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PRODUCTION OF CARBON-NEUTRAL HYDROCARBONS FROM CO_2 AND H_2 IN LIEU OF CARBON CAPTURE AND SEQUESTRATION (CCS)

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INTRODUCTION

To ensure an environmentally sustainable future, the problem of CO_2 emissions must be addressed by implementing carbon-neutral energy systems. Carbon Capture and Storage (CCS) is a group of technologies designed to capture CO_2 emissions and sequester them in geological formations. However, CCS is currently hindered by high capital costs and technological challenges. This work discusses the potential to capture CO_2 emissions from power plants and chemically combine them with hydrogen from renewable sources to produce carbon-neutral products.

Alternatives to Carbon Capture and Storage

Potentially useful reformed products include methane, methanol, and green biodiesel. Wind, solar, biomass, and nuclear sources show the most future promise as sources of renewable hydrogen. The technological and economic issues involved in the energy input required to produce H_2, capture CO_2, and create hydrocarbons is discussed.

A significant portion of the costly technology of CCS goes toward transporting and sequestering the CO_2 underground. Rather than attempting to store the emissions in geological formations, which is no guarantee against leaks that would release CO_2 into the atmosphere anyway, it may be possible to convert the CO_2 into useful products. For example, CO_2 can be reacted with hydrogen to create hydrocarbons. For instance, the Sabatier reaction could be used to create methane, CH_4. Although the combustion of the product hydrocarbon would release the CO_2 back into the atmosphere, this creates a carbon-neutral, relatively clean-burning fuel cycle.

Methane Production

The Sabatier reaction shown in Eq. 1 ($\Delta H_{298} = -165$ kJ /mol) is a well-established process for producing methane by reacting CO_2 with H_2 over a metal catalyst, the most effective catalysts being nickel and ruthenium.[11]

$$CO_2 + 4H_2 \leftrightarrow CH_4 + 2H_2O \quad (1)$$

Methanol Production

Another potentially useful product that could be made from reformed CO_2 is methanol, CH_3OH. Methanol is an important chemical feedstock and alternate fuel source, with fewer toxic emissions than gasoline.

A first step involves the formation of synthesis gas via the combined steam and CO_2 reforming of CH_4:

$$\begin{aligned} &CO_2 + CH_4 \rightarrow 2CO + 2H_2 \\ &H_2O + CH_4 + \rightarrow CO + 3H_2 \end{aligned} \quad (2)$$

Following the reforming step, methanol is synthesized by reacting the resultant synthesis gas. The overall process can be described as:

$$\begin{aligned} &CH_4 + CO_2 + 2H_2O + 177\,kJ \rightarrow 4CH_3OH \\ &\Delta H^0_{773K} = 177\,kJ \end{aligned} \quad (3)$$

Sulfur-free green diesel fuel

The first step involves the reforming of CH_4 to produce synthesis gas while in the second step the resulting synthesis gas is reacted to produce the diesel fuel:

$$\begin{aligned} &3CH_4 + CO_2 + H_2O + 23kJ \rightarrow 0.667C_6H_{12} + 3H_2O \\ &\Delta H^0_{773K} = 23kJ \end{aligned} \quad (4)$$

Renewable hydrogen sources

We describe and compare a few methods for producing hydrogen from renewable sources. Advances in wind power have reduced the cost of utility-scale wind electricity to 3-7 cents per kW hr, making wind electrolysis an attractive option. Wind electrolysis involves the wind turning a wind turbine containing an electrical generator, which can power an electrolyzer to dissociate water into O_2 and H_2. A potential advantage of wind electrolysis systems is the improved ability to dispatch electricity; that is, the wind turbine can produce hydrogen to store energy, later using a fuel cell to create electricity in high-demand periods. For wind electrolysis to become cost-effective, there will need to be a decrease in wind electricity prices, increase in electrolyzer efficiency, and an increased effort to integrate wind/electrolyzer systems.

Discussion

If current CO_2 capturing cost could be reduced by 35-40 percent CO_2 and natural gas reforming can be potentially sustainable from CO_2 recovered from flue gases. Wind, biomass, and nuclear show the most future promise as sources of renewable hydrogen. Due to the energy input required to produce H_2, capture CO_2, and create hydrocarbons, this proposal has admittedly a net energy loss. Ultimately, if the cost of renewables can compete with the cost of carbon energy using CCS methods, the departure from fossil fuel dependence will happen all the more rapidly.