Carbon-Negative Production of Methanol via Direct Air Carbon Capture

(Technical Paper)

Renewable Energy's Land Demands and Native Peoples in the U.S.: An Analysis of Renewable Energy Infrastructure Development on Native Lands

(STS Paper)

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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General Research Problem

How can renewable energy systems see effective, widespread implementation?

Global atmospheric carbon dioxide concentrations have exceeded levels that have not been seen in approximately 3 million years (Wuebbles et al., 2017). Carbon emission rates associated with societies powered by fossil fuels have influenced these trends and create anthropogenic climate change. Resulting amplification of the Earth’s natural greenhouse effect impacts sensitive environmental systems and therefore human safety and development. Transitions from energy infrastructures reliant on fossil fuels to renewable energy sources have therefore already begun. While developments in green energy technology have been promising, many major obstacles still demand attention.

Carbon-Neutral Production of Methanol via Direct Air Carbon Capture

How can methanol be produced from sustainable technologies rather than fossil-fuel based synthesis gas?

The purpose of the technical project explored is to design a carbon-neutral methanol synthesis process that incorporates the utilization of renewable hydrogen and carbon capture technology (fig.1). Hydrogen will be acquired through a third-party source, which produces its hydrogen via large-scale electrolysis supported by renewably generated electricity. Carbon dioxide will be obtained through a direct air capture system, which will be designed in this project. Next, a methanol synthesis will take place with the combination of a reverse water gas shift reaction (RWG), and the hydrogenation of carbon monoxide. Both of these processes will be described in greater detail below:

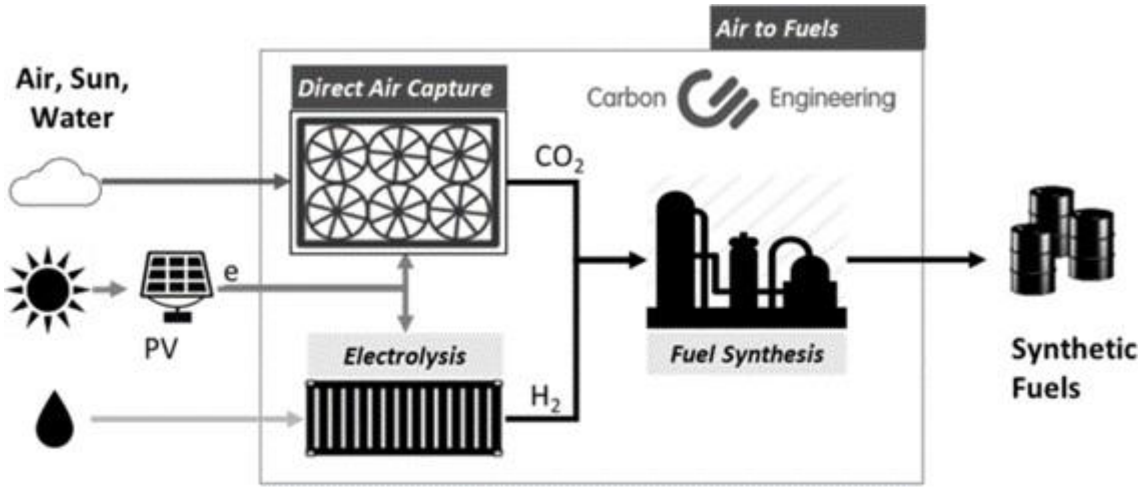

Figure 1. Overall Project Process (Macfarlane, 2019)

Designed Process #1 - Direct Air Carbon Capture (DAC)

The first technology that will be designed in this project is a direct air carbon capture system (DAC), which will produce pure CO_2 from ambient air (fig.2). The DAC system featuresan air contacting system which will introduce air to a liquid alkaline solution, capturing the CO_2.Then, a pellet reactor will be used to initiate the separation of CO_2 from the absorbent species.

Lastly, a calciner will produce a pure stream of carbon dioxide gas, and a slaker will be used to regenerate the absorbing species upstream (Keith, 2018).

There are two choices for DAC technology: high-temperature aqueous solutions (HT DAC) and low-temperature solid sorbent (LT DAC) systems, where the HT DAC system is cited to be the most robust and developed of the two (Broehm, 2015). HT DAC improves upon LT DAC as the capacity is higher and it is a continuous process (Keith, 2018). Therefore, HT DAC will be used in this design process.

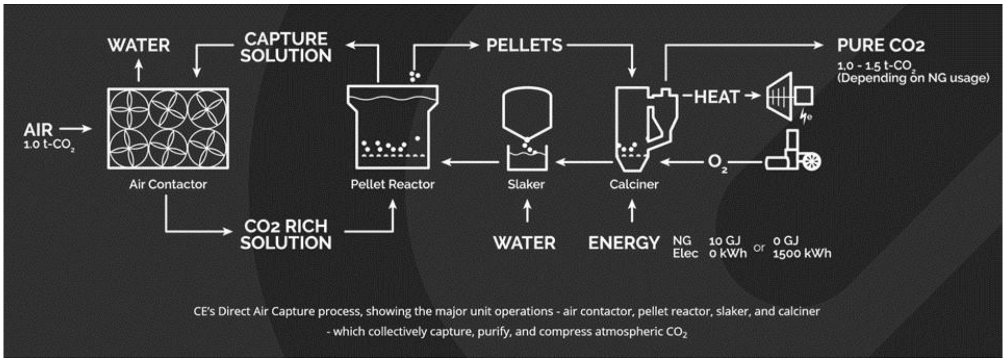

Figure 2. Process Flow Diagram for DAC (Carbon Engineering, 2021)

Thus far, only one company has implemented wide scale HT DAC (Fasihi, 2019), so there is opportunity for competitors to develop their own versions. This proposed project provides an avenue for improvement with the addition of downstream processing of CO2. Therefore, providing a novel way to improve the economics and utility of DAC as traditional DAC design usually sequesters carbon in geological formations, or uses it for enhanced oil recovery.

Process #2: Methanol Synthesis

The second step in our design process will be a methanol synthesis, which will occur via two chemical reactions. The sequence of these reactions can be referred to as the CAMERE Process. The first step is to convert the CO_2 to CO via the reverse water-gas shift reaction, the reaction is outlined below in Eq. 1:

$$\text{(Eq. 1) } CO + H_2O \Leftrightarrow CO_2 + H_2$$

In order to get the desired reverse reaction, catalysts are needed (Yang, et al. 2020). The hydrogenation of the carbon monoxide is the next step to form the desired product, methanol. The hydrogenation reaction occurs as follows in Eq. 2:

$$\text{(Eq. 2) } CO + 2H_2 \Longrightarrow CH_3OH$$

This reaction also requires a catalyst, which is used to drive the reaction to produce the desired product. As both reactions involve a selective choice of catalysts that is essential for product formation, respective catalysts used will be one of our critical design choices. Design of the unit operations as well as the scale of the process will determine what catalysts are used. Figure 3 displays an example methanol synthesis process flow diagram from a study performed by Joo et al., 1999.

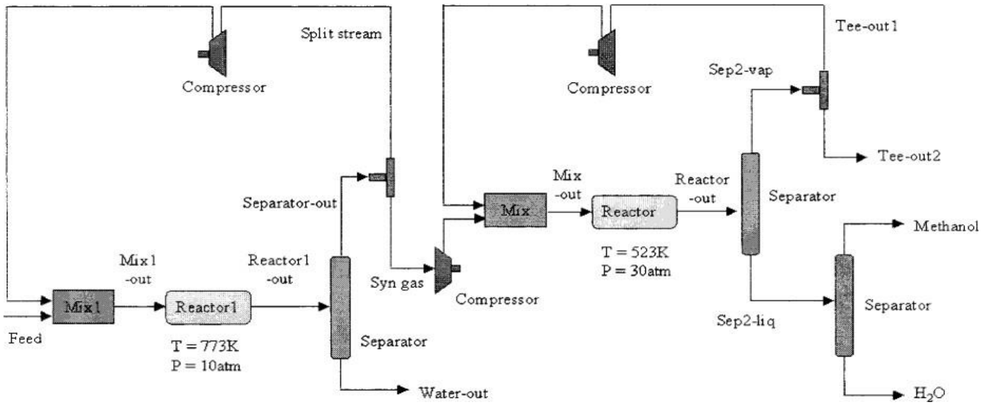

Figure 3. CAMERE Process Flow Diagram (Joo et al., 1999)

This study was performed to minimize operation costs but can serve as a basis for this section of the project. The CAMERE process utilizes two reactors, one for the RWGS reaction and one for hydrogenation of carbon monoxide, and various separators through the process to produce methanol.

Currently, the world’s energy supply and chemical processes are heavily reliant on fossil fuels (U.S. EIA, 2021). Although efficient and energy dense, these fuels are unsustainable, and catalyze global climate change due to associated emissions of greenhouse gases (fig. 4).

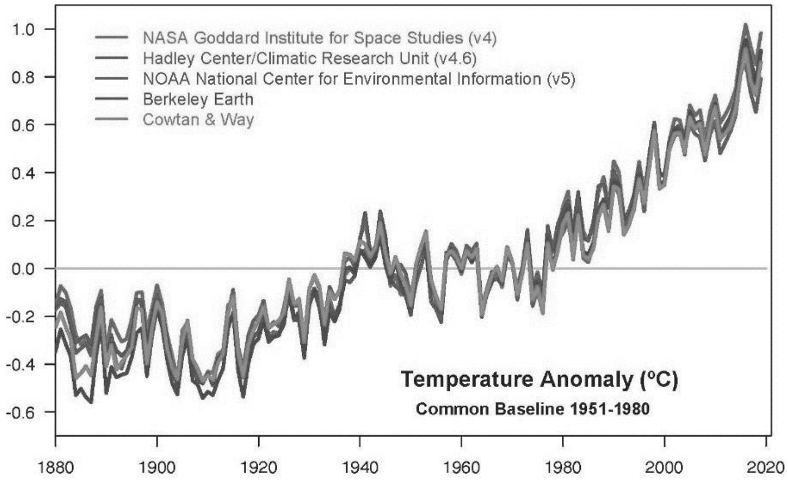

Figure 4. Global Temperature Trends Post-Industrialization (Brown, 2020)

A significant issue with the reduction of greenhouse gas emissions is the transition to more sustainable fuels as large transportation infrastructure requires a high-level of energy density that cannot be achieved by alternatives. In addition, many chemicals used in manufacturing are produced from sources that use fossil fuels. So, novel methods of production of fuels and chemicals are needed as energy production costs increase and the depletion of current fossil fuel sources continues. With continued shifts in public opinion on climate change, there is a hopeful outlook that investment in sustainable energy and chemical production methods is economically feasible (Funk, 2021). Moreover, based on recent research, the methanol market is expected to have a compound annual growth rate of 3.55% through 2026, worth 41.54 billion USD (*Global*, 2021). As such, this project aims to design a sustainable methanol production process to be later used as a carbon-neutral, energy-dense fuel, or supplement chemical manufacturing supply chains. Simultaneously, this project functions to further work within direct air capture and alternative fuel production processes, both of which are relatively novel fields in the energy sector.

The outlined capstone project will be completed over a course of two semesters as part of CHE 4474/4476 curriculum under technical advisor, Eric Anderson. The proposed process will be based upon research from a carbon capture company called Carbon Engineering which is derived from in-house experimental data, pilot plant data, commercial vendor information, and commonly known thermodynamic information. The process will be subsequently modeled using a simulation software package, Aspen, with specified operating conditions. To begin modeling the methanol synthesis, publicly available experimental data is available that optimizes for different qualities such as maximizing product quantity and purity levels.

The work will be divided into the group by the following subtopics: direct air capture, methanol synthesis, and byproduct formation. The main deliverables in the Fall of 2021 will include a prospectus, pitch, and design basis memorandum. In the Spring of 2022, progress report presentations and a final written report will be due. Within these deliverables, the process will have a well-defined heat and material balance analysis, process flow and control diagrams, equipment design, process economics, and analysis of safety, social, and environmental concerns. Using a Gantt chart to track progress, the team will meet weekly to discuss achievements and setbacks faced during the week and goals for future meetings.

Renewable Energy’s Land Demands and Native Peoples in the U.S.: An Analysis of Renewable Energy Infrastructure Development on Native Lands

How are promoters of renewable energy and defenders of native lands influencing the extent of renewable energy installations in Tribal lands?

Many Tribal lands are prime geographical locations for renewable energy infrastructure and could provide a key piece of the puzzle to nationwide reliance on clean energy (Greenhowe, 2013). It is estimated that while Indian land comprises 5% of US soil, it has 535 billion kWh/yr wind potential and 17,600 billion kWh/yr solar electric potential (Pierce, 2002). So, there is promise for significant contribution to the total US electrical energy demand, which is 3.8 trillion kWh/yr as of 2020 (U.S. EIA, 2021). However, the impact on native peoples due to the proliferation of renewable energy infrastructure on tribal lands must be considered.

Native peoples in the United States have faced a long history of land dispossession, losing approximately 90 million acres of reserved territory because of the 1887 General Allotment Act (OSPA, n.d.). As a result, territory has been checkerboarded between native areas and areas which have been open to white settlement. This has created issues with farming, ranching, and other activities that require large amounts of land, which have had significant economic and cultural impacts (ILTF, n.d.). Installing large-scale solar or wind farms could continue this trend as it is found that “even the “greenest” of technologies disturbs land, both directly and indirectly” (Bronin, 2013).

Proponents of such land developments have argued that more important than land protection, native peoples would benefit due to the associated economic boost and improved access to energy resources, given that reservation homes are 10 times more likely to be without electricity compared to the remainder of the US (Spears et al., 2020). However, large-scale projects are expensive to evaluate, plan, and implement. While grants are offered by entities like the Department of Energy and the Environmental Protection Agency, this may not be enough. Lack of support can lead to tribes having to lease their territory to renewable energy companies, rather than enter joint venture relationships. This can result in lost revenue and difficulty negotiating energy to their own peoples (Bronin, 2013). To this end, Zimmerman (2021) states, "concerns about large corporations taking advantage of tribes and disrupting sacred sites is prevalent among Native American communities."

Native peoples and the tribal governments and advocacies that represent them must work with promoters of green technology to overcome obstacles and to responsibly pursue clean energy access for all.

Social groups have organized to fight for native lands and tribal sovereignty. Examples of these groups include the Ah-Mut Pipa Foundation, which has "also been a strong advocate for the protection of Sacred Sites and the desert ecosystem in and around the lower Colorado region" (AMPF, n.d.). And, the Oceti Sakowin Power Authority, who is "an independent, non-profit, governmental entity formed to jointly develop Tribal renewable energy resources by financing, developing, constructing and operating power generation and transmission facilities for the wholesale market", currently run by six Sioux tribes (OSPA, n.d.).

The native people who will be directly impacted by renewable technology installations must be considered. For example, the Colorado River Indian Tribes is a group of tribes who have already been directly impacted by industrial-scale solar projects (CRIT, n.d.).

Moreover, participants also include those who are concerned with infrastructure implementation, like NextEra Energy, a company claiming to be the "world's largest producer of wind and solar energy" (NextEra Energy, n.d.). Yet NextEra has already faced opposition from Tribal peoples (Krol, 2021). On the other hand, Apex Clean Energy is in a joint venture agreement with a collection of Sioux tribes to install 570 MW of combined electricity generation from wind farms on native lands (Apex Clean Energy, 2020).

Government agencies are also involved, such as the Office of Indian Energy Policy and Programs. It promotes renewable technology on tribal lands and helps tribes and businesses collaborate (OIEPP, n.d.).

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