Carbon Removal Technologies (DAC & BECCS)

The climate change is a major challenge faced by humankind. Greenhouse gases (GHGs) are the reason of this phenomenon has occurred. Among all of the gases, Carbon dioxide (CO_2) is the human-produced gas that is most significant contributor. According to Nunez (2019)[1] the CO_2 responsible for about three-quarters of global emissions. Such emissions mainly come from the power generation sector by burning fossil fuel like coal, oil, gas, wood and solid waste. Similarly, European Union[2] also claims CO_2 as the largest contributor to global warming. They also recorded, since pre-industrial era (before 1750), the concentration of CO_2 in the atmosphere had risen by 48% more in 2020. Beside burning fossil fuels, they also added deforestation as another source of the carbon production. Below is the total global GHG based on each sector in 2018 (in percentage).

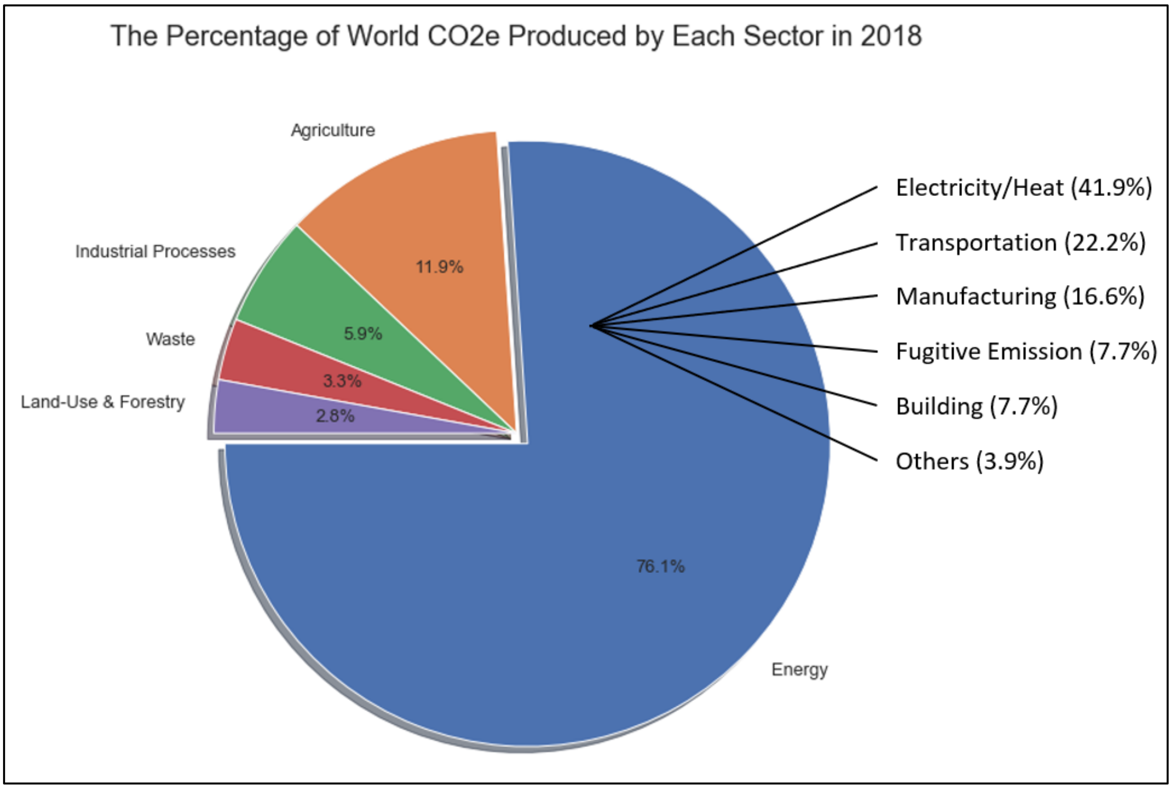

Figure 1. *The Percentage of Global GHG (in CO_2e) Produced by Each Sector in 2018* (Data: Climate Watch Data Explorer - CAIT)[3]

The original data comes from CAIT[3], the **Figure 1** consists of 2 chosen data, which are main sector data[4] and energy sub-sector data[5]. CAIT found in 2018 the total of global emission was 48.94 $GtCO_2e$ (equivalent to 100% of GHG in **Figure 1**). As we can see, from the main sector data[4], the energy production has accounted more than three-quarters of total GHG in 2018, with 76.1%. Later followed by, Agricultural (11.9%) and Industrial Processes (5.9%) respectively. The huge discrepancy between the energy sector with other sectors indicates that the global energy sector production was the main cause to the world emissions. More importantly, CAIT emphasized that electricity/heat, transportation and manufacturing are the top 3 contributors for the carbon production as energy sub-sector, with 41.9%, 22.2% and 16.6% respectively (energy sub-sector data[5]). Generally, most of energy sector carbons are caused by burning the fossil fuels and released the CO_2 to the atmosphere. Like we discussed before, CO_2 is the major contributor to the world GHG emissions. Thus, there is no doubt, if the energy sector leaves huge amount of carbon to the atmosphere and reaches such substantial figure in 2018 carbon production compare to other sectors.

Since our world is in the transition towards the future carbon neutrality, many actions need to be taken. For instance, in December 2015, there is declaration for Paris Agreement which adopted by 196 countries. The goal is to limit global warming to well below 2, preferably to 1.5 degrees Celsius, compared to pre-industrial levels (United Nation Climate Change)[6]. Moreover, they also set for long-term carbon neutral and temperature goal by 2050, by reaching the global greenhouse gas emissions peak as soon as possible before 2050. This international movement looks promising, as they just celebrate its anniversary last December 2020 (Guterres, 2020)[7]. Thus, the sole enterprise, government and locals from every nation need to work together to achieve this goal as well.

Nowadays, as we can see many different sets of solutions can be done to contribute towards future earth's sustainability and low carbon. Especially in the current era, the technology-based solution has the edge compare to traditional solution. As with technology, the solution could scale exponentially, which ease the carbon mitigation rate and reach future carbon neutrality as soon as possible. Before we are going to deeper on this technology solution, we need to understand other potential solutions as well. To reach future low carbon, we are going to categorize the solution into 2 different measures, one is carbon production solution, the other one is carbon removal solution.

Figure 2. Carbon Production Solution (Source: Andreus)[8]

The carbon production solution is believed as a popular solution across the countries and industries to achieve low carbon. The concept is to reduce as much new carbon production or greenhouse gas emission in the environment. This can be done by replacing the fossil fuel energy production with the clean and renewable energy production technology. This definitely can be applied in the problems in **Figure 1**. For example, the wind, solar or biomass energy powered electricity for energy production or create resilience building, Electric Vehicles (EVs) for transportation and vertical farming system for agriculture. Beck et al. (2021)[9] also encourage the transition towards low carbon future by reducing the production of oil and gases.

It is true that the clean and renewable energy production will help the world to reach the carbon neutrality. However, in fact it is not enough, considering the existing carbon on the atmosphere which produced in the past. Without further action and measure, the carbon on the atmosphere will always be there and the earth's temperature will not get cooler soon. Thus, the second solution, which is carbon removal solution is very crucial as the carbon mitigation role. Unlike the first solution, the carbon removal is able to remove and create a negative carbon emission. This system can be called as Carbon Capture Storage (CCS) as well. The concept is to remove the existing carbon on the atmosphere by capture and store it underground, which resulting in negative carbon emission on the atmosphere. Generally, there are 2 strategies for CCS application, which are the biological strategy and technological strategy.

The biological strategy can be defined as the natural strategy to remove carbon from the atmosphere. Trees are the core of this solution, they have a role to sequester the CO_2 from the atmosphere. The action of planting trees, reforestation and preserving forest will help this strategy to success. International Energy Agency (IEA)[10] recorded in 2021, the global CO_2 emissions from just energy sector reaches around 33 Gt CO_2 or 33 billion tons CO_2. However, CO2METER (2021)[11] stated if a typical hardwood tree can absorb around 24 kg of carbon dioxide per year, which means it requires 40 year to sequester approximately 1 ton of CO_2. To reach the 2050 global carbon neutrality goal, we only have less than 30 years to realize it. Hence, the tree planting will not be enough to achieve this target, considering another greenhouse gas from different sectors, there will actually more than 33 Gt CO_2e need to be removed. Moreover, it requires time and massive empty lands to grow so many trees just to remove certain number of carbons.

This concern has led the human to do more research and manage to invent technologies that could both remove and reduce the carbon emissions in atmosphere in more efficient way (IEA, 2021)[12]. Like we stated before the CCS is the system of carbon removal, however with technologies we can utilize the carbon that is captured by the machine. Therefore, the second strategy also can be called as Carbon Capture, Utilization and Storage (CCUS). In the CCUS, the carbon actually can be extracted and captured by the chemicals from the technologies, which later the extracted carbon can be utilized for further use.

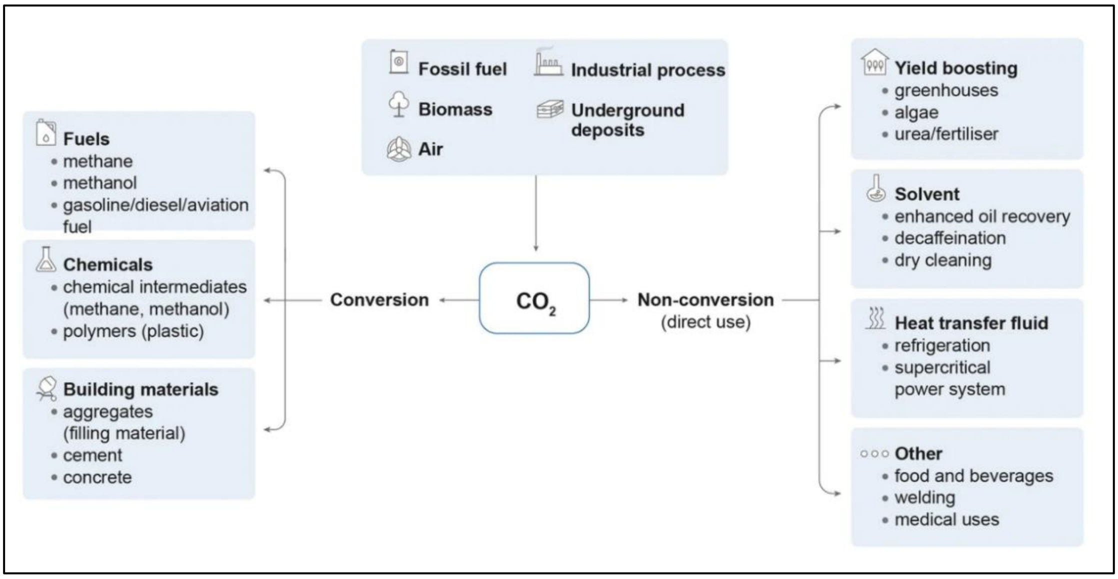

Figure 3. Variety on Carbon Utilization (Source: IEA, 2021)[13]

In the **Figure 3**, it shows many different functions of CO_2. The middle components are the input source for the CCUS, either to produce electricity, manufacturing or just sole reason to remove carbon from the air. Thus, it is no surprise there is air as the input component. Next, after carbon being extracted, there are 2 ways conversion, which are the direct and indirect conversion.

The direct conversion, basically the raw carbon that are captured will be utilized right away without intervention of other chemical mixture. For instance, IEA (2021)[13] claims around 230 $MtCO_2$ are used globally each year, where primarily around 125 Mt to produce fertilizer for agriculture and around 70-80 $MtCO_2$ to enhance oil recovery. Other popular use of CO_2 includes the food and beverage production, like water treatment, cooling and soda production (right hand side of **Figure 3**).

The indirect conversion, is the transformation of CO_2 to a useful product through chemical and biological processes. For instance, by mixing CO_2 with hydrogen will produce hydrocarbon fuel which useful for transportation and in building material, the CO_2 can replace water in concrete (IEA, 2021)[13] (left hand side of **Figure 3**).

With such utilization, it will result with no new carbon being produced. In other words, it is a carbon neutral loop, which means the products we use are actually came from CO_2 recycling. Beside the utilization, the carbon that are captured also can be stored underground which will result to negative carbon emission. Basically, the carbon will be buried underneath the ground in gas or solid form, which removes it from the atmosphere.

Currently, there are many prototypes of CCUS, yet in this report, we are going to discuss specifically for Direct Air Capture (DAC) and Biomass Energy Carbon Capture Storage (BECCS) Technology.

The Direct Air Capture (DAC) is a technological method that involves the chemical reaction to separate and capture the CO_2 from the incoming air. Like we stated above, air is also one of many inputs for CCUS. Generally, technology that has the air as input are meant only to capture the CO_2 on the technologies. The process is as follow:

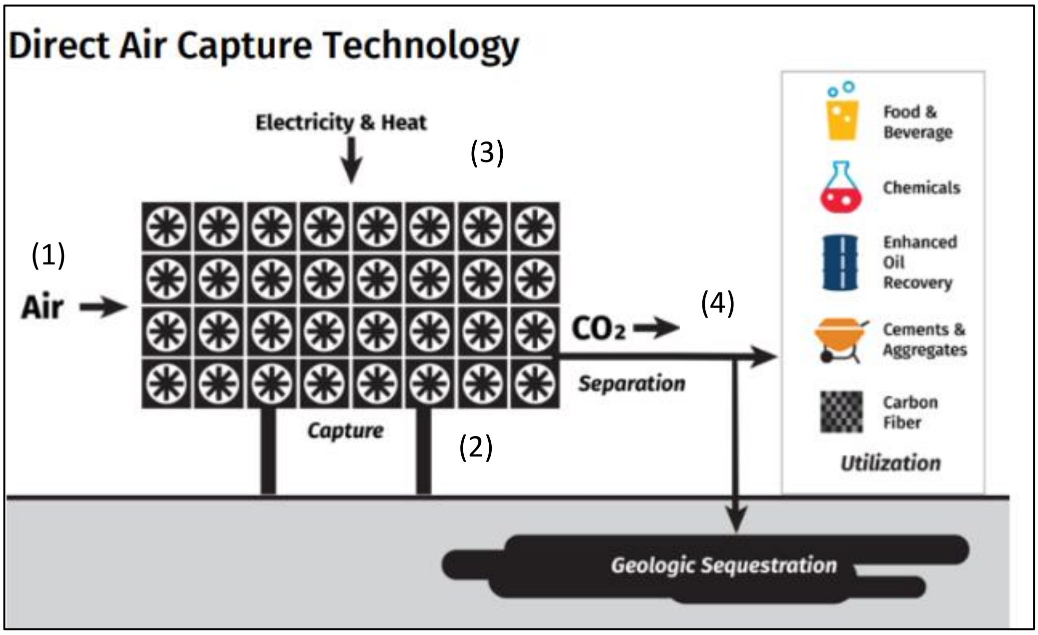

Figure 4. DAC Process (Source: Rhodium Group, 2019)[14]

(1) The ambient air is absorbed into the technology by the active fan, which next will be drawn to the middle part.
(2) In the middle part, it exists a layer of surface filter which is meant to capture as much as CO_2 from the air. This filter contains certain chemical substance which able to separate the CO_2 from other air components.
(3) Once enough CO_2 is captured, the collector will be closed and heated, causing pure CO_2 to be released and collected.
(4) Finally, the final product of pure CO_2 can be injected underground for permanent storage (Negative Carbon Emission) or benefitted by utilizing it for product (Zero Carbon Emission).

There are reasons why this technology is very fond of in the future. First, in the long term, it is expected that there will be less or no more production that produce new CO_2. As this technology utilize the recycled CO_2 which makes the product that produced from DAC to be very sustainable and zero carbon. Second, compare to the tree planting, DAC have better impact on the land area requirements. According to Lebling (2021)[15], to capture 1 million tonnes of CO_2, reforestation requires around 862 km^2 area (global average), whereas a DAC plant would need approximately 0.4 to 24.7 km^2 for the plant and energy resources. Finally, DAC provides the solution to achieve the negative carbon emissions by injecting the CO_2 underground. Lebling (2021)[15] also stated this geological sequestration will result in the biggest climate change benefit.

A Canadian-based company leading the commercialization of direct air capture technology namely Carbon Engineering, have been working on "Air to Fuel" project since 2018.

Figure 5. Carbon Engineering DAC (Source: Carbon Engineering)[16]

The project uses renewable electricity to generate hydrogen from water, and then combines it with CO_2 captured from the atmosphere to use it as an input to produce synthetic fuels that can substitute for diesel, gasoline, or jet fuel. According to Shah (2018)[17], for capturing CO_2, the carbon engineering estimate cost announced around \$94 to \$232 per ton. Moreover, through the "Air to Fuel" project, they hope to produce fuel for less than $1 per litre, once it scaled up. Therefore, cost and funding has become the limitation for DAC to scale up nowadays.

Biomass Energy Carbon Capture Storage (BECCS) is the process of extracting bioenergy from the biomass (trees, crops) while the captured carbon can be stored underground or utilized for products. Hence, this technology consists of 2 important output which are the energy production from the Biomass Energy (BE) and carbon storage from the Carbon Capture Storage (CCS). The process is as follow:

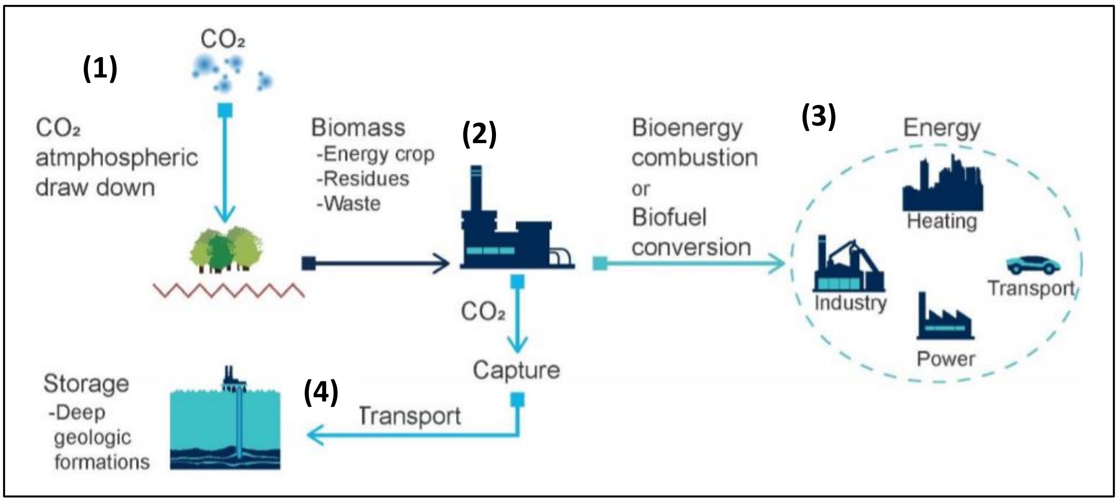

Figure 6. BECCS Process (Source: Global CCS Institute, 2019)[18]

(1) Initially, the CO_2 on the atmosphere is stored through the natural sequestration (Trees, Crops).
(2) The biomass such as energy crop, trees residues and waste are going to be input for the technology.
(3) **Output 1:** Energy is extracted in useful forms (electricity, heat, biofuels, etc.) as the biomass is utilized through combustion, fermentation, pyrolysis or other conversion methods.
(4) **Output 2:** Some of the carbon that are still remained from the natural sequestration will be extracted which can be stored by the geological storage (Negative Carbon Emissions) or utilized it for products (Zero Carbon Emission).

Nowadays, the global energy production comes from the bioenergy (BE) is huge. With just BE technology, the zero-carbon emission can be achieved, since the CO_2 released will be sequestered by the trees again. This eventually become a loop cycle. However, in the BECCS, we add more efficiency to the technology through the carbon capture and storage system, by utilizing the CO_2 for zero-carbon product or stored the CO_2 underground for negative carbon emissions. Global CCS Institute (2019)[18] also added BECCS is emerging as the best solution to decarbonise emission-intensive industries which meet the global warming targets.

In the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (2014)[19], the BECCS was reviewed as the reliable solution to carbon removal system. Based on the analysis, they suggested there is possible of 0 to 22.000 Mt CO_2e negative emissions per year through the BECCS (Simth and Porter, 2018)[20]. Moreover, BECCS would also cost $60 to $250 per ton of carbon eliminated, according to IPCC (Doyle, 2014)[21].

Despite its reliability, but similar to the DAC, BECCS has the cost and funding problem. Especially, it requires larger land for the bioenergy plant and the CCS technology. The land and time for planting tree would be another concern of this technology, as we discussed before on the natural strategy part.

In future, these technologies definitely will come in handy for meeting the carbon neutrality targets. This also similar for China, as they personally declared for 2030 carbon peak and 2060 carbon neutrality. Fuhrman et al. (2021)[22] found certain numbers for the future China projection to reach the 2060 carbon neutrality goal. Through certain simulation, they learned that DAC in particular can contribute to China's meeting the goals. In a year, the negative emissions can be mitigated around 3 Gt CO_2, including the difficult-to-mitigate sectors such as freight transportation and heavy industry. Out of total, the 1.6 Gt CO_2 could be contributed from DAC which accounted around 60% of China's negative emission requirement. Despite that, the DAC range efficiency still in range of 30%-60% and the remainder fulfilled by BECCS and afforestation. In fact, they also found that the DAC, BECCS and afforestation, has not yet been demonstrated at anywhere approaching the scales required to meaningfully contribute to climate mitigation in China. Yet, deploying massive scale of the Negative Emission Technologies (NETs) in given time limit will have impact on China's financial system and natural resources (Fuhrman et al., 2021)[22].

Suggestion and Conclusion:

There is no doubt that the carbon removal system such as CCUS technologies will be very crucial and essential, yet we cannot just rely on this mitigation scheme only. It is important to consider other carbon mitigation plan contribution. Like explained in the introduction, beside the carbon removal solution, there is carbon production solution as well. Both schemes work differently and they have own function to achieve future zero carbon. For example, the renewable and clean energy project which function to halt more of new carbon emissions being produced. Thus, it is essential to encourage every action that could contribute towards future low carbon, no matter how big or small it is.

Moreover, we cannot also underestimate the natural carbon sink. It is true that they have the time and land area issues, yet it is more affordable, provide cooler ecosystem, preserve the biodiversity and wildlife habitat, visual serenity and most importantly it could work as carbon storage. In the future, more research can be conduct in natural carbon sink, in terms of planting system for scalability and efficiency rate in grow duration. Further research on the CCUS technologies also required, this in order to create more affordable technologies which expected can be accessible by majority of global companies in the future, more efficiency in the technologies capture rate and less power usage also important. Finally, scaling more renewable and clean energy will assist both carbon removal works and carbon neutral goals. Therefore, by having all schemes working together, it will speed up reaching the 2050 world carbon neutrality target and I believe there will be no more transition as we embrace the world of low or zero carbon emission in 2050.

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