Feasibility of Small-Scale Carbon Capture Device

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Introduction

- The purpose of this research is to evaluate the current and future feasibility of capturing carbon on a consumer-based, small-scale.
- Since the signing of the Paris Agreement in 2015, "negative emissions technologies" have become necessary tools for climate mitigation efforts to succeed (Limit global warming to well below 2°C by 2100)[1].
- Large scale carbon capture projects have been established to capture from both atmospheric air and from carbon emission sources.
- Small-scale implementation has few present-day information and projects.

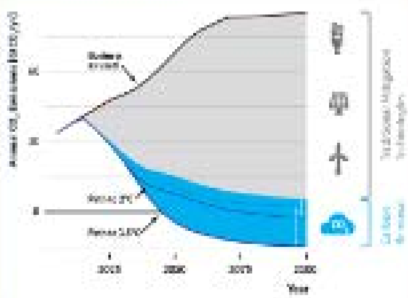


Figure 1: CO2 Emissions Necessary to Limit Global Warming[2]

Methods

Feasibility was determined by the following:

- Literature review of past and current studies and papers written surrounding the technical aspects of carbon capture.
- Evaluation of present-day large scale projects implementing carbon capture.
- Communicating with current small-scale companies
- Evaluation of present and future economic markets for a small-scale technology (consumer, business, etc.)

Background

The general process of carbon capture is as follows:

1. A gas stream is pulled in using fans or ambient air (wind).
   - Either atmospheric air (DAC) or flue gas stream (PCC)
2. A sorbent solution or material is used to chemically or physically bond to the CO2 molecules.
3. The CO2-rich sorbent is "regenerated" through a temperature or pressure change, releasing a pure stream of CO2 gas.
4. The pure CO2 is captured and utilized in various ways described in "Economic Feasibility" section.

Technical Feasibility

Three Major Capture Methods:

1. Solvents (Liquid Solution Absorbents)
   - Benefits: Extremely high bonding strength to CO2
   - Drawbacks: Extremely high energy requirements to regenerate and release the CO2 (upwards of 900 °C), solvent degradation, and equipment corrosion
   - Current Examples: Carbon Engineering

While liquid solvents are efficient at capturing CO2, their large energy and heat requirement afterwards make them effective only at large scale, and unfeasible for small-scale applications.

2. Sorbents (Solid Adsorbents)
   - Benefits: Low energy consumption to regenerate (low-moderate temperatures), suitable for both dilute and concentrated CO2 gas streams
   - Drawbacks: Sensitive to moisture (flue gas)
   - Current Examples: CleanO2, Earthly Labs, Climeworks, Global Thermostat

Solid sorbents present themselves both in the literature as well as current projects and technologies as a very applicable method of capturing carbon at nearly any desired scale.

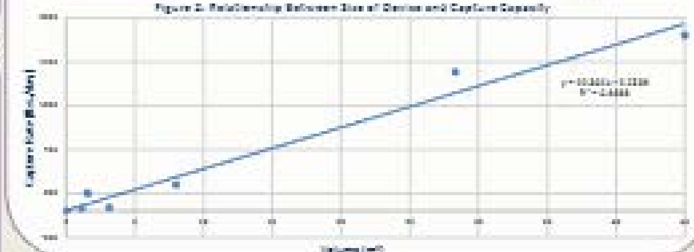
3. Membranes
   - Benefits: Suitable for ambient and moderate temperature gas streams, utilizes pressure and temperature swings
   - Drawbacks: High fabrication cost, large surface area requirements
   - Current Examples: [illegible]

While membranes are industrially used to separate gases, their applications are not nominally used for capturing CO2, and typically require large size and high-cost projects for applicable use.

For Small-Scale Analysis:

- The average individual carbon footprint in the U.S. is about 90 lbs. of CO2 per day (16 tons per year)
- The size of a refrigerator is roughly 1.5 m^3
- Realistic Expectation: A device between 1-8 m^3 that captures 80-100 lbs. of CO2 per day

Figure 2: Relationship Between Size of Device and Capture Capacity



Scale	Company / Reference	Capture Method	Gas Stream	Volume (m^3)	Capture Rate (lbs/day)	Energy (kWh/lbs)	Listed Company/ Reference Cost	Electricity Cost Per Year (US Average)
		Technical Measurements					Economic Measurements	
Small	Yu (2017)[3]	Solid Sorbent	DAC	0.014	1.10	0.98	-	$62
	Methanology	Solid Sorbent	DAC	1.140	30.86	2.21	$21,500	$3,239
	EarthlyLabs	Solid Sorbent	PCC	1.561	205.50	-	$75,000	-
	CleanO2	Solid Sorbent	PCC	3.131	42.25	0.02	$20,000 + $5,000 install	$39
Large	Climeworks	Solid Sorbent	DAC	8.000	302.00	1.20	$75 per ton CO2	$17,238
	Global Thermostat[1]	Solid Sorbent	DAC	26.317	1583.67	0.75	$150 per ton CO2	$537,789
	Carbon Engineering[1]	Liquid Solvent	DAC	45.000	2000.00	1.07	$94-$232 per ton CO2	$101,422

Table 1: Technical and Economic Measurements of Large and Small-Scale Carbon Capture Technologies

Economic Feasibility

Economic Analysis Constraints:

1. Most economic assessments of carbon capture technologies focus on large scale figures
2. Current project assessments are on the scale of millions of dollars and millions of tons captured per year

What Can Be Assessed?

1. Current small-scale projects and companies
2. Carbon utilization (both large and small scale)

Economic Uses for Carbon Capture:

1. Fertilizers (Global Thermostat, CleanO2)
2. Carbonated Beverages (Global Thermostat, Earthly Labs)
3. Greenhouse Feed (Global Thermostat, Earthly Labs, ClimeWorks)
4. Synthetic Fuels (Global Thermostat, Carbon Engineering, Methanology)
5. Energy Efficiency (CleanO2, Earthly Labs)

Small Scale Business Models

CleanO2:

- Market: Commercial Building Heating (boilers)
- Create pearl ash for detergents and fertilizer
- Customers: Energy savings and pearl ash payments

Earthly Labs:

- Market: Breweries and Greenhouses
- Recycle factory CO2 to use for carbonation
- Customers: Unnecessary purchases of outside supply of carbon dioxide

Methanology:

- Market: Homeowners
- Use CO2 and water to create methanol
- Customers: Self-sufficient (renewable) fuel

Considerations

- The focus of industry and individual action should be to minimize carbon emissions as much as possible (electrification, sustainable practices, etc.)
- A small-scale device must be a carbon neutral or carbon negative device in its lifetime (manufacturing, use, and after-life)
- Understanding the socioeconomic implications of a carbon capture technology (who can afford it, how will the ability to capture CO2 affect their other CO2 emitting actions, etc.)

Conclusions

- Liquid solvent capture requires an extremely high energy requirements and can involve harmful chemical solvents.
- Membrane capture requires expensive fabrication, large surface area, and high energy penalties for CO2 release and membrane regeneration.

Recommendation:

Solid sorbent capture conveys itself as the most practical method for small-scale implementation. Sorbents require moderate temperatures for practical regeneration, are less harmful to operators (consumers), and have present day demonstratable applications.

Future Work

- In the future, additional research should be completed to determine what method of carbon capture is the most feasible to make a cost-effective and energy efficient device on a small-scale
- Gather enough information to inform a potential Capstone design project to develop a prototype

References

[1] UNFCCC, 2015. Adoption of the Paris Agreement [illegible] United Nations Framework Convention on Climate Change. Paris, France.

[2] [illegible] Research Institute on Global Commons and Climate Change (MCC). [illegible] Negative Emissions. [illegible]

[3] Yu, [illegible] "Design strategy for CO2 adsorption from ambient air using a supported amine based sorbent in a fixed bed reactor." [illegible]

[4] [illegible] "Techno-economic assessment of [illegible] capture plants." Journal of Cleaner Production [illegible]

[5] Keith, David W., et al. "A process for capturing CO2 from the atmosphere." Joule [illegible]