Title
An Innovative Take on Filtering Carbon Dioxide Through CryoCapture

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An Innovative Take on Filtering Carbon Dioxide Through CryoCapture

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Design Prompt

One of the most relevant problems in today's world is climate change. Year after year, the average temperature around the globe has been steadily rising, current projections, by Berkeley Earth, predict that by 2060 the 'global temperature anomaly' will be 2 °C. The effects of this temperature anomaly can already be 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. Now is the time to address the problem and make a lasting impact; not only to stop adding greenhouse gases and other pollutants into the atmosphere, but to actually take harmful chemicals, such as carbon dioxide, out. The scope of this project aims to address the latter.

Due to human induced climate change atmospheric carbon dioxide levels, one of the most harmful and prominent pollutants, have been increasing every year since the dawn 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, The team proposes 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

Overview (Air Mover):

Carbon dioxide plays an important role in the earth's ecosystem; the lives of many organisms are based on the balancing of this gas. Plants and animals need it for survival however, an excess of carbon dioxide can also end the organism's life. The production of the gas mostly comes from the combustion of fossil fuel, power plants, big industries, vehicles, and processes involving natural gasses. One of the most known issues of carbon dioxide pollution is global warming. The greenhouse gas essentially traps heat in the atmosphere, increasing the global temperature.

The methodology provided is an innovative solution towards the creation of an environmentally friendly carbon dioxide filter. Current air filtration systems are restricted to industrial environments limiting the ability to filter the air. Due to the large noise and low range of operation of axial fans the filtration systems need controlled environments for longevity. The paper presents a versatile air mover that can be mounted onto multiple surfaces due to its low profile and bracket mounts. Furthermore, the usage of a diagonal fan inside of a PVC pipe allows for a durable system that can operate at high efficiency and low noise.

The main challenge in designing the air mover was figuring out how to quantify the scalability of the device and what parameters could be changed in order to make the device more viable. The designs most prominent feature are the inclusion of a modular enclosure that can be adapted to multiple areas and environments while withstanding harsh conditions due to the PVC piping that can be coated with a diagonal fan for high volumetric flow rates and pressure differential for versatility in environments the device is placed in as well as efficiency.

Overview (Carbon Storer):

The Civil and Environmental Engineering team is responsible for finding a cost effective and sustainable way to transport, store and recycle the carbon caught in the air from the Carbon Catcher designed by the other engineering teams. In the team's design, the Carbon Catcher will reduce the harmful emissions in the air by capturing CO_2, store it and then utilize it in another industry which will reduce the need to mine for more raw materials which would thus further reduce the pollution emitted into the environment.

Our plan is to recycle the carbon emitted from a factory and utilize it in CO_2 dry ice. It's the Civil and Environmental Engineers' job to find a way to connect a sustainable solution with a solution that improves the public's quality of life. There are many industries that pollute immense amounts from the mining of raw material or the emission of pollutants. The team wants to show industries that the economic solution can also be the sustainable solution.

Overview (Membrane):

The team's solution focuses on the use of cryogenic carbon capture, a method in which the selective freezing points of the gaseous components of air are used to separate out carbon dioxide. For this process, the team will be utilizing a 4 step filtration process. First, the flue gas will be run through a particulate filter to catch all macroscopic particles that may be present within the air. Afterwards, the gas is then passed through a dehumidifier where a majority of water content will be extracted. Following this, The gas was then run through a long pipe and progressively cool it down to the freezing point of carbon dioxide. Finally, the filtered gas is extracted, and a bubbler is used to separate the solid carbon dioxide. The carbon dioxide is then compressed and recycled around the feed pipe to help in the cooling process.

Along the process of this design, the team encountered problems finding the optimum materials for temperatures this low. As well, coming up with a way to eliminate heat transfer from the outside posed a huge problem. Through the experience, the team was able to gain a greater view of what benefits and drawbacks must be balanced, along with the economic interest that comes with designing an efficient process.

Unlike how most designs are focused, It was understood that using a membrane only provided so much creativity when it came to filtration. As a result, the team researched other successful methods and arrived at utilizing cryogenics to filter.

Goal

Research to provide a single solution to remove levels of carbon dioxide in the immediate atmosphere, transport it to a storage mechanism, and find a way to recycle it. Powerful research is required to ensure effective methodologies, material usage, and flexible scalability of the overall device. This particular team seeks to find an alternative separation process to membrane filtration, the efficacy of which has not been demonstrated beyond the scale of a laboratory.

Objectives

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

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

Project Outline

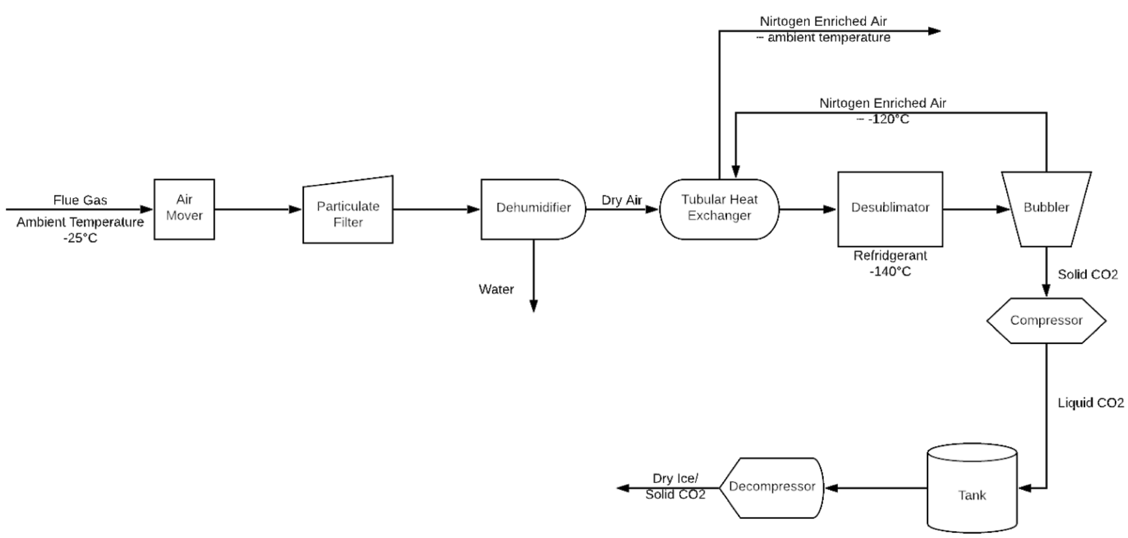


Fig. 1 The project outline

Air Mover

The modular PVC pipe is composed of a mouth (frontal section that can be adapted and substituted based on needs), mid-section (fan and electronic housing), and rear section (electronic and membrane storage). The core of the device lay in the mid and end section as these two hold the fan and membrane while the mouth can be replaced to grant a larger inlet or have a grate mounted for boundary separation between environment and the system.

Membrane

For this process, a particular filter will be utilized, dehumidified, and finally the cryogenic carbon capture process. The cryogenic process includes the use of stainless steel pipes, fluoroform refrigerant, and Isobutyl Mercaptan as the bubbler solution.

The method of carbon dioxide separation utilizes the freezing points of the flue gas constituents to selectively freeze out and separate carbon dioxide.

The process of cryogenic carbon capture has been previously conducted and shown to obtain a maximum of 99% carbon capture at the operational temperature of -140°C. It was estimated that roughly 80% will be achieved on average. With a flow rate of 6.5 ft/s into a 2-ft diameter by 30 ft long pipe, It was estimated that about 4000 tons of carbon dioxide sequestered annually.

Near future maintenance for this process is minimal and includes ice build-up from the remaining water content in the air, filter replacement from the particulate filter, and solvent replacement for the bubbler.

Carbon Storer

Our design focuses on finding the connection between the economical and environmental side. WeThe will utilize carbon steel pipes to transport clean CO_2 from the membrane to a storage tank fabricated from carbon steel and then use another series of pipes to transport CO_2 into a factory and find a way to recycle it into a material for a new product. WeThe choose to use dry ice since it's a relatively easy way to utilize the carbon without too much energy being required to actually be able to use it. WeThe wanted to lower the emissions in the environment from all sources which includes power from electrical generation.

Py Control

Through the use of multiple sensors, field controllers, and machine learning, not only can the team automate the process and have the least amount of human supervision, but it can also optimize the system so that the amount of carbon extracted from the air is maximized while still keeping into account the amount of power used by the system. While doing this, the team does not sacrifice safety and user input. There are measures in act that monitor the system constantly to ensure that if a critical error were to occur, then it will send an immediate response to the system.

Design Breakdown

Air Mover

PVC was chosen over metals due to its lightweight, resistance to harsh environments, relatively high strength, and cost effectiveness. A diagonal fan was chosen since it grants high volumetric flow rates and has been documented to consume less energy while outputting volumetric flow rates that rival those of an axial fan. The device was made modular in order to guarantee scalability and ease of maintenance.

Figure 2 - Air mover ventilation unit with diagonal fan and PVC enclosure (Exploded view)

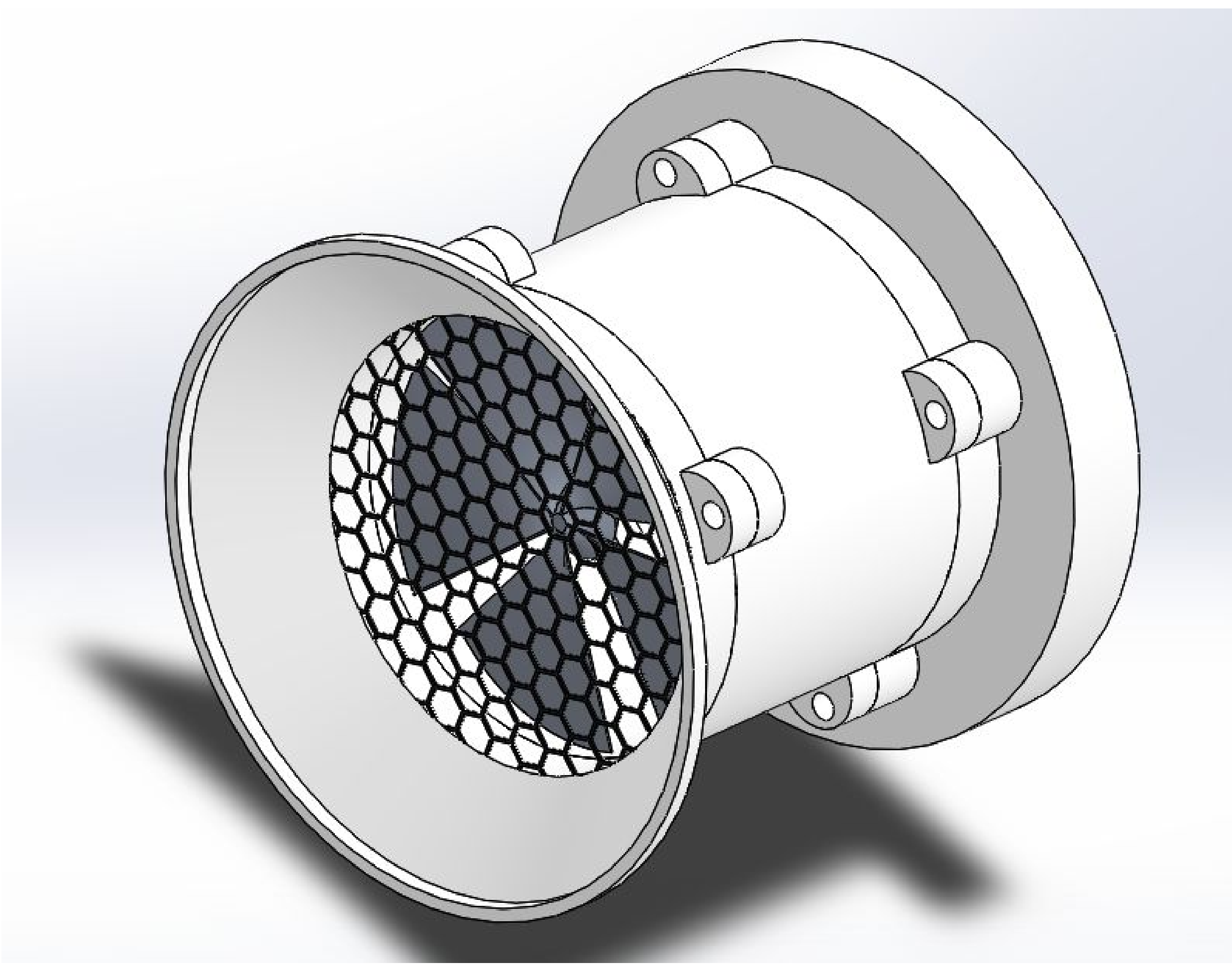


Figure 3 - Air mover ventilation unit with diagonal fan and PVC enclosure

A diagonal fan was selected for this project as it offers reliable and efficient performance in a multitude of environments. It offers volumetric flow rates rivaling those of the more traditional axial fan at higher pressure differentials. Because of this the fan is capable of performing suction in environments where the air is more dense due to some pollutant.

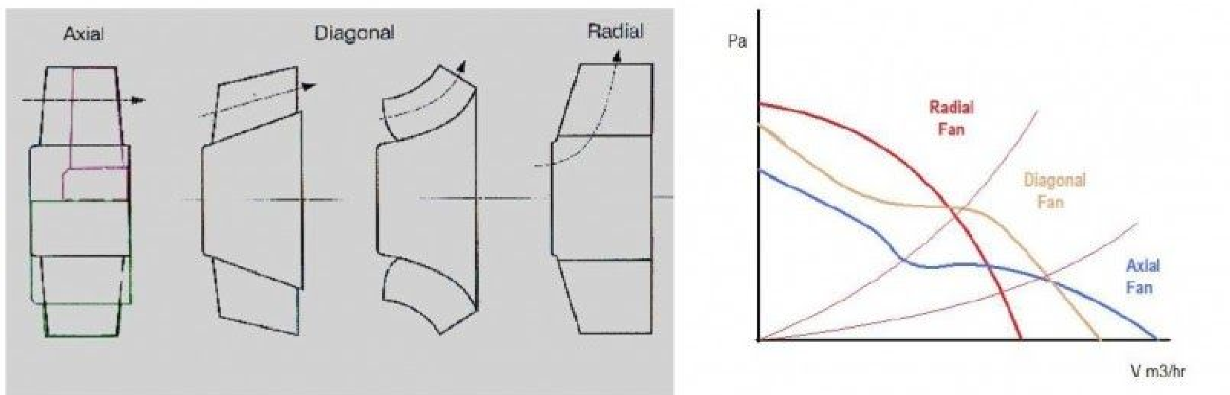


Figure 3.1 - Pressure as a function of volumetric flow rate for axial, diagonal, and centrifugal fans (https://www.rs-online.com/designspark/fan-types-why-choose-an-mixed-flow-diagonal-fan)

Polyvinyl chloride was chosen for the pipe material as it is lighter than stainless steel, has similar corrosion resistance, and a relatively high tensile strength.

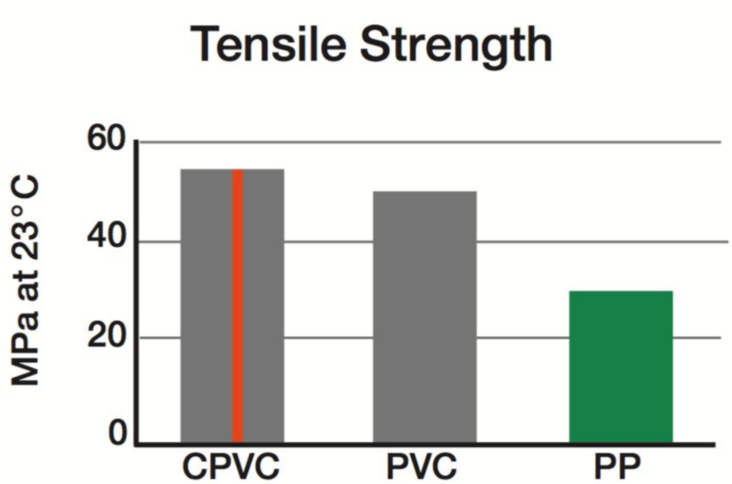


Figure 3.2 - Tensile strength of PVC (https://www.flowguard.com/blog/should-i-choose-cpvc-or-ppr-piping)

Simulations were performed to determine the effectiveness of the system. The CFD resulted in streamlines that approach the fan with decent speed due to the pressure differential and slow down after passing the fan. This means that the motion of the flow will not be too eradicate and will indeed meet the membrane at a decent velocity.

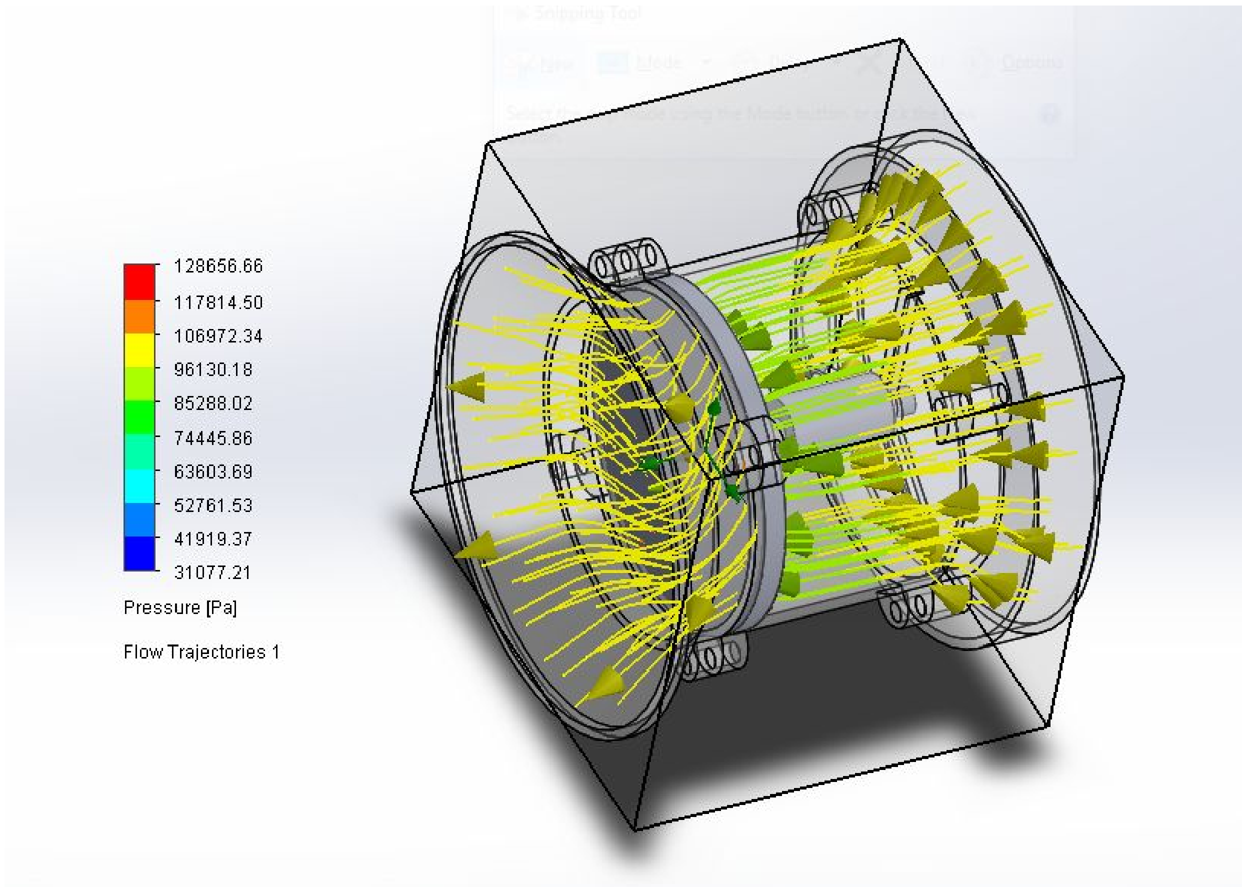


Figure 4 - CFD of ventilation system

A finite element analysis was also performed to determine the strength of the enclosure. The results indicate that while the most stress results towards the bottom of the enclosure, the values and stresses reached are well within a reasonable range.

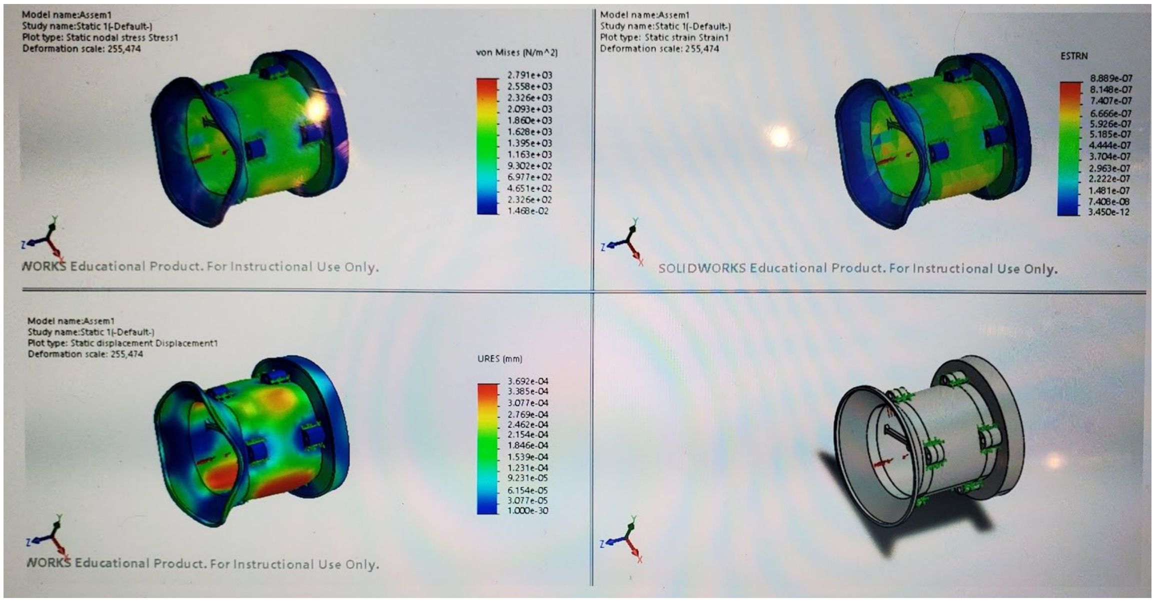


Figure 5 - FEA of ventilation system

Membrain

For this project, the final design that was decided on was a cryogenic approach as opposed to that of a membrane because. The team felt as though with membrane selectivity, as it currently stands, one can only get so far in terms of filtration. As a result, other solutions were researched and cryogenic carbon capture was the most viable option found. Unlike membranes, where there is a dependency on elevated temperatures for filtration efficiency, cryogenic carbon capture relies on colder temperatures which are much easier to scale. Additionally, this process has been shown in prior industrial tests to obtain up to 99% isolation of carbon dioxide from the inlet gas.

The process works by first running the inlet air through a particle filter and dehumidifier to remove most water content and macroscopic particles. From here the air is then flowed into a tubular heat exchanger where the gas is progressively cooled until reaching the desubliminizer where final cooling is achieved. Next, this supercooled gas is bubbled through a solvent capable of liquid state at low temperatures (Isobutyl Mercaptan) to slowly dissolve and then crash solid carbon dioxide out of the solution. This solid is then sent to a compressor and then finally sent to carbon storerer to for further processing.

- Assumptions:
  - 6.5 ft/s inlet flow =>
  - Coolant stange is at -140°C, steady state
  - Inlet pipe 2 ft diameter, recyclers 4 in diameter
    - All piping ⅛'' thick
  - Flue gas has 10-15 mass% CO_2
  - Desublimation achieves perfect separation (only CO_2 drops out of gas)
  - Separation efficiency 80-90% (conservative, 99+% feasible if -140°C steady state is maintained)

- Calculations -

$$\dot{m} = \dot{Q} \cdot \rho = Vavg \cdot A \cdot \rho$$

$$\dot{m}_{CO2} = Wb_{CO2} \cdot \dot{m}_{total}$$

  - CO_2 yield based on assumptions and provided equations: 3400-3660 tons yearly
    - Calculated accounting for the carbon released in process of compression and refrigeration
  - Mass of pipe required:

$$m_{steel} = \pi * (r_{out}^2 - r_{in}^2) * L * \rho_{steel}$$

  -
  - Total mass: 6.64 tons steel

Carbon Storer

Storage

The storage plan for the system is to have liquid carbon dioxide transported through carbon steel pipes and simply stored into a carbon steel tank above the ground. This method of sequestering carbon dioxide was chosen for its cost-effectiveness compared to other methods such as geological sequestration through oil wells or saline aquifers. For what the team intends to do in the recycling process, the CO2 has to be clean since it's intended for human use and consumption.

The main reason why the team chose carbon steel as the main material for the storage tank is due to its durable properties, resistance to corrosion and resistance to permeability CO2 which is vital to the design to ensure that there are no leaks that may endanger public safety or the environment. It also keeps the material of the pipes consistent as well.

By choosing a carbon steel storage tank rather than something that relies on geological properties whether it's man-made such as an oil well, or natural such as a saline aquifer. This allows for a greater amount of industries being able to utilize the design rather than just people in a certain area. The team wants something that works in a place such as southern California to also work in Africa or Europe. This allows a much greater amount of people to be able to find an economic benefit to the project. Another reason why the team chose an above-ground carbon steel tank is that it is intended to recycle the carbon dioxide for human use so it must be clean. One of the most important things to remember as an engineer is public safety. Even if it may be cheaper to use a saline aquifer for storing carbon dioxide in its large natural cavern. It would be too difficult to ensure that the compound would remain clean so that is why a tank will serve as the storage unit.

The size of the carbon steel tank that the team intends to use is a horizontal bulk storage tank design that has a length of 21 feet and height and width of 10 feet. The thickness of the tank will be (1.25/12) ft which means that the total volume will be 108 ft^3.

Transport

During the process of transporting the liquid carbon dioxide is to use schedule 40 carbon steel pipes with a 4'' diameter with a 0.237'' wall thickness in the pipe. The design will also use

CPVC 4’’ diameter joints. The team is using an AISI 1018 Mild/Low Carbon Steel (AZoMJul 5). The reason the design has chosen to go with a carbon steel pipeline is due to its corrosive resistance and its cost-effective properties. The transport of the carbon dioxide will happen in its liquid state due to the membrane team finishing its process with the carbon dioxide being a liquid. The carbon pipe will be able to withstand the pressure change from the transition from the membrane to transportation. Below is the cross-section of the transition of the two connecting pipes due to the fact that the outlet pipe design is also a diameter of 4’’ from the membrane. Their pipes outlet have a wall thickness of around 0.25’’ so some welding will need to be done to make the two pipes coincide into one pipe.

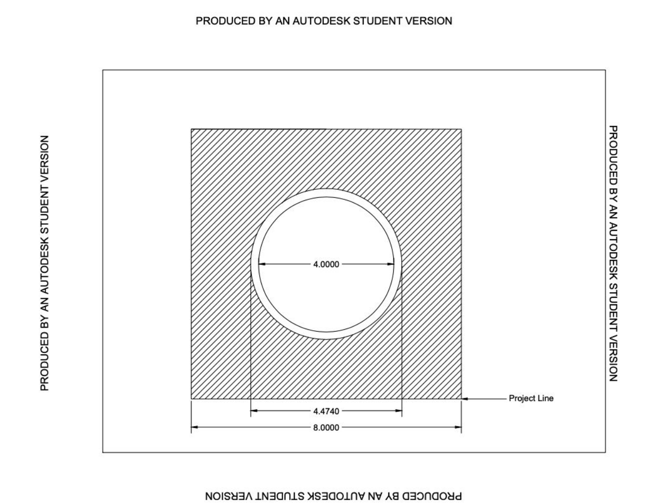


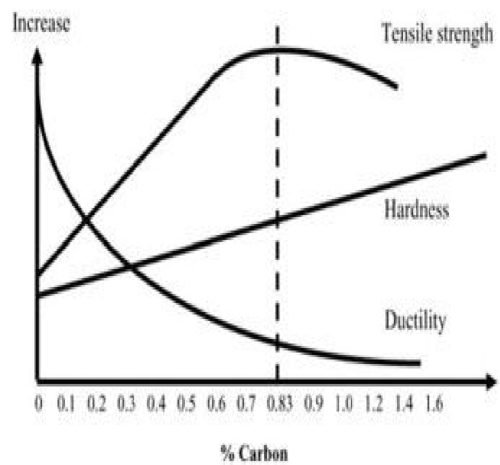
Figure 6 - Diagram of the pipe

The pipes will need to be maintained at a constant pressure of around 10 Mpa and at a temperature controlled at around 216.4K - 304.1K. The only issue to watch out for, is for the carbon dioxide to stay away from the triple point of carbon dioxide. That occurs at 216.4K and 0.52 Mpa. At these conditions changes in pressure and sudden pressure drops can occur which is not ideal for the transportation of carbon dioxide (Linde AG). The easiest state to transport and store the carbon dioxide is in its liquid state. That is why if the temperature is kept in the range above and keeps a constant pressure of 10 Mpa, then the carbon dioxide can remain a liquid throughout the transportation process. Another problem to look out for is cavitation. Since this is a liquid transporting in a pipe cavitation occurs when sudden pressure changes within the pipes cause little air pockets to form in the liquid. If this occurs then cracks will begin to form.

However, since the teams are using carbon steel pipes which have a tensile strength of around 440 MPa. Also pycontrol will be monitoring the carbon steel pipes using supervisory control and data acquisition.

Why carbon steel, what are its properties? Depending on whether it is high, low, or plain carbon steel it will have different strengths and durabilities. The team is going with low to plain carbon steel pipes because it is needed to take the properties from the other metals in order to make a stronger and more corrosive resistant pipe. But this material isn't just economically friendly but it is also environmentally friendly. Around 50 percent of all carbon steels are made out of recycled materials. 90 percent of all steel manufacture is made as carbon steel.

Fig. 5. Carbon steel



Source: AZoMJul 5 Source: *A Quick Guide to Welding Weld Inspection*

Above is also the determination of the percent carbon need in carbon steel depending on what the project is looking for. Since the team is using low to plain carbon steel the hardness and tensile strength will be higher which is exactly what is needed out of the pipe. These pipes will take the liquid carbon dioxide from the membrane to the steel tank then it will take the carbon dioxide out of the steel tank and take it to the decompression station in order to take the liquid carbon dioxide and turn it into dry carbon dioxide which will then be sold.

Production

To produce dry ice, the liquid CO_2 will be transported from the storage tank when in demand to the decompressing, pressure chamber in a facility. Solid CO_2, also known as dry ice exists below 0.52 megapascals pressure and below -79 C degrees (From liquid CO_2 into dry ice), If decompressed to that pressure rapidly, less than 17 seconds then liquid carbon dioxide will become part solid and part gas (Zheng). The conversion rate from liquid to gas of CO_2 is about 40-45% dry ice and 55-60% gas (Dry Ice Production). This gas will then be separated from the “snow” powderlike solid CO_2, and be piped back into storage. The snow will then be collected and pressed with a hydraulic press into dry ice blocks. This process requires less than 3kW per hour to create 700kg of dry ice per hour, which is the maximum yield with one chamber (Dry Ice Production). This means that per hour at maximum production speeds and yields, the cost of energy consumption of the decompression chamber would be less than $0.242 if done in a southern Californian city.

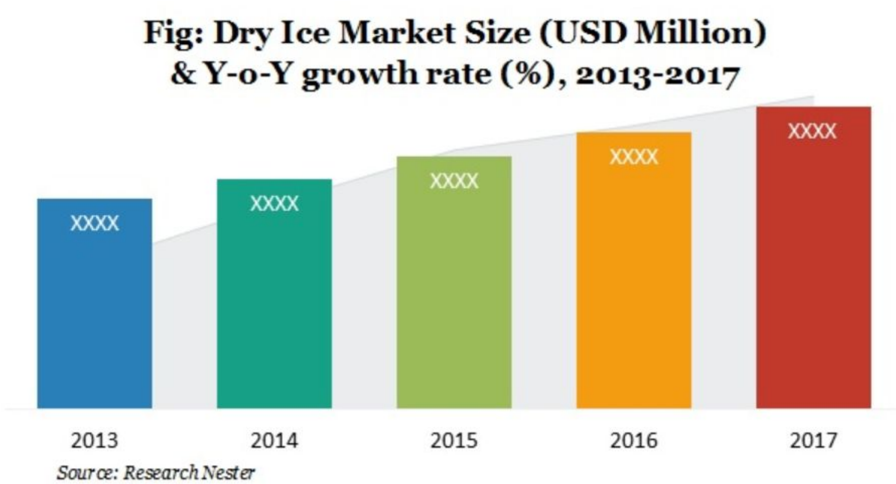


Figure 7 - Dry Ice Market Size 2013-2017

As of the end of 2019, the dry ice market displayed a pattern of growth, expected to reach 234 million dollar industry by the end of the forecast period, It's expected to grow 6.8% in the next ten years, meaning that that carbon dioxide needs to be increasingly sourced, this proposal suggests a “close in the loop” for the dry ice market (Dry Ice Market), in order to minimize the damage of a market that will not falter. Dry ice has a purpose not only in being sold in local grocery stores, but also as a non-cyclic refrigerant for the food industry or medical purposes, and industrial cleaning with ice blasting. The cryocaptures solution to the removal of carbon dioxide out of the atmosphere will lead to profit once the process reaches a steady state system.

Py Control

I/O Layer

The goal in this layer is to collect as much data as possible. This data will be used by the team’s AI to establish trends and adjust the system in such a way to maximize CO2 extraction. The sensor data will also be used to inform the supervisor when equipment needs maintenance. With that being said:

CO_2 Sensor

Clearly, one way to ensure that the system is working is to be able to monitor the carbon dioxide levels before the filtration. The team used CO2Meter’s K30 10,000ppm CO2 Sensor because the sensor has the capacity to report the carbon dioxide levels to an accuracy of about 0-1% without compromising the budget. While there are other carbon dioxide meters that have a degree of accuracy to the thousands of places, they were substantially more expensive and required more maintenance compared to its counterpart.

Air Flow

When deciding which sensors to use for air flow and pressure, It was important to keep in mind the pressure at which the turbines are going to be running at. Keeping accurate readings of these is important when it comes to filter efficiency and health. The system so a Mass Airflow meter is required to get accurate measurements.

Temperature

The system relies heavily on the temperature of the air both coming in and the temperature of the carbon coming out of the system. If we can control or measure the temperature as it enters the fan and optimize the system as it enters the cooling/filtration system then the cooling unit could run at significantly less power. An industrial grade sensor is necessary because the extraction system runs at very low temperatures (-140C).

Pressure

The filtration system can only work at certain pressures so to ensure that the air pressure from the fans does not exceed that threshold, The team included sensors to monitor the pressure from the fan until it reaches the filter. After the carbon is extracted and is in liquid state, the pressure needs to be constantly monitored so that it stays in liquid state and does not affect the flow from filtration to storage.

Humidity

Gases, and equipment both behave differently under distinct conditions. For that reason, it is imperative to gather information that can be correlated to the CO_2 extraction efficiency. Fortunately, the team was able to gather this data at a very low cost. Using MEAS's HS1101LF HUMIDITY SENSOR it is possible to collect BOTH the temperature and humidity of the air before and after the filtration. Collecting both sets of data will allow the AI to identify any correlation between certain combinations of parameters and if possible, changes can be made to the plant as a whole to achieve said maximum efficiency.

Pipe Corrosion

"Corrosion costs the Oil and Gas industry over five billion dollars a year in the United States alone" Despite the obvious costs associated with corrosion, there are also obvious safety concerns associated with the sudden leakage of a 10 million pascal pressurized fluid. For said reasons, despite an additional cost, it is crucial that a pipe corrosion sensor is incorporated into the system. Using IButtonLink's Copper Corrosion Wafer, The team hopes to reduce the risk of any potential emergencies. The sensors will be placed mostly along the carbon transport system, as in it will monitor the pipes transporting the extracted to storage.

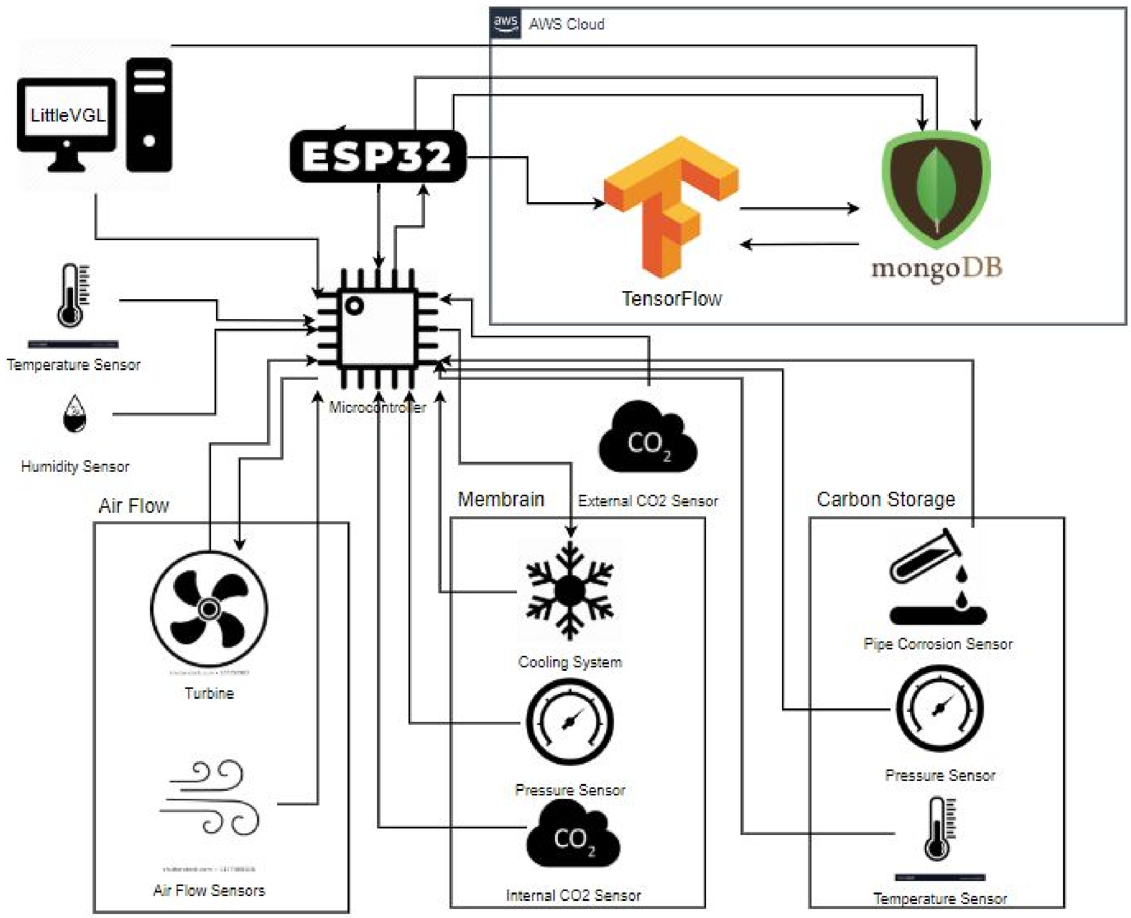


Figure 8 - Overall structure of the control system

Field Control

The objective of this layer is to receive, process, and control I/O in a clear and controlled manner that would allow the team to achieve the set goals of reliably and efficiently. The team's choice of microcontroller was influenced by its low purchase price and cost of operation, as well as flexibility in operation.

Sensors send data to the Analog to Digital Converter (ADC), which then sends a digital signal to the field controller. This signal is then processed and sent to the ESP32 WiFi module that enables it to connect to the Amazon Elastic Compute Cloud and communicate with Tensorflow and MongoDB. This data is displayed by the microcontroller in real time to give the user a clear understanding of the system.

Once this data is processed, an output signal is sent from MongoDB back to the ESP32, which is then sent back to the microcontroller for processing. Once the signal is processed, the microcontroller outputs a signal to the actuator, through a Digital to Analog Converter (DAC), if corrective measures are to be completed. The user is able to interfere and control the actuator manually, as well as adapt the AI model on Tensorflow as they see fit. There is also an immediate response system built in. For this, the team will have the microcontroller constantly reading data that could give information about critical system errors. If a critical moment were to occur, there would be an immediate response from the microcontroller to take corrective action, such as cutting the power to shut off the turbine. The main actuaries that are going to be controlled by the system are going to be the fan and cooling systems. This is to ensure that the system as a whole can extract as much carbon from the air as possible while using the least amount of energy possible. For example, if there is not a lot of carbon in the immediate atmosphere to extract, the fan can run at a slower speed because it would be more efficient to do so.

Data Layer

Our goal for this layer is to store and clean data that was collected from all sensors and real-time weather information from openweathermap.org API. The output of sensors are delivered from the microcontroller to the cloud via HTTPS protocol and POST request for safety. The complex logic after the cloud receives data from the microcontroller is handled by a servlet running on the AWS EC2, which both creates a document for the new input in MongoDB and fits the input into a pre-trained machine learning model to get a reasonable prediction.

Amazon Elastic Compute Cloud

Amazon Elastic Compute Cloud (A.K.A AWS EC2) is a service offered by Amazon that allows the users to rent a virtual machine and run applications. It is widely used in industry, stable, powerful, and relatively cheap in the long term. The team chose to use it as our cloud platform because it is needed to hold a database and train machine learning algorithms. This could also be achieved with a controller with enough storage and computational power but is too expensive to be scalable and needs too much power.

Weather API

We could deduct the spend of sensors by utilizing APIs to retrieve pressure and wind speed information. openweathermap.org offers free API which takes the longitude and latitude of a location and returns a JSON with metrics that are needed.

{"coord":{"lon":145.77,"lat":-16.92},"weather":[{"id":802,"main":"Clouds","description":"scattered clouds","icon":"03n"}],"base":"stations","main":
{"temp":300.15,"pressure":1007,"humidity":74,"temp_min":300.15,"temp_max":300.15},"visibility":10000,"wind":{"speed":3.6,"deg":160},"clouds":{"all":40},"dt":1485790200,"sys":
{"type":1,"id":8166,"message":0.2064,"country":"AU","sunrise":1485720272,"sunset":1485766550},"id":2172797,"name":"Cairns","cod":200}

Figure 9 - . An Example of a JSON String with useful information

HTTPS Protocol

Hypertext Transfer Protocol Secure (HTTPS) is a protocol which is widely used for transmitting secret messages. It has multiple steps verifying the identity after establishing the connections, and encrypt messages with a private key. Using the HTTPS protocol, it can be ensured that the sensor information will be delivered to the cloud safely and completely.

POST

POST request is one of the most common HTTP requests. Different from the GET request, it does not have a length limit and it is safer because it will never be catched. The team will need to send many parameters, which represent detailed status of all sensors, so it is needed to use POST request so the team can send all information in one request to avoid making unnecessary connections.

```
{
    _id: DATETIME_ID
    datetime: DATE_TIME,
    external_temp: DOUBLE,
    external_humidity: DOUBLE,
    fan_power: DOUBLE,
    fan_rpm: DOUBLE,
    fan_temp:DOUBLE,
    post_fan_pressure: DOUBLE,
    post_fan_corrosion: DOUBLE,
    post_filter_corrosion: DOUBLE,
    post_filter_pressure: DOUBLE,
    post_filter_humidity: DOUBLE,
    post_dehumidifier_humid: DOUBLE,
    post_dehumidifier_temp: DOUBLE,
    post_heat_exchange_temp: DOUBLE,
    desublimator_temp: DOUBLE,
    desublimator_power: DOUBLE,
    post_compressor_corrosion: DOUBLE,
    post_compressor_pressure: DOUBLE,
    post_compressor_temp: DOUBLE,
    storage_temp: DOUBLE,
    storage_pressure: DOUBLE,
}
```

Figure 10 - The database schema

MongoDB

MongoDB is a document-oriented database system. It is one of the most popular NoSQL databases. MongoDB is easy to scale, it offers good support for most programming languages and rich queries. And it uses internal memory to store the working set, so it is much faster when accessing data. It was chosen to use MongoDB because the schema of the data is simple and the team does not need complex join operations. The team will have 2 collections with the same schema above, one stores historical metrics of all sensors and the actuator for professional users to analyze, the other one stores outputs that users have adjusted for training the intelligent agent.

Servlet

Servlet is a program that runs on the server. It extends the functionality of the server. In the project, the cloud receives the sensor data and needs to both save the data in the MongoDB, and input the data into the trained model to get the prediction. For this complex process, a servlet is needed to handle the logic.

Tensorflow

Tensorflow is a free, open source platform for machine learning. It is universal and powerful. It can work on different systems from portable machines to clusters. It offers strong official support and sufficient documentation. The team also chose it because it is a light-weighted application so the cloud can handle it while keeping the database running.

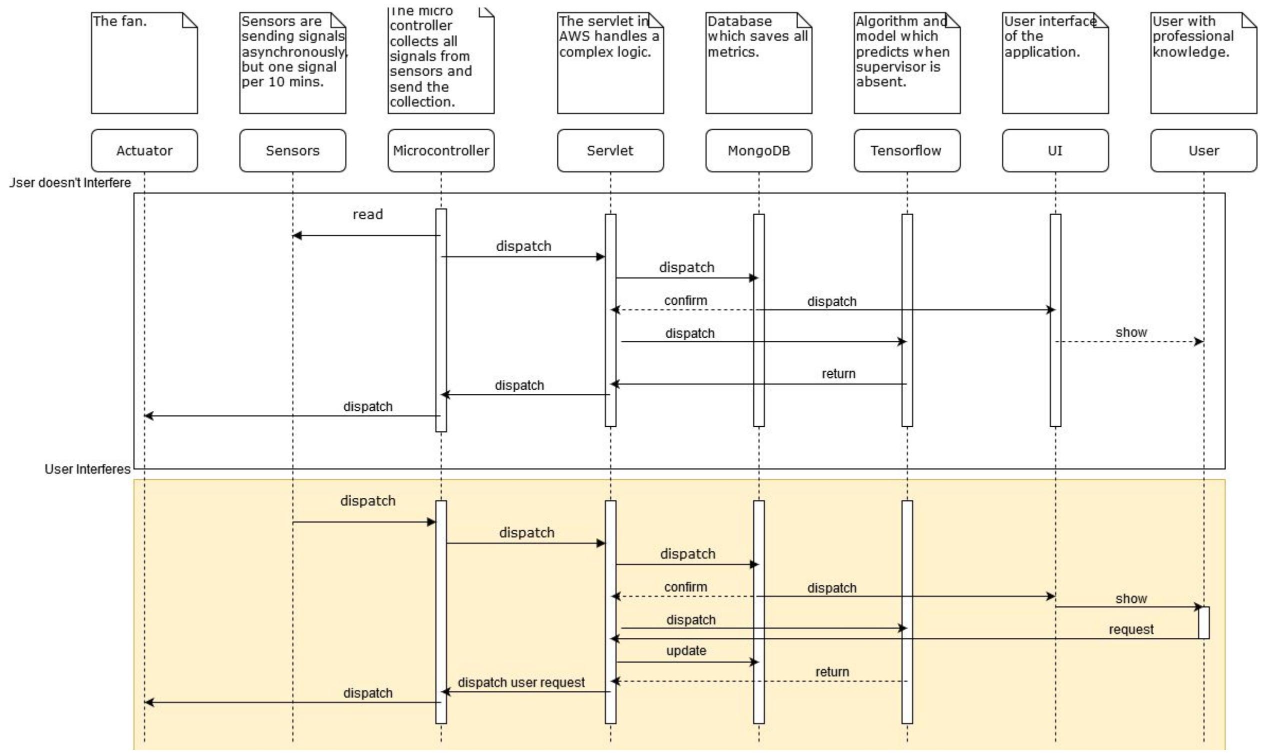


Figure 11 - General Execution of System

Supervisory Layer

Intelligent Agent with Semi-supervised Learning

Although Carbon Catcher runs ceaselessly, it cannot be promised that the professional user is always available when the weather changes and an adjustment is needed for the system to perform efficiently. To deal with this problem, The team decided to create an intelligent agent which can imitate the control of a real professional user with semi-supervised learning algorithm. The team chooses semi-supervised learning because it is expected to get feedback when the supervisor is online, and will use the feedback from real humans to be references for the AI. But the majority of the data is unlabeled. Semi-supervised learning algorithm can yield a reasonable output with a limited amount of labeled data.

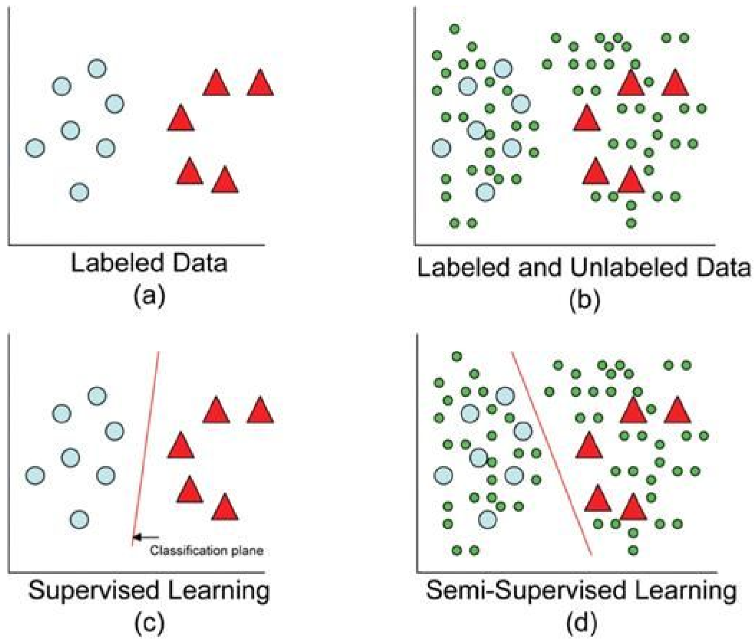


Figure 12 - Analogy between supervised learning and semi-supervised learning

A sensor status for a certain 10 minutes time frame is represented by a document in MongoDB. It is necessary to run the learning process frequently with new known data in the database to keep the model updated. Because the user cannot be online and give feedback to the model all the time, most of the data in the training set will be unlabeled. When a user interacts with the UI panel by manually changing the status of the actuators, the document in database will get updated with the new speed the user set, becoming a labeled data for further learning process. The algorithm constructs a high-dimensional Voronoi diagram with the labeled data. Voronoi diagram is a partition of the plane where any random points in each partition are closest to the given point of this partition. When a new point representing the current status goes into the model, the algorithm solves a clustering problem: the new data point is placed in the Voronoi partition to see which known, labeled data point is the closest. The closest known point has a relative similar status as the new, unknown point so the model will output the user input of the known point.

Fig. 12 The machine learning algorithm example (simplified to 2 dimensions)

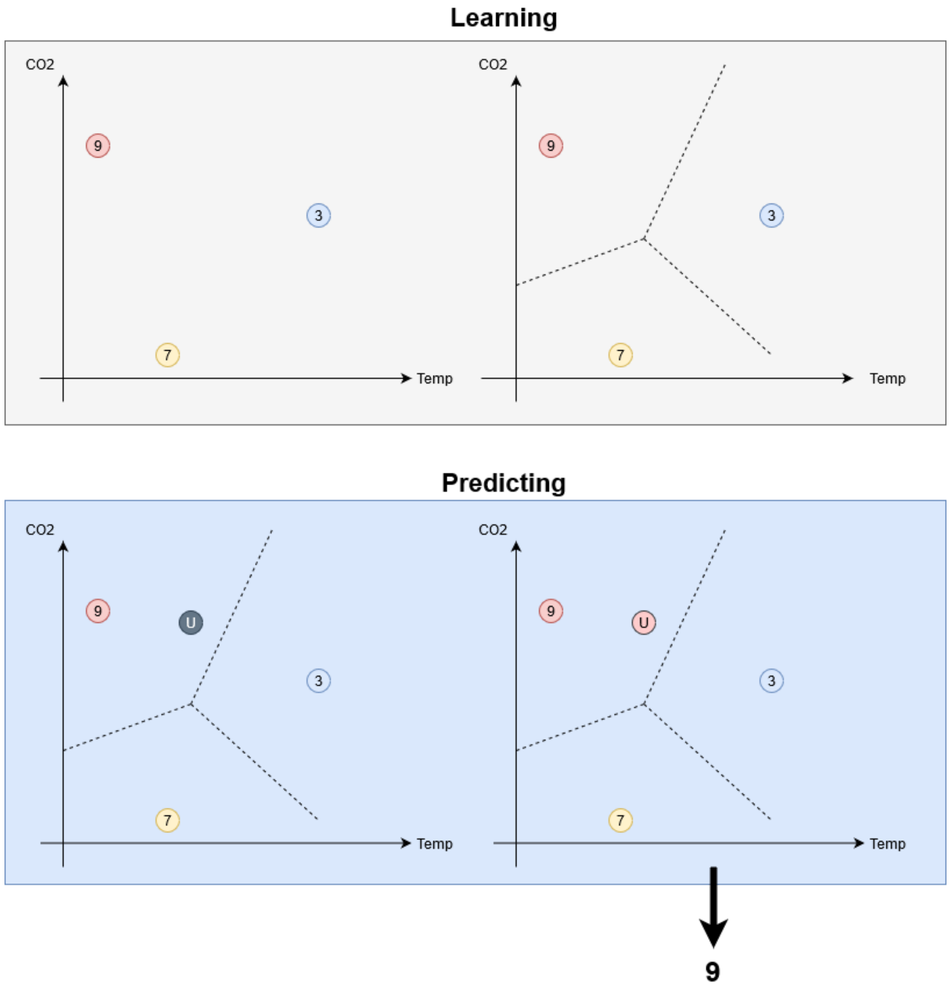


Figure 13 - flowchart of machine learning system

With more user input, the algorithm will have more possible outputs and become more precise.

User Interface

The embedded GUI will be built using LittleVGL, which is an open source graphic library that allows the user to directly communicate with the microcontroller and adjust any values as needed.

The home page will display each component's summary individually, along with the accumulated statistics at the bottom. The user is also able to go into each component individually and either view the historical data for that specific component or control different values such as turbine speed or filter settings.

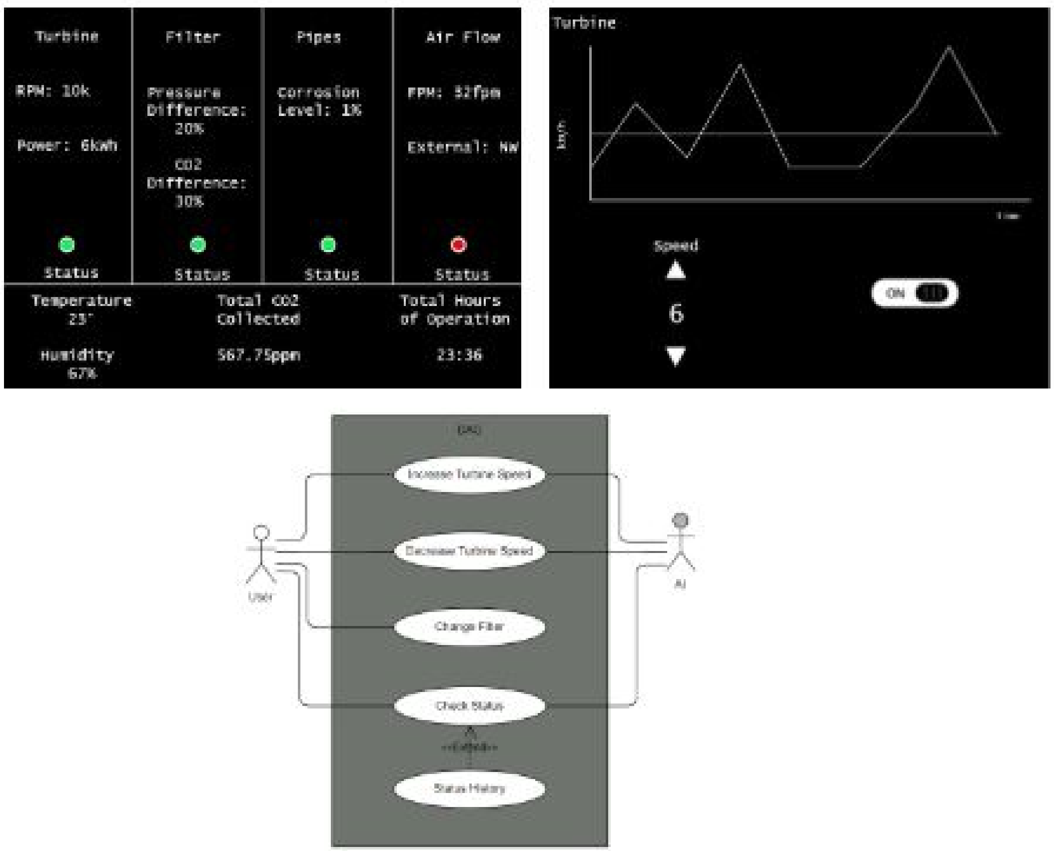


Fig. 6 UI diagrams.

Interface Diagram (Left). Individual Component (Right)

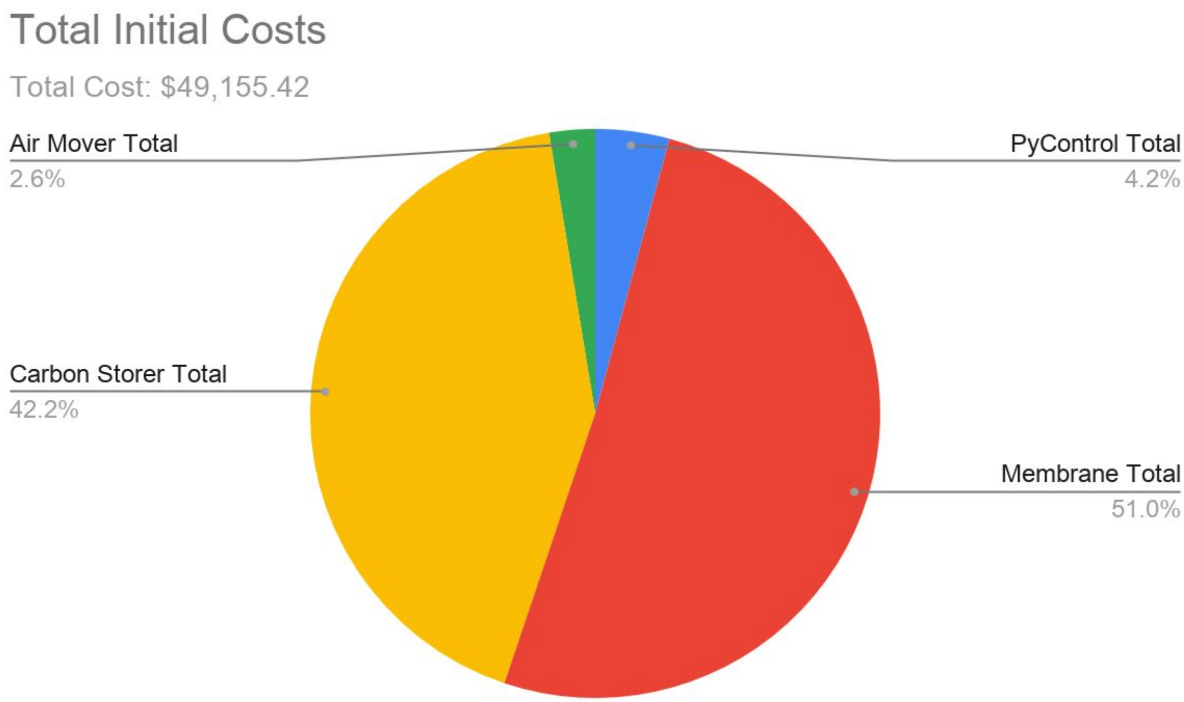
Use Case Diagram (Bottom)

Bill of Materials

PyControl						
Item	***Description***	***Link***	***Manufacturer***	***Price per unit***	***Quantity***	***Total price***
K30 10,000ppm CO2 Sensor	Industrial CO2 Sensor	CO2	CO2Meter	$85.00	1	$85.00
HS1101LF HUMIDITY SENSOR	Industrial Humidity/Temperature Sensor	Humidity Sensor	MEAS	$7.00	3	$21.00
Mass Flow Meter SFM4200	Air Flow Sensor	Air Flow Sensor	Sensirion	$110.00	1	$110.00
SDP2000-L	Pressure Sensor	Pressure Sensor	CYNERGY3	$96.18	4	$384.00
iButtonlink Corrosion Sensor	Corrosion Monitor	Corrosion Monitor	ibuttonLink	$50.00	3	$150.00
STM32GO	Microcontroller	Microcontroller	STMicroelectronics	$62.50	1	$62.50
ESP32	Wifi Module	Wifi	ESP	$2.00	1	$2.00
P5-11 Proximity Sensor	Tachometer	Tachometer	Monarch	$115.00	1	$115.00
MONNIT INDUSTRIAL WIRELESS LOW TEMPERATURE SENSOR	Industrial Thermostat	Industrial Thermostat	Monnit	$264.00	4	$1,056.00
Barometer	Measure Outside Pressure	Barometer	TE	$18.00	1	$18.00
Power Meter	Power Meter	Power Meter	Amazon	$30.00	2	$60.00
AWS EC2	Server Storage	Server/Data Storage	Amazon	$20-30	1	~$20-$30

PyControl Total	$2,063.50					
Membrane						
Item	***Description***	***Link***	***Manufacturer***	***Price per unit***	***Quantity***	***Total price***
Austenitic Stainless Steel Pipes	24" diameter		Shandong Taigang International Trade Co., Ltd	$1000/ton	0.95 tons	$950.00
Austenitic Stainless Steel Pipes	4" diameter		Shandong Taigang International Trade Co., Ltd	$1300/ton	5.7 tons	$7,400.00
Dehumidifier	Liquid remover			$1,500.00	1	$1,500.00
Refrigerant Pump	Refrigerant			$10,000.00	1	$10,000.00
Bubbler	eparates phase			$5,000.00	1	$5,000.00
Compressor	Liquefies CO2			$200.00	1	$200.00
Membrane Total	$25,050.00					
Carbon Storer						
Item	***Description***	***Link***	***Manufacturer***	***Price per unit***	***Quantity***	***Total price***
Carbon steel 4'' diameter pipes	Pipes	Pipes	Grainger	$505.00	20	$10,100.00
CPVC 4" Connecter Pieces	Elbow	Elbows	Grainger	$60.51	20	$1,210.10
Carbon Steel Storage	Storage Tank	Tank	Alibaba	$7,354.00	1	$7,354.00
Solid CO2 Energy costs	Energy			$0.24	8760	$2,102.00
Carbon Storer Total	$20,766.10					
Air Mover						
Item	***Description***	***Link***	***Manufacturer***	***Price per unit***	***Quantity***	***Total price***

Pipe of 24"x1"	PVC Enclosure	PVC	PVC Pipe Supplies	$64.99	1	$64.99
Pipe of 36"x1"	PVC Enclosure	PVC	PVC Pipe Supplies	$125.00	1	$125.00
Pipe of 36"x1"	PVC Mouth Mount	PVC	PVC Pipe Supplies	$70.83	1	$70.83
Cables, bread boards, screws, bolts, nuts,.	Hardware	Hardware	Amazon	$133.00	4	$274.00
Blade and Conical Impeller	Fan	Fan	EBM Papst	$100.00	1	$100.00
CNC	CNC					$348.00
Welding	Welding					$160.00
¼ HP 2000 RPM Motor	Motor	Motor		$133.00	1	$133.00
Air Mover Total	$1,275.82					
Grand Total	$49,155.42					



Conclusion

In order to efficiently filter the excess carbon dioxide from the atmosphere and allow for the creation of a scalable device that has applications outside of an industrial environment the project proposes a modular ventilation system that connects to a cryo capture mid section whose main purpose is to treat and separate the carbon dioxide from the air which is then stored and repurposed. Through this process we are expecting a 99% efficiency of carbon dioxide removal from the air with a high profit margin. Air is collected and funnelled through an air mover where it is then filtered and liquid carbon dioxide is isolated. It is collected, depressurized then sold as solid dry ice. The product has a multitude of applications for which it can be used for including the food industry for carbonated drinks along with inert gas production for industrial fuel processes.

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