Title
Team One Carbon Catcher Design Report

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Design Prompt

We are currently facing a climate change crisis. The average temperature around the globe has been steadily rising yearly and current projections by Berkeley Earth predict that by 2060 the ‘global temperature anomaly’ will be 2 °C. The effects of this temperature anomaly is felt by several ecosystems and human settlements: global water sources are drying up, countries and cities are becoming too hot to live in, and wildfires are more common than ever before. This problem must be addressed now before the effects are irreversible by not only halting the addition of greenhouse gases and other pollutants into the atmosphere, but by actually taking harmful chemicals like carbon dioxide emissions out of our biosphere. The scope of this project aims to provide a method of extracting the CO2 emissions out of our biosphere.

Carbon dioxide levels have been increasing every year since the start of the industrial revolution. Efforts to reduce greenhouse gas emissions by proliferating green energy are stronger and in higher demand than ever before. Yet humankind is far from limiting its aggregate global warming to 1.5 °C, as outlined by the 2016 Paris Agreement. To mitigate catastrophic environmental damage, we are proposing the design of a ‘Carbon Catcher,’ which actively extracts and repurposes carbon dioxide from the atmosphere through utilizing a passive filtration system: membrane diffusion.

Overview

The burning of fossil fuels largely contributes to the increase of CO_2 in the atmosphere. The US Department of Transportation alone contributed almost 6 million metric tons of carbon dioxide emissions in 2018 (EIA). Due to this, this report proposes recycling captured CO_2 into a base for cleaner burning fuel in order to reduce emissions from the transportation industry and many others, which has the potential to impact many areas.

Extraction of atmospheric CO_2 is possible through a membrane filtration system based on traditional nitrogen generation. The passive filtration system autonomously separates the CO_2 from other air components, thereby reducing energy consumption. The system's working sensors and actuators utilize similar energy saving strategies, such as distributing cloud-computing services over multiple servers and mainframes to reduce computing power. The movement of air is directed by a scalable fan device, which is presented as a modular design to allow customization of fan parts to specific size and installation requirements. As an integrated device, Team 1’s Carbon Catcher operates with a high efficiency in order to maximize the commercial opportunity of converting captured CO_2 into cleaner fuel while also reducing CO_2 emissions and the greenhouse effect.

Goal

The goal of Team 1's Carbon Catcher project proposal is to design a cost-effective, scalable, and modular atmospheric carbon dioxide removal system that is capable of being utilized in a range of urban environments and may fit a variety of different customer requirements or requests.

Objectives

The inter-committee objectives and requirements for the aforementioned scalable system are listed below.

1. (AirM/PyC) Monitor air temperature and flow through systems, maintain inflow velocities for the filtration phase.
2. (CarS/PyC) Tailor User Sequence or UI to preferences of identified commercial audience.
3. (MemB/CarS) Determine a unit amount of CO2 gas through the membrane and propose a maintenance plan.
4. (MemB/AairM) Integrate components of filtration system into modular design form. Maximize flexibility of design and scope of applicability.

Project Outline

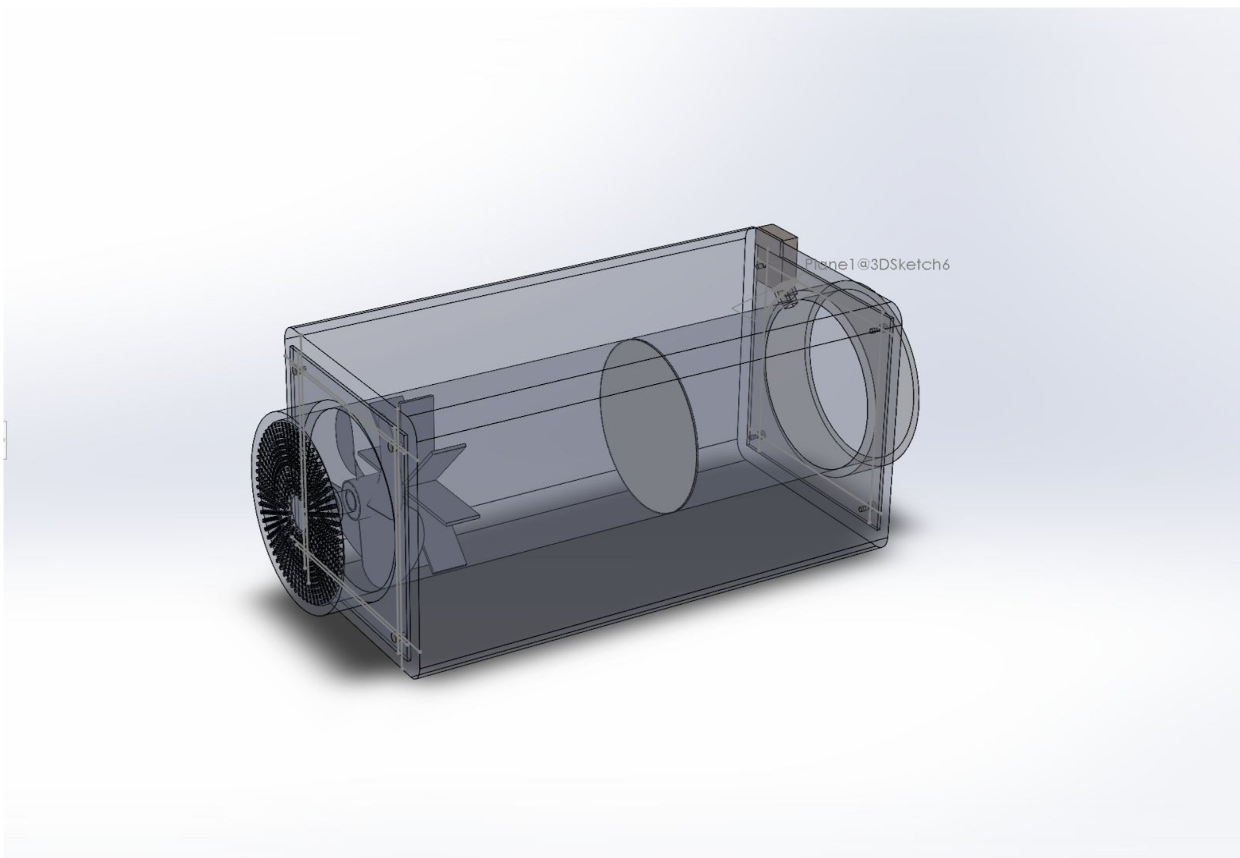
Ambient air is collected from the front of the fan tower. As air accelerates towards the fan, rain is blocked by an overhang at the top of each module. The air passes through a metal screen, which protects from large debri. Any rainwater that makes it past the overhang and metal screen will simply drain out the down sloped front opening. The air passes the vaneaxial fan, entering a high-pressure area in front of the filtration membrane. The air passes through the membrane and returns directly to the atmosphere. Some air passes through the electronic control box, dissipating heat buildup.

Design Breakdown

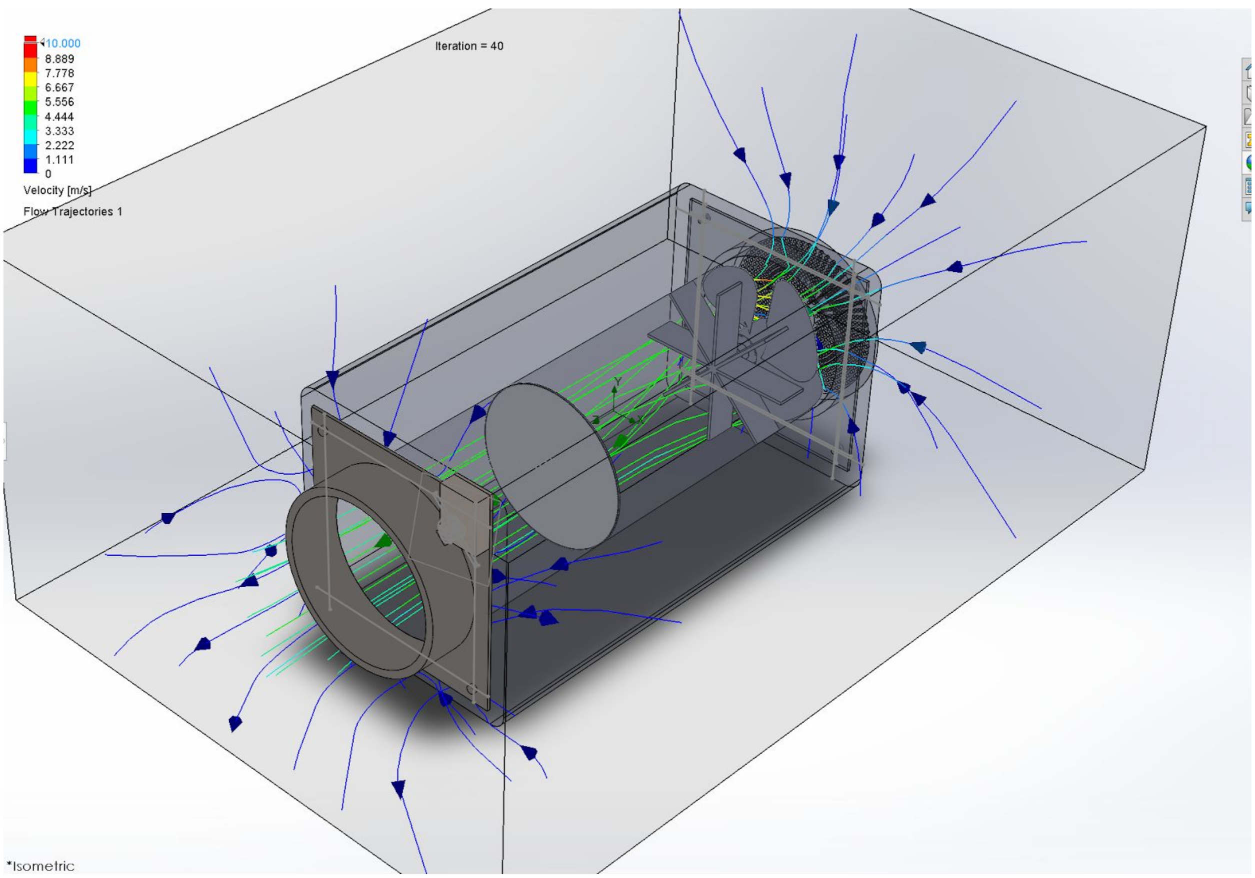
Air Mover

A single fan delivers constant air pressure to the front of the filtration membrane. It will be a vaneaxial fan with 4 foil blades. A vaneaxial fan was chosen because it is the most efficient option, as the vanes give it a higher pressure capability. Foil blades are also far more efficient than straight blades when running at the correct speed.

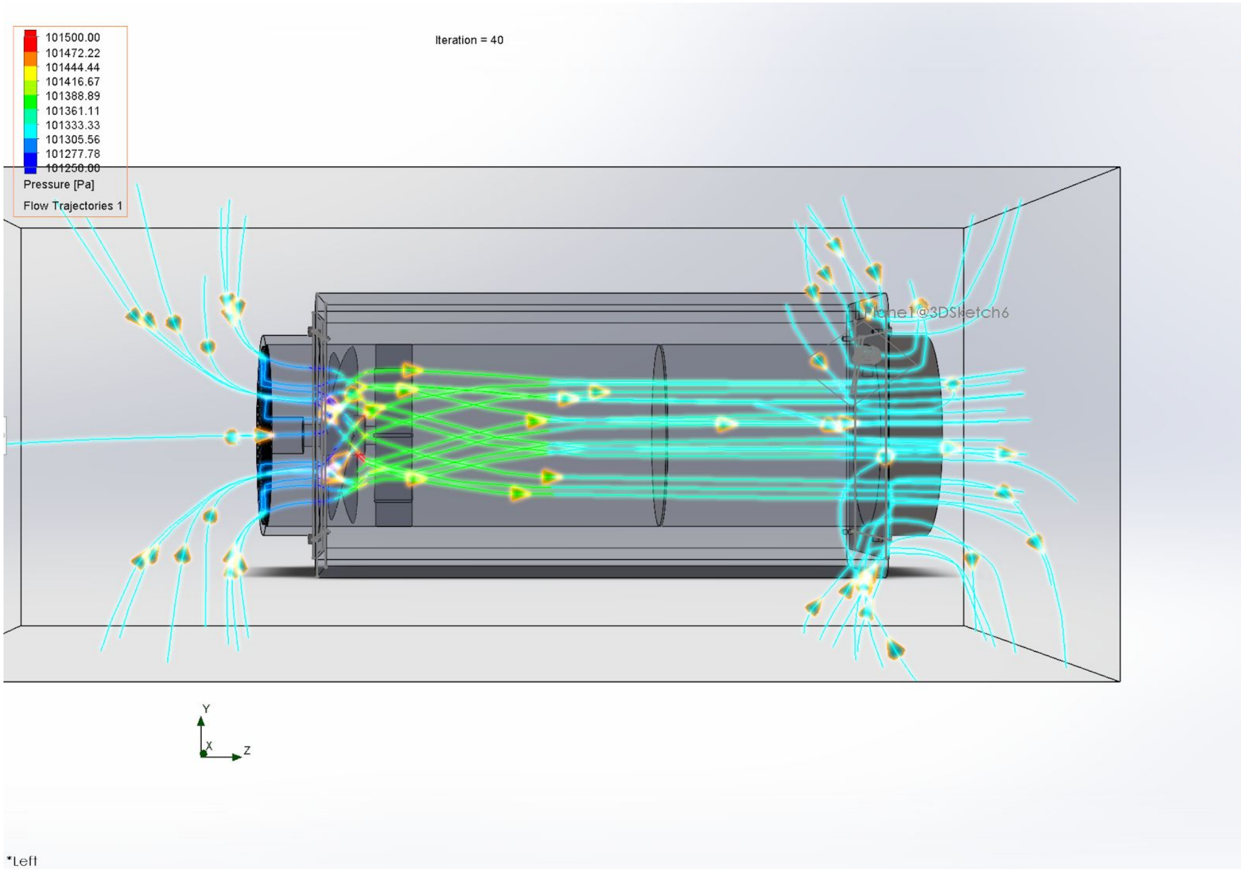
Enclosure



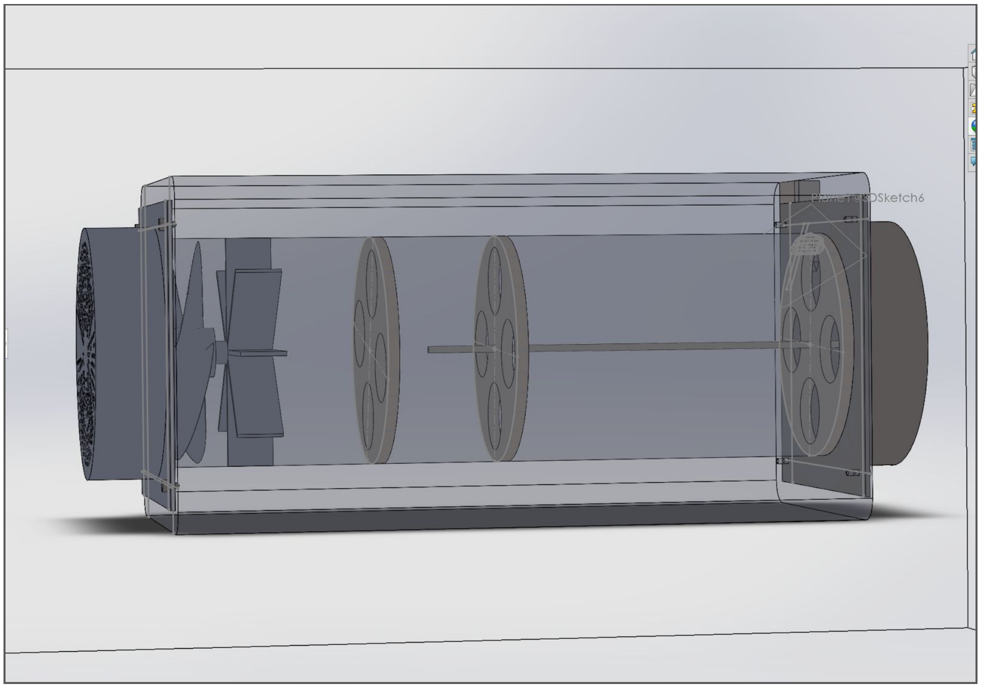
The air flow is contained by a cylinder-in-a-box shape, which contains the fan and membrane. The simple square shape allows for versatile mounting and small scale stacking of the modules. A simple I-beam support structure provides a sturdy base for which to attach all of the appliances. An external structure was chosen instead of a stacking design was chosen in order to maximize ease of maintenance and allow for external wiring and ducting. The electronics are placed in a control box on the rear of each module. An open mesh structure allows the scrubbed air to pass through, cooling the system for more efficient power usage. A protective mesh screen covers the entrance to the fan and membrane, protecting from large debri and wildlife, without having a significant effect on airflow.



This shows the velocity vectors and air flow path of the assembly, with the color indicating speeds along the flow.



This shows the pressure of the air along the fluid flow path of the assembly, with the color indicating the pressure at each point along the path. The materials were chosen based on durability and cost effectiveness. It was found that the best option for the structure of the model would be 304 stainless steel. This material is corrosion resistant. 316 steel is more corrosion resistant but is also more expensive. It was found that the price of the 316 steel would not justify the extra corrosion resistance. The fan blades were made of aluminum to reduce weight, while maintaining a high strength. In order to push air through the membranes efficiently, the design will be required to create a pressure of 10 atm. In order to accomplish this, a piston system is introduced after the fan.



Once the fan fills the area inside the piston, the holes shown will be closed using valves of the same design as supercharger exhaust valves, allowing air into the piston chamber but not back out. These valves will be made out of a light steel alloy that will allow for maximum strength and minimum weight of the structure. There will be a 1 meter space between the piston and the next wall, which will be compressed to 29.8 cm by the piston, and compress slightly farther to maintain the required pressure until the sensors tell the system that the CO_2 levels of that section are too low to be worth further filtering, at which point the piston will retract to refill with air and begin a new cycle. The piston will be powered by pneumatics to ensure efficiency throughout the process.

Calculations

$P_i = dp\ q$

where

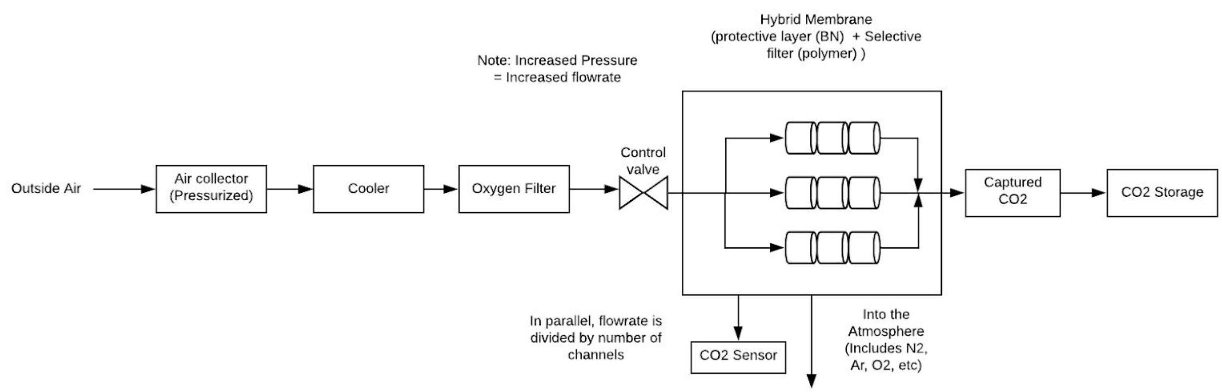
P_i = ideal power consumption (W)

dp = total pressure increase in the fan (Pa, N/m^2)

q = air volume flow delivered by the fan (m^3/s)

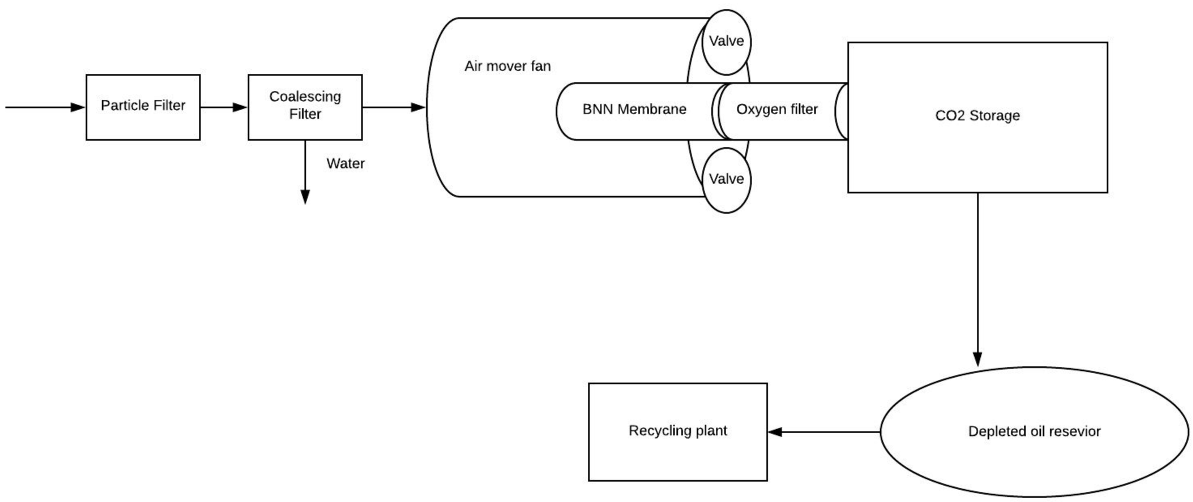
According to our simulations, pressure after the fan is 101444 Pa, and the velocity in the middle of the enclosure is 5.556 m/s, giving us a power usage of 521.2 W. Given the the average efficiency of these fans of 70%, we get a power usage of 744.6 W, or 1.04 Hp, well within the range of our motor. This is all based on a blade speed of 1432 rpm, which is also well within our motor's range. In order to create the required pressure of 340kPa from a 1 meter diameter piston, we will require a force of 267kN, or 60,000 lbs, which is within our the limits of our piston motors, though two of the motors in question will be required to create this force.

Membrane



A schematic of the CO_2 separation process design.

The process first begins with the outside air collected from *Air Mover* as the inlet. It is pressurized and cooled to desired temperature and pressure parameters. The inlet air stream must be cooled before going through the filter to ensure the highest permeability of CO_2 and to prevent degradation of the polymer filter. The air goes through an oxygen filter first to remove as much as possible before it enters the nitrogen removal process. The boron nitride nanosheet was chosen as the membrane as the N_2 selectivity was the most optimized for our purposes compared to similar polymer membranes. Since N_2 makes up ~78% of air, the removal of N_2 is the most important process for carbon capture. For the boron nitride nanosheet (BN), the optimal temperature is 373K with a ratio of CO_2 to N_2 of 23 to 0, essentially complete separation of the two gases. Although the boron nitride separates most of the nitrogen, other gases like H_2, He, Ar may still be present. The Pebax membrane then removes any additional molecules in the air besides CO_2, increasing the purity of the CO_2 stream. The purity of CO_2 stream is important later for storage efficiency for the CO_2 storage process.



The redesigned diagram for the integration of Air Mover and Membrane designs.

The separation process must be done in batches in order to maintain desired pressure values for the most effective CO_2 selectivity. This prevents the inlet air stream from mixing with the separated air streams. The control valve is used to allow a batch of outside air inside the process and closes off the inlet to ensure complete separation of the initial batch. The valve will be controlled through a technological algorithm. The CO_2 sensor detects if the air has a low enough concentration of CO_2 in order to release into the atmosphere, and prepare for the valves to draw in the new batch of outside atmospheric air. The membranes are designed in parallel to allow for a decreased flow rate to maximize permeance of CO_2 while maximizing total air moved through the system. The parallel membranes also allow a slow flow rate in a specific section of the process, optimizing time efficiency in the whole process while increasing CO_2 permeance.

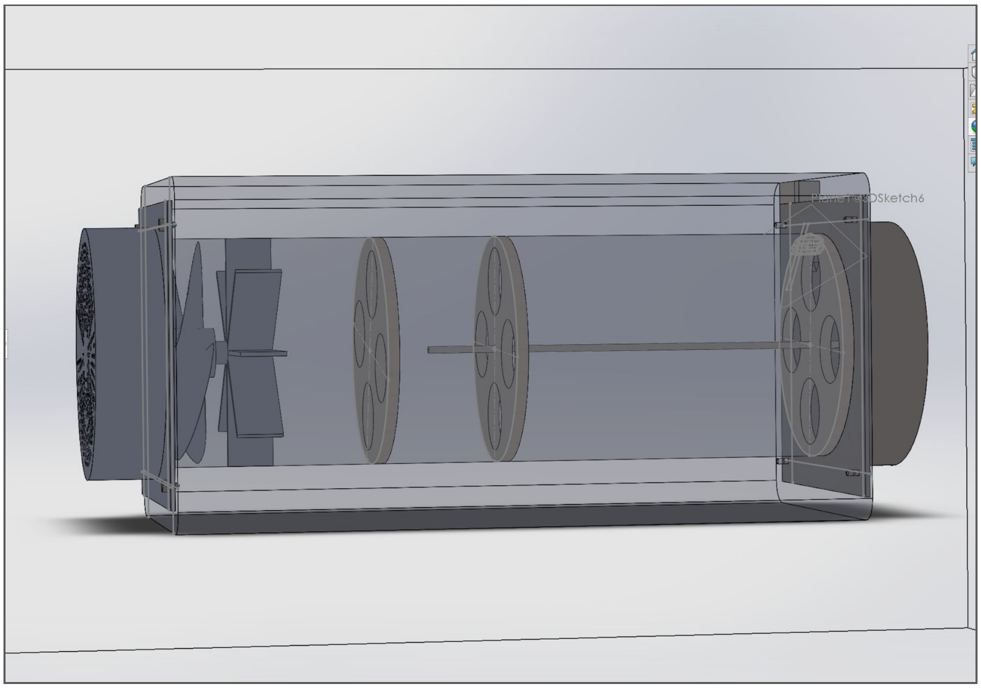
Design Justification

Initially, the design schematic consisted of a linear filtration path of cooled outside air flowing straight into the filtration membrane and into a collector canister. The air would then be monitored by a CO_2 sensor and would either send the gas mixture into storage or back through the membrane, essentially creating a feedback/recycling loop. This plan was deemed unfeasible as the design did not take into account the need of separating the CO_2 and remaining gasses from one another after filtration.

The design revisions consisted of dividing the heated pressurized air into two separate channels in parallel using a mullite and alumina membrane in conjunction with a membrane blend of high molecular weight amorphous polyethylene oxide (HMA-PEO) and Pebax 2533 SA 01(P1-50), in order to maximize CO_2 permeance and minimize flow rate as higher flow rates were shown to decrease CO_2 permeability [6]. The mullite and alumina membrane proposal was deemed irrelevant in our design as this membrane combination was found only to be effective when used with natural gases [3]. Upon further research, a finalized design was chosen which does not utilize the feedback loop and integrates the pressurized chamber with the membrane filter.

The finalized design is essentially two large chambers of air with the membrane filter placed inside of the second chamber. The first chamber contains a CO_2 sensor and cooled pressurized air that is kept sealed until our control valve opens and allows the captured air to flow in. The pressurized collector chamber is then filled up to a predetermined pressure and sealed off. Another valve placed downstream of the membrane filter will then open and the CO_2 will flow through the membrane filter due to the pressure gradient inside and outside of the pressurized chamber. CO_2 will flow across this valve and be collected for storage. Simultaneously, there is a third valve connected to a CO_2 sensor that will measure CO_2 concentration compared to the first chamber, which will open when the CO_2 readings are below

50ppm. The opening of this third valve will allow the pressurized air to escape into the atmosphere, and the first valve will open to repeat the cycle. Our design will be able to become fully automated with the only maintenance required being periodic replacing of membranes once every 35 years, and periodic liquid nitrogen refills.



Finalized Integrated Design of Air Mover and Membrane

The final integrated design consists of the membrane filter in the shape of a cylinder placed in the outlet of the air canister, with pressure valves present in order to vent air into the atmosphere to maintain the desired pressure gradient. CO_2 will continuously permeate through the membrane due to the pressure differences of air between the outlet and inside the canister. The pressure vents will be actively opening and closing based on CO_2 sensor readings, controlled through *PyControl*'s design.

Calculations

We will calculate the temperature of air within the first chamber using the Ideal Gas Law: PV=nRT, where *P* is pressure, *V* is volume, *n* is numbers of moles(of air), *R* is the gas constant, and *T* is temperature. Assuming both chambers have equal *V, n,* and *R*, (as the air has not reached the filter membrane yet) our equation becomes $T_1=(T_2*P_1)/P_2$. This yields us a T_2 = (35°C *

340kPa)/(101.35kPa) = 117.4°C using our desired experiment values. This value will later be used to calculate cooling costs of the system.

The material cost of the Boron Nitride nanosheet will be calculated assuming a surface area of 1050 m^2/g

Cost of (BN nanopowder) at market price: $18.6/g ,

r(radius of membrane cylinder)=0.3 m, *l*(length of membrane cylinder)=1 m

lateral surface area of a cylinder (S_{AL})= $2\pi * r * l$= 1.885 m^2

Material cost per nanosheet cylinder: [($18.6/g)/(1050 m^2/g)/]*(1.885m^2) = $0.033 per cylinder

The material cost of a scaled version of the membrane cylinder will be able to be calculated through the modified dimension values of the cylinder.

Using Bernoulli's equation, we are able to find that the velocity of the air flowing into the filtration chamber will be greater than the velocity of the collection chamber due to the difference in pressures of the two chambers.

Assuming constant height ($h_1=h_2$) *and constant air densities* ($\rho_1=\rho_2$), P_1*(Canister air)*=101.444 kPa, P_2*(atmospheric air)*= 101.325 kPa, v_1*(canister air velocity)=5.556 m/s,* ρ_1*(density of atmospheric air)*= 1.225 kg/m^3 = ρ_2

Rearranging Bernoulli's equation yields: $v_2 = \sqrt{}[((2(P_2-P_1)/\rho) + v_1^2]$

$v_2 = \sqrt{}[((2(101{,}444 - 101{,}325(kg/m*s^2))/(1.225(kg/m^3)) + (5.556\ m/s)^2 = 15.005\ m/s$

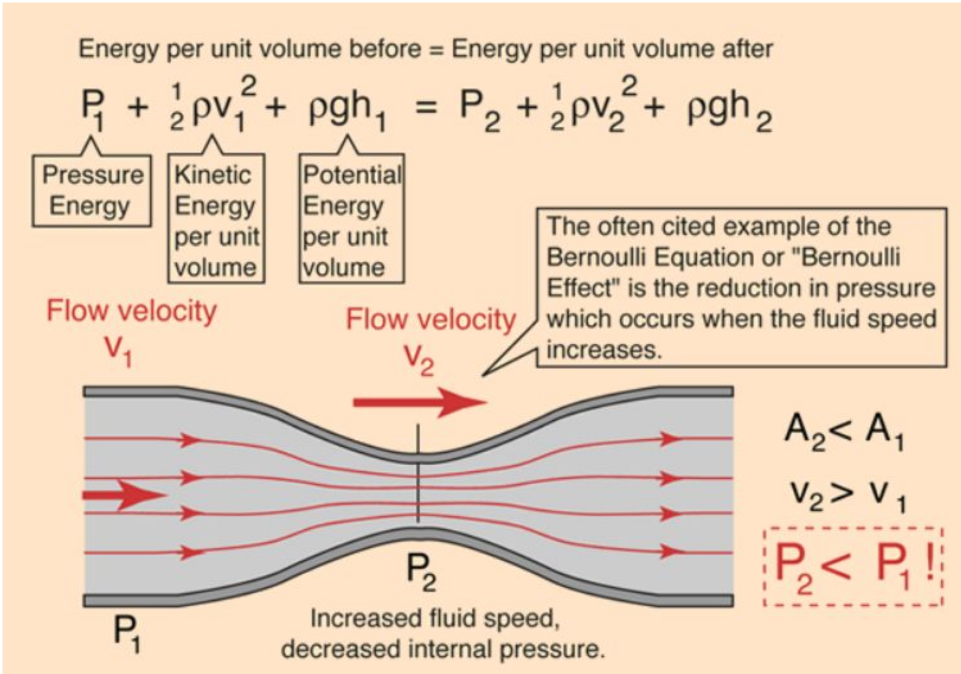
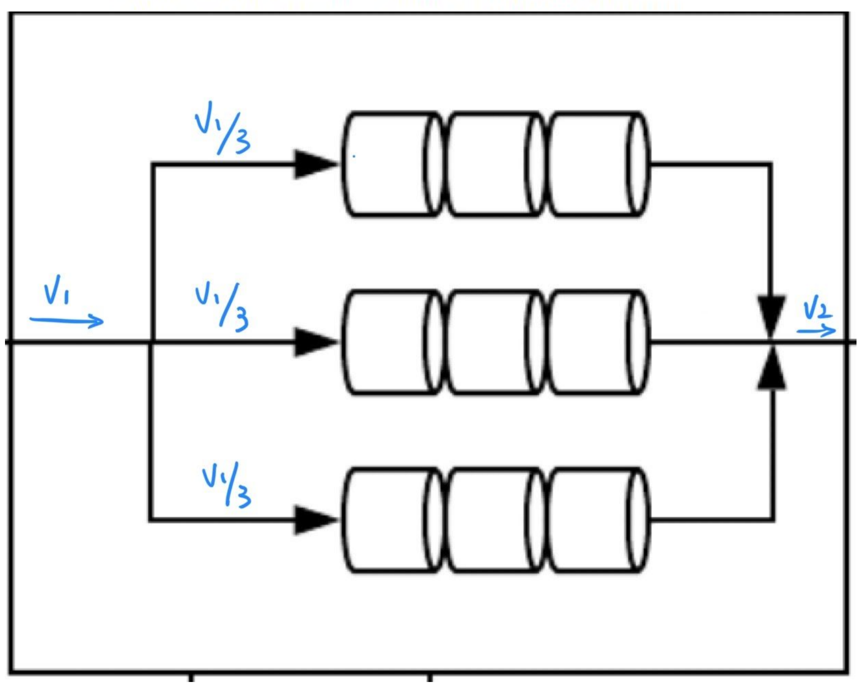


Figure 2: Explanation of the Pressure-Velocity Relationship [11]

Parallel Flow Channels

Figure 2: The division of flow of channels in parallel



Placing the membrane filters in parallel allows us to reduce the flow rate within each individual channel, yielding the desired flow rate as too high of an individual flow rate will be undesirable due to the decreased CO_2 permeability in the membrane. Assuming negligible membrane resistance, friction, and equal channel lengths: we are able to precisely control the amount of air flowing towards the filter membranes by pressurizing the inlet air flow accordingly and through Bernoulli's Equation. As two chambers only differ in pressure and temperature, the density, volume, and potential energy remain constant allowing us to find our initial and final velocities.

Technology Used

The design will be controlled through the use of computer processors and computer code, written using if-else statements based on the CO_2 sensor readings and valves will open or close based on our desired measurement value of 50ppm.

Material selection: Oxygen filter

Figure 3: Oxygen filter from PRISM that removes 40% of oxygen and allows for a nitrogen rich air stream

The PRISM oxygen filter takes out 40% of the oxygen in the inlet air (PRISM). The filter is placed before the hybrid membrane to remove most of the oxygen. Since oxygen makes up 21% of atmospheric air, it is the second most important component that must be removed. After the air moves through the oxygen filter, the nitrogen-rich air is then moved through the hybrid membrane to remove all the nitrogen.

Material selection: Selectivity Layer

		TFC blend membranes[a]		Selectivity layer[b]			
Sample	PEO content (%)	CO_2 permeance (GPU)	CO_2/N_2 selectivity	CO_2 permeance (GPU)	CO_2 permeability (Barrer)	CO_2/N_2 selectivity	l^c (nm)
Pebax® 2533	0	305	23	373	157	26	400
P1-25	25	443	24	602	253	28	430
P1-33	33	574	23	914	384	31	440
P1-50	50	899	24	1850	778	40	420
P1-66	66	1130	14	–	–	–	–
P2-25	25	479	23	685	288	29	420
P2-33	33	675	23	1080	452	31	420
P2-50	50	1070	22	2290	960	38	410
P2-66	66	1190	14	–	–	–	–

Table 4: The main numerical data that must be considered is selectivity. Selectivity is directly related to how well the gases are separated. Increased selectivity of CO_2 indicates that a larger amount of CO_2 is permeating through the membrane compared to N_2.

Pebax® 2533 SA 01 is a thermoplastic polymer utilized as the main material for CO_2 selective membranes. In order to further enhance the membrane's CO2 permeance and selectivity, the high molecular weight polyethylene oxide (HMA-PEO) is incorporated into the Pebax selective layer of the membrane.[5] PEO augments the membrane's CO2 separation performance because the ethylene oxide (EO) shows favorable interactions with CO2 instead of high gases (ex. H2, He, N2, CH4) (Fu, Qiang, et al.). The selective layer of the membrane is still Pebax® 2533 SA 01, but it would be coated with a thin blend film. The thin film is composed of both Pebax® 2533 SA 01 and the HMA-PEO. Unlike the conventional CO2 separation membrane materials, the novel blend layer shows super-permeable characteristics (high permeance) and unprecedented CO2 separation ability (high selectivity). CO2 permeance and selectivity are the two determining factors of the membrane's performance but often conflict one another. In Dr. Fu and Dr. Qian's research, 50% HMA-PEO content out-performs other selectivity layers. With 50% HMA-PEO blended in Pebax® 2533SA 01, the selectivity layer of the membrane can have CO2 permeance up to 2290 GPU and CO2/N2 selectivity of 38.

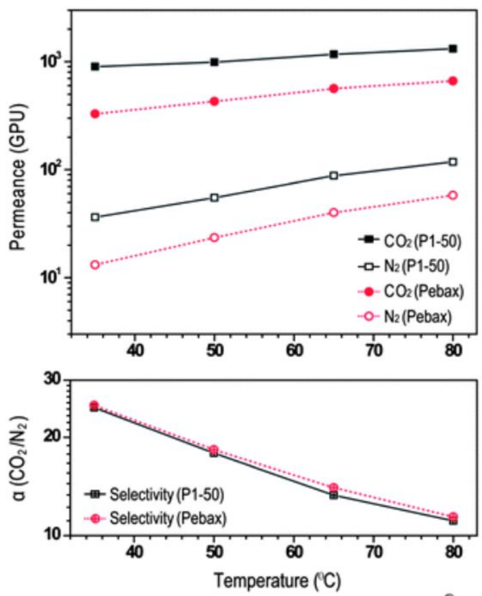


Table 3 Gas separation performance of Pebax® 2533 and P1-50 TFC blend membranes tested at 340 kPa

	Pebax® 2533		P1-50	
Temperature (°C)	CO_2 (GPU)	CO_2/N_2 selectivity	CO_2 (GPU)	CO_2/N_2 selectivity
35	329	25	898	25
50	430	18	986	18
65	563	14	1170	13
80	662	11	1320	11

Figure 5 & Table 6: The graph and table shows the relationship between temperature, permeance, and selectivity (Fu).

In Pebax, the permeance for CO_2 increases as temperature decreases. It shows that around 35℃ (313K), it is the most optimum temperature for CO_2 permeance and selectivity. This aligns closely with the temperature requirement for boron nitride.

Materials Selection: Boron Nitride Nanosheets

The boron nitride nanosheet (BNN) was chosen due to it's high permeance of CO_2 compared to N_2. The data for "pore 3" correlates to the H^- and F^- functionalized BNN. In table 2, it shows that the passage of CO_2 through the BNN is 17, while that of N_2 is 0. The selectivity of N_2 to CO_2 is extremely low at a value of 3×10^{-11} which means that almost no nitrogen passes through the BNN membrane (Azamat).

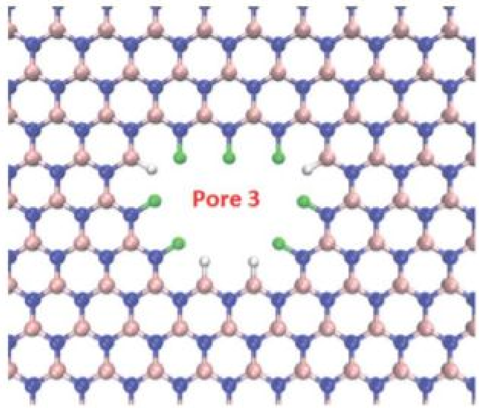


Table 2 Pore area, the number of permeates gas molecules, the permeation ratio of gases, selectivity and gas permeance of different pores in 298 K

System	Pore 1		Pore 2		Pore 3		Pore 4	
Pore area (Å^2)	58.55		74.94		35.13		46.84	
Gas	CO_2	N_2	CO_2	N_2	CO_2	N_2	CO_2	N_2
Passage	5	42	6	46	17	0	0	44
$P_x \times 100$	9.09	76.36	10.91	83.64	30.91	0	0	80.0
S_{N_2/CO_2}	8.4		7.66		3×10^{-11}		2×10^6	
Gas permeance (GPU)	1.058×10^4	8.88×10^4	9.91×10^3	7.605×10^4	5.99×10^4	0	0	1.162×10^5

Table 7: Pore 3 shows the selected BNN that is being used and shows the numerical value of how much CO_2 and N_2 permates. It shows high permeance of CO_2 (Azamat).

Table 3 The number of permeating gases in different pores at various temperatures

Temperature (K)	Pore 1		Pore 2		Pore 3		Pore 4	
	CO_2	N_2	CO_2	N_2	CO_2	N_2	CO_2	N_2
298	5	42	6	46	17	0	0	44
323	9	41	9	45	19	0	0	45
348	14	38	13	42	21	0	0	46
373	17	37	18	39	23	0	0	48
773	24	32	25	33	33	1	6	50
873	27	31	28	31	35	3	9	52

Table 8: Shows the direct relationship between temperature and CO_2 permeance (Azamat).

The optimum temperature is determined by analyzing the data from table 3. Within the temperatures of 298K to 373K there is almost complete separation of CO_2 and N_2, therefore these range of temperatures for the process is the best.

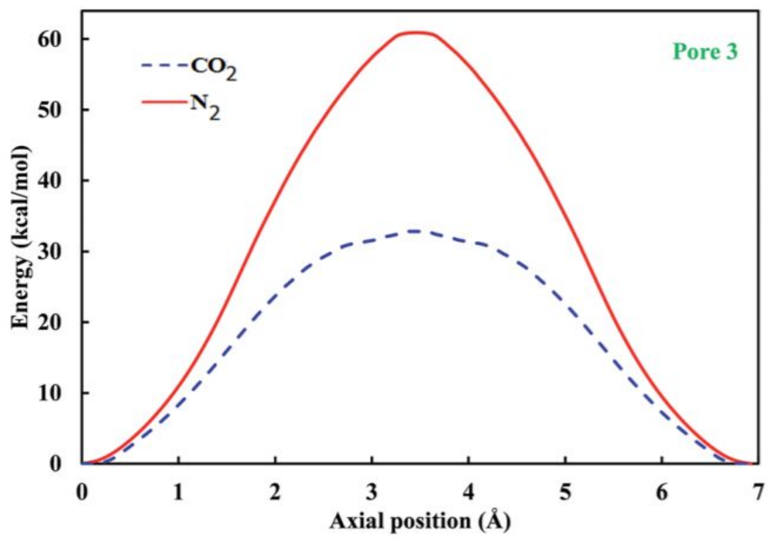


Figure 9: The graph above shows the potential of mean force of CO_2 and N_2. These values affect which molecules will permeate through the BNN.

The graph of energy (PMF) vs axial position represents the potential of mean force (PMF) of CO_2 and N_2. The nitrogen has a higher PMF which means that the nitrogen will not permeate through the membrane. CO_2 has the lower PMF which indicates that it will easily pass through the membrane. The BNN is used as a protective layer for the polymer membrane to allow a longer lifespan of the polymer membrane, but to also increase and ensure complete CO_2 purification.

The lifespan of a reverse osmosis membrane was determined to be 3 to 5 years and the major material component of the membrane is cellulose acetate ("Extending the Life-Cycle of Reverse Osmosis Membranes"). The young's modulus of cellulose acetate is about 3GPa (Semilab Semiconductor Physics Laboratory). The young's modulus of boron nitride nanoparticles is about 35 GPa, so the lifespan of BN was determined by scaling in reference to the lifespan and young's modulus of the reverse osmosis membrane (American Elements).

$\frac{30GPa}{3GPa} \times 4\ years = 40$ years. The BN membrane is estimated to last about 40 years. The young's modulus is used to calculate the lifespan because during the separation process, the membrane's lifespan is strongly dependent on how much the membrane swells and deforms, which is common in polymer membranes. Therefore if the membrane has a high young's modulus and stiffness it will last for a longer amount of time. Polymer membranes alone can easily deform due to the high pressure environment of a flowing gas and other stresses during the separation process, therefore comparing the young's modulus to calculate the lifetime is a viable approximation. The maintenance and replacement of the filter only needs to be replaced every 35 years in order to ensure that the membrane does not fail during processing.

Membrane Thinning

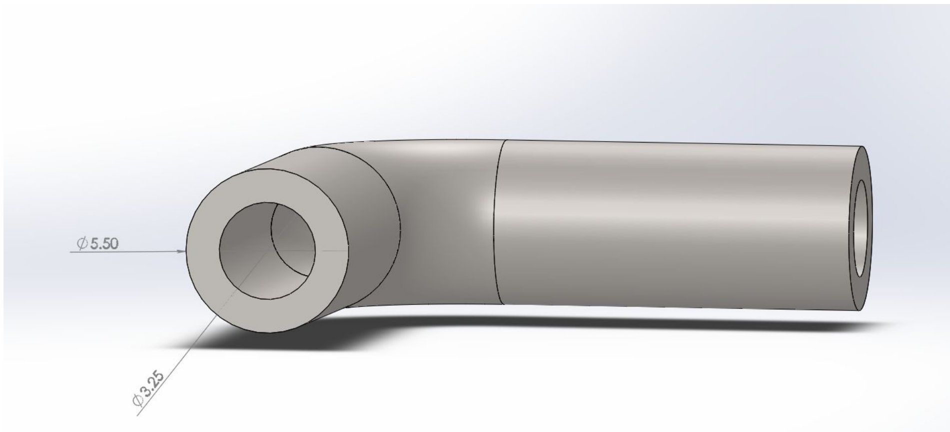
Membrane thinning is also a vital aspect of maximizing CO2 filtration efficiency. With our design of three thin membranes per stream (three streams in total) in the filtration chamber, the filter system would be able to separate more CO2 per unit volume membrane used than a filter that consists of thicker membranes. A thin membrane has a small thickness (l), and a small thickness would increase total CO2 flux since membrane thickness (l) is inversely proportional to the air flux (J_A).

Carbon Storers

Piping Materials

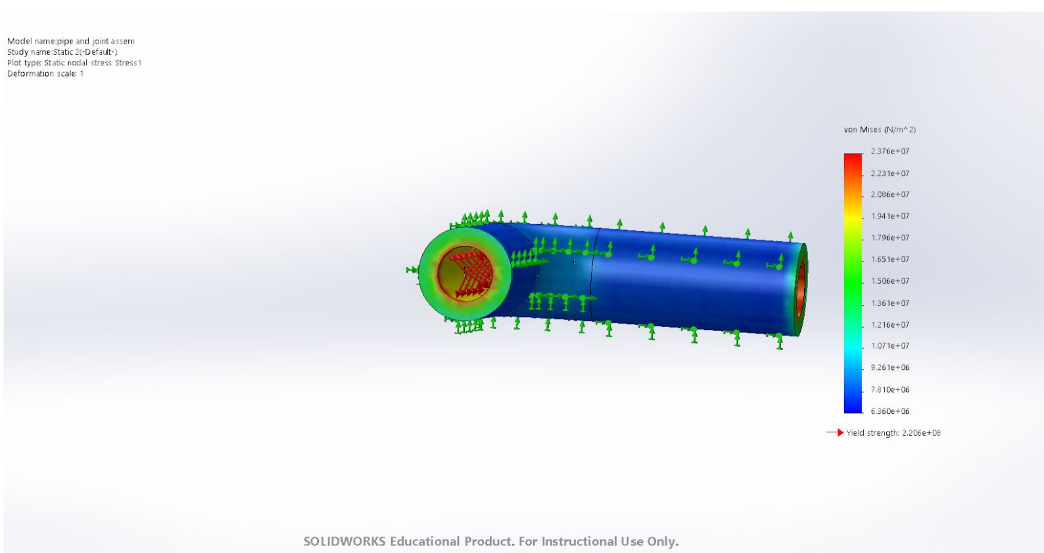
The optimal choice of material is carbon steel piping for the transportation of CO2 due mainly to its high strength and toughness and resistance to permeability. Currently, the existing oil and CO2 transport pipes have a diameter of 5.5 inches and a wall thickness of 1.125 inches. The approximate volume capacity is 0.78 gallons per linear foot. This existing pipeline leads to oil wells, 2500 feet under ground level, for storage.

A cross-sectional diagram of the proposed carbon steel pipe is presented below through Solidworks. Heat analysis can further be calculated from measurements of volumetric flow and other components such as material properties of the gaseous mix of CO2 .



Schematic of Design with Outside Diameter and Inside Diameter

The joints and welds are the weakest points in our pipeline. Due to shear stresses and weaker connections, these sections are prone to failure and higher corrosion rates. The majority of pipelines involve polymers to support these weaker more corrosive sections which we will also include in our proposal. Lining the weak spots with polymers with low permeability to CO2 is the most economical and safest option. We ran a simulation in solidworks applying the maximum pressure of 20 MPa to study the results on the piping and joints.



Resulting Stresses with Internal Maximum Pressure of 20 MPa

This simulation was done at a 90 degree elbow joint, which is the weakest point of our pipeline. Under the maximum pressure, the maximum stress is seen to be 2.376E07 N/m^2. The yield strength of the material is 2.206E08 N/m^2. These results mean that the carbon steel piping is able to easily withstand the forces of the CO2 flowing through it.

We propose adding a 2600 additional feet worth of pipe with an internal diameter of 1.047 inches leading to the CO2 recycling plant. This pipeline allows for the maximum flow rate or Qmax. This pipeline is composed of the same carbon steel and polymer lined weak spots.

Further specifications of the pipeline proposed include compressor stations, metering stations, valves, and a supervisory and data acquisition system (SCADA). Compressor stations including originating stations positioned at the inlet and booster stations positioned along the pipeline help to convert gas to the desired phase in order to compensate for pressure changes. We are using centrifugal, single-stage, radial-split pumps for recompression. Metering stations measure flow rates of CO2 along the pipeline. Valves work as gateways to start and stop flow around recompression and metering stations and are useful for isolating sections of pipe for maintenance. Block valves reduce flow volume and check valves prevent backflow. SCADA systems monitor data from compressor stations and metering stations, such as flow rate, operational statuses, pressure, and temperature. This is integratable with Pycontrol to work with their user interface for operators to easily monitor and control the pipeline and compression system.

These additions along the pipeline are crucial to maintaining constants pressures of >8MPa in order to efficiently transport the gaseous CO2. Careful control of the pipeline parameters can also prevent cavitation which is a leading cause of damages within pipeline systems.

Cavitation Prevention

The cause of cavitation is when vapor pressure in the pipe is larger than the pressure in the CO2 fluid, bubbles will be formed in the pipes and when it collapses, it will create a high energy shock wave inside the pipe that can damage the pipe or the pump. In order to prevent cavitation, action below will be enforced:

- Joint ring will be checked
- Construct booster pumps into our pump system to split the workload
- Increase the diameter of the center of the impeller to increase the strength.

- Pressure of the pipe will be maintained between 0.1MPa to 20 MPa.

Piping Calculations

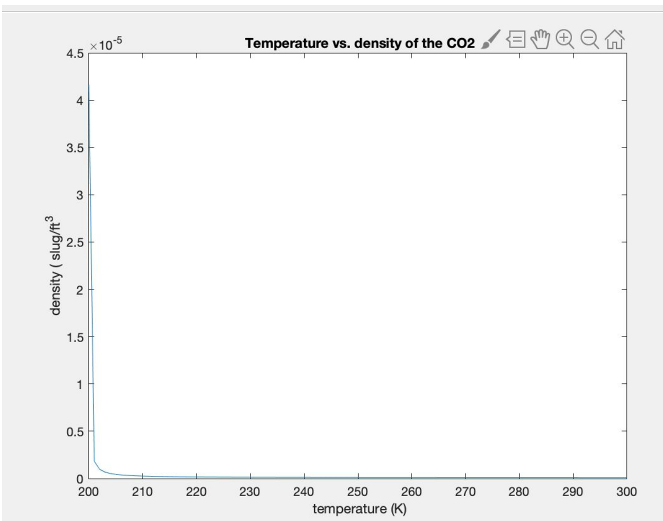
Two main components of the pipe will be used and constructed for transportation of CO_2 . The input pipe we are using is the existing oil pipe, the length of the existing pipe is 2500 ft long , outer diameter is 5.25 inch and inner diameter is 3.25 inch. Valve will be built on the ground to control the flow of CO_2 . Since the density of the CO_2 is heavier than the air, The CO_2 is driven by gravitational force and flows down to the depleted reservoir in the ground.

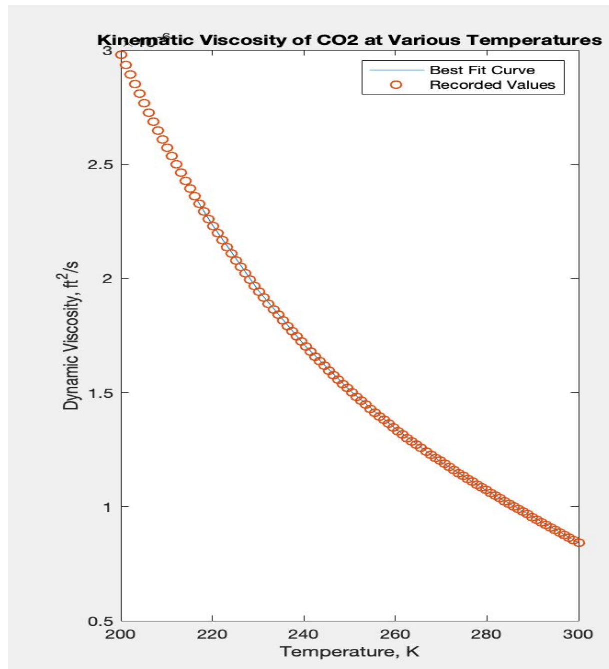
The output pipeline will be constructed and the total length of the pipe is around 2600 ft long and the inner diameter is 1.0474 in and outer diameter is 3.0474 in. Pump and a booster pump will be constructed which transports the CO_2 out from the reservoir. Also, a valve that can control the flow rate of the CO_2 will be built. The calculation was done by Matlab and the equation that was used to calculate the design was shown below.

The Reynolds number equation is used to find the relationship between the density of the CO_2 (p) and the temperature (T).

Which D is diameter, V is velocity of the fluid, v is the kinetic viscosity. The chart below states the relationship between temperature,density of the CO_2 , and dynamic viscosity.

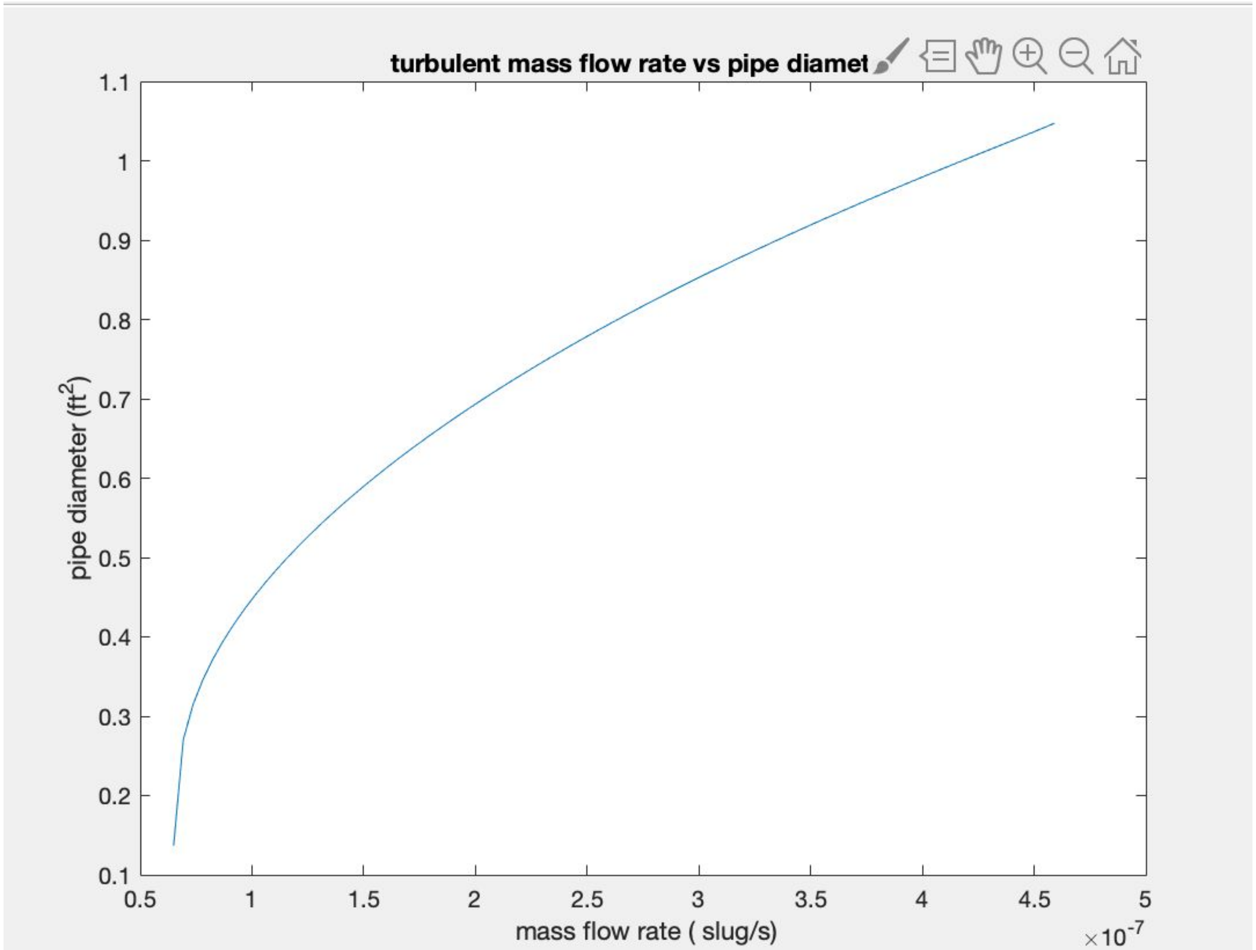
$$\mathrm{Re} = \frac{DV\rho}{\mu} = \frac{DV}{\nu} \qquad \nu = \frac{\mu}{\rho}$$





$$D = \left(\frac{8 \cdot f \cdot Q_m^2 \cdot L}{\rho \pi^2 \left[\rho g (z_1 - z_2) + (p_1 - p_2) \right]} \right)^{1/5}$$

In order to calculate the diameter, equation(Vandeginste & Piessens (2008)) above is used. Which f is the friction factor, the average friction factor of carbon steel pipe is 0.022, Qm is mass flow rate, L is the length of the pipe, g is gravitational constant (32.2 ft/s2), and p is the pressure. The pressure of the design should be maintained between 0.1 MPa and 20 MPa.



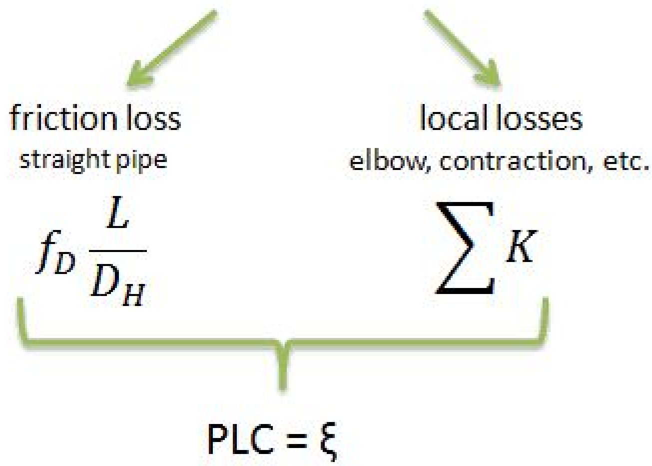
According to the calculation, **the optimal diameter of the output pipeline is 1.05 inch**, and **the maximum flow rate is 25 liter/s (0.7868 ft^3/s).**

Pump Pressure and design calculation

Head loss of the output pipe is needed to determine the total pump head and pump pressure. The equation below shows that the hydraulic loss is made up with friction loss in a pipe and local loss.**The hydraulic loss is calculated and it is equal to 175 ft**. By using the energy equation , we are able to calculate the total pump head which is equal to 9000 ft. So the primary pump and booster pumps will totally **provide 9000 ft pump head** to transport the CO2 to the recycle facility.

$$\Delta p = \xi \frac{\rho V^2}{2}$$

$$\Delta p = \left(f_D \frac{L}{D_H} + \sum K\right) \frac{\rho V^2}{2}$$



$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} + h_A - h_R - h_{L\,or\,f} = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$$

where:

E = Energy

p = pressure ($\frac{lb}{ft^2}$ or $\frac{N}{m^2}$)

γ = specific weight of the fluid ($\frac{lb}{ft^3}$ or $\frac{N}{m^3}$)

z = elevation (ft)

v = velocity ($\frac{ft}{s}$ or $\frac{m}{s}$)

g = gravity (32.2 $\frac{ft}{s^2}$ or 9.81 $\frac{ft}{s^2}$)

h_A = head added by pump (ft)

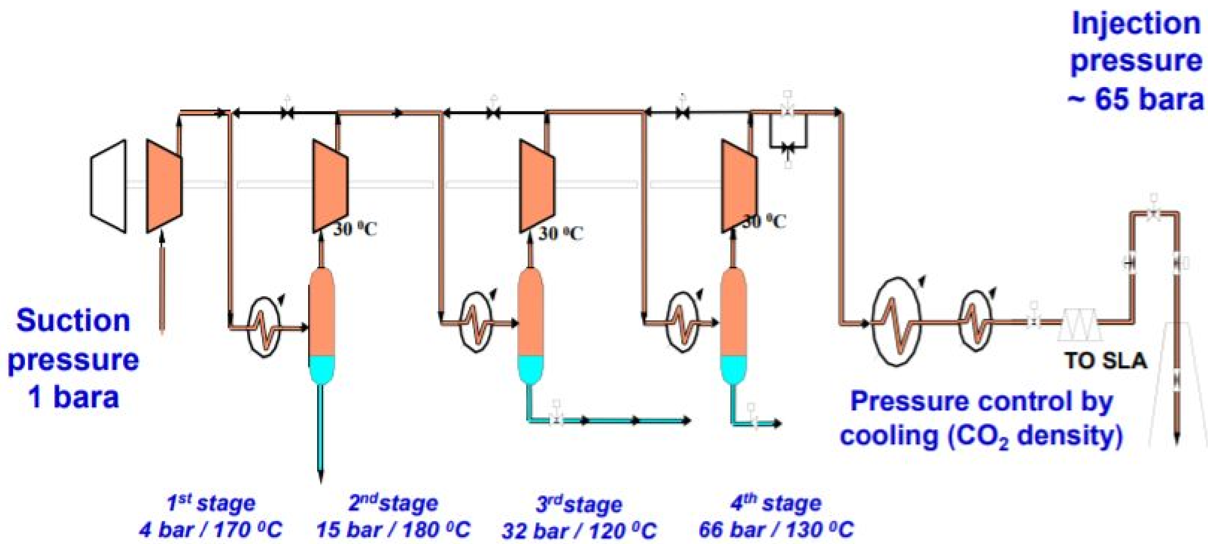
h_R = head removed (turbine) (ft)

$h_{L\,or\,f}$ = head loss due to friction (ft)

Oil Well Storage

After the carbon dioxide is transferred from a carbon collector, the pipes lead into an already existing depleted oil well that will be the basis in storing the collected carbon dioxide. We came to the decision of using used oil wells instead of other storage methods like mineral storage because it was clear that the convenience of oil wells and the utilization of the carbon dioxide after storage would output more recycling opportunities than other methods.

In order to have the carbon dioxide pumped into the empty oil well, we will be reusing the existing pipe that was previously used to extract the oil as our input channel for the incoming carbon dioxide. Since these pipes are already made out of carbon steel, they already have the capability of withstanding the stresses and strains. We can use this to our advantage by only adding an output pipe with the assistance of compressors and pumps to a recycling center, where the material can be reused into a new alternative material.



CO2 Compression and Injection System

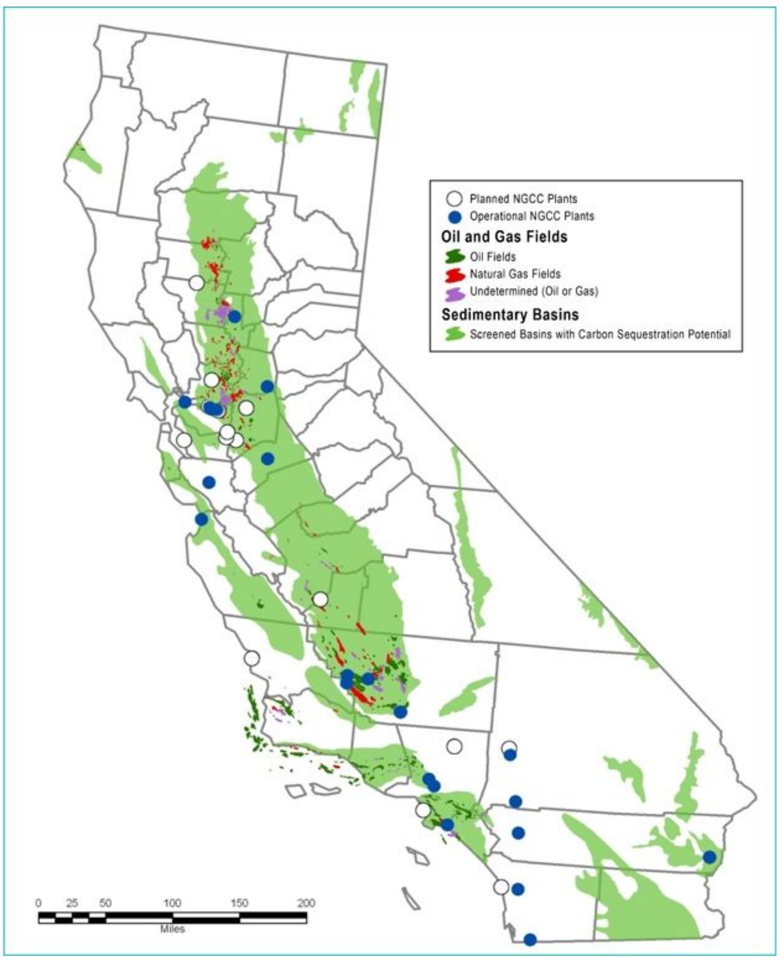
$$\text{Head}_p = ZRT_1 \frac{n}{n-1}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right]$$

Compressibility Factor and Polytropic Head Relation

The compression system for the CO2 pipeline leading into the oil well for storage allows the gaseous CO2 to be compressed from an inlet condition to a desired pressure for discharge. The equation above allows us to determine the amount of polytropic head required, or foot-pounds of work per pound of gas, that will affect the power and speed of the compression system.

Having the previous documentation of where previous oil reservoirs are reduces unnecessary work needed to find locations to store the material. With mineral storage, as an example, you would need to find specific minerals that fit the specifications to store the carbon dioxide plus have additional piping to insert the carbon dioxide into the material for storage. Even after storing and extracting from the minerals, the usages of the carbon dioxide from mineral storage are very limited.

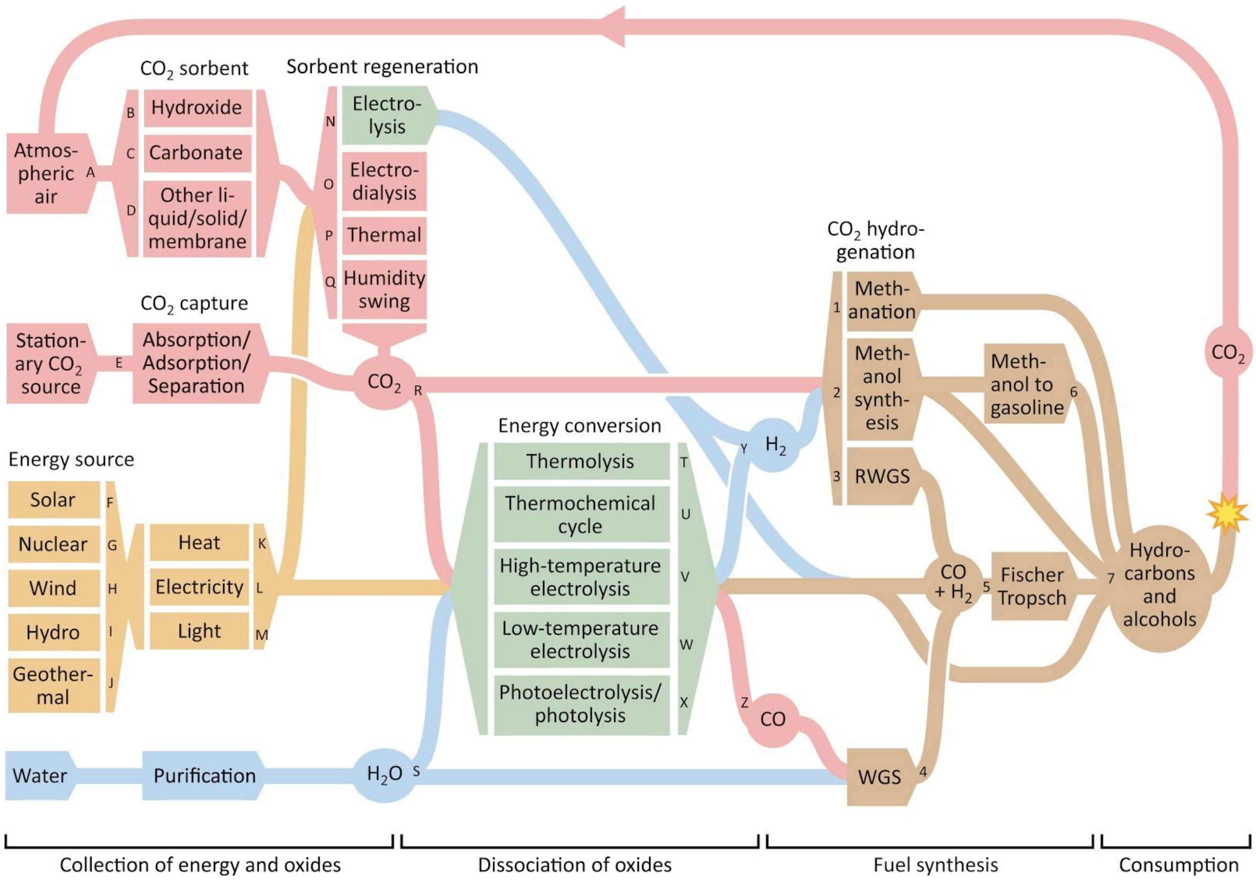
The below diagram of California and the overall locations of oil fields, natural gasses and basins with carbon sequestration potential shows the vast amount of land that is covered that can be utilized for the carbon dioxide storage. It does bring up the issue that the majority of the oil wells have not been completely extracted, if not touched at all, which can lead to many to believe that this method may not work out as well as planned. However, this does only show California as an example, where the location can be anywhere on the planet that involves empty oil reservoirs. Since fossil fuels are being more scarce, resulting in the emptying of many oil fields, this yields us to take advantage of the abandoned oil fields and reutilizing its use in a more environmental way to not only aid space usage, but also help solve the major problem of the decreasing amount of fossil oil that produce fuels.



A major benefit of storing CO_2 in oil wells is that it allows for enhanced oil recovery. As CO_2 is injected into the oil wells, residual oils are forced out and can be recovered. This residual oil would otherwise be unused. Enhanced oil recovery results in a positive net gain as the injected CO_2 will remain safely stored, and the profits from enhanced oil recovery will accelerate the market to further pursue CO_2 capture.

The proposed CCS system is more cost-effective compared to conventional methods. A notable example is the Kemper County CCS project in Mississippi, which involved the use of a CCS plant and had a cost of nearly $6.66 billion in addition to numerous delays. CCS plants not only require a larger budget, but consume even more energy when implemented with coal plants compared to those without CCS plants.

CO2 Synthetic Fuel Recycling



The carbon dioxide from the reused oil reservoirs will be transferred into a recycling plant, where we plan to have the carbon dioxide converted into a form of fuel. The diagram above shows a descriptive flowchart on the process of transforming the carbon dioxide into the fuel. The carbon dioxide from both the atmosphere and the storage would be put into a process of dissociation from a water source, which will allow the combination of the carbon dioxide and water to go through a fuel synthesis process to have the transformation turn into a renewable fuel source. Of course the byproduct of the used renewable fuel source will result in the production of more carbon dioxide, but the overall emission from the new fuel source will only produce about half the amount of carbon dioxide than a conventional fossil fueled vehicle.

One drawback of carbon dioxide reduction is that the catalysts tend to suffer from low energy efficiency, poor product selectivity, and rapid deactivation. A solution to these issues would be to use gold (Au) nanoparticles in order to reduce CO2 . Au oxide reduction can accelerate CO2 reduction catalysis and result in overpotentials as low as 140 mV, which means that much less energy is lost in the process. Compared methods are shown to require at least 200 mV more overpotential. By using these Au nanoparticle reduction techniques, our project remains more energy and, thus cost efficient, than those currently in the market.

A new experimental technique that can be used for syngas production involves high temperature co-electrolysis of H2O and CO2. The input gas mixture is composed of 20.6% steam, 59.2% N2, 6.7% H2, and 13.5% CO2. Production of H2 through the electrolysis of steam forces the reverse shift gas reaction equilibrium, resulting in CO being produced and H2 and CO2 being consumed. The reverse gas shift becomes kinetically frozen at 700 degrees Celsius or 973 K, thus the electrolysis should be carried out above this temperature. As the electrolysis current increases, the CO2 concentration decreases and the syngas yield increases linearly.

$$CO_2 + H_2 \overset{k_{RSR}}{\Leftrightarrow} CO + H_2O$$

Reverse Gas Shift Reaction

Having the ability of turning atmospheric carbon dioxide into a reusable fuel not only solves the issue of getting rid of it from the air, it also solves the issue of having a reusable fuel for the world to use. Since oil is a very important resource for many countries to have as a way to run their infrastructure, it is crucial that they have enough to keep their system running, but because of the limited amount of locations to buy, prices can be risen to increase the competition of prices and profit. Eradicating the carbon dioxide from the atmosphere and using it as a form of fuel for all forms of transportation and electricity will greatly aid in the economics of an area. Most western states in the United States have high gas and electric prices, but having this renewable energy will allow more fuel for these areas, reducing prices and helping the economy as a whole.

Pycontrol

I/O Layer

The sensors that are in place will monitor the temperature, humidity, voltage/current sensors, pressure, rain, CO_2 concentration, and air direction/speed. This data will then be sent digitally to the DDC, which will receive this info and use it to determine how fast the fans should spin and take in CO_2. These sensors, which will be simple analog sensors, will output their analog signals to an analog-to-digital converter (ADC). These digital messages then travel along an I2C Bus into the Direct Digital Controller (DDC) and depending on the signals it receives, will cause the fan to spin at variable speeds. It is important to record this data because certain scenarios, such as high winds, will help with fan speed thus requiring less energy to cause continual spinning. Additionally, analog sensors are preferred because analog sensors are cheaper, more sensitive, easier to work with, and easier to maintain.

Sensors:

- Tachometer
- Pressure
- Humidity/Temperature
- Voltage
- Current
- CO2 concentration sensor

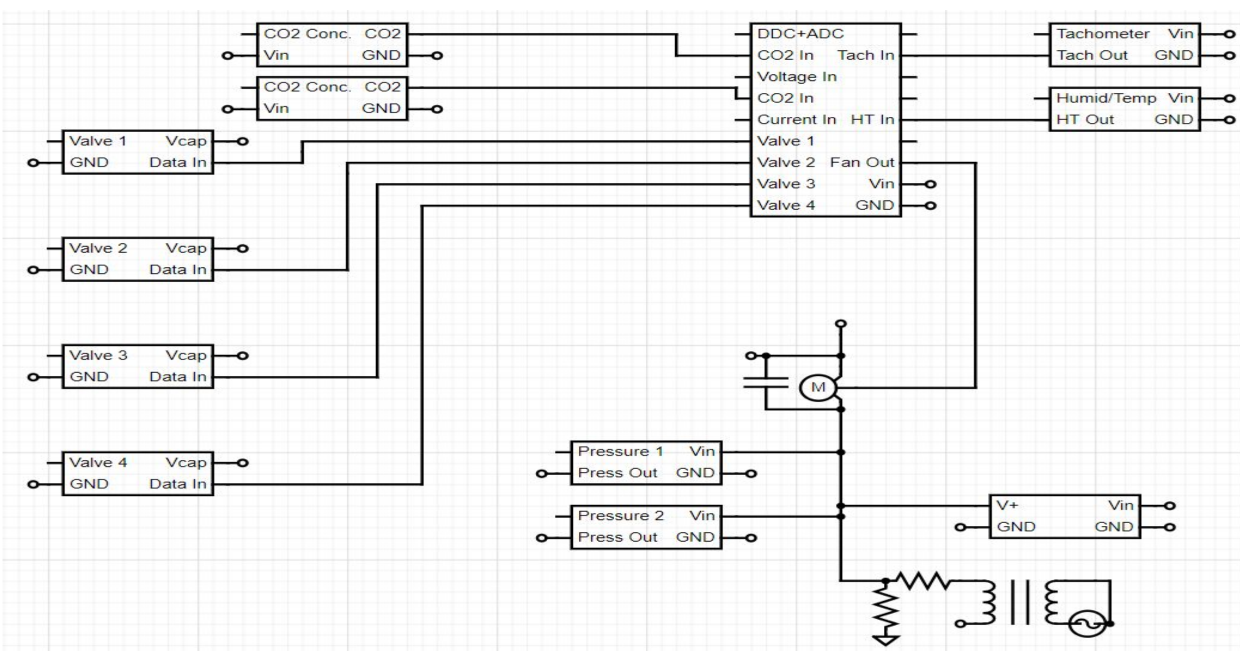


Fig 3. Field Controller circuit schematic

Containerization of Field Controllers

The DDC upon receiving the digital signals from the I/O layer will then interpret that data and decide how much energy is needed to make the fans rotate. The importance of collecting specific data is that if on a certain day there is low levels of CO_2, the fans do not need to spin as hard as it would need to on a day with high levels of CO_2. Data from nearby weather applications are also considered too, as they could indicate that the weather will become windier later in the day and thus will be considered by the DDC in calculating the most optimal amount of energy spent on the fans. After all the data is interpreted into fan speed data, the same data then gets sent to a onsite server, where it will be stored for a month before being
containerized into docker containers and then transferred over to an offsite server. The reason why a docker container is chosen is because of its "return on investment", where it "dramatically reduces infrastructure costs" for those who are using it [3]. Additionally, these containers are used as they help facilitate the transfer of large data much faster than sending the raw data over a cloud or the internet. The reason why they are so efficient is that everytime the docker creates "a container for every process and does not boot an OS…. data can be created and destroyed without worry that the cost to bring it up again would be higher than affordable" [1].

Data Tier

For this design, an Azure SQL database which is local to the system will store the most recent data for 30 days. The data, after 30 days, will then be compressed and uploaded to the Amazon DynamoDB, a noSQL database. SQL databases organize the data into relations in a predefined schema. One advantage of SQL databases is that it is faster to access counterparts for joins, queries, updates, etc. This way the local database will have faster access to organized data for quick analysis and onsite debugging. On the other hand, the advantage of a noSQL database is that it "can ultimately become larger and more powerful, making these databases the preferred choice for large or ever-changing data sets" [2]. This means that the operator can work with analytics of large data applications and is easier to scale [4]. One upside to using SQL for a local machine is that it supports ACID properties: Atomicity, Consistency, Isolation, and Durability. This means that the most recent data will be more stable to access than on a noSQL system. Furthermore, a downside to noSQL is that it is not built for complex queries. To overcome this problem, DynamoDB will share its data to ElasticSearch, which uses key words and prefixes to locate relevant data.[4] ElasticSearch is a database search engine that surf for keyword and prefixes to locate the unorganized data.

```
{
    "ADC":{
        "sys": "ref (system)";
        "Fans" : ["Fan_1","Fan_2"];
        "Membrane" : ["Membrane_1","Membrane_2"];
        "Actuator" : ["Actuator_1","Actuator_2"];
        }
    "Fan" :{
        "Fan_1":{
            "fan_id" : "ref";
            "Operation" : "Boolean";
            "Speed" : "Boolean";
        "Fan_2" :{
            "fan_id" : "ref";
            "Operation" : "Boolean";
            "Speed" : "Boolean";
            }
        }
    "Actuator" :{
        "Actuator_1":{
            "Actuator_ref" : "ref";
            "speedometor" : "Boolean";
            "direction" : "number";
        "Actuator_2" :{
            "Actuator_ref" : "ref";
            "speedometor" : "Boolean";
            "direction" : "number";
            }
        }
        }
    "Membrane" :{
        "Membrane_1":{
            "mem_id": "ref";
            "temp" : "number";
            "humd" : "number";
            "co2"  : "number";
        "Membrane_2" :{
            "mem_id": "ref";
            "temp" : "number";
            "humd" : "number";
            "co2"  : "number";
            }
        }
    "Pipeline" :{
        "Membrane_1":{
            "id" : "ref";
            "temp" : "number";
            "pressure" : "number";
        "Membrane_2" :{
            "id" : "ref";
            "temp" : "number";
            "pressure" : "number";
            }
        }
}
```

Pseudo Code for our data organization

Supervisory Layer

The supervisory layer will extract the data from the onsite and offsite servers using ElasticSearch where the user will be able to analyze the data using a thin client. We decided to use thin clients over thick and zero clients to take advantage of the cost advantages over the thick client while providing more flexibility and control than the zero client. Thin clients could "be cheaper, consume less power, space and cooling; the processor, storage and memory could be centralised, more secure and more efficient" [5]. This is a highlight of our design as the solution to reducing our carbon footprint should use the least amount of electrical power as possible. This is why we also included a 'smart' case where the user will be able to control the fan speed and the direction that the fan is facing. Facing the fan towards the incoming wind will allow the fan to continue to rotate and filter CO2 emissions while unpowered. Moreover, the control of the fan will be handled autonomously by the direct digital controller using sensor data and will only be accessible to the user via override.

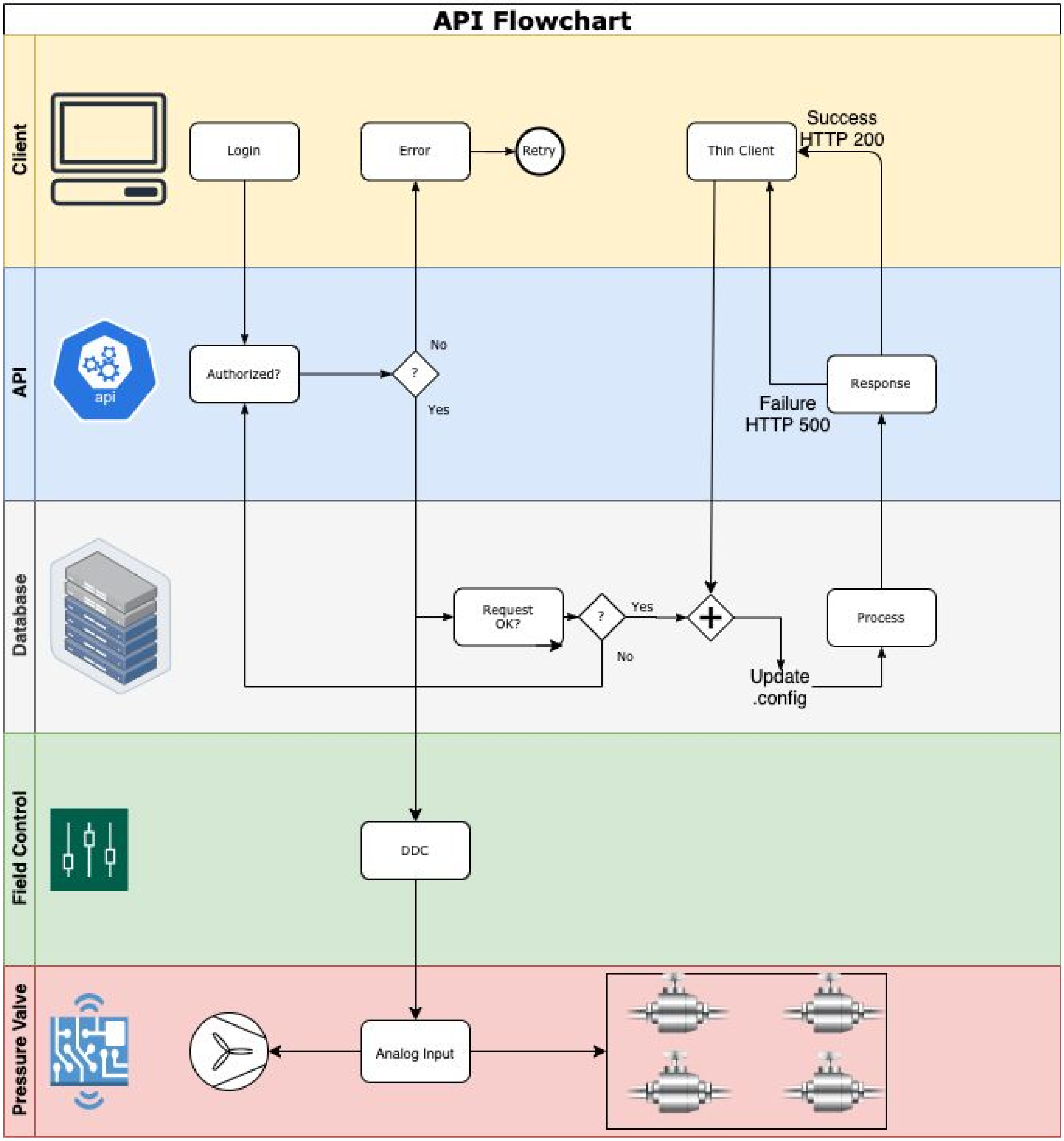


Fig 5. A diagram breaking down the API

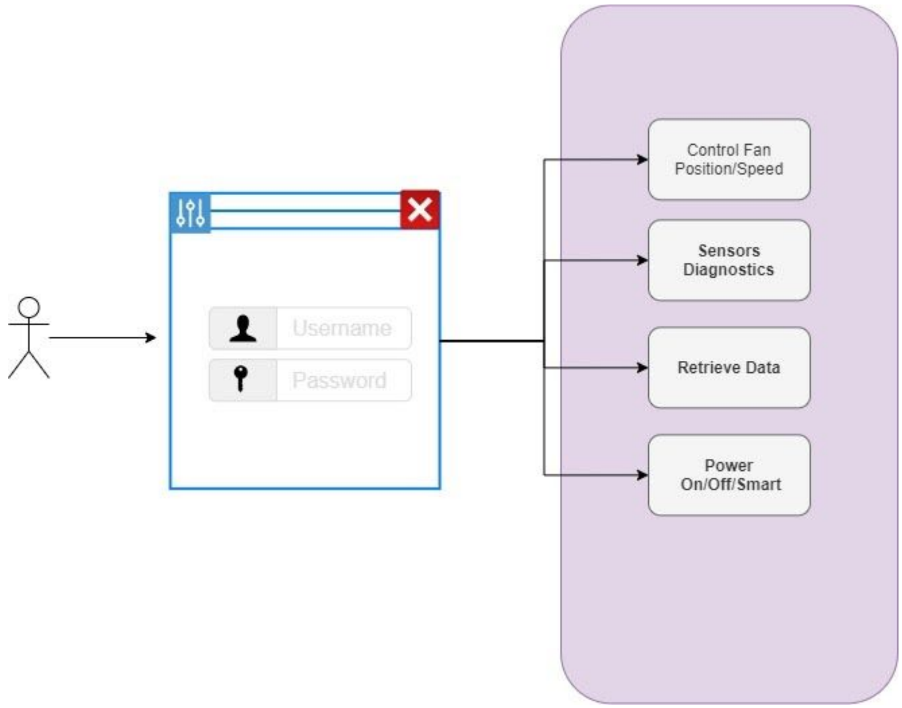


Fig 6. A diagram demonstrating the UI use cases

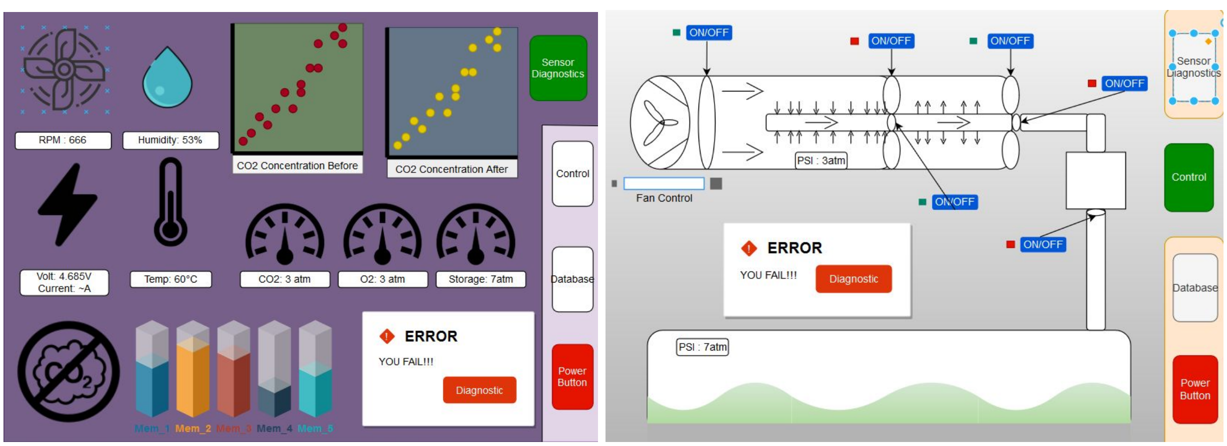


Fig 7. User Interface

Carbon Storer

Piping Materials

Carbon steel is employed as the main pipe material due to its resistance to carbon dioxide permeation and high factors of strength and toughness. The proposed design allows for an inlet diameter of 2 1/2 in. with extension or joints placed at intervals of 12 ft. Carbon steel pipes with a nominal (interior) diameter of 2 ½ in. have a volume capacity of .2833 gallons per foot.

Based on the internal, external, and steel transverse areas stated in the ASME/ANSI B 36.10 Welded and Seamless Wrought Steel Pipe, a cross-sectional diagram of the pipe can be presented. The internal volumetric flow for both the gas and liquid components of the fluid may be measured as well, which provides information for heat and energy analysis of the system.

Figure 17: Carbon Steel Pipe (2 ½ in. diameter)

Munkejord et. al recommends schedule 40 carbon steel for carbon fluid transport, due to the need for moderately-high corrosion-proof structures. The cost of materials reflects the necessity for high-performing materials for safety considerations and to prevent expenses related to replacing corroded joints.

Joints and welds constitute the weakest points of any piping configuration. These weak spots in the piping configuration will be supported by seals and liners composed of CPVC, a material that is flexible and resistant to corrosion. Multiple engineering companies that supply CPVC piping advise that their products undergo a maximum temperature of 200F, so the material qualifies for the conditions demanded by the carbon dioxide-water mixture.

Figure 18: CPVC union, 45° joint, 90° joint (2 ½ in. diameter)

CO2 Transport Calculations

Optimally, CO2 is transported in a supercritical condition, which can be maintained through 7.5-20 MPa and 273.15-303.15 K (Li et al, 2009). We also consider the possibility of depressurizing the pipe under failure or maintenance, which widens the required range to 0.1-20 MPa for pressure and 200-300 K for temperature.

Munkejord et. al presents a method for calculating the transport and depressurization for two-phase carbon dioxide mixtures of multiple components. The Soave-Redlich-Kwong (SRK) equation of state allows us to determine the thermodynamic and transport properties of a CO2-CH4 mixture. The pipe flow is represented using a drift-flux model, which is comprised of a system of nonlinear hyperbolic differential equations. The resulting analysis resolves the pressure and mass waves through applying the multi-stage centered scheme.

The drift-flux model reduces the two-phase flow of the pipe to a one-dimensional two-fluid model which requires fewer transport equations to be solved. This is done by relating the difference in gas (g) and liquid (l) velocity, the slip velocity, as a function of flow variables. One commonly used slip relation is given by Zuber and Findlay's equation

$$\phi = \frac{(K-1)u_g + S}{K u_l} \qquad \text{Equation 9}$$

Phi represents the slip velocity, the difference between velocity in the gas and liquid phases, in terms of K and S, which are constants that depend on flow. The Zuber-Findlay slip relation has been experimentally confirmed to apply to a wide range of parameters. Values of K = 1.07 and S = .216 m/s have also been experimentally verified to serve as acceptable benchmark values to model the slip relation. The graphs below illustrate the effect of slip velocity on the pressure profile and constituent phase velocities. To assume slip velocity is 0 would neglect the changes on the internal pressure and the different velocities of the phases.

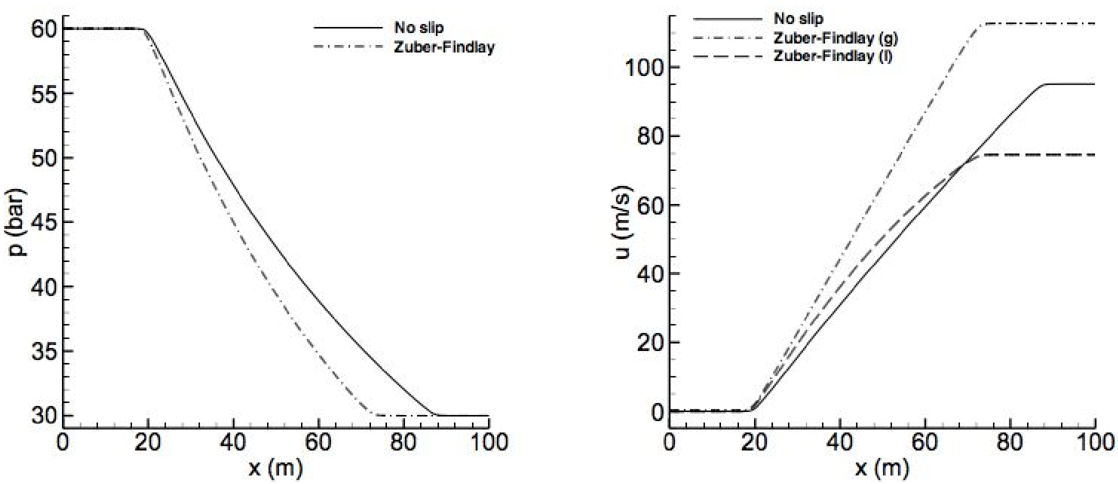


Figure 4: Zuber-Findlay Pressure vs Displacement, Slip vs Displacement models

We now calculate the heat transfer of the system to the surroundings. Under basic conditions, heat transfer can be modelled according to the following internal and external parameters.

$$Q = \frac{2(T_e - T\ )}{\frac{r}{\eta} + \frac{r^2}{\eta_e r_e} + \frac{r^2 ln(r_e - r)}{\lambda}} \qquad \text{Equation 10}$$

where Te is the temperature of the surroundings, T is the temperature of the fluid, while r and re are the pipe's inner and outer diameters.

For the convective boiling of CO2, we take inner and outer heat transfer constants of n = 5 kW/(m^2K) and n_e = 10 W/(m^2K). We assume the exterior temperature to be 300 K and the interior temperature to be maintained at 250 K. The remaining coefficients are the inner diameter r = 2.469 in and the outer diameter r_e = 2.875 in. Carbon steel composed of 1% carbon is has a thermal conductivity of λ = 43 W/(mK). This provides the necessary terms to calculate the energy supplied by the surroundings Q =

-1180.1 W/m. This figure indicates that every meter of piping experiences a heat loss of 1180.1 Watts to the surrounding environment. This information may be useful to other departments during the integration phase.

Storage: Geological Sequestration

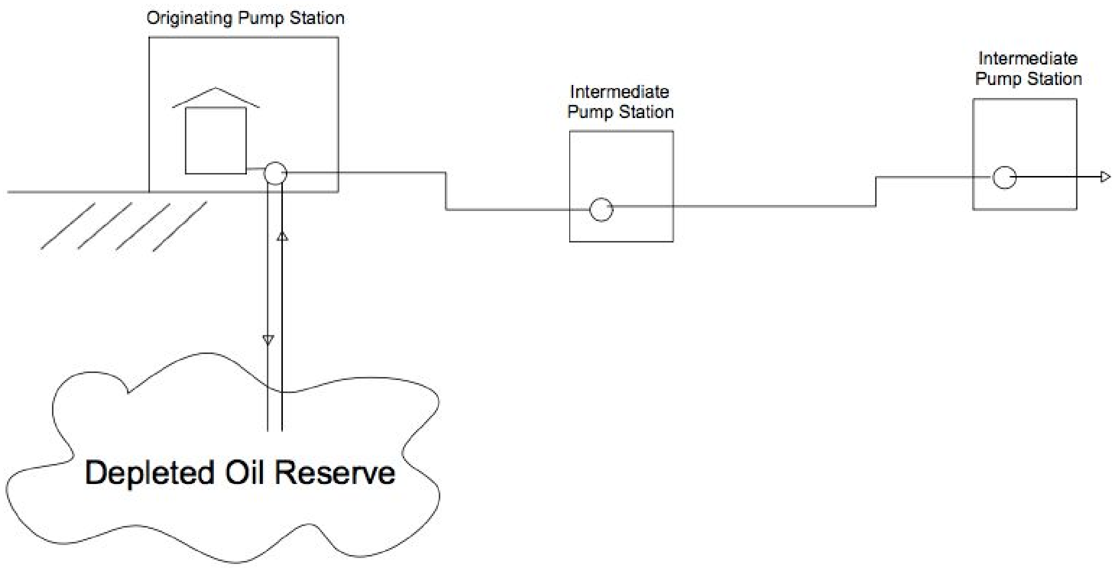


Figure 19: Oil Reserve Sequestration

Geological sequestration is the practice of storing carbon dioxide in porous and permeable rock formations. There are several methods of accomplishing this process, including enhanced oil recovery (EOR), injection into depleted gas and oil reserves, and injection into deep saline reserves. This design employs depleted oil reserve sequestration, which returns carbon dioxide into naturally occurring oil reservoirs which have previously been drilled. The reasons for the selection of this storage method are twofold: first, this method takes advantage of existing reservoirs and wells thus requiring little in part of new installations; secondly, replacing carbon dioxide to depleted oil reservoirs improves the geological health of the area, which mitigates man-made losses to the natural carbon cycle.

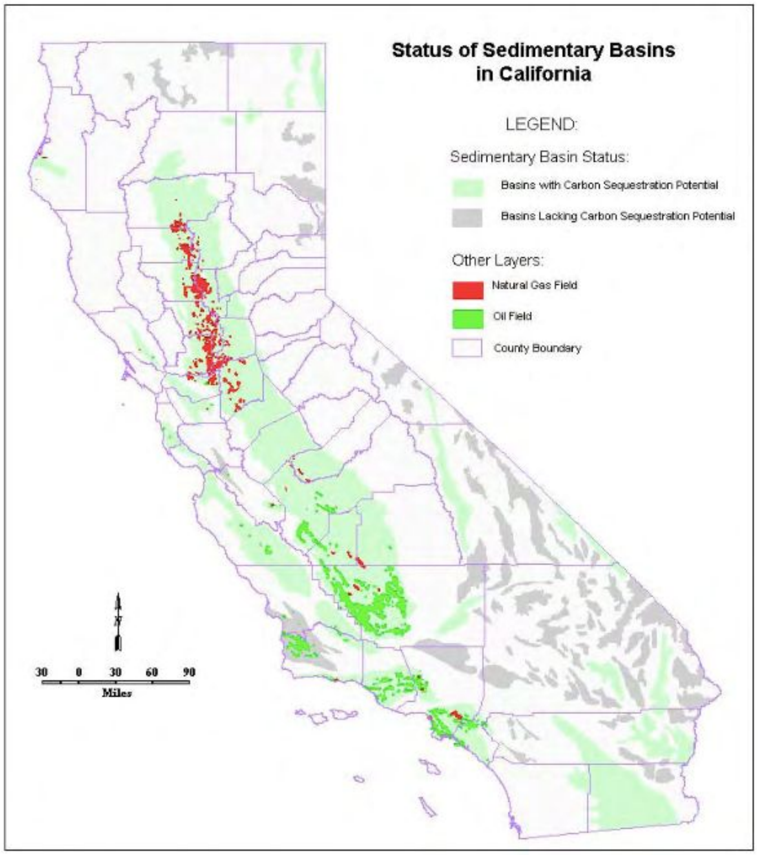


Figure 20: Geological Sequestration Potential in California (CEC)

According to the California Energy Commission, the Los Angeles County and Orange County areas possess oil fields with adequate depth and geological composition to perform carbon sequestration. The Los Angeles Basin in particular is one of the most hydrocarbon-rich per unit volume in the world, making its sedimentary lining highly suitable for the storage of carbon dioxide. For the purposes of the report, however, we assume applications of this design to be centralized near Irvine, Orange County. The Huntington Beach oil fields located 10 miles west of Irvine constitute a more accessible option for storing carbon dioxide in depleted fields.

GIS data of the oil reserves in Huntington beach reveals dozens of wells that have already been installed in the area. The existing infrastructure and present ownership rights over the site make the cost of carbon sequestration dependent on partnerships or agreements with the entities in control of the depleted fields. A cost estimate of several methods of carbon dioxide sequestration performed by the MIT

Laboratory for Energy and the Environment indicates that storing oil in depleted oil fields will cost \$3.82 per ton of CO2 on average. This estimate is reflected in the Bill of Materials section.

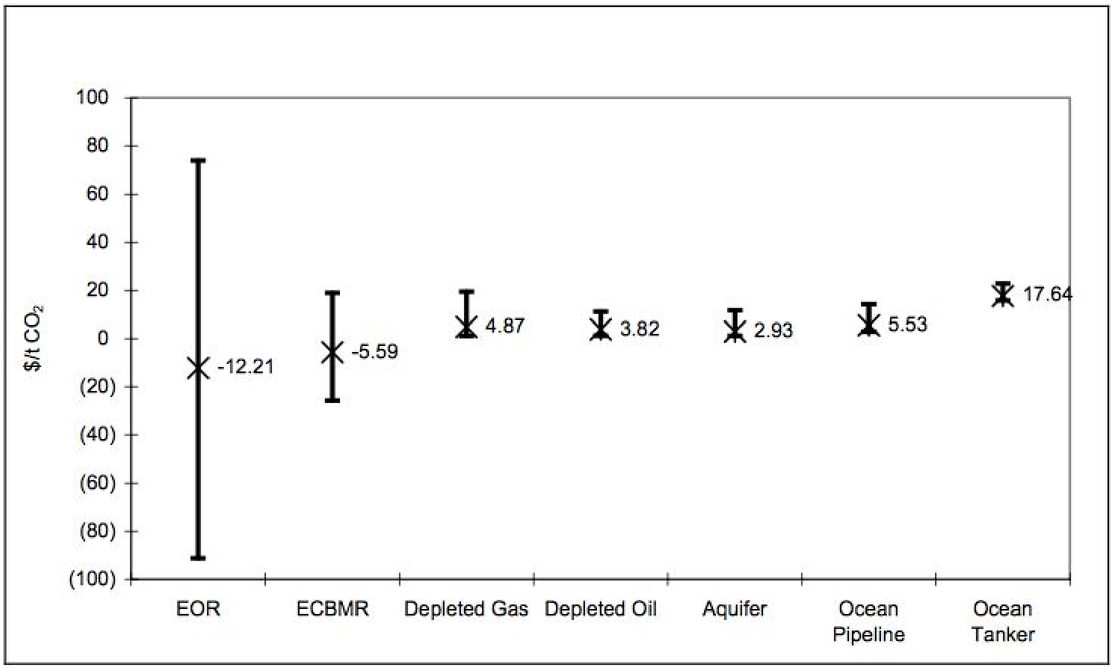


Figure 21: Cost Comparison of Sequestration Methods (MIT)

CO2-Enhanced Concrete

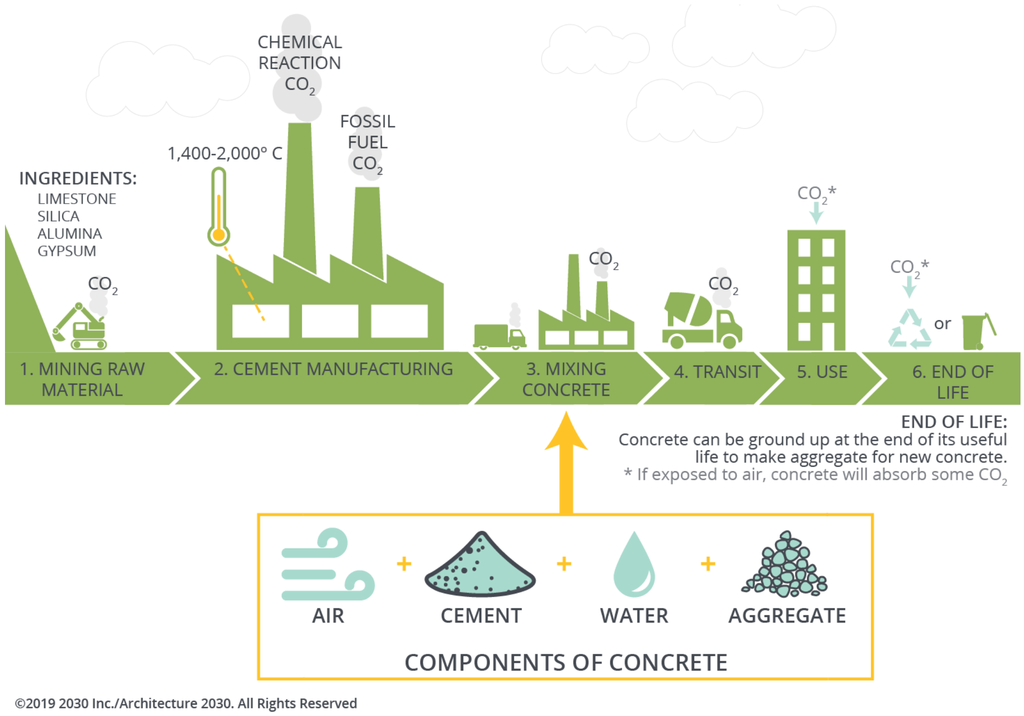


Figure 22: CO2-enhanced Carbon Process

The proposed solution is to recycle the captured carbon dioxide into a base for calcium carbonate concrete. CO2-enhanced concrete is comparable in strength to traditional Portland cement while diverting carbon dioxide emissions from the atmosphere to load-bearing structures (Sant). Construction companies like CarbonCure in Canada and research groups like CarbonUpcycling in the U.S. presently inject their own captured carbon dioxide to manufacture concrete and cement at scale. Carbicrete, a manufacturing company based in Montreal, provides construction crews with the materials and equipment they need to implement carbon-negative concrete into their own projects.

This report refers to Carbicrete's determine a mixture content for enhanced concrete. Carbicrete's manufacturing process injects 1kg or 2.2 lbs into every standard block of concrete, which will weigh 30-35 lbs. Thus, every ton of captured CO2 can be expected to produce about 14 tons of concrete. For a standard 1:3:3 ratio of cement base (hydrated lime for this mixture), sand aggregates, and large aggregates, concrete of that quantity would require 2 ton of hydrated lime, 6 tons of sand aggregate, and 6 tons of large aggregates. The costs of these constituents per ton of collected CO2 are included in the Bill of Materials. It is noteworthy that CO2 concrete has a high revenue potential, especially because the captured carbon dioxide does not need to be processed before use (Carbicrete). CO2-enhanced concrete has great profitability in the growingly environmentally-conscious construction and development industries.

Bill of Materials

AIR MOVER BOM

Item	Description	Link	Manufacturer	Price per Unit	Quantity	Total price/module
Aluminum Fan blades	1m diameter	https://www.alibaba.com/product-detail/ss304-316-stainless-steel-800mm-axial_60809927968.html?spm=a2700.7724857.normalList.27.710772b7OqQKXX	Laizhou Fan Factory	~$400/unit	1	$400
Steel Pipe	1m diameter,	https://www.alibaba.com/product-detail/large-diameter-specification-1-m-diameter_60597203170.html?spm=a2700.7724857.normalList.53.5553ae8dQYUMv0	Tianjin Youfa Steel Pipe Group Co LTD	600/metric ton ~460/meter	2m	920

304 StainlessSteel plates	3'x6'	https://getmetals.com/stainless-steel/plate?0=xjfllnmonjzin4tx62qjz8zg2epi7pe&1=0.25&2=PLTSS14-304MIL&gclid=Cj0KCQiA7aPyBRChARIsAJfWCgLWxyUZ87X8xJ3g6vt8pXXgoylgZ0vo7p9Kvbf_lCUAdnTc6tnx8O8aAumMEALw_wcB	Get Metals	530.12/sheet	4	2120.48
Vanes	0.075" 304 Stainless steel sheets	https://getmetals.com/stainless-steel/sheet?0=x990emxn1wmgm6j33y9p2715kg06n62&1=0.075&2=SHTSS14GA-304-2B&gclid=Cj0KCQiA7aPyBRChARIsAJfWCgLHkhQ8Id8rqvy36Y3gkDk1AF5gOSeBPKw9-9XeREB2anyUWdGP	Get Metals	34.22	8	273.76

		OI8aAmWwEALw_wcB				
Protective Screen		https://www.twpinc.com/industrial/projects/industrial-factory/16-mesh-aluminum-018-wire-dia	TWP	750	0.03	22.5
Motor	2 hp, max RPM 1750, 79.5%Efficiency,	https://www.toolots.com/oem-customized-centrifugal-kitchen-roof-exhaust-fan-cksfgm200.html?cid=1469602941&gclid=Cj0KCQiA7aPyBRChARIsAJfWCgIQ0TJYfIzl1yS6xkp9Qq9ILeIbhEOVMbyLHi99tp1LMSh67D4Zv-gaAvRaEALw_wcB	CKS Global Fan California INC.	$174	1	$174
Poston Motor	RSX 096 electric actuator, with HT1 option. Capable of applying 30,000lb force	file:///C:/Users/domin/Downloads/2171-4000_13_rsx-flyer.pdf	Tolomatic, INC.	Unknown (prices must be discussed with the company, and will vary based on a variety of factors)	2	Unknown
Total						$3910.32

Materials Cost						
Assembly Costs	Estimated to be 30% of material costs on average	https://www.sciencedirect.com/topics/engineering/assembly-cost				$1203
Total Costs						$5113.32

CARBON STORER BOM

Item	*Description*	*Link*	*Manufacturer*	*Price per unit*	*Quantity*	*Total price*
Piping Materials (per 1,000 ft)						
Carbon Steel (CS) Pipes	Main pipes for CO_2 transport	Carbon Steel Pipe	Grainger	$273 / 10ft	100	$27,300
CPVC Joints	Unions and joints	Polymeric Joints	Grainger	~$0.60 / joint	100	$60
Total:						$27,360
CO_2 processing (per ton CO_2)						
Power/Electri-city	Pump Energy	Oil Reserve Sequestration	Huntington Beach Oil Reserves	$3.82 / ton	1	$4
Hydrated Lime	Concrete component	Hydrated Lime	Alibaba	$500 / ton	2	$1,000
Aggregates (sand)	Concrete component	Sand Aggregate	Cairo Fresh	$1/ton Note: min 15,000 ton	6	$6
Aggregate (>20mm)	Concrete component	Concrete Aggregate	Cairo Fresh	$30/ton Note: min 1,000 ton	6	$180
Total:						$1,190

Maintenance/Replacements						
Carbon Steel (CS) Pipes	Keep 3% of original quant. on hand	Carbon Steel Pipe	Grainger	$273 / unit	3	$819
CPVC Joint testing	Perform every 6 months	PVC Pressure Gauge	Grainger	$99/ unit	12	$1188
Total:						$2,007
Committee Total						**$30,557**

PYCONTROL BOM

Item	*Description*	*Link*	*Manufacturer*	*Price per unit*	*Quantity*	*Total price*
INA169 - Breakout	Breakout board for current sensor	Link	Adafruit	$9.95	3	$29.85
SNG-QPLA-00 0	Hall effect sensor wheel speed	Link	Honeywell	$35	1	$35
K30 SE0018	CO2 Sensor	Link	CO2 Measurement Specialists	$85	2	$170
SPT25 Pressure transmitters	Pressure Sensor	Link	Prosense	$123	2	$246
SHT3x-ARP	Humidity and temperature IC	Link	Newark	$1.91	10	$19.10
BOB-09056	Analog to Digital Converter	Link	Digi-key	$5.50	3	$16.50
AWS ElasticSearch	Search Engine	Link	Elastic	$157	1	$157
Docker	Containers	Link	Docker	$84	1	$84
Azure	SQL database	Link	Microsoft	$13	12	$156
Amazon DB	Data transfering	Link	Amazon	$25	12	$0.25
ZP6-ESP	DDC	Link	BlackHawk	$441.25	1	$441.25
MP1584EN	Buck Converter	Link	Amazon	$9.95	1	$9.95

Committee Total:	$1365.22

MEMBRAiN BOM

Item	*Description*	*Link*	*Manufacturer*	*Price per unit*	*Quantity*	*Total price*
B_2O_3	Powder to synthesize BN nanosheet	Price link	Sigma Aldrich	$80.90 per gram	5	$404.50
control valve	controls fluid flow by varying the size of the flow process	Price link		$300	3	900
CO_2 Sensor	CO_2 sensor (ppm)	Price link	CO_2 measurement specialist	$120 per sensor	1	$120
Air collector	enhances the quality of air released by collecting impurities using disposable filters	Price link		$2500	1	$2500
Pebax2533 SA 01	applied in the separation of gas mixtures	Price link	foster polymer distribution	878 dollars	9	$7902
coolant	it is used to remove heat			0.5 dollars		$1000

Oxygen Separator		Price link	PRISM	$3000	1	$3000
Committee Total: $13326.50						
GRAND TOTAL			**$202,029.62**			

Conclusion

A key feature of the Air Mover fan design is the separation into modular components, which allows for easy scaling of the device to fit the needs of the implementing facility. This modular design for the fan allows for easy customization to client-specific needs and requests. The airflow is kept consistent as it reaches Membrane, who employs a Nitrogen Generator system with a CO2 membrane to extract the CO2. The design utilizes passive movement, thus operating in a highly economical and efficient manner. The sensor/actuator network installed by Pycontrol allows for flexible readings of Carbon Catcher conditions, while consuming little storage space or energy through the implementation of distributed cloud computing services. The resulting CO2 is transported and processed through Carbon Storer's stabilized carbon steel piping system, finally being used to create a cleaner fuel alternative to gasoline.

Carbon Catcher provides a broadly applicable solution to the very real and imminent consequences of global warming. High-polluting industries often cannot reduce their emissions due to demands for production. The carbon catcher device provides the opportunity for high-polluting entities to reduce their greenhouse gas emissions without interfering with output. In the past, environmental reforms such as a carbon tax could not feasibly be passed due to the economic burden it would place on companies. Carbon Catcher is the key to scaling initiatives to incentivize ecological restoration or pollution-reduction measures.

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