants. Wind, biomass, and hydropower are all forms of solar energy that are employed as backup sources [19].

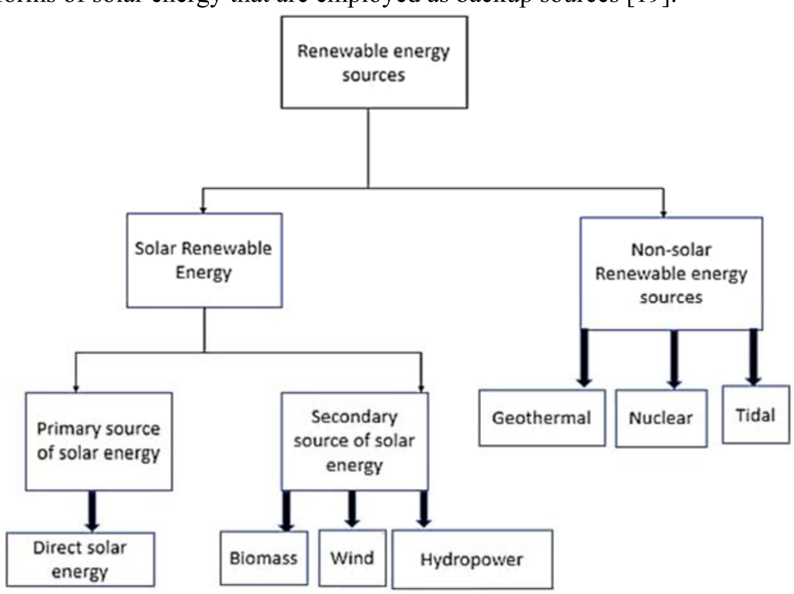

Fig. 4. A flowchart showing various types of renewable energy sources [19]

1.2.1.1 Types of Renewable energy sources

Different types of renewable energy technologies are wind energy, solar energy, hydro energy, biomass energy, tidal energy and geothermal energy.

1.2.1.1.1 Wind energy

Wind energy is one of the fastest-growing renewable energy source, adopted by a number of countries in an effort to cut emissions. The method uses wind to generate electricity by using the kinetic energy provided by moving air. Wind turbines convert this kinetic energy into electrical energy [18].

1.2.1.1.2 Solar energy

Solar energy is the process of converting solar energy into thermal or electrical energy, and it is one of the cleanest and most abundant renewable energy source. Solar photovoltaic (PV), along with wind, is the most well-established of the low-carbon energy technologies, and development costs are falling as the technology scales up [20].

1.2.1.1.3 Hydro energy

The gravitational force of flowing water is used to generate hydroelectricity. Hydropower plants release fewer greenhouse gases than fossil-fuel-powered electricity plants, but the plants and dams themselves demand a significant investment [21].

1.2.1.1.4 Biomass energy

Biomass is a phrase that refers to all plant and animal material. It can range from plants and wood to animal and agricultural waste. It is typically utilized in power generation as wood pellets, which are gathered from forests and burned to produce energy [22].

1.2.1.1.5 Tidal energy

Tidal energy is produced by turning energy from the strong tides into electricity, and its output is more predictable than wind and solar energy. Despite the fact that the world's first large-scale tidal power plant was operational in 1966, tidal power is still not commonly used. However, the growing global focus on generating electricity from sustainable sources is projected to enforce the development of new tidal energy systems [23].

Several studies in the literature have discussed the efficiencies of the renewable energy sources [24]. When looking at the relationship between renewable energy consumption (REC) and CO_2 emissions, it's clear that increasing renewable energy consumption can minimize global carbon dioxide emissions or enhance quality of the air [25]. Furthermore, with the exception of few studies [26], almost all researchers have investigated the relationship between the use of renewable energy and CO_2 emissions in a single country or a group of countries or regions, as shown in Table 1. It is highly needed that the use of the renewable energy sources should be globally promoted in order to achieve rapid economic development while producing as little CO_2 as possible.

Table 1. Representative papers in the years (2015–2021) on the relationship between renewable energy consumption (REC) and CO_2 emissions

Author(s) and Year	**Region and Period**	**Method**	**Major Findings**
Apergis et al., 2015 [27]	11 South American countries 1980-2010	PCM	CO_2 decreases due to REC
Attiaoui et al., 2017 [28]	22 African countries 1990–2011	ARDL	CO_2 decreases due to REC
Souza et al., 2018 [29]	Argentina, Brazil, Paraguay, Uruguay and Venezuela 1990–2014	ARDL	CO_2 decreases due to REC
Bhat, 2018 [30]	Brazil, Russia, China, India, and South Africa 1992–2016	STIRPAT	CO_2 decreases due to REC
Hanif, 2018 [25]	34 emerging countries 1995–2015	GMM	REC helps to enhance air quality by reducing carbon emission
Dong et al., 2018 [31]	128 countries 1990–2014	STIRPAT	CO_2 decreases due to REC
Chen et al., 2019 [32]	China 1980–2014	ARDL	CO_2 decreases due to REC
Dong et al., 2019 [26]	120 countries 1995–2015	PCM	CO_2 decreases due to REC
Chen et al., 2019 [33]	China 1995–2012	FMOLS	CO_2 decreases in eastern and

			western regions due to REC
Naz et al., 2019 [34]	Pakistan 1975–2016	ARDL	CO_2 decreases due to REC
Rahil et al., 2019 [35]	Libya 2015	SAM	CO_2 decreases due to REC, which has economic advantages
Toumi et al., 2019 [36]	Saudi Arabia 1990–2014	ARDL	CO_2 decreases due to REC
Lee, 2019 [37]	European Union 1961–2012	PCM	CO_2 decreases due to REC
Jia et al., 2021 [38]	World is divided into seven regions. 1971-2016	LDMI	CO_2 decreases due to REC

For a panel of 11 South American countries from 1980 to 2010, panel co-integration techniques were used to estimate the long-run relationship as well as the causal dynamics between renewable energy consumption per capita, real gross domestic product (GDP) per capita, carbon dioxide emissions per capita, and real oil prices. Estimation was performed in order to assure that the long-run elasticity for real GDP per capita, carbon emissions per capita, and real oil prices are all positive and statistically significant. The panel error correction model's results demonstrate a feedback link between the variables in issue, indicating the importance of renewable energy consumption in both production growth and carbon dioxide emission reduction [27].

Using an autoregressive distributed lag model based on the pooled mean group estimation, the links between renewable energy consumption (REC), CO_2 emissions (CE), non-renewable energy consumption (NREC), and economic growth (GDP) were estimated. It was concluded that the substantial causality from GDP and CE to REC is neutral. According to the long-run estimations, NREC and GDP raise CE, whereas REC decreases CE [28].

1.2.2 Carbon dioxide capture and storage technique

CO_2 can be captured in a variety of ways. Post-combustion, pre-combustion, and oxyfuel are the most common strategies. CO_2 is removed from flue gases using the post-combustion technology. Pre-combustion technologies entail turning the fossil fuel into a mixture of hydrogen and carbon dioxide before burning it. CO_2 is compressed into a liquid condition and transferred by pipeline, ship, or road tanker once it has been captured. CO_2 can then be injected underground, typically to depths of 1 km or more, and stored in depleted oil and gas reservoirs, coalbeds, or deep saline aquifers where the geology allows. CO_2 could potentially be used to make items that are commercially viable. This is referred to as carbon capture, storage, and utilisation (CCSU). Enhanced oil recovery (EOR), in which CO_2 is injected into oil and gas reservoirs to maximize extraction, is the most well-known method of CO_2 utilisation. Other methods of CO_2 utilisation are still being researched [39-41]. Renewable energy technology has come a long way in the previous decade. Wind and solar power's costs have been cut down by 66 and 85 percent, respectively [42]. Despite remarkable advances in renewable energy technology, humans continue to depend on conventional fuels to meet world energy demand. It is expected that 78 percent of the total global energy consumption will be based on the fossil fuels (coal, natural gas, and oil) until 2040 [43]. It is important to focus on carbon dioxide capture and storage strategy until the renewable energy technologies totally replace fossil fuels [39-41]. According to the IPCC 2014 report, the quantity of CO_2 that will need to be stored by the mid-century would be approximately 5000–10,000 million tonnes annually. Due to the excessive CO_2 emissions, anthropogenic activities have resulted in a global warming of more than 1 degree Celsius, with a CO_2 content of the atmosphere of more than 409 ppm [44]. The Paris Accord was drafted in 2015 with the purpose of keeping global warming below 2 degrees Celsius by 2100, with a 1.5-degree Celsius target [45].

The research related to carbon dioxide capture and storage is crucial because it is predicted to be the only option for halving carbon dioxide emissions from large-scale power facilities by 2050 [46]. Pre-combustion, post-combustion, and oxyfuel combustion are the three main carbon capture strategies. Until 2018, the first two strategies accounted for 96.6 percent of all the captured carbon dioxide, whereas oxy-fuel combustion accounted for only 3.4 percent of all the captured carbon dioxide. In the field of pre- and post-combustion technology, liquid solvents are typically used in a counter-current direction in an absorber packed-bed. Pre-combustion gas mixture or drained exhaust gases (post-combustion) is transported from the base to the top of the chamber, whereas the solution travels from high to low. The bulk of collected CO_2 is released from the CO_2-rich solution during a thermal or force change and returned to the absorbent reactors [47]. Fig. 5 shows process flow diagram of carbon capture and storage [48]. Table 2 shows commercial facilities in operation for CCS [49].

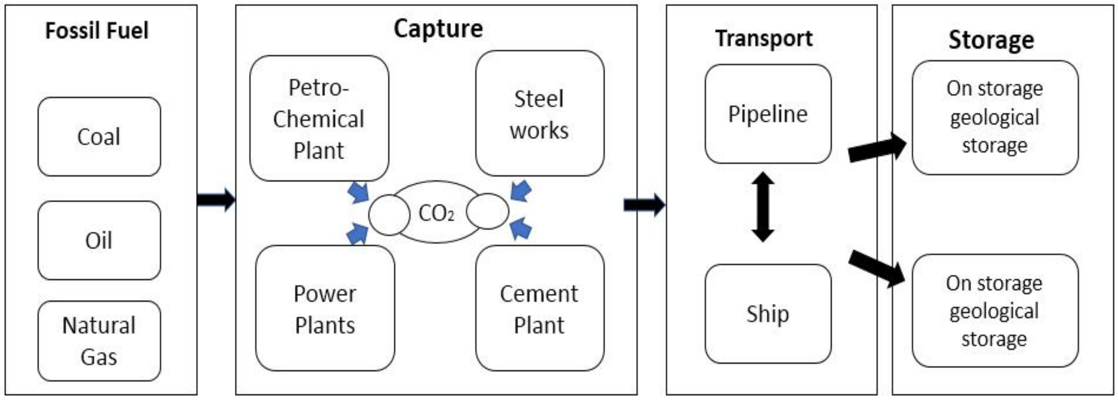

Fig. 5. Process flow diagram of carbon dioxide capture and storage [48]

Table 2. Commercial facilities in operation for CCS [49]

Facility Title	Status	Country	Operation Date	Industry	Capture Capacity (Mtpa) (MAX)	Capture Type	Storage Type
Terrell Natural Gas Processing Plant (formerly Val Verde Natural Gas Plants)	Operational	United States	1972	Natural gas processing	0.40	Industrial Separation	Enhanced Oil Recovery
Enid Fertilizer	Operational	United States	1982	Fertilizer production	0.20	Industrial Separation	Enhanced Oil Recovery
Sleipner Project	Operational	Norway	1996	Natural gas processing	1.0	Industrial Separation	Dedicated Geological Storage
Century Plant	Operational	United States	2010	Natural gas processing	5.0	Industrial Separation	Enhanced Oil Recovery
Boundary Dam Carbon Capture and Storage	Operational	Canada	2014	Power generation	1.00	Post combustion capture	Enhanced Oil Recovery
Abu Dhabi CCS (Phase 1 being Emirates Steel Industries)	Operational	United Arab Emirates	2016	Iron and steel production	0.80	Industrial Separation	Enhanced Oil Recovery
Illinois Industrial Carbon Capture and Storage	Operational	United States	2017	Ethanol Production- ethanol plant	1.00	Industrial Separation	Dedicated Geological Storage
Gorgon Carbon Dioxide Injection	Operational	Australia	2019	Natural gas processing	4.00	Industrial Separation	Dedicated Geological Storage
Qatar LNG CCS	Operational	Qatar	2019	Natural gas processing	2.10	Industrial Separation	Dedicated Geological Storage
Alberta Carbon Trunk Line (ACTL) with Nutrien CO_2 Stream	Operational	Canada	2020	Fertilizer production	0.30	Industrial Separation	Enhanced Oil Recovery
Alberta Carbon Trunk Line (ACTL) with North West Red water	Operational	Canada	2020	Oil refining	1.40	Industrial Separation	Enhanced Oil Recovery

Carbon dioxide capturing and geological burial is a process that involves catching CO_2 from flue emissions, transferring it, compressing it, and injecting it in gaseous or liquid form into suitable geological formations, such as deep coal seams, depleted oil and gas reservoirs and deep saline aquifers [50-52]. Carbon dioxide should be injected to sufficient depths in order to keep it in supercritical form. Numerous confinements offer the necessary storage barriers to protect CO_2 from moving upward and leaking [53]. Table 3 shows the summary of commercialized carbon sequestration and storage plants on a huge scale that are working in Europe.

Table 3. Summary of large-scale commercial CCS facilities that are working in Europe [54]. (Status: ED—Early Development; AD—Advanced Development; Mtpa (million tonnes per annum), tpa (tonnes per annum), tpd (tonnes per day).

Facility Title	Status	Country	Operation Date	Industry	Observations
Hydrogen 2 Magnum (H2M)	ED	Netherlands	2004	Power generation	H2M produce hydrogen to be used in gas power plant in Eemshaven, Germany, Equinor, Vattenfall and Gassunie
CIUDEN: CO_2 Storage Technology Development Plant	AD	Spain	2015	Various	The site includes one injection well and a monitoring well; 10,000 tonnes are planned to be injected in period 2017-2020
Acorn (Minimum Viable CCS Development)	AD	United Kingdom	2021-22	Various	CO_2 is separated from natural gas and discharged to an offshore transport pipeline that connects to a well-known offshore basin with plenty of storage.
Caledonia Clean	ED	United Kingdom	2024	Power generation	CO_2 capture would be 3 Mtpa and transported via re-purposed pipeline for geological storage in the North Sea of Scotland Energy
Langskip CCS–Fortum Oslo Varme	AD	Norway	2024	Waste Incineration	It is in construction to capture about 0.4 Mtpa of CO_2 by 2024 from its cement production plat in southern Norway; the offshore Aurora, a combination ship and pipeline transit system has been examined as the initial storage site.
Norway Full Chain CCS	AD	Norway	2023-2024	Various	Aim of 0.8 Mtpa; Two proponents involved in cement manufacture are conducting CO_2 capture studies. CO_2 would be transferred to an offshore facility via ship and pipeline.
The Clean Gas Project	ED	United Kingdom	2025	Power generation	CO_2 is gathered and transferred via pipeline to a formation beneath the Southern North Sea for storage.

1.2.3 Carbon dioxide capture and utilization technique

The technique of trapping carbon dioxide (CO_2) and recycling it for future use is known as carbon capture and utilisation (CCU). Carbon capture and utilization could provide a solution to the worldwide challenge of lowering greenhouse gas emissions from major stationary sources. CCU varies from carbon capture and storage (CCS) in that it does not aim for permanent carbon dioxide geological storage. Instead, CCU tries to convert the captured carbon dioxide into more useful chemicals or products, such as plastics, concrete, or biofuel, while maintaining the industrial processes' carbon neutrality. CO_2 may be captured and transformed into a variety of products, including hydrocarbons like methanol, which can be used as biofuels. Plastics, concrete, and chemical synthesis reactants are among the other commercial goods [39-41, 55, 56]. In terms of technological and economic viability, various CO_2 utilization techniques have been successfully investigated. Global CO_2 usage is currently less than 200 million tonnes per year, which is negligible in comparison to global carbon dioxide emissions (higher than 32,000 million tons per year) [55, 56]. Waste CO_2 is currently used in a variety of fields; materials, chemical industries and fuels [57, 58]. Other industrial applications of CO_2 include food production, refrigeration, water purification, and horticulture, as well as building materials (using CO_2 in the production of building materials to replace water in concrete or as a raw material in its constituents). CO_2 is employed in the production of fertilizer (about 125 Mt/year) and enhanced oil recovery (approximately 70-80 Mt/year) around the world [59]. Through the use of industrial waste and waste concrete, CO_2 capture and utilization were examined, biobutanol and a greener copolymer that emits 5.55 million tons of CO_2 annually [60]. Similarly, CO_2 was successfully converted to CO (98%) with an overall energy efficiency of 80% [61]. Table 4 shows the summary of large-scale commercial carbon dioxide utilization facilities. Fig. 6 summarizes the carbon dioxide storage and utilization processes.

Table 4. Summary of large-scale commercial carbon dioxide utilization facilities that are working in Europe [54]. (Status: ED—Early Development; O-Operational, Mtpa (million tonnes per annum), tpa (tonnes per annum), tpd (tonnes per day).

Facility Title	Status	Country	Operation Date	Industry
Arcelor Mittal Steelanol Ghent	ED	Belgium	2020	Iron and steel production
Port Jérôme CO_2 Capture Plant	O	France	2015	Hydrogen production
Twence Waste-to-energy CO_2 Capture and Utilization	O	Netherlands	2014	Waste Incineration

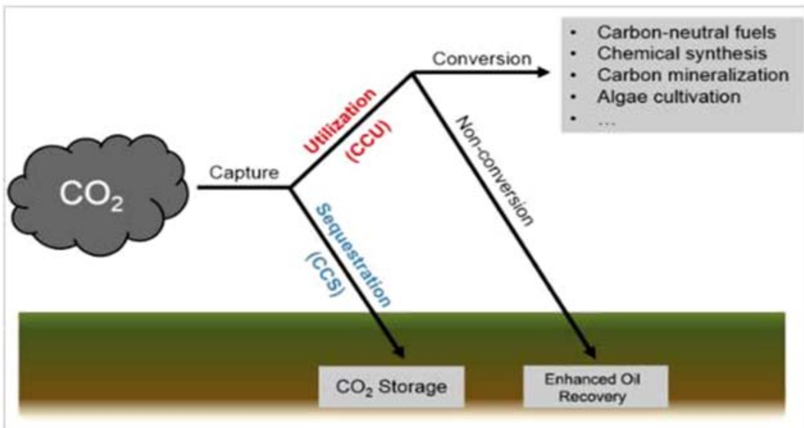

Fig. 6. Storage and utilization of the captured carbon dioxide [61]

2. Conclusion

One of the defining challenges of the current time is to limit the global temperature rise. The burning of the fossil fuels accounts for two-third of the greenhouse gas emissions. To avoid the adverse effects of global warming, at least 85% of world electricity should be generated from renewable energy sources by 2050, with at least two-third of total energy coming from renewable sources. A multitude of technology-specific obstacles (in relation to price) should be overcome in order for renewable energy (RE) to considerably increase its contribution to reducing CO_2 emissions. Proper design, implementation, and evaluation of process can reduce negative impacts and can increase the global installation of the renewable energy sources.

International climate commitments, particularly the Paris Accord, necessitate rigorous monitoring and reporting of greenhouse gas emissions, allowing for the tracking of CO_2 emissions through time. These alarming figures make it clear that quick action is required to reduce emissions. CO_2 capture, utilization, and storage have shown a significant promise for reducing global warming. There are numerous obstacles to overcome when it comes to carbon capture, storage, and utilization. Continuous knowledge advancement is required to improve the economic and environmental feasibility, as well as the technological potential. As may be seen, a number of projects are being investigated to increase CO_2 capture and utilization/storage. Some technologies may, in the future, provide a variety of potential prospects for a sustainable global industry, including support for climate change goals, the circular economy, renewable energy deployment, and the evolution of CO_2 collection systems, among others. Based on the Paris Accord, the CO_2 emissions should be sufficiently minimized in order to limit the global temperature increase to less than 1.5 degree centigrade until 2050. As a result, there is still a long way to go, in order to achieve the desired results.

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