A TRANSFORMATION IN UTILIZING CO_2 AS AN ENERGY SOURCE AND ITS ECONOMIC IMPORTANCE

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ABSTRACT

Carbon dioxide (CO_2) emissions and utilization in developing countries are closely tied to their economy and play crucial role in the world's future emissions. Owing to the need of the carbon dioxide (CO_2) rejection and rather than treating it as disposal waste or geological storage molecule, the current study provides an overview on opportunities and prospects of CO_2 utilization. The increase in carbon emissions results in robust global economic growth, lower fossil-fuel prices and weaker energy efficiency efforts. This study is aimed at presenting approaches toward utilization of CO_2 as an energy source, give a realistic situation on the potential applications that will lead to future development of commercial scale technologies, which will lead to value added products by carbon dioxide capture and utilization (CCU) and establishing CO_2 economy rather than its disposal as waste, and what economic importance it will have. The increased use of primary energy resources in Nigeria was influenced more by the fact that the natural resources were available within the country. It is noted that series of changes and transition in the use of different primary energy sources (from coal, to crude oil, to natural gas) is obvious in order to satisfy the growing demand for energy. Discussion on CCU is relevant to a community of energy researchers and practitioners, including energy modelers and policy-makers as it influences their work.

Keywords: CO_2, CCU, Emissions, Nigeria, Energy Source, Economic Importance.

INTRODUCTION

Carbon dioxide (CO_2) emissions and utilization in developing countries are closely tied to their economy and play crucial role in the world's future emissions. Carbon emissions, also known as a key component of greenhouse gas emissions, are considered to be the main cause of global climate change and seriously threaten the sustainable development of society (Wu *et al.,* 2006). Global energy-related CO_2 emissions grew by 1.4% in 2017, reaching a historic high of 32.5 gigatonnes (Gt), a resumption of growth after three years of global emissions remaining flat. The increase in CO_2 emissions, however, was not universal, while most major economies saw a rise, some others experienced declines, including the United States, United Kingdom, Mexico and Japan. The biggest decline drop came from the United States, mainly because of higher deployment of renewables. Industrialization is often accused of having such an adverse effect as releasing large amounts of carbon dioxide and generating serious global environmental pollution, which seriously affect normal social production activities and human life (Solomon *et al.,* 2009). Carbon dioxide (CO_2) has been a subject of interest since its discovery by "Joseph Black" in 1755 (Foregger, 1957). In past few decades, carbon dioxide sequestration has drawn global attention due to its contribution towards global warming (Jacobson, 2009). The concentration of carbon dioxide in atmosphere has been increasing due to anthropogenic emissions which have laid a great challenge among scientific community for reducing CO_2 level in atmosphere (Park *et al.,* 2004). The culpable effect of increased concentration would lead to significant imbalances in the ecosystem by Increasing earth's average temperature, influencing the patterns and amounts of precipitation reduce ice and snow cover, as well as permafrost, raise sea level, and increase in the acidity of the oceans (Song, 2006).

At present, the carbon emissions caused by the consumption of natural resources and energy has reached an extent not experienced in the past. The climate change that takes place due to this concentration of carbon emissions is largely irreversible (Nordhaus, 2007). Carbon emissions are not only a pollution that triggers the greenhouse effect and brings about an ecological crisis, but also a development right that is related to a country's industrialization and urbanization (Qiao, 2016). Rapid shift to a green growth paradigm turns to be a vital determinant of the long-term economic growth (Li and Wang, 2012). As a result, many international treaties and national policies have been promulgated to deal with carbon emissions and slow climate change. The earliest international treaties date back to the 1992 United Nations Framework Convention on Climate Change. This treaty developed and developing countries differently in terms of their obligations and procedures to carry out the commitments involved. Energy has been an important topic of political and scientific debate for many centuries. In line with these debates, energy models representing energy systems have been developed. The energy system directly and indirectly interacts with economic, social and environmental systems. Through these interactions the systems influence the (sustainable) development of each other. Energy is a central driver for economic and social development as well as environmental and climate issues. Owing to the need of the carbon dioxide (CO_2) rejection and rather than treating it as disposal waste or geological storage molecule, the current study provides an overview on opportunities and prospects of CO_2 utilization. The increase in carbon emissions results in robust global economic growth, lower fossil-fuel prices and weaker energy efficiency efforts.

METHODOLOGY

To carry out this study, the descriptive research method was employed. Descriptive research is such that it is amenable to other types of research and describes the characteristics of phenomena and their relationship to deepen understanding (Obasi, 1999). This identified strength enables this work to explore diverse sources of data and elicit their relevance to the current state of gas energy. Also, secondary data sources are drawn from special reports, journal publications, and other credible sources. While the information was described, a textual analysis was done to appropriate its substances to the context of the study. This study employed the use of exploratory documentary research tools by exploring documents, official data and statistics on the different aspects of the life and history of Nigeria in connection with trade, traditional energy use, culture, and norms. Documents and archives from several sources were used in data collection and analysis to have a better understanding of how the historical events of the time influenced and affected energy infrastructure provisions. Secondary data analysis was used in this research to analyze the data collected from the various literatures and documentary archives.

How to minimize CO_2 Emission

Global energy-related CO_2 emissions rose by 1.4% in 2017, an increase of 460 million tonnes (Mt), and reached a historic high of 32.5 Gt. Last year’s growth came after three years of flat emissions and contrasts with the sharp reduction needed to meet the goals of the Paris Agreement on climate change. The increase in carbon emissions, equivalent to the emissions of 170 million additional cars, was the result of robust global economic growth of 3.7%, lower fossil-fuel prices and weaker energy efficiency efforts. These three factors contributed to pushing up global energy demand by 2.1% in 2017. The trend of growing emissions, however, was not universal (Figure 1). While most major economies saw a rise in carbon emissions, some others experienced declines, such as the United States, the United Kingdom, Mexico and Japan. The biggest decline came from the United States, where emissions dropped by 0.5%, or 25 Mt, to 4 810 Mt of CO_2, marking the third consecutive year of decline (Geco, 2017). While coal-to-gas switching played a major role in reducing emissions in previous years, last year the drop was the result of higher renewables-based electricity generation and a decline in electricity demand. The share of renewables in electricity generation reached a record level of 17%, while the share of nuclear power held steady at 20%.

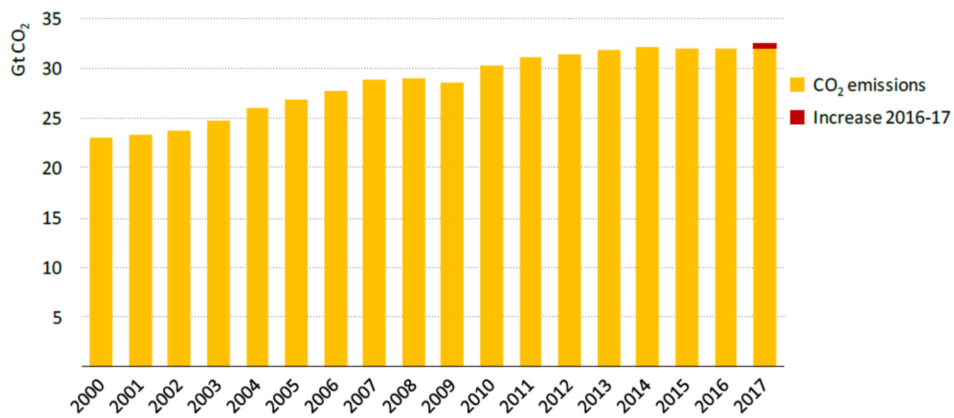

Figure 1: Global energy-related CO_2 emissions, 2000-2017 (Geco, 2017).

Three different strategies (Figure 2) have been proposed for minimizing anthropogenic carbon dioxide emissions such as:

- Avoiding or decreasing CO_2 production by using renewable energy sources like solar, hydro and wind or by increasing energy efficiency.
- Extracting produced carbon dioxide from the climate by reforestation or geological storage in deep sea sediments or underground storage.
- Utilization or conversion of carbon dioxide.

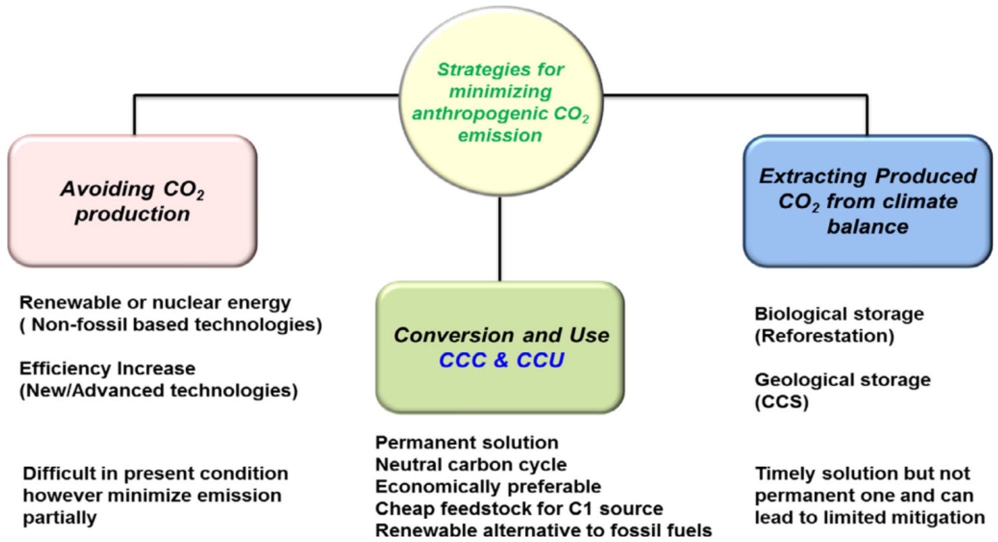

Figure 2: Strategies for minimizing carbon dioxide (CO_2) emission (Gulzar, *et al.*, 2020).

In recent years there has been a boom in the area of carbon dioxide capture and storage (CCS) (Dowd *et al.*, 2012; Shackley and Dütschke, 2012; Markewitz *et al.*, 2012). The CCS has become a topic of debate among scientific community and questions are raised on its feasibility and as well as on its long-term consequences. Several ideas have been proposed for the long-term storage of CO_2 which include: storing CO_2 in various geologic formations (e.g., oil and gas fields, coal beds, and saline aquifers), injection of CO_2 into the Deep Ocean and chemical transformation of CO_2 into thermodynamically stable minerals or bicarbonate brines (House *et al.*, 2006). Energy expert Michael Economides stated that CCS is a profoundly non-feasible option for the management of CO_2 due to overwhelming challenges in both physical needs and cost, and it entails several components including capture, gathering and injection (Ehlig-Economides and Economides 2010). In his presentation to the "Society of Petroleum Engineers", he stated that estimated CO_2 cuts on the order of the U.S.-shunned Kyoto Protocol would require the drilling of 161,429 injection wells by 2030 at a cost of $1.61 trillion (Economides, 2009). In addition to estimates above there is surplus cost of capturing the CO_2 at the point of generation, purchasing rights of way for pipelines, pipeline installation costs, and liability insurance. The expected annual cost is as high as $1 trillion without any guarantees that the CO_2 would stay sequestered.

CO_2 Utilization

Despite of several barriers many developing nations have adopted CCS. In the present era CCS is being derailed by the scientific community due to long-term liability issues, limited cost-effective storage capacity, possibility of leakage, public acceptance of onshore storage locations (Oltra *et al*, 2012), whereas in case of deep ocean sequestration immediate effect would be the lowering of pH, increasing the acidity of the water and may lead to imbalance in ecosystem (Newmark, 2010). The potential alternative to CCS would be Carbon dioxide capture and utilization (CCU) which is prevailing attention due to sustainable development and is presumed to be a permanent solution for CO_2 problem. In recent years there have been enormous progress in this area and efforts towards CO_2 utilization are being demonstrated as chemical feedstock (Sakakura *et al.*, 2007) , refrigerant (Pearson 2005) , cleaning liquid (Dale Spall *et al*., 1998), solvent medium (Dale Spall *et al*., 1998; Baiker, 1998), gas etc. as shown in figure 3. The growth in energy-related carbon dioxide emissions in 2017 is a strong warning for global efforts to combat climate change, and demonstrates that current efforts are insufficient to meet the objectives of the Paris Agreement.

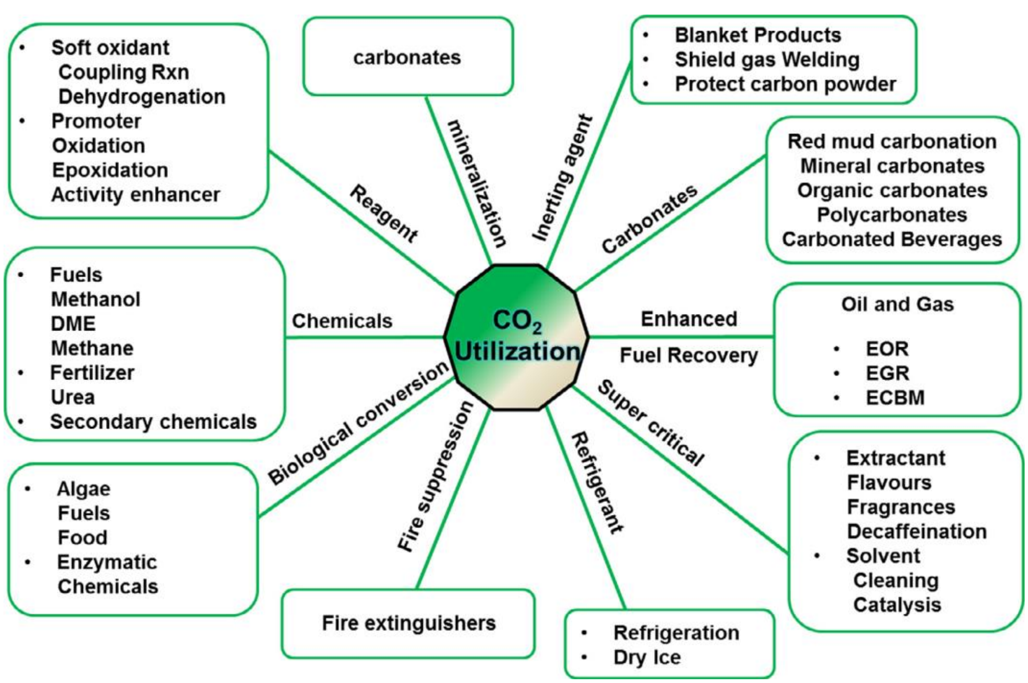

Figure 3: Overview of CO_2 utilization (Gulzar, *et al.*, 2020).

Carbon dioxide capture and utilization

As discussed earlier, one of the important parts of CCU is carbon dioxide utilization which is considered to be superior in terms of value. Moreover, it has the potential to reduce CO_2 emissions by at least 3.7 gigatons per year (Gt/y) which is equal to 10% of world's current annual emissions (Dodge, 2014). There has been enormous development in this area in recent decades whereby carbon dioxide is utilized in form of carbonated drinks, super critical form as solvent media for reaction or extraction, metal carbonates, synthesis of organic chemicals, synthesis gas production from dry reforming, soft-oxidant in dehydrogenation reactions and also as promoter. Apart from these, it has been utilized in cleaning industry and various chemical processes. These processes can be broadly classified into two non-conversion and conversion methods.

Non-conversion use of CO_2

The most familiar non-conversion method of carbon dioxide utilization dates back to 1772 whereby Joseph Priestley reported a paper on "impregnating water with fixed air" as a refreshing drink (Priestley, 1972). At present, there are many carbonated drinks available like seltzer water, flavored water, carbonated alcohols etc. The carbonated beverages contain 2.5 – 4.5 volume percent of carbon dioxide. The initial studies of CO_2 as refrigerant dates back to 1880s (Lake, 1884), however in last 130 years Carbon dioxide has been used as a refrigerant in vapor compression systems of many types, but it is only in the last decade the inventive minds and modern techniques have found new ways to exploit the uniquely beneficial properties of this remarkable substance (Pearson, 2005; Lorentzen, 1994).

Utilization of CO_2 as Energy Source

Super critical CO_2 ($ScCO_2$) usage as solvent is emerging as one of the popular alternatives to environmentally hazardous organic solvents (Leitner, 2000). Its use in catalysis and extraction has been gaining industrial attention and several technologies are under development and progress in this area of research has been growing rapidly. CO_2 is said to be in a supercritical state when it has exceeded its critical temperature 31.04°C (304.19 K) and pressure 72.8 atm (7380 kPa). Beyond its critical point there is no discernable phase of CO_2 and it behaves as neither a gas nor a liquid; furthermore, the viscosity, dielectric constant, and heat capacity are differed from the vapor and liquid phases. Due to these properties, $ScCO_2$ have gained diverse range of applications that vary between large/industrial to small/laboratory scale. Some of the applications of $ScCO_2$ include: Supercritical fluid extraction (SFE), Supercritical fluid fractionation (SFF), Supercritical fluid impregnation (SFI), Supercritical fluid chromatography (SFC) and Supercritical CO_2 Catalysis (SCC). **Super critical fluid extraction (SFE)** of natural products is one among the most widely studied application of supercritical CO_2 (Figure 4). SFE shows several advantages over traditional extraction techniques such as flexible and tuned process parameters, possibility of continuous modulation of the solvent power/selectivity for extract, it allows the elimination of polluting organic solvents, post- processing of the extracts for solvent elimination and moreover it is readily available, safe and has a low operational cost (Reverchon and Macro,2006) . $ScCO_2$ can be regarded as promising solvent for extracting a wide range of chemicals due to its dense properties which are high enough to allow good solubility while its diffusivities are 10–100 times higher than those of other liquids, which improve mass transfer and reduce extraction times. The only limitation of SFE is the higher initial investment in comparison with traditional atmospheric pressure extraction techniques. However, the base process scheme is relatively cheap and very simple to be scaled up to industrial scale.

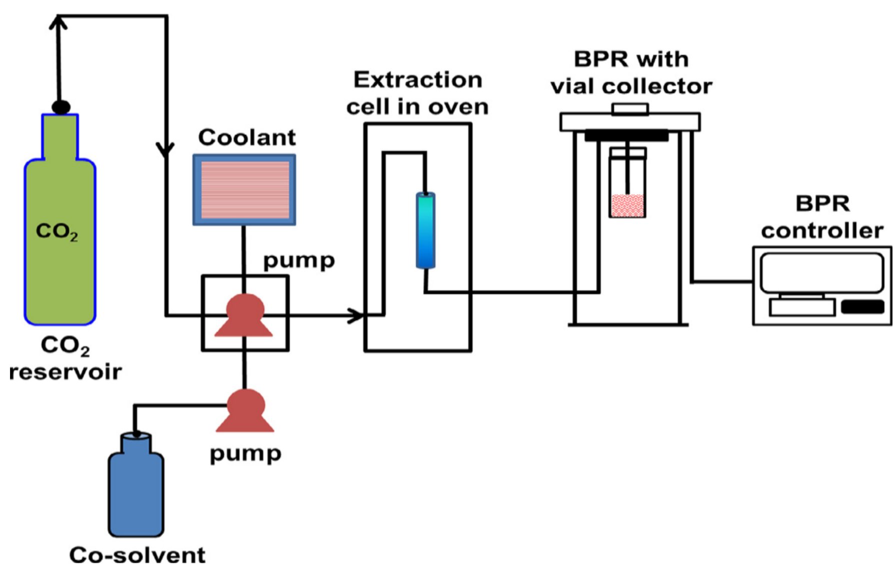

Figure 4: Schematic diagram of supercritical CO_2 fluid extraction unit.

Enhanced oil recovery (EOR) by CO_2 or improved oil recovery or tertiary recovery is a generic term for techniques used for increasing the amount of crude oil that can be extracted from an oil field. One among the methods extensively used for enhanced oil recovery is gas injection or miscible flooding with CO_2 (Gao *et al*, 2013; Leung *et al*, 2014). The injection of CO_2 into depleted oil wells to enhance the further recovery of oil is also well established. Indeed, this is presently the only commercially viable technology for carbon capture and storage (CCS). It has been estimated that CO_2 injection can increase oil recovery from a depleting well by about 10 to 20% of the original oil in place. This injected carbon dioxide will be in supercritical state when the depth of the reservoir is more than 2000ft. (high-pressure reservoirs). The supercritical CO_2 ($ScCO_2$) is highly miscible with oil, which in turn leads to its swelling and reducing its viscosity, moreover the $ScCO_2$ also contributes towards reduction of surface tension with the reservoir rock. Whereas, in low-pressure reservoirs or heavy oils, the CO_2 may contribute to partial mixing or form an immiscible fluid, however it still contributes towards oil swelling and reduction in oil viscosity significantly. A pictorial representation of the enhanced oil recovery process with carbon dioxide is shown in Figure 5. In EOR process with CO_2, about 50–75% of the injected CO_2 returns with the produced oil and is usually re-injected into the reservoir to reduce operational costs. The remainder is trapped in the oil reservoir by various means. CO_2 as a solvent has the benefit of being more economical than other similarly miscible fluids such as propane and butane.

Energy perspective in CO_2 utilization

Despite the fact that CO_2 remains a molecule of low reactivity due to both thermodynamic and kinetic barriers however, certain reaction are made possible by use of appropriate catalyst and supplement of energy. The processes in which entire CO_2 molecule is incorporated in the products such as carboxylates, carbonates and carbamates require low energy whereas, the process in which splitting or reduction of CO_2 molecule occurs requires large input of energy. Overall, it can be stated that the activation of CO_2 for its utilization is an energy trade, which adversely affects the economics restricting its industrial utilization. The supply of energy is an important perspective when we consider CO_2 utilization. Currently the energy sector is mainly dependent on the fossil fuels which in turn produce CO_2 (Jacobson, 2009). This led to a debate among the scientific community "Does CO_2 conversion at the expense of fossil fuels will have positive impact on environment?"

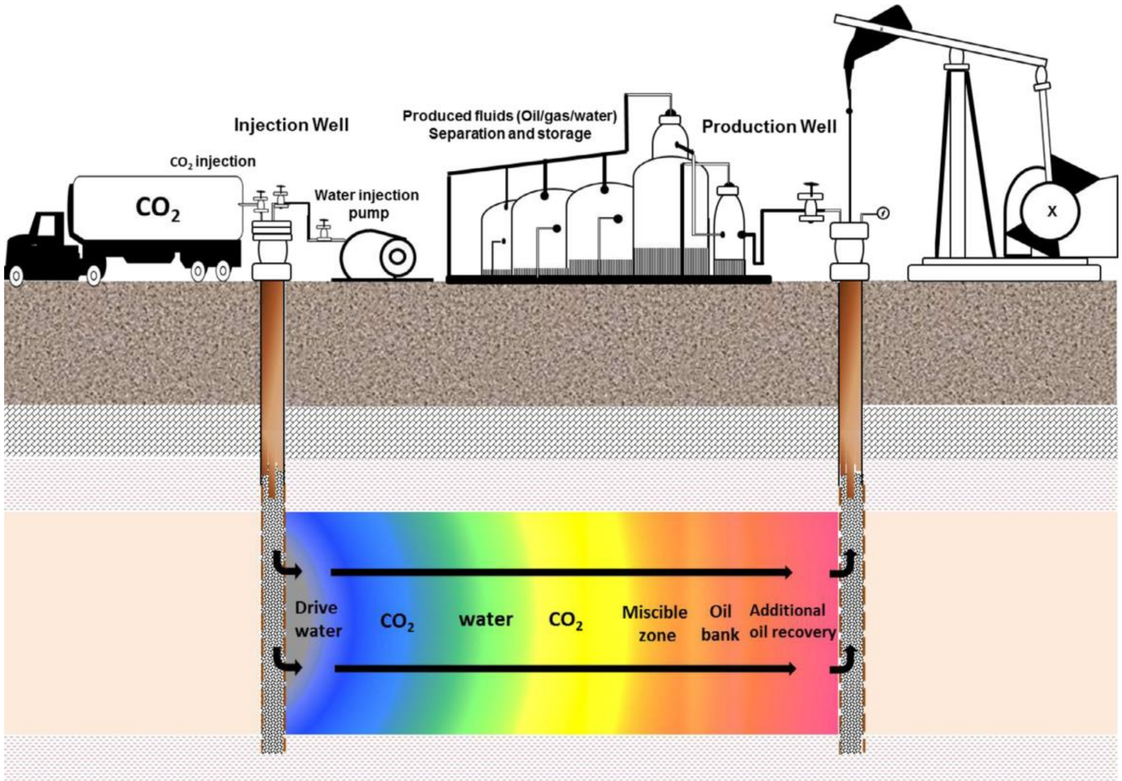

Figure 5: Enhanced oil recovery using CO_2.

One must consider the following aspects to establish an industry for using CO_2 as feedstock:

i) Total impact on reduction of CO_2 levels also including the amount of energy used and CO_2 produced from fossil fuel.

ii) Whether the process contribute to safer chemicals with alternative route.

iii) On site CO_2 capture and conversion (integrated industry system)

iv) Nevertheless, from energy perspective use of renewable energy resources

v) It must be less energy and material intensive compared with on stream processes

vi) Economic viability In order to make CO_2 conversion processes completely renewable one must adopt renewable energy resources and design better conversion systems without negative impacts on the environment (Song, 2006).

There is a long-term need to make more active use of renewable sources of energy such as solar energy (Devabhaktuni *et al*., 2013), hydroelectricity (Darmawi *et al*., 2013; Liu *et al*, 2013), biomass (Dhillon *et al*., 2013), biofuel, wind power (Abrantes, 2012; Sun *et al*.,2012), geothermal (Frick *et al*., 2011), wave power, tidal power (Zhou *et al*., 2013; Defne *et al*., 2012, Zhu *et al*., 2012). Nevertheless, renewable energy source in integration with CO_2 conversion in industry is better solution for production of chemicals and fuels.

Economic Importance of Utilizing Co_2 as Energy Source

Carbon dioxide (CO_2) utilization is presumed to contribute towards reduction of CO_2 levels, reduce CO_2 emissions and contributes towards development of sustainable technologies that utilizes waste as energy source. The economic importance of this process includes:

1. The carbon capture utilization and storage (CCUS) will help strengthen the framework for building collaborative partnerships between the public and private sectors.
2. It will also bolster and complement existing CCUS efforts led by the Carbon Sequestration Leadership Forum, the international Energy Agency (IEA), the IEA's Greenhouse Gas Research and Development program, mission innovation, and the Global CCS institute.
3. CO_2 utilization helps to provide energy security by securing energy diversity, stimulating our economy and furthering investments made in existing infrastructure.
4. The geologic utilization of CO_2 such as CO_2 - EOR, CO_2 shale, enhanced coal bed methane, enhanced water recovery, and enhanced geothermal will help to create market demand for anthropogenic CO_2 which will in turn helps in creating a revenue stream to offset the costs of capturing carbon dioxide.
5. Development of carbon utilization would provide a number of important pathways for decarbonization.

CONCLUSIONS

International agreement to reduce greenhouse gas emissions in 2016 demonstrates a global recognition of the need to reduce CO_2 emissions. In order to meet mid-century climate goals, nations and other actors need to ramp up CO_2 utilization quickly. The increased attention recently devoted to carbon utilization by both the private and public sectors suggests the potential processes that may have to drive decarbonization. However, because the levels of technology and commercial readiness differ so widely from sector to sector, no proposed single policy reform needed to address technology development, financing, and market preferences. Moreover, public sector action alone is not sufficient. Private sectors may be in the best position to tailor policies that address their specific needs for carbon utilization and how to transform it to economic product.

RECOMMENDATIONS

While the CO_2 utilization described in this paper is technically feasible and economically beneficially, it will not happen by itself and therefore I suggest the following focus area where sectors, policy and decision makers need to focus on:

1. **Transformation into the strong conjunction between energy efficiency and renewable energy:** This should be among the top priorities of energy policy design because their combined effect can deliver the bulk of energy-related decarbonization needs by 2050 in a cost-effective manner.
2. **Planning of a power sector for which renewables provide a high share of the energy**: This, in turn, requires long-term energy system planning and a shift to more holistic policy-making and more co-ordinated approaches across sectors and countries. This is critical in the power sector, where timely infrastructure deployment and the redesign of sector regulations are essential conditions for cost-effective integration of solar and wind generation on a large scale. These energy sources will become the backbone of power systems by 2050.
3. **Increase use of electricity in transport, building and industry**. Urban planning, building regulations, and other plans and policies must be integrated, particularly to enable deep and cost-effective decarbonization of the transport and heat sectors through electrification. However, renewable electricity is only part of the solution for these sectors. Where energy services in transport, industry and buildings cannot be electrified, other renewable solutions will need to be deployed, including modern bioenergy, solar thermal, and geothermal. To accelerate deployment of these solutions, an enabling policy framework will be essential.
4. **Foster system-wide innovation.** Just as the development of new technologies has played a key role in the progress of renewable energy in the past, continued technological innovation will be needed in the future to achieve a successful global energy transition.

Efforts to innovate must cover a technology's full life-cycle, including demonstration, deployment and commercialization. Delivering the innovations needed for the energy transition will require increased, intensive, focused and coordinated action by national governments, international actors and the private sectors.

5. **Align socio-economic structures and investment with the transition**. An integrated and holistic approach is needed by aligning the socio-economic system with the transition requirements. Implementing the energy transition requires significant investments, which adds to the investment required for adaptation to climate change already set to occur. The shorter the time to materialize the energy transition, the lower the climate change adaptation costs and the smaller the socio-economic disruption. The financial system should be aligned with broader sustainability and energy transition requirements. Investment decisions made today define the energy system of decades to come. Capital investment flows should be reallocated urgently to low-carbon solutions, to avoid locking economies into a carbon-intensive energy system and to minimize stranded assets. The increased participation of institutional investors and community-based finance in the transition should be facilitated and incentivized.
6. **Ensure that transition costs and benefits are fairly distributed.** The scope of the transition required is such that it can only be achieved by a collaborative process that involves the whole of society. To generate effective participation, the costs and benefits of the energy transition should be shared fairly, and the transition itself should be implemented justly. Universal energy access is a key component of a fair and just transition. Beyond energy access, huge disparities exist at present in the energy services available in different regions. The transition process will only be complete when energy services converge in all regions. Transition scenarios and planning should incorporate access and convergence considerations. A social accounting framework that enables and visualizes the transition contributions and obligations from individuals, communities, countries and regions should be promoted and facilitated.

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