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Mohammed A A Elgzoly

Elsadig Mohamed Yousuf

Aladeen Elhaj

Al-Neelain University

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Mohammed A A Elgzoly[1], Elsadig Mohamed Yousuf Ahmed[1], and Aladeen Elhaj[2]
[1]Dept. of of Chemical Engineering, Faculty of Engineering, Al Neelain University, Khartoum, Sudan.
[2]Applied Research Center for Environment & Marine Studies, King Fahd University of Petroleum & Minerals (KFUPM), Dhahran 31260, Saudi Arabia
[*]Corresponding author E-mail: hajerosman@hotmail.com

Abstract

Carbon Dioxide CO_2 has taken attention in the environment due to its increasing effect on air pollution and climate change. The Intergovernmental Panel on Climate Change (IPCC) estimates that by the end of the 21st century, greenhouse gas emissions will have raised the average global temperature by 1.8° to 4.0°C. If global average temperatures climb by more than 2 degrees Celsius, the IPCC's climate models predict that there would be catastrophic climatic repercussions. To avoid such a severe temperature increase, the IPCC recommends that global GHG emissions be reduced by 50-80% by 2050. CO_2 is a big factor in GHG, accounting for about 76 percent of total greenhouse gas emissions in 2015. Kenana Co. Ltd, Sudan's largest sugar company, 2009 year inaugurated the ethanol plant which produces 200,000 liters/day of anhydrous alcohol with an approximate grade of 99.6 % W/W at 20°C, the fermentation section produces 0.76 kg of CO_2 for every liter of ethanol produced, therefore, the CO_2 by-product of kenana ethanol plant from fermentation emission capacity is about 55,632.00 tons/year. The CO_2 produced during the alcoholic fermentation it's nearly pure, so at low cost can be utilized, its straightforward capturing just captures, dihydrate, compressing, and storage. Carbon dioxide (CCU) utilization will allow a negative emissions balance to develop a key strategy for reducing atmospheric carbon emissions, and also can provide economic benefits by using the captured CO_2 as a feedstock or converting it to other chemicals or fuels.

Keywords: Carbon Dioxide capture; Environment; Utilization; Kenana

Introduction

Carbon dioxide levels in the atmosphere have risen since the Industrial Revolution and the widespread use of fossil fuels such as coal. Since then, atmospheric CO_2 levels have been rising, contributing to the ongoing warming of the global climate. Levels have now reached around 417ppm in March 2021, a 50% increase over the 1750-1800 average. Figure 1 below shows atmospheric CO_2 levels from 1970 to 2021[1].

The rising carbon dioxide levels are caused to deforestation, air pollution, and the increase. The International Energy Agency (IEA) recently stated that the development in order to achieve the goals set out in the Paris Climate Agreement, the use of carbon capture and storage (CSS) technology is "not optional." In the foreword to 20 Years of Carbon Capture and Storage Accelerating Future Development, IEA executive director Fatih Birol said, "IEA scenario analysis has consistently highlighted that CCS will be important in limiting future temperature increases to 2 degrees Celsius, and we anticipate that this role for CCS will become increasingly important if we are to move towards well below two degrees Celsius." [2]. The predicted increase in the average Earth temperature During the 21st Century is about 1.8° and 4.0°Celsius (3.2° and 7.2°F)[3] [4]. Carbon dioxide and the greenhouse gas effect are required for Earth's survival. However, human creations like as power plants and automobiles that run on fossil fuels emit more CO_2 into the atmosphere. Because humans have contributed (and continue to add) carbon dioxide to the atmosphere, more heat is stored on Earth, causing the planet's temperature to gradually increase, a process known as global warming. Water vapor, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride are some of the other greenhouse gases (GHGs). According to scientists, human-caused global GHG emissions grew by over 70% between 1970 and 2004. Carbon dioxide emissions alone increased by 80% throughout the same time [5]. The majority of GHG emissions come from Carbon dioxide,[6] 65% of global emissions and 82% of US emissions its carbon dioxide. Many academics researcher believe that carbon capture and storage (CCS) can help us reduce this figure to a healthy level. Carbon capture has long been employed in the oil and gas industry to improve oil and gas recovery (CO_2-EOR) [7].

Carbon capture has been used for many years using various methods and technologies such as absorption, adsorption, membranes, cryogenic, enzymatic, and so on. However, in the last four years, adsorption has taken precedence. [8][9].

As a by-product of the fermentation process, the Ethanol plants make almost pure carbon dioxide. The total amount of ethanol that can be made in the United States is about 16,500 million gallons per year (MGY), which will release 50 million tons (Mt) of CO_2 in 2019 [10]. This is just the CO_2 from fermentation, not the CO_2 from the fuel used to heat the mash, which contributes to air pollution. Ethanol is made when yeast is mixed with glucose and left to grow. Yeast has enzymes that make it easier for glucose to breaking down into ethanol and carbon dioxide.

$$C_{12}H_{22}O_{11}\,(aq) + H_2O \xrightarrow{\text{Yeast Enzymes}} 4C_2H_5OH\,(aq) + 4CO_2\,(g) \quad \text{(Equation 1)}$$

In 2021, ethanol biorefineries plant captured around 2.7 million tons of CO_2, which was used for a variety of purposes ranging from beverage carbonization and meat processing to wastewater treatment, dry ice manufacture, and other applications. Furthermore, the sector is aggressively advocating the deployment of carbon capture and sequestration as a critical step in combating climate change [10].

Additionally, the CO_2 captured is employed in enhanced oil recovery. The ethanol business now delivers around 270,000 MT of CO_2 per year for EOR in Kansas and Texas, and ADM anticipates injecting up to 1.1 million MT per year for saline storage in Illinois. In comparison, the global leader in CO_2-EOR, Occidental Petroleum, injects 47 million MT of CO_2 yearly [11].

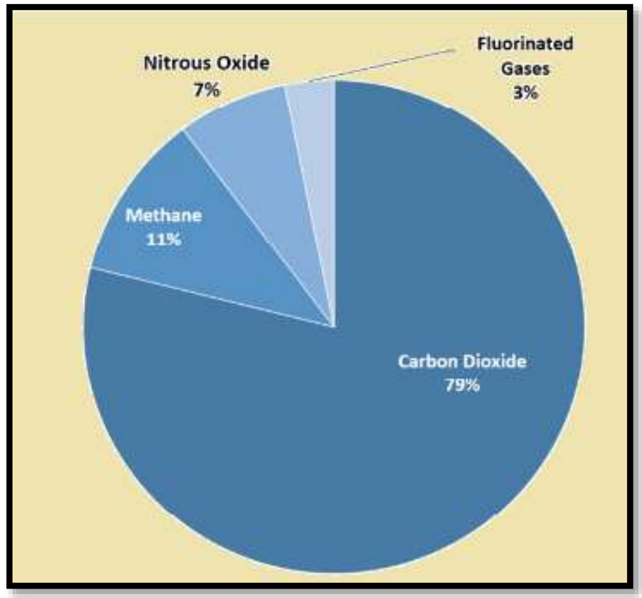

Figure 1 Greenhouse Gas Emissions in 2020 (GHG)[12]

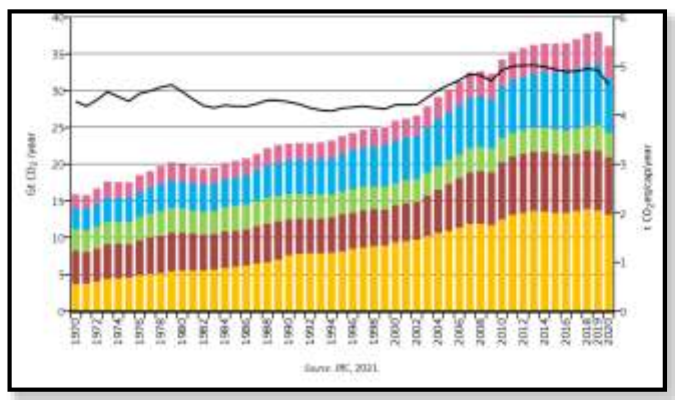

Figure 2 Total yearly worldwide fossil CO_2 emissions in Gt CO_2/yr by sector (left axis) and by capita (right axis).CO_2 emissions from fossil fuel consumption, industrial operations, and product use (combustion, flaring, cement, steel, chemicals, and urea) are all sources of fossil CO_2) **[1].**

- **Power Industry** - **Buildings**
- **Other sectors** (non-metallic minerals, non-ferrous metals, solvents, and other product use, chemicals),

agricultural soils (urea fertilization and lime application), and waste.

- Other industrial combustion (industrial manufacturing and fuel production.)

- **Transport** **- CO_2eq/cap**

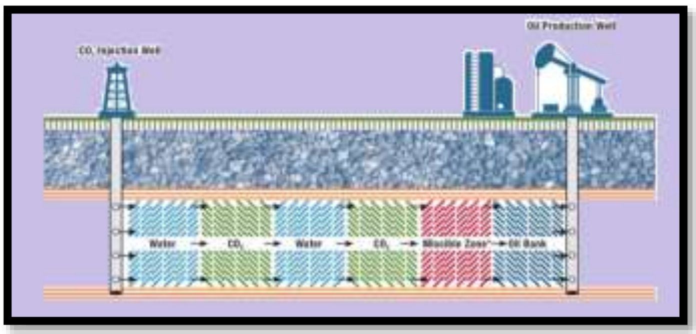

Figure 3 Methods of Using Carbon Dioxide Injection for Better Oil Recovery (CO2-EOR) [11]

2. Kenana Ethanol Plant production process

Kenana Ethanol Plant product 200,000 liters/day of anhydrous alcohol with an approximate grade of 99.6 % W/W at 20°C.[13]. Molasses are used as feedstock, which is a by-product of the kenana sugar cane factory. During fermentation, around 0.76 kilograms of carbon dioxide is produced for every liter of ethanol[14]. Therefore, the CO_2 emission capacity from the fermentation section of the Kenana Ethanol Plant is about 55,632.00 tons/year.

Ethanol, often known as ethyl alcohol, is a flammable, colorless, volatile substance. It may be manufactured from petroleum by ethylene chemical transformation, but it can also be made through glucose fermentation using yeast; present fuel ethanol facilities produce ethanol through fermentation [15].

The basic formula of ethanol production from sugar glucose (Molasses) is as follows:

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

The production of ethanol from sugar-based feedstock (molasses) consists of two principal processes:

1- Fermentation
2- Distillation

2.1 Fermentation

The Molasses pumped from the sauger factory to the Ethanol plant receiver tanks, the concentration is adjusted in a form that makes fermentation more efficient by mixt molasses with water, the mixture calls Mash which presents a final concentration around 16 to 23°C Brix (non-dissolvable solid).

Fermentation occurs in tanks named biofermenters where the mash is mixed to vat base in a 2:1 ratio respectively.

Sugars (sucrose, glucose, and fructose) are transformed into alcohol according to the Gay-Lussac reaction:

$$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6 \qquad (*)$$

$$C_6H_{12}O_6 \rightarrow 2\ CH_3CH_2OH + 2\ CO_2 + 23.5\ kcal \qquad (**)$$

(*) Sucrose + Water → Glucose + Fructose

(**) Glucose/ Fructose → Ethanol + Carbonic Dioxide + Heat

As shown above, fermentation releases carbonic dioxide and heat. The gas is washed in a form that can recover the alcohol dragged by it. Due to the released heat and the necessity of keeping a constant fermentation temperature around 32°C, it is used as a cooling system. After a period of 4 to 12 hours, fermentation generates a final product (fermented beer) with an alcoholic tenor of around 7 to 10% W/W, then the beer is pumped into the centrifugal machine to separate the yeast which is returned to the fermentation tank and the beer send to the Distillation section.

The yeast used in fermentation is recuperated usually through the ferment beer centrifugation process, this process is given the name of Melle-Boinot. This recuperated ferment receives the name of yeast milk and it returns to pre-fermenters it avoids bacterial infections since recuperated yeast suffers a treatment with water and sulfuric acid add up to pH = 2.5.

2.2 Distillation

To separate the alcohol the distillation process is used, in which the different boiling points of the components of the mixture are responsible for the separation concentration, to obtain an alcohol content of approximately 93.0% W/W, the Ethanol goes to the Dehydration Process via Molecular Sieve, whose object is to extract the water contained in the hydrous alcohol with a minimum grade of 93.0% W/W (weight), to obtain Anhydrous Alcohol with a grade of 99.6% W/W (weight) to at 20ºC.[16]

2.3 Dehydration Process

Molecular Sieves are complexes made up of a stable ceramic mixture, with controlled porosity, of a rigid, hollow structure, in which fluids such as water may be stored or retained in its pores using adsorption, thanks to its great desiccating power and its active surface of $800 m^2/g$. [16]

The principle for obtaining Anhydrous Alcohol via Molecular Sieve consists of using columns or vessels, duly filled with this ceramic mixture, also known as “Resin” which, using controlled temperature and pressure will allow the passage of approximately 93% W/W(weight) grade alcohol in the vapor phase through its bed, promoting the absorption of the water molecules and releasing the anhydrous alcohol.

Separation occurs because there are water molecules with a diameter of 2.8⊕ in the Hydrous Alcohol, while in Ethanol the molecules are 3.2⊕ in diameter. For this case, ceramics or resins of the crystalline structure are used, which have pores of approximately3⊕ in diameter, through which there will be low adsorption efficiency of ethanol molecules and greater separation of water molecules.[16]

Afterward, the water accumulated in the resin is removed using a vacuum, so that the recovered resin can be re-used. so that there are two systems one will under process the other under drying.

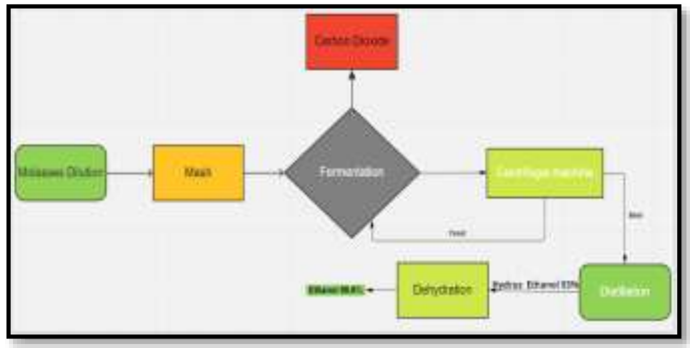

Figure 4 Kenana Ethanol Plant production process Block Diagram

3. Exiting Technology of Carbon Dioxide Capture from Ethanol Plant:

CO_2 capture is the isolation and trapping of CO_2 from massive gas flow sources, whereas CO_2 storage is the injection of CO_2 into geologic formations or marine reserves that were used hundreds or thousands of years ago (CCS).

There are now various CO_2 separation technologies in use, including absorption, adsorption, membrane, microalgae, cryogenic, etc.[17].

Each of these technologies works by separating things in a different way. To get high efficiencies, it is important to choose the right technologies for different industrial emission sources. The efficiency depends on different parameters (e.g., stream conditions, flue gas composition, economics, and target products)[18].

There are three main basic CO_2 capture systems for different types of combustion. [19], Figure 5 shows Pre-combustion, Post-combustion, and Oxy-fuel Combustion. Each technology is best for a different industrial process or type of power plant

- ✓ Pre-combustion capture: This method extracts CO2 from fossil fuels before combustion.
- ✓ Post-combustion capture: The most recommended approach for retrofitting existing facilities is post-combustion capture (PCC), which refers to capturing

CO_2 from fossil fuels after combustion is complete. Syngas is a combination of hydrogen, carbon monoxide, CO_2, and trace quantities of other gaseous components such as methane. With post-combustion capture, a variety of separation processes might be used. Adsorption, physical absorption, chemical absorption, cryogenic separation, and membranes are examples of these.

- ✓ Oxyfuel combustion: One of the top technologies being examined for collecting CO_2 from power plants with CCS is oxygen fuel combustion. Instead of using air to burn fuel, this method uses practically pure oxygen.

According to the IPCC (2005), carbon capture and storage (CCS) has the potential to collect between 85 and 95 percent of all CO_2 generated, but net emission reductions are only around 72 to 90 percent. This is because it requires energy to separate the CO_2 from the upstream emissions [20].

CCS is a tried-and-true combination of technologies that involve the separation and capture of more than 90% of CO_2 emissions from industrial and power production sources, with capture rates of up to 98% attainable at a low marginal cost [21].

Once the CO_2 has been successfully "captured" from a process, it needs to be transported to a safe storage facility. When compressed to pressure more than 7.4 MPa and a temperature greater than around 31 C, CO_2 can be transported with minimal loss of energy. The CO_2 is a supercritical liquid, exhibiting properties more typical of gas, under these circumstances. So, similar to how regular natural gas is delivered through steel pipes, carbon steel pipelines would be used to carry CO_2, and if the gas had to traverse a large body of water, ships would be used. Large-scale CO_2 pipelines are already in existence, but mostly in unpopulated areas and in the United States for better oil recovery (EOR). To yet, there have been no CO_2 ships in operation, although this is not expected to result in any technological difficulties [22].

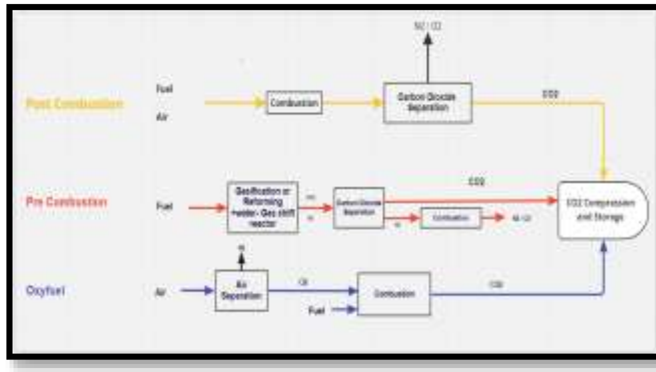

Figure 5 Modificative Diagram of Three types of the CO_2 Capture system [23]

Projects using carbon capture and storage (CCS) as a means of lowering emissions of greenhouse gases (GHG) have been widely discussed [24]. Intergovernmental Panel on Climate Change IPCC concludes that this technology will be crucial in achieving the necessary level of emission reductions in the future [25], Future emission reductions will be impossible to achieve without this technology.

Currently, there are two different strategies and techniques to promote CO_2 removal (CCR) via direct capture:

1- Carbon Capture Sequestration (CCS).
2- Carbon Capture and Utilization (CCU).

To avoid direct emissions into the environment, CCS systems absorb and store CO_2 as a waste product. The CCU approach, on the other hand, is based on the collection of CO_2 and its subsequent use as a raw material in the creation of other value-added goods via chemical transformation processes.[26][27].

According to the Global CCS Institute (GCCSI), there are now 55 CCS projects in the works throughout the world, with just 14 of them operating, as of March 2014.[24].

Bioenergy with carbon capture and storage (BECCS), Various BECCS technologies are being investigated across the world, and one option that warrants special attention applies CCS to ethanol production. Through the capture and storage of CO_2 emitted during fermentation, which is part of sugarcane-based ethanol production in Brazil, it is now possible to reduce 27.7

million tonnes (Mt) of CO_2 emissions per year.[24]. Around the world, several technical approaches to BECCS are being investigated, and one alternative that merits special attention is the technique used in sugarcane-based energy ethanol plants [24], [28].

Regarding BECCS in Brazil, the key benefit for the country would be to capitalize on the country's ethanol successes, as the fuel would be the first to deliver negative emissions across its life cycle carbon balance.[24], [29].

Brazil's Ethanol Fuel Program is a successful example of a creative energy strategy. By utilizing sustainable biomass, BECCS investments might promote both socioeconomic growth and environmental conservation. Rural economic development in sugar cane producing regions, for example, and fewer CO2 emissions in the transportation sector result in improved air quality in big cities. The need for investments in the sugar/ethanol industry is enormous, given Brazil's strong proportion of the worldwide market and the potential for ethanol demanded by the ongoing expansion of the flex-fuel automobile fleet[30][24].

4. Carbon Dioxide Utilization

CO_2 characteristics It is a non-flammable substance that is effectively "free for the taking." These characteristics make the manufacture of commercial chemicals, fuels, and materials can benefit greatly from the utilization of CO_2 as a feedstock [31]. Furthermore, CO_2 has distinct physical and thermodynamic characteristics. At 78.5 °C, it transitions straight from a gas to a solid state (as dry ice). Dry ice is a low-cost refrigerant that is extensively used as a chilling agent in grocery shops, labs, and the food processing industry. At pressures more than 5.1 atm, liquid CO_2 develops, and the very cold liquid possesses cryogenic qualities. In addition, the CO_2 critical point is 31.1 °C and 7.4 MPa. The critical point is the temperature and pressure level at which a gas cannot be liquefied regardless of pressure. Above the critical point, matter exists as a dense gas, or in this case, supercritical CO_2 [32]. The unique nature of the CO_2 phase position makes it an exceptionally adaptable chemical, ideally suited for a wide range of applications such as chemical, food, puffing, and extraction, with new applications being developed on a regular basis [33].

Recent increases in the exploitation of natural resources and the creation of products and services have resulted in environmental degradation, climate change, and ecological distortions as the most significant issues [34]. Utilizations of CCU technologies are vital to reducing the influence of greenhouse gases and managing the environmental pollutant in a manner that is both economically and energy-efficiently sound, also it has the potential to replace fossil carbon value chains and even produce negative emissions [35].

It has been determined that the development of technology for the collection and usage of carbon dioxide is essential in order to curb pollution and slow the progression of global warming [36].

Carbon utilization is the idea that the CO_2 collected through carbon dioxide capture technologies can be stored. Concentrated CO_2 is a versatile product and can have many productive uses such as cement, carbonated beverages, fuels like syngas, and enhanced oil recovery (EOR)[37].

CO_2 capture from gas streams is not a new concept. CO_2 capture systems based on chemical solvents (amines) were first commercially employed in 1930 in natural gas production to extract CO_2 and other acid gases from methane. Before 1972, all CO_2 captured were released into the environment, except for a small percentage that was used or sold for other uses such as urea synthesis or beverage carbonation [38]. The next wave of CCS investment is beginning to take the form of industrial CCS centers and clusters. Numerous industrial sources of CO_2 have access to centralized infrastructure for CO_2 transport and injection through these hubs. Through economies of scale, CCS hubs dramatically lower the unit cost of CO_2 transport and storage. They also provide commercial and technological synergies that lower investment risk and further cut costs. An industrial hub, for instance, offers the chance to aggregate numerous tiny carbon dioxide streams from various industrial processes into one large stream for compression in a single facility, lowering the unit cost of compression due to economies of scale. By fostering an ecosystem of companies that demand

CO_2 management and storage services, CCS hubs also reduce counterparty or cross-chain risk as well as the risk of underutilizing infrastructure for CO_2 transport and injection. The concentration of supply chains, the accessibility of the necessary production inputs, and the availability of the necessary transportation infrastructure all benefit the co-location of industries [38].

With an emphasis on cutting-edge technologies that are at, or nearly at, large-scale demonstration or commercialization, examine CO_2-utilization technologies that turn CO_2 into commercial products via chemical and biological reactions. The various technological methods of CO_2 utilization are categorized, including electrochemical, photocatalytic, photosynthetic, catalytic, biological (using microorganisms and enzymes), copolymerization, and mineralization. The status of CO_2-utilization technology is evaluated, as well as recent advances. The life-cycle analysis of CCU is also used to discuss its environmental impact[39].

Due to the high purity of Carbon dioxide from the fermentation by-product of the Ethanol Plants, a lot of ethanol facilities in the US create and sell CO_2 as marketable for Food industries, dry ice, beverage, metal welding, pH control, and chemicals, some of the CO_2 consumption potentials outside of Enhance Oil Recovery (EOR)[40].

The CO_2 that is produced as a byproduct of fermentation and syngas is extremely pure and, as a result, simply has to be dehydrated before it can be compressed and sequestered. [41].

The chemical conversion, mineralization, and biological processes that are all part of the carbon capture and utilization (CCU) technology that is now in use may turn CO_2 into a variety of useful products, including ethanol[42].

There are trends in CO_2 hydrogenation to ethanol. CO_2 is recognized to be a GHG, which causes a problem known as global warming, which is a severe issue today. To deal with rising CO2 levels, the CCU approach may be used to create catalysts that trap CO_2 and convert it into useful fuels such as ethanol. Various reaction pathways have been hypothesized, and intermediates have been identified as being critical for ethanol production. Furthermore, the catalyst should be built in such a way that it inhibits the methanation routes, which are undesired. To choose a greener path, one should develop a catalyst that uses less energy, has greater selectivity for ethanol, is stable when reused, and avoids the creation of chemicals in the product that is hazardous to the environment, such as CH4 and CO[43].

The act of producing ethanol results in the generation of a large number of by-products, most of which are discarded as waste. One of these by-products, carbon dioxide, is a material of our interest, particularly involved in the food industry.[44].

As calculated above in section 2, CO_2 emission capacity from the Kenana Ethanol plant is about 55,632.00 tons/year, all this quantity is released directly into the atmosphere, by the high purity of the CO_2 stream, which can capture simply.

The Kenana Ethanol Plant has the ability to emit about 55,632 tons of carbon dioxide per year, from the fermentation unit as was stated in section 2 of this article. All of this quantity is discharged straight into the atmosphere, Because of the high purity of the CO_2 stream, it's simply can capture and utilize.

In comparison to other CO_2 carputer techniques, the ethanol fermentation CO_2 capture technique is very simple and cost-effective. The CO_2 produced during fermentation in an ethanol plant is concentrated and nearly pure, the only purifying operations necessary are dehydration and compression. The dehydration to remove the remaining moisture in the gas is to prevent corrosion in the CO_2 pipes line. Following that, the CO_2 gas is compressed to conventional pipeline pressures[33].

The cost of collecting (including dehydration and compression) from ethanol facilities has been estimated to be between \$6 and \$12 per ton of CO_2. The costs of capturing CO_2 from other big point sources range from \$20 to \$95 per ton of CO_2 from fossil power plants, \$5 to \$70 per ton of CO_2 from hydrogen and ammonia production or gas-processing facilities, and \$30 to \$145 per ton CO_2 from other industrial sources.[45].

In some situations, a purification process is also required to eliminate odor components in order to meet the stringent criteria of the food and beverage sectors. However, odor removal is not required for other industrial or storage uses.

5. Conclusion

Carbon capture and utilization (CCU) for CO_2 fermentation by-product of Kenana Ethanol Plants offers a good opportunity to share on CO_2 mitigation which leads to energy and environmental sustainability.

Currently, the fermenting unit of the kenana ethanol plant discharges the CO_2 straight into the surrounding atmosphere. Because the CO_2 that is produced during fermentation is highly pure and concentrated, it is possible to sell captured carbon dioxide (CCU) to the food and beverage industries. Additionally, a small unit for refilling CO_2 fire extinguishers can be created, there are a lot of cylinders in the Kenana enterprises (Ethanol plant, sugar factory, Animals feed factory, foundry, and kenana city). Through the operation of this CCU, had reduced the amount of carbon dioxide emissions, so the environment was protected, and increased the economic value of the CO_2 by-product.

In the future we can convert CO_2 to ethanol which increases the production of ethanol, there are research trends in CO_2 hydrogenation to ethanol.

References*:*

[1]"How have CO2 levels changed since the industrial revolution? | World Economic Forum." https://www.weforum.org/agenda/2021/03/met-office-atmospheric-co2-industrial-levels-environment-climate-change/ (accessed Apr. 14, 2021).

[2]"8 future technologies for carbon capture - JWN Energy." https://www.jwnenergy.com/article/2017/3/8/8-future-technologies-carbon-capture/ (accessed Apr. 14, 2021).

[3]"Climate change: a serious threat to the world and Pakistan - Daily Times." https://dailytimes.com.pk/491675/climate-change-a-serious-threat-to-the-world-and-pakistan/ (accessed May 03, 2021).

[4] US EPA, "International Climate Impacts".

[5]"Carbon Capture, Utilization & Storage | Aramco." https://www.aramco.com/en/making-a-difference/planet/carbon-capture-utilization-and-storage?utm_source=googleads&utm_medium=ppc&utm_campaign=GO_KSA_EN_Carbon_PH&gclid=Cj0KCQjw38-DBhDpARIsADJ3kjl2gNe6lZ5Nq2U10L5DtOrzSd5NnAeGQlpoHXY1PZCbFQSqF0Qn7-MaAvFkEALw_wcB (accessed Apr. 12, 2021).

[6]P. Bains, P. Psarras, and J. Wilcox, "CO2 capture from the industry sector," *Prog Energy Combust Sci*, vol. 63, pp. 146–172, Nov. 2017, doi: 10.1016/J.PECS.2017.07.001.

[7]S. Yousefi, B. Ghasemi, M. Tajally, and A. Asghari, "Optical properties of MgO and Mg(OH)2 nanostructures synthesized by a chemical precipitation method using impure brine," *J Alloys Compd*, vol. 711, pp. 521–529, Jul. 2017, doi: 10.1016/j.jallcom.2017.04.036.

[8]A. M. Alkadhem, M. A. A. Elgzoly, A. Alshami, and S. A. Onaizi, "Kinetics of CO2 capture by novel amine-functionalized magnesium oxide adsorbents," *Colloids Surf A Physicochem Eng Asp*, vol. 616, no. August 2020, p. 126258, 2021, doi: 10.1016/j.colsurfa.2021.126258.

[9]A. A. Abd, S. Z. Naji, A. S. Hashim, and M. R. Othman, "Carbon dioxide removal through physical adsorption using carbonaceous and non-carbonaceous adsorbents: A review," *Journal of Environmental Chemical Engineering*, vol. 8, no. 5. Elsevier Ltd, Oct. 01, 2020. doi: 10.1016/j.jece.2020.104142.

[10]"Ethanol Co-Products." https://ethanolrfa.org/ethanol-101/ethanol-co-products (accessed Aug. 07, 2022).

[11]"Capturing and Utilizing CO 2 from Ethanol: Adding Economic Value and Jobs to Rural Economies and Communities While Reducing Emissions," 2017.

[12]M. Saunois *et al.*, "The global methane budget 2000-2017," *Earth Syst Sci Data*, vol. 12, no. 3, pp. 1561–1623, Jul. 2020, doi: 10.5194/ESSD-12-1561-2020.

[13]Dr. O. M. E. S. Khayal and M. I. Osman, "The TECHNICAL AND ECONOMIC FEASIBILITY STUDY OF ESTABLISHING ETHANOL FUEL PLANT IN KENANA SUGAR COMPANY," *GPH-International Journal of Applied Science*, vol. 2, no. 10, pp. 01–36, Oct. 2019, Accessed: Aug. 13, 2022. [Online]. Available: http://gphjournal.org/index.php/as/article/view/253

[14]H. S. Kheshgi and R. C. Prince, "Sequestration of fermentation CO2 from ethanol production," *Energy*, vol. 30, no. 10, pp. 1865–1871, 2005, doi: 10.1016/J.ENERGY.2004.11.004.

[15]"Ethanol Production - General Information | EGEE 439: Alternative Fuels from Biomass Sources." https://www.e-education.psu.edu/egee439/node/646 (accessed Aug. 13, 2022).

[16]Kenana Ethanol Plant, "Kenana Ethanol Plant Manual".

[17]A. Stangeland, "A model for the CO2 capture potential," *International Journal of Greenhouse Gas Control*, vol. 1, no. 4, pp. 418–429, Oct. 2007, doi: 10.1016/S1750-5836(07)00087-4.

[18]C. Song, Q. Liu, S. Deng, H. Li, and Y. Kitamura, "Cryogenic-based CO2 capture technologies: State-of-the-art developments and current challenges," *Renewable and Sustainable Energy Reviews*, vol. 101, pp. 265–278, Mar. 2019, doi: 10.1016/J.RSER.2018.11.018.

[19]D. Y. C. Leung, G. Caramanna, and M. M. Maroto-Valer, "An overview of current status of carbon dioxide capture and storage technologies," *Renewable and Sustainable Energy Reviews*, vol. 39, pp. 426–443, Nov. 2014, doi: 10.1016/J.RSER.2014.07.093.

[20]P. Viebahn *et al.*, "Comparison of carbon capture and storage with renewable energy technologies regarding structural, economic, and ecological aspects in Germany," *International Journal of Greenhouse Gas Control*, vol. 1, no. 1, pp. 121–133, 2007, doi: 10.1016/S1750-5836(07)00024-2.

[21]J. M. English and K. L. English, "An Overview of Carbon Capture and Storage and its Potential Role in the Energy Transition," *First Break*, vol. 40, no. 4, pp. 35–40, Apr. 2022, doi: 10.3997/1365-2397.FB2022028.

[22]"CO2 capture technologies | Climate Technology Centre & Network | Tue, 11/08/2016." https://www.ctc-n.org/technologies/co2-capture-technologies (accessed Nov. 08, 2021).

[23]S. K. Gebremariam, "Modelling a Membrane Contactor for CO2 Capture," *Norwegian University of Science and Technology, Trondheim*, 2017.

[24]J. R. Moreira, V. Romeiro, S. Fuss, F. Kraxner, and S. A. Pacca, "BECCS potential in Brazil: Achieving negative emissions in ethanol and electricity production based on sugar cane bagasse and other residues," *Appl Energy*, vol. 179, pp. 55–63, Oct. 2016, doi: 10.1016/J.APENERGY.2016.06.044.

[25]O. Edenhofer and al et., "Technical Summary In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Technical Report," 2014, Accessed: Aug. 20, 2022. [Online]. Available: http://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_technical-summary.pdf

[26]K. Roh *et al.*, "Sustainability analysis of CO2 capture and utilization processes using a computer-aided tool," *Journal of CO2 Utilization*, vol. 26, pp. 60–69, Jul. 2018, doi: 10.1016/J.JCOU.2018.04.022.

[27]J. Yan and Z. Zhang, "Carbon Capture, Utilization and Storage (CCUS)," *Appl Energy*, vol. 235, pp. 1289–1299, Feb. 2019, doi: 10.1016/J.APENERGY.2018.11.019.

[28]"Biofuels in the EU: A Vision for 2030 and beyond - BiofuelsBiofuels." https://www.biofuelstp.eu/ (accessed Aug. 20, 2022).

[29]S. Pacca and J. R. Moreira, "Historical carbon budget of the brazilian ethanol program," *Energy Policy*, vol. 37, no. 11, pp. 4863–4873, Nov. 2009, doi: 10.1016/J.ENPOL.2009.06.072.

[30]USDA – United States Department of Agriculture Sugar: world markets and trade Foreign Agricultural Service (2016), "USDA – United States Department of Agriculture Sugar: world markets and trade Foreign Agricultural Service (2016)."

[31]S. K. Ritter, "What can we do with CO2?."

[32]C. M. White, B. R. Strazisar, E. J. Granite, J. S. Hoffman, and H. W. Pennline, "Separation and Capture of CO2 from Large Stationary Sources and Sequestration in Geological Formations—Coalbeds and Deep Saline Aquifers," *http://dx.doi.org/10.1080/10473289.2003.10466206*, vol. 53, no. 6, pp. 645–715, 2012, doi: 10.1080/10473289.2003.10466206.

[33]Y. Xu, L. Isom, and M. A. Hanna, "Adding value to carbon dioxide from ethanol fermentations," *Bioresour Technol*, vol. 101, no. 10, pp. 3311–3319, May 2010, doi: 10.1016/J.BIORTECH.2010.01.006.

[34]T. S. Adebayo, A. A. Awosusi, and I. Adeshola, "Determinants of co2 emissions in emerging markets: An empirical evidence from mint economies," *International Journal of Renewable Energy Development*, vol. 9, no. 3, pp. 411–422, Oct. 2020, doi: 10.14710/ijred.2020.31321.

[35]S. Valluri, V. Claremboux, and S. Kawatra, "Opportunities and challenges in CO2 utilization," *Journal of Environmental*

Sciences (China), vol. 113. Chinese Academy of Sciences, pp. 322–344, Mar. 01, 2022. doi: 10.1016/j.jes.2021.05.043.

[36]S. Valluri, V. Claremboux, and S. Kawatra, "Opportunities and challenges in CO2 utilization," *J Environ Sci (China)*, vol. 113, pp. 322–344, Mar. 2022, doi: 10.1016/J.JES.2021.05.043.

[37]K. S. Lackner, S. Brennan, J. M. Matter, A. H. A. Park, A. Wright, and B. van der Zwaan, "The urgency of the development of CO 2 capture from ambient air," *Proc Natl Acad Sci U S A*, vol. 109, no. 33, pp. 13156–13162, Aug. 2012, doi: 10.1073/PNAS.1108765109/-/DCSUPPLEMENTAL.

[38]KAPSARC, "Carbon capture and storage," Aug. 2020.

[39]Q. Zhu, "Developments on CO 2-utilization technologies," *Clean Energy* , vol. Volume 3, no. Issue 2, pp. 85–100, Jul. 2019, doi: 10.1093/ce/zkz008.

[40]H. Ne *et al.*, "Cost Analysis of Carbon Capture and Sequestration of Process Emissions from the U.S. Industrial Sector," *Cite This: Environ. Sci. Technol*, vol. 54, p. 7532, 2020, doi: 10.1021/acs.est.9b07930.

[41]C. H. Geissler and C. T. Maravelias, "Analysis of alternative bioenergy with carbon capture strategies: present and future," *Energy Environ Sci*, vol. 15, no. 7, pp. 2679–2689, Jul. 2022, doi: 10.1039/D2EE00625A.

[42]U. Lee, T. R Hawkins, E. Yoo, M. Wang, Z. Huang, and L. Tao, "Using waste CO2 from corn ethanol biorefineries for additional ethanol production: life-cycle analysis," *Biofuels, Bioproducts and Biorefining*, vol. 15, no. 2, pp. 468–480, Mar. 2021, doi: 10.1002/BBB.2175.

[43]S. S. Ali, S. S. Ali, and N. Tabassum, "A review on CO2 hydrogenation to ethanol: Reaction mechanism and experimental studies," *J Environ Chem Eng*, vol. 10, no. 1, p. 106962, Feb. 2022, doi: 10.1016/J.JECE.2021.106962.

[44]R. B. D. A. Filho, L. Danielski, F. R. de Carvalho, and L. Stragevitch, "Recovery of carbon dioxide from sugarcane fermentation broth in the ethanol industry," *Food and Bioproducts Processing*, vol. 91, no. 3, pp. 287–291, Jul. 2013, doi: 10.1016/J.FBP.2012.09.009.

[45]N. Wei, X. Li, R. T. Dahowski, C. L. Davidson, S. Liu, and Y. Zha, "Economic evaluation on CO2-EOR of onshore oil fields in China," *International Journal of Greenhouse Gas Control*, vol. 37, pp. 170–181, Jun. 2015, doi: 10.1016/J.IJGGC.2015.01.014.