A New Paradigm for CO_2 Capture and Conversion Systems

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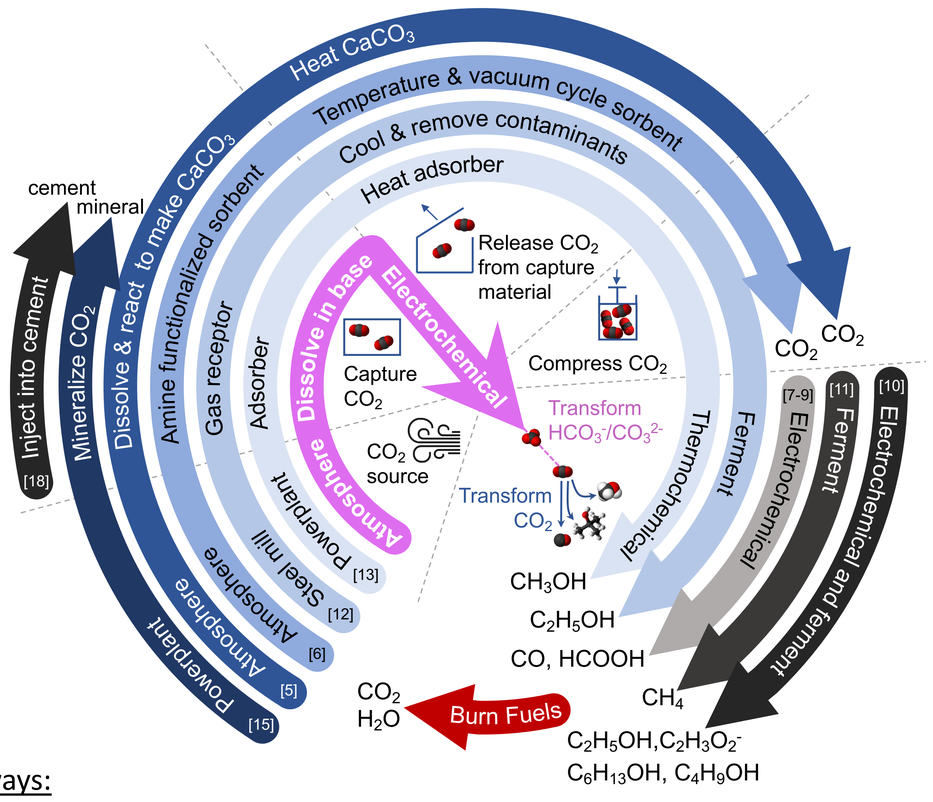
Motivation and Overview

Designing a complete system to capture CO_2 from the air and transform it into valuable chemicals is of utmost importance for mitigating climate change. The processes of CO_2 sequestration, CO_2 transformation, and product separation all require significant energy inputs - therefore devising a system that simultaneously minimizes all of these steps is challenging. To date, a variety of CO_2 sequestration and/or conversion systems have been built targeting these individual aspects. Here we propose a new paradigm for designing CO_2 capture and conversion systems: (i) formation of bicarbonates/carbonates through dissolution of CO_2 into basic solutions; followed by (ii) electrochemical reduction; and (iii) transformation into valuable chemicals via industrial processes. Unlike traditional systems in which gaseous CO_2 reacts with a catalyst, our design focuses on the transformation of bicarbonate or carbonate ions from solution which offers several advantages. First, the CO_2 sequestration from the atmosphere does not require an energy intensive heating step to recover gaseous CO_2 for later transformation, and 75% of the CO_2 is removed on the first pass. Second, by transforming bicarbonate/carbonate ions, the process avoids any energy intensive CO_2 compression and allows for significantly higher conversion percentages. Taken together, we anticipate significant reductions in overall energy consumption can be achieved by focusing attention on the conversion of carbonate/bicarbonate ions instead of gaseous CO_2.

Summary of Current CO_2 Capture and Conversion Methods

CO_2 Source	Capture CO_2	Release CO_2 from capture material	Compress CO_2	Transform CO_2	Products
Environment - Air - Seawater Point Source - Petrochemical Industry - e.g. ethylene - Iron and Steel - Cement production - Natural gas sweetening - Fossil fuels or Minerals - e.g. coal	Absorption - e.g. amines Adsorption - e.g. zeolites Membranes - e.g. fibers Biological - e.g. algae Other - e.g. mineralization	Heat Vacuum cycle	~15 PSIA for fermentation ~15-50 PSIA for electrochemical processes ~250-1450 PSIA for thermo-chemical processes	Electrochemical Fermentation Photo-electrochemical Photocatalysis Thermocatalytic Thermolysis Industrial Processes	$C_xH_yO_z$ C_xH_{2x} C_xH_{2x+1} C_xH_{2x+2} Diesel Syngas Ethylene Butanol Hexanol Propanol Ethanol Plastics

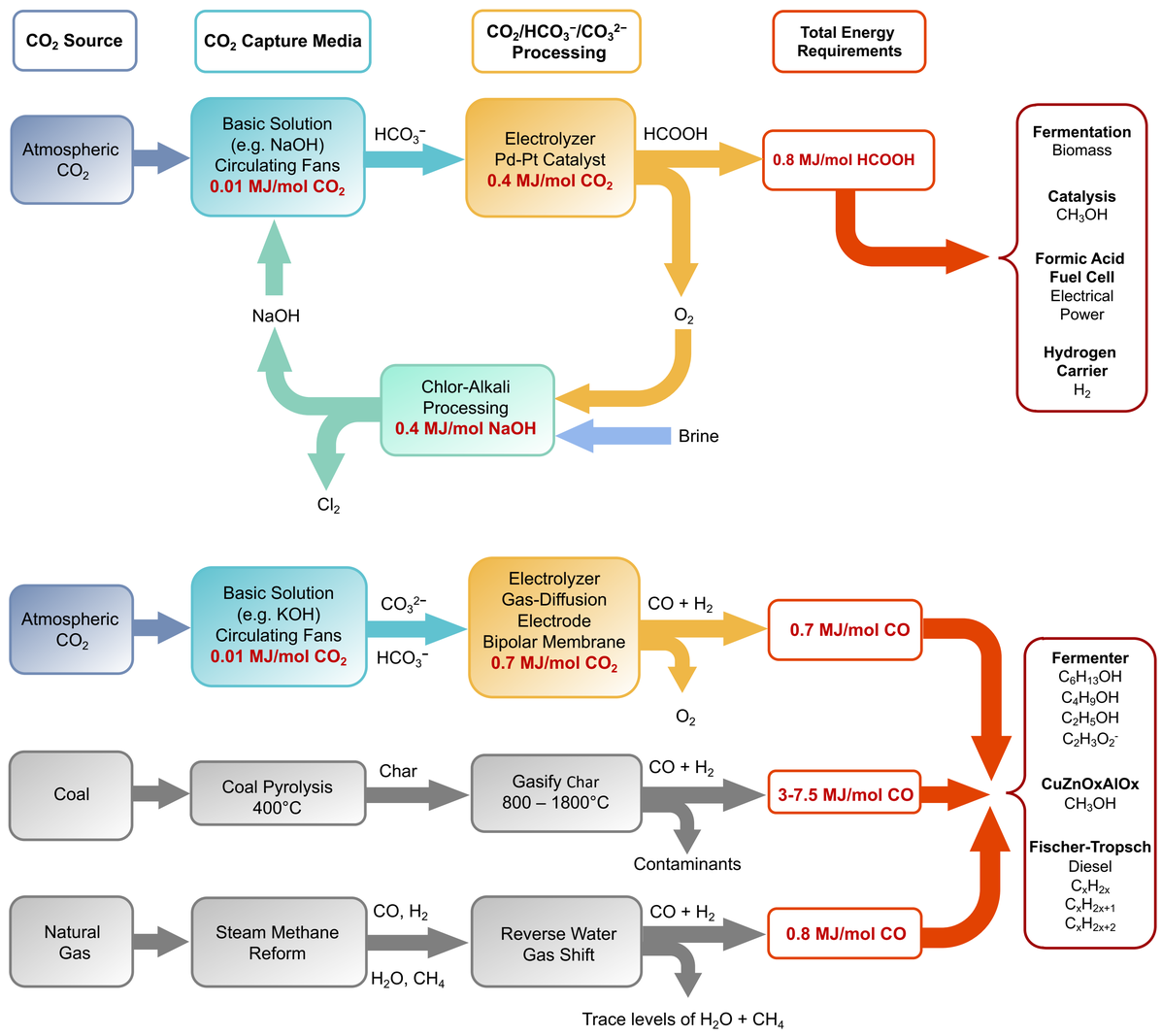
Summary of Current CO_2 Capture and Conversion Companies



Take Aways:

- Releasing CO_2 from the capture media and compressing CO_2 for storage or for use by conversion processes is energy intensive
- Direct air capture is more difficult than point-source capture, and CO_2 transformation is more energy intensive than CO_2 capture
- Significant energy savings are possible when you do not have to compress the CO_2 or release it from the capture material

Results



Take Aways:

- The proposed process generates syngas for 0.7 kJ/mol CO_2, which could then be used in a variety of industrial processes to generate valuable chemicals
- Generating syngas in our proposed method leads to an extremely pure syngas feed unlike industrial processes
- Generating syngas from coal and natural gas is more energy expensive than our proposed process, and the reported energies do not include the energy required to mine the coal or drill for the natural gas
- Our proposed processes would allow for 100% utilization of captured CO_2
- Energy required by other pilot CO_2 capture and conversion companies is higher than what we have proposed for a system that does both direct air capture and syngas synthesis

Comments on Calculations:

- All electrolyzers are assumed to perform the oxygen evolution reaction at the anode
- The total energies calculated would most likely be higher in a realistic plant due to the need for pumps, possible catalyst regeneration, etc.

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