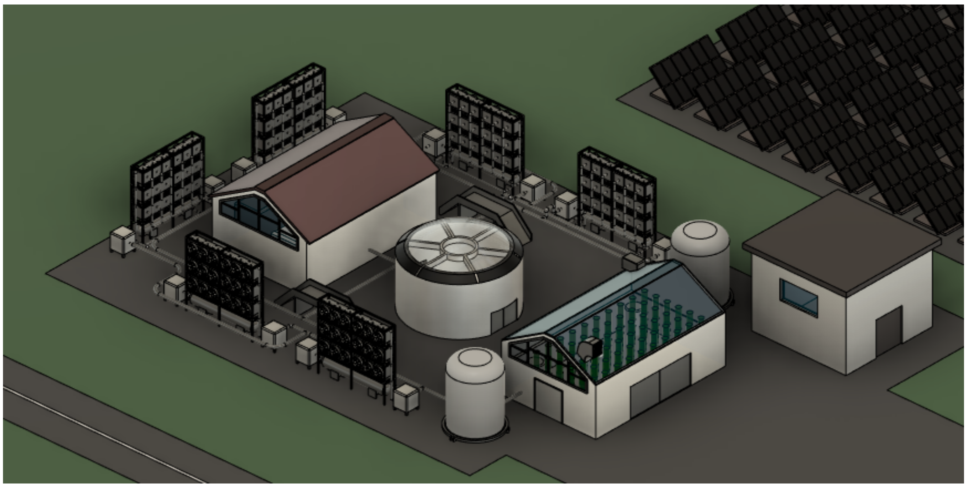
School of Engineering
Integrated Design Project 2 Assignment 1
Concept Design
2021/22
Group: 55

Direct Air Capture Facility 55 -Sydney



11/03/2022

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CONTENTS

EXECUTIVE SUMMARY

The report breaks down the aims for designing an efficient and effective direct air capture facility, and explains considerations and complications involved. Before starting the research and design, it was important to understand team members and their individual abilities and then to apply those abilities to the project to get the best input from members. To get this a Belbin tests was done, and results were used to assign roles for each member. A Gantt chart was also used to track progress and to ensure continuous work from each member.

The research itself was broken into several parts: structure, absorption, desorption, transportation, storage, reuse, and energy consumption. It is imperative that each member understands what they are looking for in their research; requirements and objective trees were created so each member knew what they were looking for in their research and their role in the DAC facility. Energy consumption was researched by each person in their own individual journals; summation of energy requirement was used to estimate the number of solar panels and wind turbines required to power the direct air capture facility, in turn affecting the conceptual and final design. After thinking about environmental factors too, we decided to place the plant in Jerrawangala national park, Sydney (Journal 9 CO2 storage).

A lot of communication was made between members, for example, the person in charge of transportation had to consult with the person in charge of storage and reuse, to calculate energy requirements. The conceptual designs at first were a very minimal approach to the requirements of the DAC facility, and the final design was a product of a lot of calculations, critical thinking, and alterations. Thought about sustainability also heavily impacted the designs, as it was important to differentiate between materials which pose high levels of CO2 with their productions and disposal, especially when it came to renewable energy sources like wind turbines and solar panels; it was difficult to justify the number of wind turbines we had originally when we learned about the impacts on the environment (from production and disposal).

The final design was also further improved by the Triz matrix which helped identify complications and contradictions, and then solutions were generated. We have designed the facility to be as efficient and effective as possible, with 3 wind turbines and 360 solar panels to provide for 62 million kWh used per year.

PROJECT MANAGEMENT

People

Belbin results

	I	II	III	IV	V	VI	VII	VIII	IX
Khalil	7	13	5	6	7	10	11	5	6
Hassan	8	3	7	11	8	9	9	7	9
Pinyu	7	5	9	11	6	5	8	6	13
Odysseas	13	8	15	5	2	5	4	6	12
Udayan	7	8	6	9	9	7	7	7	9
Andrew	10	6	7	7	4	11	12	3	10

I: Implementor

II: Coordinator

III: Shaper

IV: Plant

V: Resource Investigator

VI: Monitor Evaluator

VII: Team Worker

VIII: Complete finisher

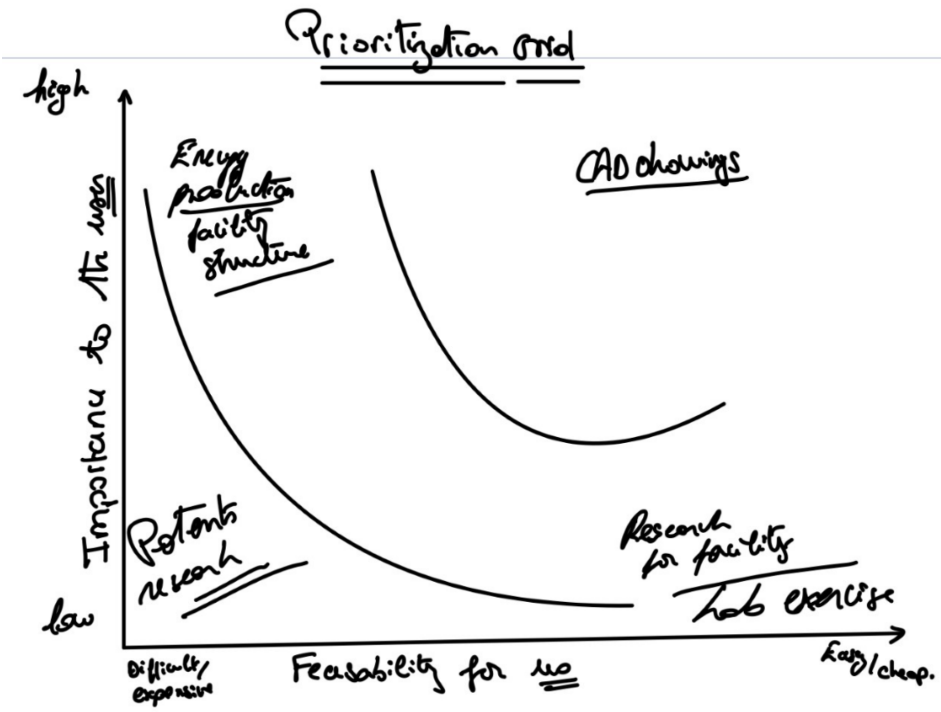
IX: Specialist

Impact on group work

The Belbin Test allowed us to understand everyone's personality and helped us to assign each group's member a specific role for the project. However, we have not only relied on the test for the role's assignment. We have discussed and decided as a group of the best ways everyone could contribute to the successful delivery of the project. We had to take in account all the communication barriers within the group, as well as the technical abilities of some of us. With this method, we were successfully able to give everyone responsibility in the field he is more comfortable in, such as designing, researching, or leading.

Design Thinking

Prioritization Grid



The prioritization grid was used by the group to determine and evaluate all the aspects of the DAC facility from the most feasible to difficult and low to high importance. We were able to get a better understanding of our priorities and to know what sections needed more focus and how the main structure of the facility would look like. The grid also made us realize how important the energy requirements is for the facility and helped us get an idea of all the facilities necessary for the energy production such as the wind turbines and the solar panels.

Planning

Gantt Chart

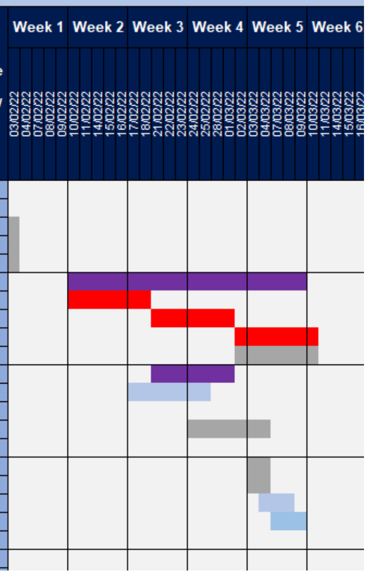
School of Engineering

Project Plan

Team Number:55
Project Title: DAC Facility 55- Sydney
Start: 03/02/22
Update 28/03/22

Activity Types	
Milestone	
Design	
Assessment	
Integration	
Reporting / Documents	
Contingency	
Completed	
Started	

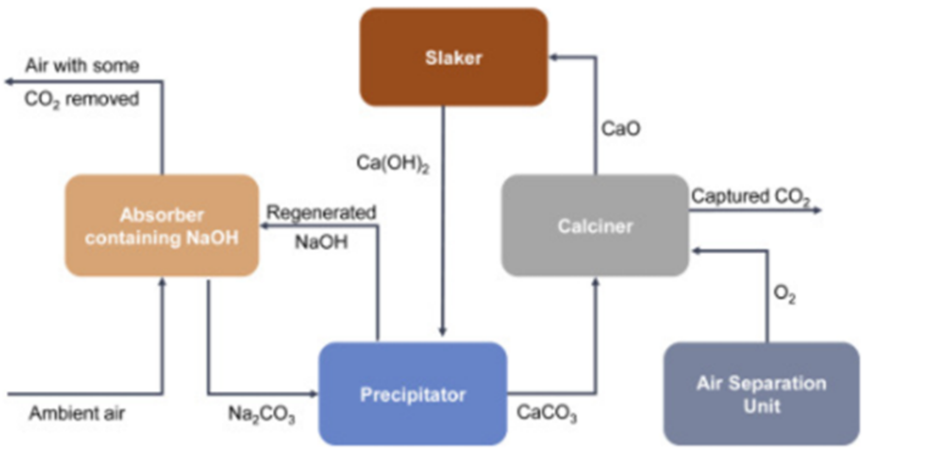
Event ID	Activity Type	Description	Preceding event ID *(if the event cannot start before the preceding event finishes)*	Event duration (days)	Start date *(auto populated if there is a preceding event in column H)*	End Date *(auto populated)*
1	Completed	Project lauch/ group meeting/ Communication		1	03/02/22	04/02/22
2	Completed	Projecxt requirements and role assignments (Belbin test)		1	03/02/22	04/02/22
3	Completed	Lab Exercise- Hopes and Fears		1	03/02/22	04/02/22
4	Reporting / Docur	Start rerasearching on all sections of DAC facility		26	10/02/22	10/03/22
5	Milestone	Completion of three Journal club documents		7	10/02/22	21/02/22
6	Milestone	Completion of six Journal club documents	5	7	21/02/22	02/03/22
7	Milestone	Journal club documents completed (additional research can still be done)	6	7	03/03/22	11/03/22
8	Completed	Lab Exercise- Sustainability	6	7	17/02/22	11/03/22
9	Reporting / Docur	Objective trees	5	7	17/02/22	02/03/22
10	Design	Conceptual designs on different sections		7	17/02/22	28/02/22
11	Design	Final conceptual design from everyone's input	10		28/02/22	28/02/22
12	Completed	Lab exercise- Risk reliability		7	24/02/22	07/03/22
13	Completed	Lab exercise- Entreprise/Business case		7	24/02/22	07/03/22
14	Completed	Lab exercise- functional flow		2	03/03/22	07/03/22
15	Completed	L:ab exercise- Triz interactive contradiction matrix		2	03/03/22	07/03/22
16	Design	CAD FINAL DESIGN		3	04/03/22	09/03/22
17	Assessment	Project presentation		3	07/03/22	10/03/22
18	Milestone	Final Report			08/03/22	08/03/22
19						



RESEARCH

Introduction/ Air capture process:

Due to the climate change, there is gradual increase in the temperature of the planet which alternates the weather conditions. To minimize this phenomenon, the use of negative emission technologies is necessary. DAC or “Direct Air Capture” is a process of capturing the ambient air from the environment and remove the carbon dioxide (Ajay Gambhir and Massimo Tavoni, 2019). Thus, the air is clean and released back to the environment creating an offset of the emissions made by humans. There are two main approaches of capturing carbon dioxide from the ambient air. The first process is absorption where a liquid solvent is used to dissolve the carbon dioxide and extract it from the air. A second approach is adsorption in which a solid solvent is used where the carbon dioxide molecules adhere to the surface of the solvent (Ibid, 2019). For this project, the absorption method was selected using potassium hydroxide as the solvent. The facility is completely powered by renewable energy from solar panels, thus minimizing as effectively as possible the carbon footprint on the environment. Two major components of the DAC facility which are based on a liquid solvent can be identified. The air contactor and the regeneration facility (A Research Agenda, 2019). The latter consists of a precipitator, slaker, calciner, the air separation unit and the filter press.



The ambient air is sucked in by fans into the air contactors while the liquid solvent is fed through a pump to the contactor and the reaction between the carbon dioxide and the potassium hydroxide take place (Ibid, 2019). The filtered air (free from CO2) is immediately released back to the environment. However, from that chemical reaction K2CO3 and H2O are also produced. These two products generated are fed to the precipitator and the regeneration process is taking place.

Energy Consumption for the air capture process:

For the air capture process and absorption method the fans and the pump consume a little amount of energy, as compared to the adsorption process. To calculate the energy consumed, many parameters, shown in appendix E, need to be taken under consideration. The methodology and equations used to calculate those parameters are shown below.

The pressure drop is needed to calculate the work done by the fans and the pumps:

$$\Delta P=7{,}4*D*v^{2{,}14} \quad (1)$$

The volumetric flow rate is calculated based on the equation below:

$$V=(\text{plant capture rate from the air}) / (\text{capture fraction of CO2 from air} * \text{concentration of CO2 in air by mass}) \quad (2)$$

The work of the fans can then be calculated:

$$W_{fan}=(V*\Delta P)/\varepsilon \quad (3)$$

The work done by the pumps is estimated to be 15% of the work done by the fans (A Research Agenda, 2019):

$$W_p=15\%*W_{fan} \quad (4)$$

$$\text{Total work done}=W_{fan}+W_p \quad (5)$$

(All the parameters that were needed for the calculation are tabulated and listed clearly shown in appendix E)

Carbon dioxide desorption:

The K_2CO_3 produced is sent to the causticizer via pipeline where it reacts with calcium hydroxide ($Ca(OH)_2$) and regenerates the potassium hydroxide and produces calcium carbonate:

K_2CO_3 (aq) + $CA(OH)_2$ (aq) = 2KOH (aq) + $CaCO_3$ (s)

A clarifier system is used to remove the $CaCO_3$ from the potassium hydroxide solution by using a lamella separator which has the $CaCO_3$ form a layer at the bottom which is removed using water [1]. This is then pressed to remove the water ready for the next stage of the process. The regenerated potassium hydroxide (KOH) solution is sent back to the air contactor to absorb more CO_2 from the air. This $CaCO_3$ is then sent to a calciner where it is heated to 900^{o}C [2] with natural gas without melting to produce high purity CO_2 and solid calcium oxide:

$CaCO3$ (s) + ΔH = CaO (s) + CO_2 (g)

Calcium oxide is then sent to the slaker with the water from the absorption process. These combine in an exothermic reaction, heating the solution produced to roughly 95^{o}C, to make calcium hydroxide:

CaO (s) + H_2O (l) = $Ca(OH)_2$ (aq)

This then feeds back into the causticizer to refuel the desorption process.

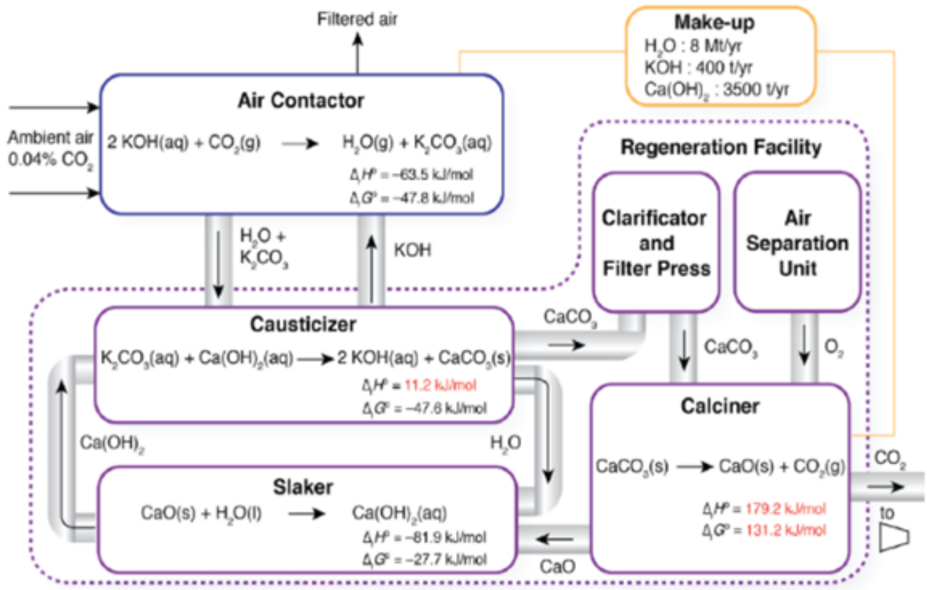


Figure 1: Simplified view of direct air capture system

A simplified view of this process can be seen in figure 1.The reaction energies can also be seen.

As the calcination process requires that the calcium carbonate be heated to 900^{o}C energy is required. It is shown that the total energy consumption for the calcination process is 220.36 kJ/mol-$CaCO_3$ [3]. This is equivalent 0.0612 kWh/mol-$CaCO_3$ which roughly equates to 1391 kWh/tCO_2. To supply the oxygen to the calciner the air separator unit consumes 888.9 kWh/tO_2 with a purity of 94% [4]. Because of the exothermic reaction that takes place in the slaker it produces 77 kWh/tCO_2 in heat energy whilst only consuming 32 kWh/tCO_2 of energy to run [5]. The CO_2 produced during the calciner process is sent off to be compressed by a multi-stage integrally geared compressor with 7 stages. Assuming an isentropic efficiency of 0.8 a specific work of 89.2 kWh/tCO_2 is observed as shown in figure 2 [6]. This process will also give a CO_2 purity of 99%.

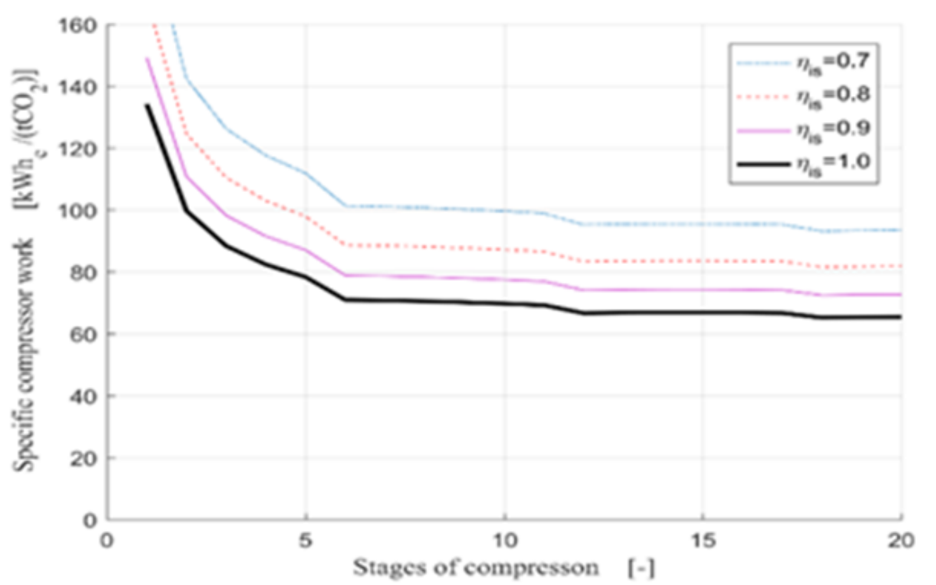


Figure 2: Specific power of the compressor with various isentropic efficiency and stages

Capture.

In the process of capturing direct carbon dioxide from air a contractor is used to bring the ambient air in contact with an alkali capture solution. The carbon dioxide then entrapped from the air is put on ~50micrometers film of solution. Further for liquefaction process carbon dioxide undergoes a compression process comprising of two loops that are connected to one another.

Energy Requirements.

These processes namely involve capture of carbon dioxide and precipitation of carbon dioxide. This process is done at a commercial scale as well and describes the main functioning of the direct air capture facility. The process of transferring or transporting the liquefied carbon dioxide has a general requirement of 80% thermal energy and 20% electricity. These can be met by renewable energy sources such as solar and wind energy. More specifically the sorbent process requires thermal energy requirement nearing 6 GJ tCO2 −1 and electricity requirements of approximately 1.5 GJ tCO2 −1. Sorbents with lower regeneration energy have reduced thermal energy requirements in order of 3 GJ tCO2 −1 and some having lower regeneration energy of 1 GJ tCO2 −1. The solvent process does not possess a great difference in energy requirements from the sorbent process having thermal energy requirements ranging from 5.25 to 8.1 GJ tCO2 −1 and having electricity requirements for 1.3–1.8 GJ tCO2 −1. However, the overall energy requirement has a great difference in the sorbent and the solvent process. The phase condition required to transport the liquid carbon dioxide is temperature being 31.1*C and pressure being 73.9 bar.

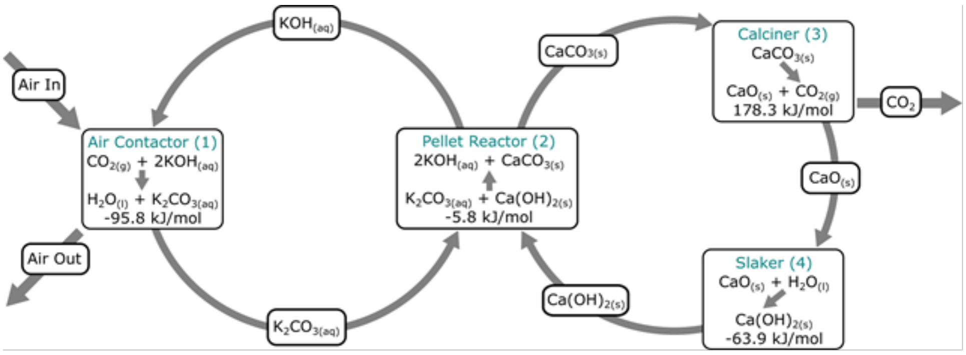


Figure: Process Chemistry and Thermodynamics

Methods used for transportation.

There are chiefly 3 methods of transportation of liquid carbon dioxide from the direct air capture facility. These are via pipelines, roadways or marine transportation:

The most used and viable method to transport liquid carbon dioxide is via pipeline. The chief materials used in the construction of pipelines are metals such as steel and 13% Cr steel corrosion resistant and polymers elastics and plastics. While designing the pipeline diameter and various other elements we keep in mind that the optimum pipeline diameter is the smallest pipe diameter large enough so that the volume of fluid is transported without reaching an excessive range of velocities. At times in unfavorable conditions a booster pump is needed to ensure the smooth flow of liquid carbon dioxide.

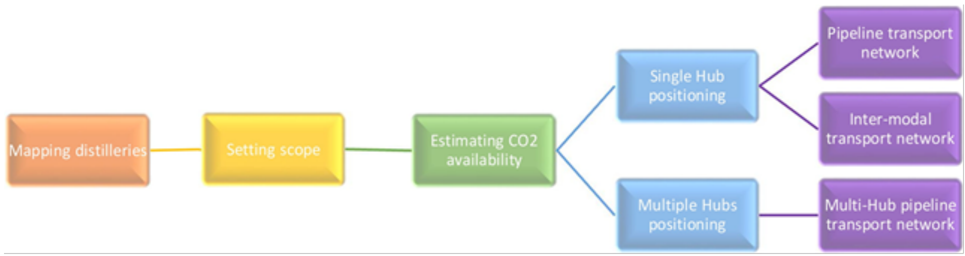


Fig. 1. Methodological scheme of the CO2 transport networks design.

Apart from pipelines liquid carbon dioxide diluted with suitable solvent is transported via roadways using LPG tankers and trucks. Likewise in optimum conditions nearing to the ones of oil and LPG/LNG carriers and ships liquid carbon dioxide can be transported via the use of oil tankers and ships.

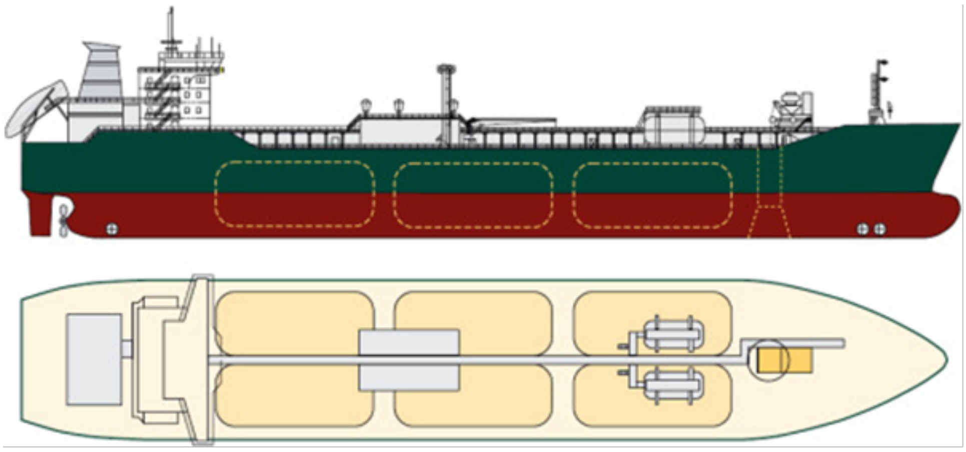


Figure: Methodological scheme of the CO2 transport networks design.

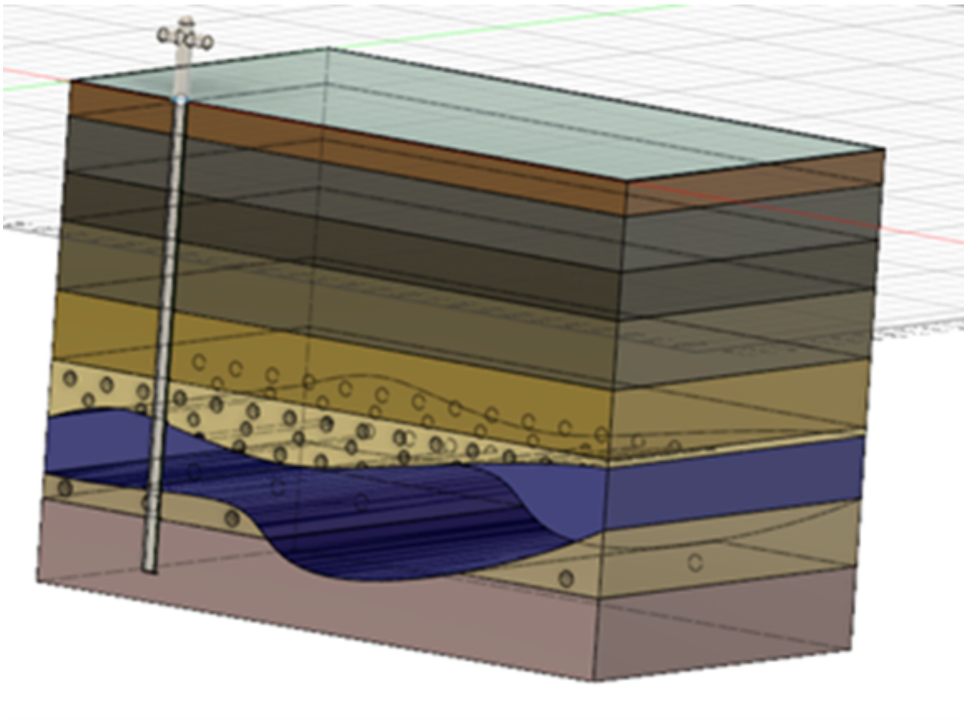
Figure: Conceptual arrangement for CO2 ship.

Source: Courtesy, Statoil/SINTEF/Teekay/Vigor, used with permission from Statoil.

The net energy consumption for the transportation process is 107,000 GJ, which is 29,722,222 kWh.

Geologic storage has been done for several decades, there are many ways to store Carbon Dioxide safely, including underwater and deep underground. [1] Other factors which affect all CO2 storage mechanisms, can include climate and levels of resident brine. There are four main phases when it comes to trapping carbon dioxide: structural trapping, solubility trapping, capillary trapping and mineral trapping. However, before all this one of the most important considerations we must take is finding a suitable location. A good location for carbon dioxide trapping is usually an area where natural gas and oil resides. If the gas or oil has ever been extracted, the site will only work if the ground was sealed with cement, not sand (normally sand is used) and as sand is porous it would not be able to keep the CO2 trapped. [7]

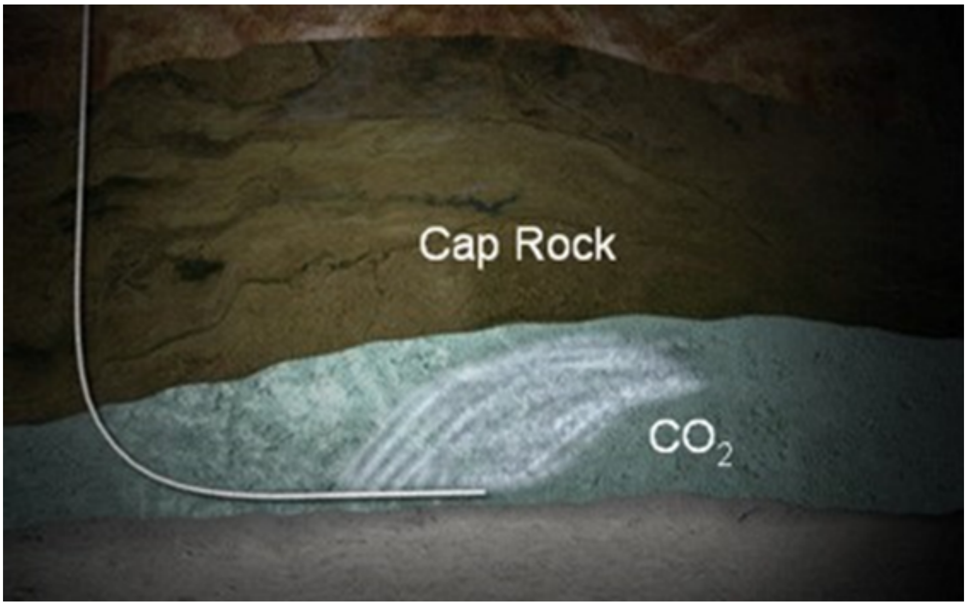
The diagram below is made on Fusion and gives a fair insight into how CO2 is injected into the basin:



After the carbon dioxide has been captured by the fans, it is cooled in the condenser and bought to the injection well. The CO2 will then be pumped into the ground as shown in the diagram, and eventually there will be four phases of trapping.

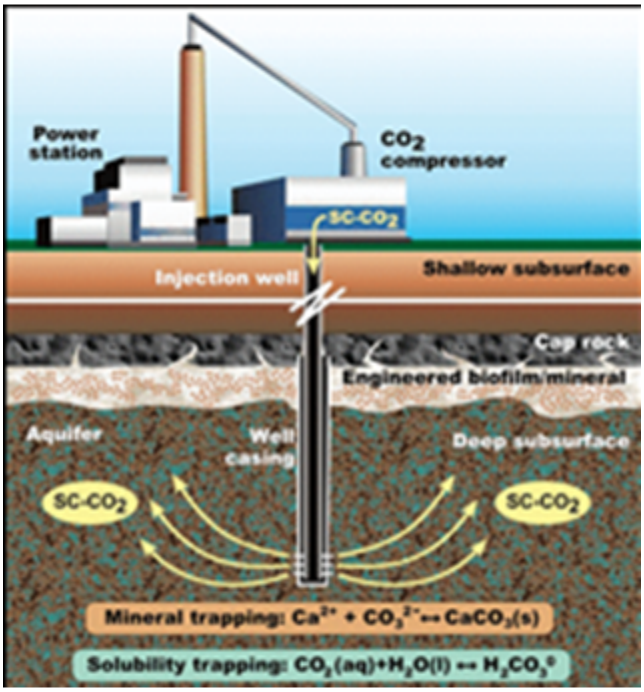
<u>Structural and solubility trapping:</u>

The primary stage of trapping is structural trapping. When the carbon dioxide is injected, travels upwards, and is relatively less dense than the resident fluids in the basin. As it travels upwards, it meets an impermeable rock known as the cap rock or shale. The carbon dioxide cannot flow through this rock, hence in essence it becomes trapped by this rock. [3] The complications however with this procedure involve making sure the cap rock has no fractures or cracks which could end up releasing the carbon dioxide. Solubility trapping is where the carbon dioxide displaces brine water through the pressure caused by the injection well, this process causes the carbon dioxide to get trapped between the brine water. [5]



Capillary and mineral trapping:

Capillary trapping is where capillary forces keep the carbon dioxide well beneath the cap rock. [4] Mineral trapping refers to how eventually the carbon dioxide trapped in the water will form weak acids like carboxylic acids, and so carbonate ions will react with alkali metals to form salts or rocks like Calcium carbonate. This method of trapping is the most promising. [6]



The ways for the utilization of CO2 are various. Nowadays, many companies and institutes research this field and give schemes using CO2 for limestone production, fuel production and even ecosystem protection.[3]

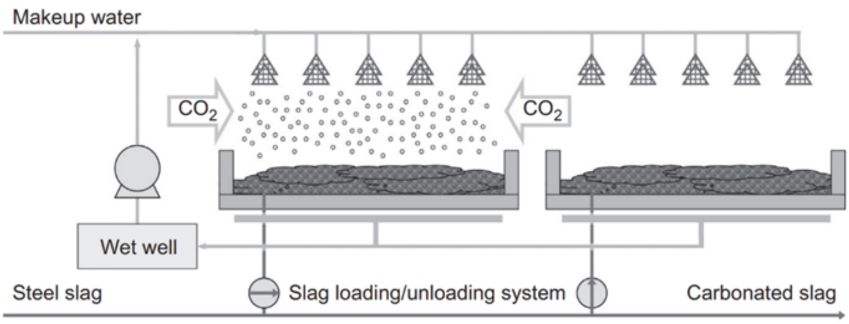
721,000 kWh of energy consumption for storage. [10]

Reuse:

PCC production:

Precipitated calcium carbonate (PCC), known as limestone, is an important feedstock for the paper, pharmaceutical, plastic, and cement industries.[4] PCC is an energy-intensive production in the industry therefore it is a good idea to produce it with CO2.

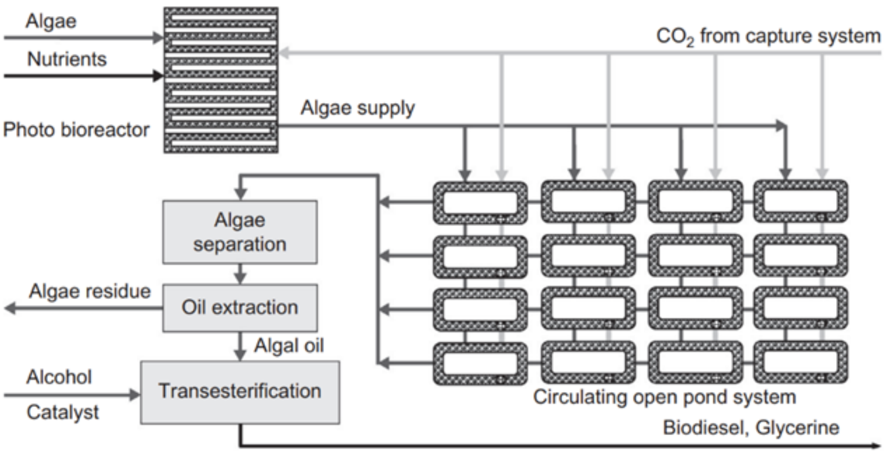
Alkaline wastes from the industrial process such as ash from coal combustion and slag from steelmaking can be used to react with CO2 to produce PPC. The simple, low-tech basins, illustrated in Figure 1, are one of the schemes using steel slag to capture CO2 and produce PCC.[4]



It is also proposed to use seawater to absorb CO2 these years. Seawater contains 0.01 mol -Ca/kg and 0.05mol-Mg/kg. Therefore, the precipitation of the carbonates can capture 1t-CO2 in 370t-seawater and produces 2.1t-Carbonates (81% MgCO3 and 19%CaCO3).[4] In this scheme, the addition of an alkali to the solution such as NaOH is needed to meet the requirement of the Ph of 10.

Algal Biomass Production:

Compared to the cultivation of corps in the terrestrial agroecosystems to produce biomass, the aqueous cultivation of algae has a lot of advantages including higher photosynthetic efficiency and a simpler system which leads to higher productivity per unit of land usage.



An open ponds system can convert 1%-2% of total incident solar energy into stored chemical energy.[4] A schematic of the system is illustrated below in Figure 2.

The biomass of algae can be used in many fields including fish farming, bioethanol production and biodiesel production. These years scientists also find it possible to produce carbon fibre which is an energy-intensive production with the glycerin in algae.[1]

Fuels Production:

Though there is a shift from internal combustion engines to electric vehicles, demand for fuel will still inevitably be high for the next coming years, hence as engineers, we can think about reusing CO2 to create fuels, trying for carbon neutrality. This can be done when energy is used to break down CO2 using carbon (C) to form carbon monoxide (CO) which can be used as fuels and precursors of other chemicals.[2] Novel technologies such as electrochemical conversion can produce CH3OH (methanol), CH2O (formaldehyde), and even HCOOH (carboxylic acids).[2] These hydrocarbons can also be used to create plastics rather than fuels, which could help relieve strain on fossil fuels. However, complications with this include the fact that a lot of energy is required.

References

Air Capture and Absorption:

Ajay Gambhir, Massimo Tavoni, Direct Air Carbon Capture and Sequestration: How It Works and How It Could Contribute to Climate-Change Mitigation

Negative Emissions Technologies and Reliable Sequestration: A Research Agenda (2019) Chapter: 5 Direct Air Capture

Desorption:

[1] Colloide (2020) *Lamella separator – How does it work* 09/03/2022

{https://www.colloide.com/lamella-separator-how-does-it-work/}

[2] Noah McQueen *et al* 2021 *Prog. Energy* **3** 032001

[3] Shinying Lin, Takashi Kiga, Yin Wang, Katsuhiro Nakayama. (2011) Energy analysis of $CaCO_3$ calcination with CO_2 capture

[4] Banaszkiewicz, T., & Chorowski, M. (2018). Energy Consumption of Air-Separation Adsorption Methods. *Entropy (Basel, Switzerland)*, *20*(4), 232. https://doi.org/10.3390/e20040232

[5] David W. Keith, Geoffrey Holmes, David St. Angelo, Kenton Heidel. (2018) A Process for Capturing CO_2 from the Atmosphere

[6] S Jackson and E Brodal 2018 IOP Conf. Ser.: Earth Environ. Sci. 167 012031

Transportation:

1)A Process for Capturing CO2 from the Atmosphere. David W. Keith, Geoffrey Holmes, David St. Angelo, Kenton Heidel.

Published by Elsevier Inc.

https://doi.org/10.1016/j.joule.2018.05.006

2) A review of direct air capture (DAC): scaling up commercial technologies and innovating for the future.

Noah McQueen, Katherine Vaz Gomes, Colin Mc Cormick, Katherine Blumanthal, Maxwell Pisciotta and Jennifer Wilcox.

Citation: Noah McQueen *et al* 2021 *Prog. Energy* **3** 032001

Progress in Energy, Volume 3, Number 3

https://iopscience.iop.org/article/10.1088/2516-1083/abf636

3) MATERIAL SELECTION FOR SUPERCRITICAL CO2 TRANSPORT.

by Dr Shiladitya Paul, Richard Shepherd, Amir Bahrami, and Paul Woollin

TWI, Abington, UK

https://www.twi-global.com/technical-knowledge/published-papers/material-selection-for-supercritical-co2-transport

4) CARBON DIOXIDE PIPELINES: A PRELIMINARY REVIEW OF DESIGN AND RISKS

J. Barrie1∗, K. Brown2, P.R. Hatcher1 and H.U. Schellhase

http://ccs-info.org/onewebmedia/Pipeline_material.pdf

CO2 Pipeline Design: A Review

Suoton P. Peletiri, Nejat Rahmanian, Iqbal M. Mujtaba.

https://doi.org/10.3390/en11092184

5) Transport of CO2.

Coordinating Lead Authors: Richard Doctor (United States), Andrew Palmer (United Kingdom)

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Contributing Author: Michael Austell (United Kingdom)

https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_chapter4-1.pdf

6) CO2 capture in ethanol distilleries in Brazil: Designing the optimum carbon transportation network by integrating hubs, pipelines and trucks.

Authors: Fabio T.F. da Silva Francielle M.Carvalhoa Jorge Luiz G.Corrêa Jr Paulo R. C.MerschmannbIsabela S.Tagomorian Alexandre Szkloa Roberto Schaeffera.

https://doi.org/10.1016/j.ijggc.2018.02.018

Transportation systems for CO2—application to carbon capture and storage.

Authors: Rickard Svensson Mikael Odenberger Filip Johnsson Lars Strömberg

https://doi.org/10.1016/j.enconman.2003.11.022

7) **Carbon dioxide transportation.**

Author: Stephen A. Rackley

https://doi.org/10.1016/B978-0-12-812041-5.00023-4

Storage:

1. Wang, Pengfei, Teng, Ying, Zhao, Yusheng et al. Experimental studies on gas hydrate-based CO storage: state of the art and future directions. Energy Technology. [Internet] [2021 May 3] [Cited 14/02/2022] Vol.9. 1-2. Available from: https://doi-org.ezproxye.bham.ac.uk/10.1002/ente.202100004
2. CCP, co2captureproject [internet], BP group, 2015. Available from: https://www.co2captureproject.org/co2_trapping.html
3. Stefan Iglauer. International journal of greenhouse gas control. Edith Cowan University, School of Engineering. 15/08/2018. Volume 77. P 82-87. https://doi.org/10.1016/j.ijggc.2018.07.009
4. Maria Rasmusson. Residual and solubility trapping during geological CO2 storage. Uppsala Universitet. Available from: http://www.diva-portal.org/smash/get/diva2:1187364/FULLTEXT01.pdf
5. Andrew C. Mitchell, Knud Dideriksen, Lee H. Spangler, Alfred B. Cunningham, Robin Gerlach. Microbially Enhanced Carbon Capture and Storage by Mineral-**Trapping and Solubility-**

Trapping environment Science Technology. 2010, 44, 13, 5270–5276. Available from: https://doi-org.ezproxyd.bham.ac.uk/10.1021/es903270w

6. CCP, co2captureproject [internet], BP group, 2015. Available from: https://www.co2captureproject.org/co2_trapping.html
7. National Energy Technology Laboratory. U.S department of energy. 2020. Carbon captureS FAQs. Accessed 05/03/2022. Available from: https://netl.doe.gov/coal/carbon-storage/faqs/carbon-storage-faqs#:~:text=Carbon%20dioxide%20(CO2)%20can,critical%20point%20for%20CO2.
8. Martin Blunt. Gratham institute for climate change. Carbon dioxide storage. Imperial college London. [Online]. Vol 4. P. 5. 2010. Available from: https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/Carbon-dioxide-storage----Grantham-BP-4.pdf
9. Australian Government. Sydney Basin. Ga.gov.au. Accessed: 05/03/2022. Available from: https://www.ga.gov.au/scientific-topics/energy/province-sedimentary-basin-geology/petroleum/offshore-eastern-australia/sydney#heading-2
10. Hussein Hoteit, Marwan Fahs, Mohamed Reza Soltanian. 2019 Assessment of CO2 injectivity during sequestration in depleted gas reservoirs. Geosciences MDPI. Departments of Geology and Environmental Engineering, University of Cincinnati. Available from: https://www.mdpi.com/2076-3263/9/5/199

Reuse:

[1] Django Mathijsen. Reinforced Plastics, Volume 64, Issue 1, January–February 2020, Pages 50-53. Algae to sustainably produce carbon fiber and simultaneously take CO2 out of the atmosphere.

https://www.sciencedirect.com/science/article/pii/S0034361719301717

[2] Azeem Mustafa, Bachirou Guene Lougou, Yong Shuai, Zhijiang Wang, Heping Tan. Journal of Energy Chemistry, Volume 49, October 2020, Pages 96-123. Current technology development for CO2 utilization into solar fuels and chemicals: A review. https://www.sciencedirect.com/science/article/pii/S2095495620300383

[3] Tereza Pultarova. Engineering and Technology. Tuesday, February 19, 2019/ Six ideas for CO2 reuse: a pollutant or a resource?

https://eandt.theiet.org/content/articles/2019/02/six-ideas-for-co2-reuse-a-pollutant-or-a-resource/

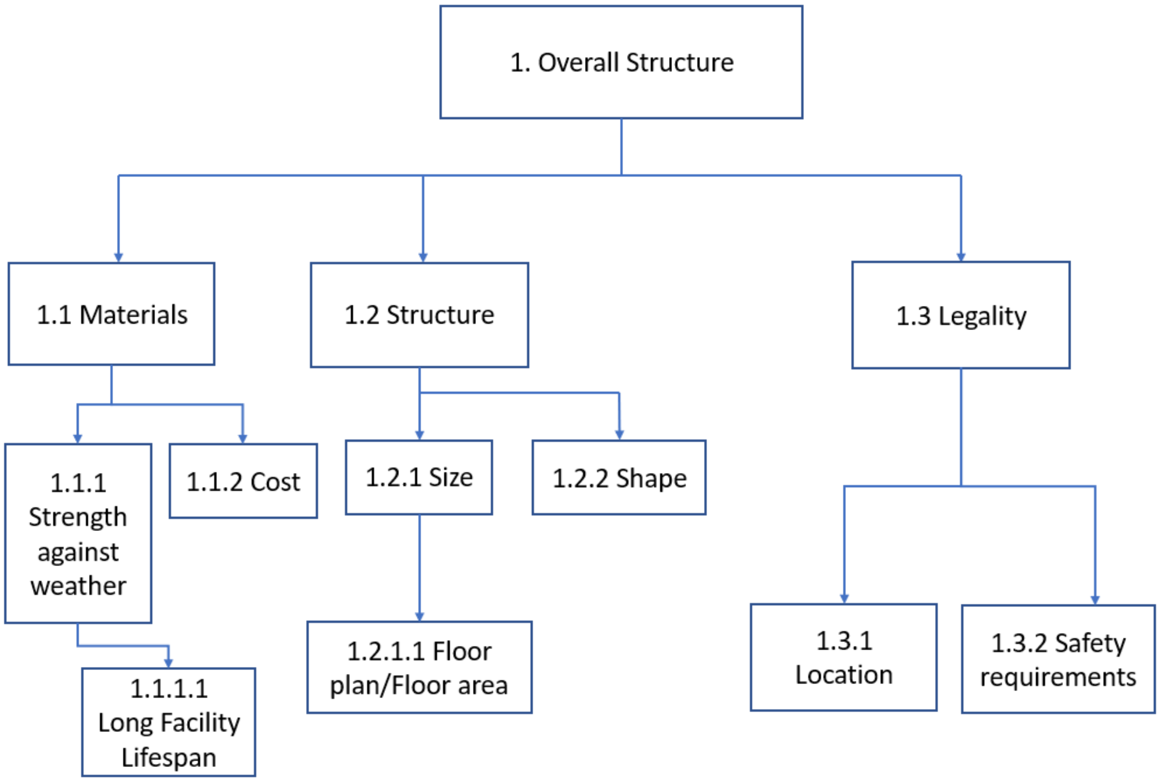
[4] Rackley, S. A. (2017). Carbon capture and storage Part 3 Chapter 22 - CO2 utilization and other sequestration options.

https://www.sciencedirect.com/science/article/pii/B9780128120415000222

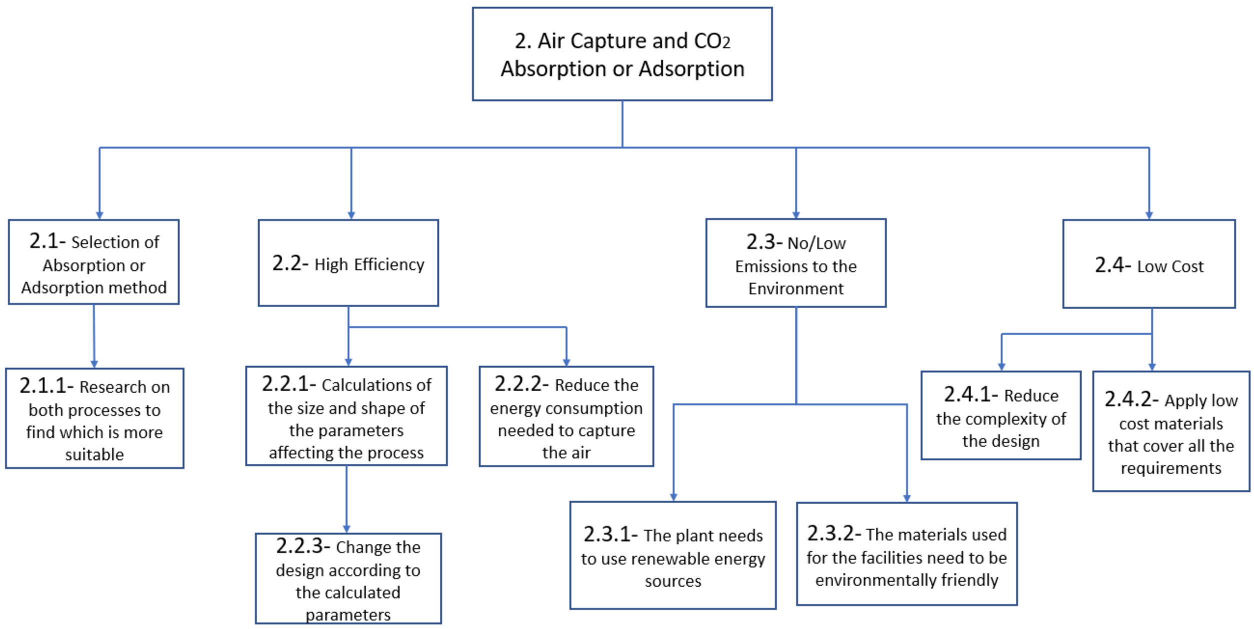
REQUIREMENTS

Objective Tree

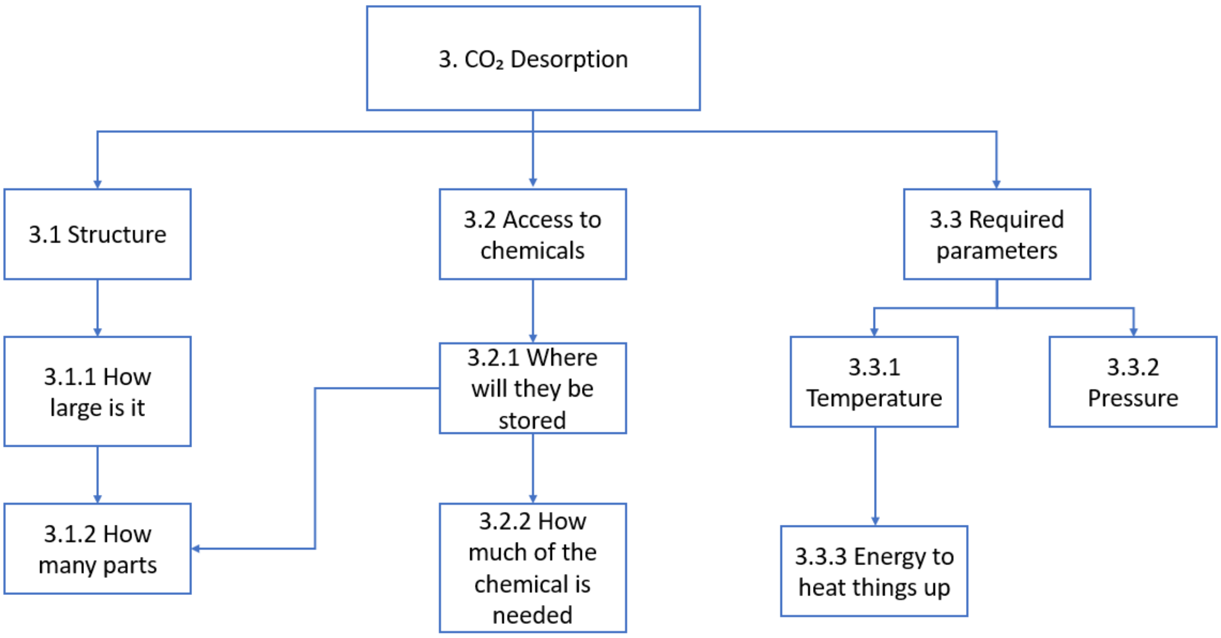
Objective Tree 1: Overall structure



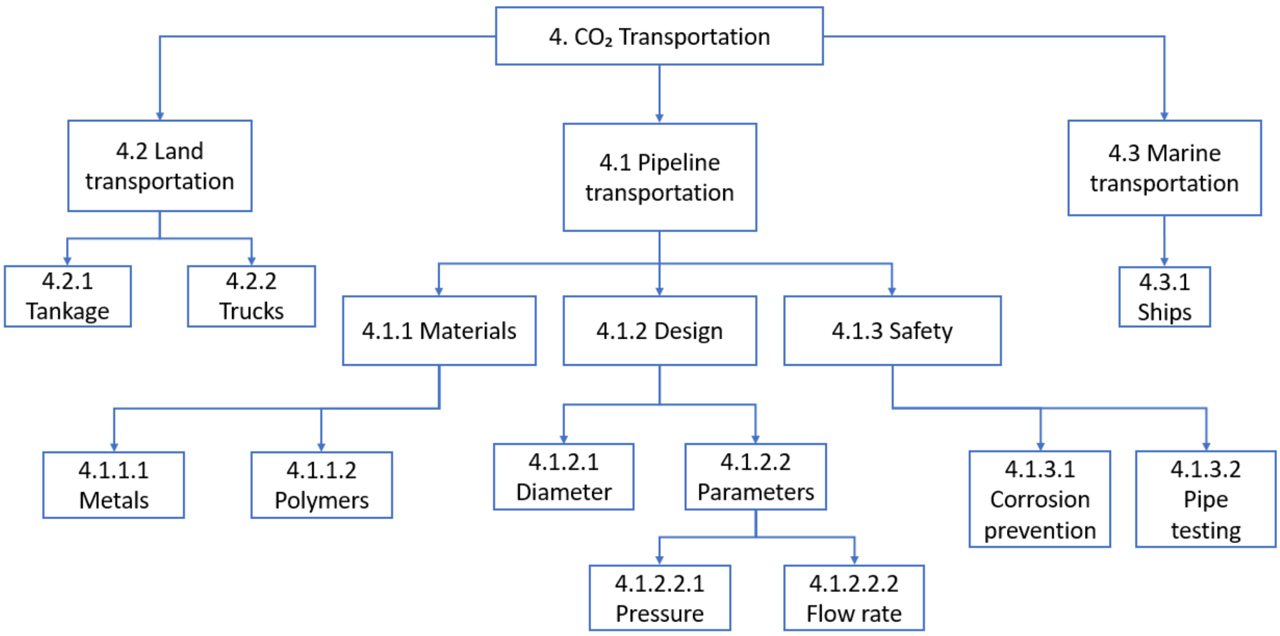
Objective Tree 2: Air capture and CO_2Absorption or Adsorption



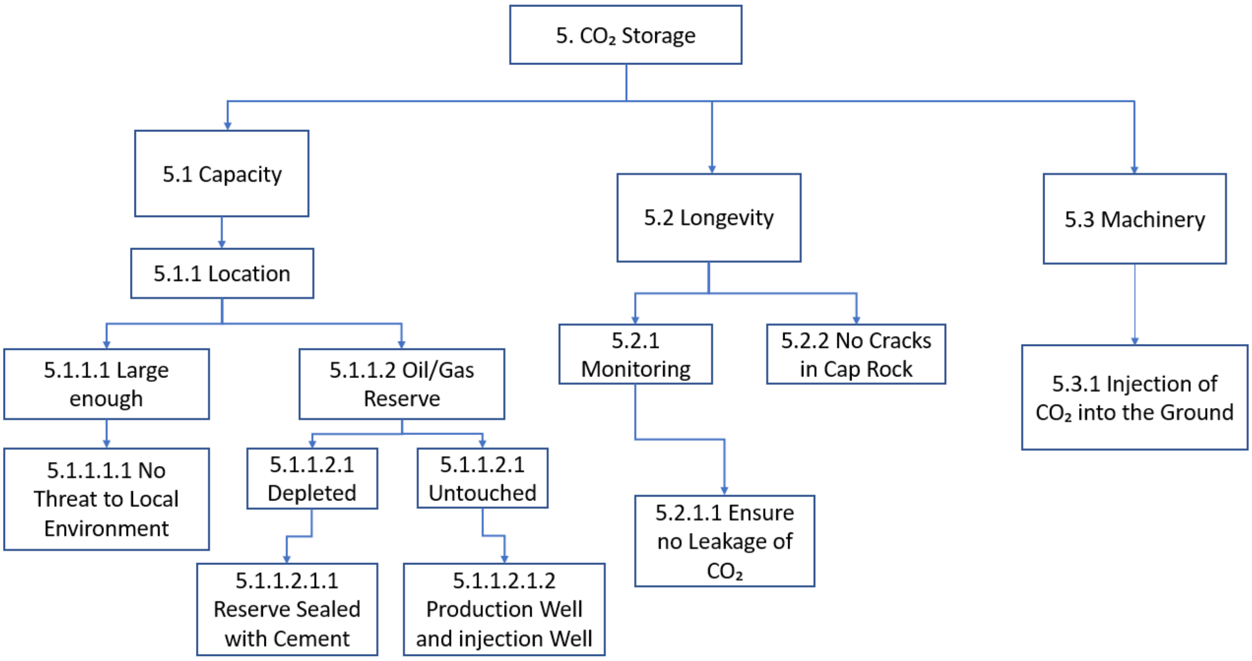
Objective Tree 3: CO_2 Desorption



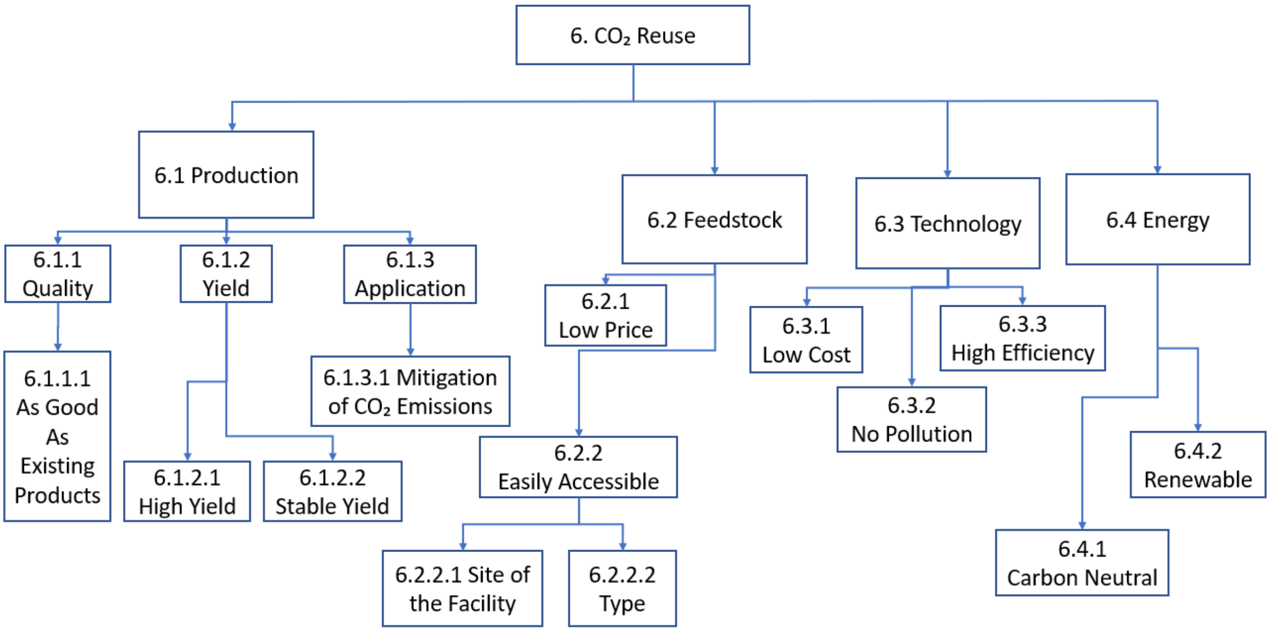
Objective Tree 4: Transportation



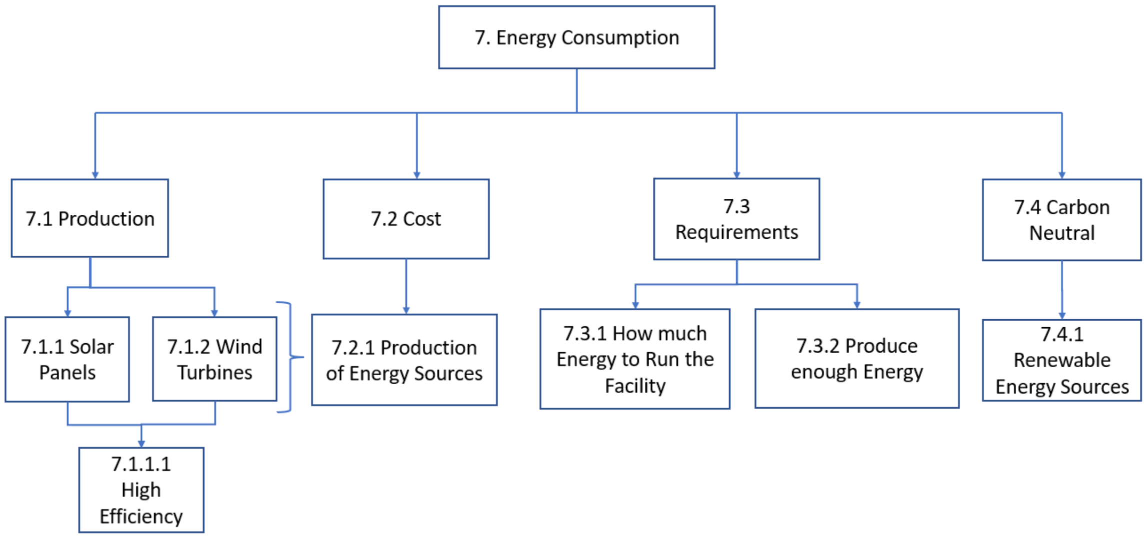
Objective Tree 5: Storage



Objective Tree 6: Reuse



Objective Tree 7: Energy Consumption



Requirements Specification and Adequacy Assessment

System	Requirement number	Description	Requirement Type	Rationale	Traceability to objective tree
1.Overall structure	1.1	Where will our facility be placed	Technical	We will need to know how large the facility can be	1.1
	1.2	What will our facility be made from	Functional	This will let us know how much the facility will cost to build and maintain	1.2
	1.3	How will our facility be in line with legal safety and building regimentation	Technical	We need to comply with governmental rules to run the facility	1.3
2.Air capture and CO_2 absorption or adsorption	2.1	Estimation of the size and shape of the fans and pumps	Functional	By calculating those parameters, the efficiency can be estimated	2.2.1
	2.2	Decide which type of solvent will be used for the facility	Functional	It will be decided what chemicals are needed	2.1

	2.3	How the cost for the sorption process can be reduced	Technical	It will make the facility more economically efficient and thus more feasible to construct	2.4
3.CO_2 desorption	3.1	What is the size of the structure and what materials are used	Technical	We need to understand the scope of the facility in size and cost	3.1
	3.2	What chemicals are needed for desorption and how much	Functional	Sourcing and storing the chemicals will be important for the long life of the facility	3.2
	3.3	What temperature and pressure will the various stages run at	Functional	Knowing these will allow us to know what energy is required and what precautions are needed at the different stages	3.3
4.CO_2 transportation	4.1	What do we need for the design of pipelines?	Functional	Knowing these parameters, we can estimate the pipeline design.	4.1
	4.2	What modifications do we need to make to LPG tankers to enable them to carry liquid CO_2?	Functional	Knowing these parameters, we can estimate the changes to be made to LPG tanks to enable them for CO2 transport.	4.2
	4.3	What changes do we need to	Functional	Knowledge of these	4.3

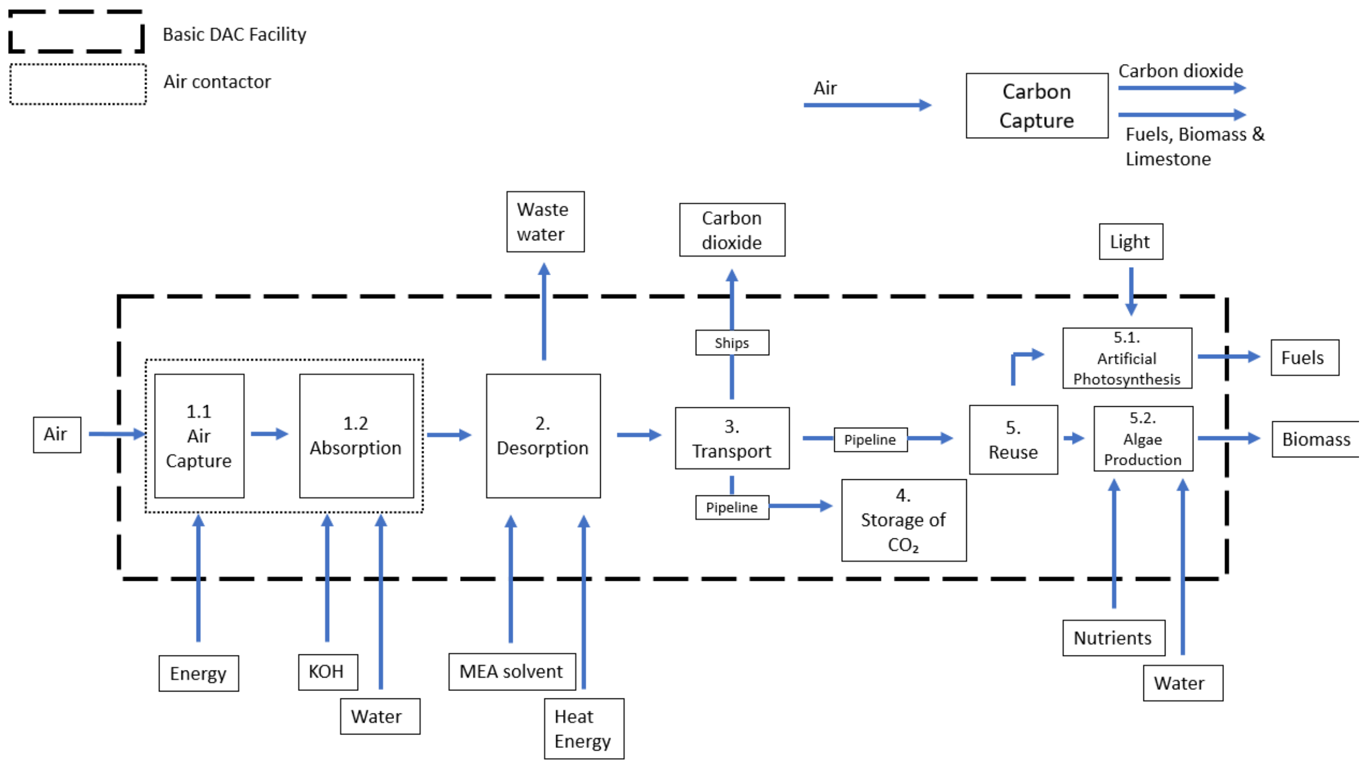
		incorporate into modifying LPG carrier ships to use them for liquid CO_2 transport?		parameters enables us to modify our design for LPG carriers in accordance with CO_2 shippage.	
5.CO2 storage	5.1	How much CO_2 can the facility store	Functional	This will allow us to design the tanks and select a valid location for the facility	5.1
	5.2	How will we keep the CO_2 stored safely	Technical	This lets us know what maintenance and safety measures need to be put in place	5.2
	5.3	What machinery is needed to inject the CO_2 into the ground	Functional	We need to know what material and energy requirements the injection process has	5.3.1
6. CO2 reuse	6.1	How will the CO_2 be used post capture	Functional	Knowing this lets us build housing and understand what products we will produce for selling or	6.1
	6.2	What feedstock will be used for the reuse processes	Functional	This tells us what costs are involved and tells us what we need to source for the reuse of CO_2	6.2
	6.3	What technology is needed	Functional	We need to know what we are going to use if we are going to make it as efficient as	6.3

				we can for the cost and energy consumption	
7.Energy consumption	7.1	How are we going to produce the energy to run the facility	Functional	If we don't know how to get enough energy the facility won't run	7.1
	7.2	What will our solution to energy cost	Functional	This will let us know our economic impact	7.2
	7.3	Will our energy production be carbon neutral	Quality	This is important as we are designing a caron capture facility which should be carbon negative	7.4

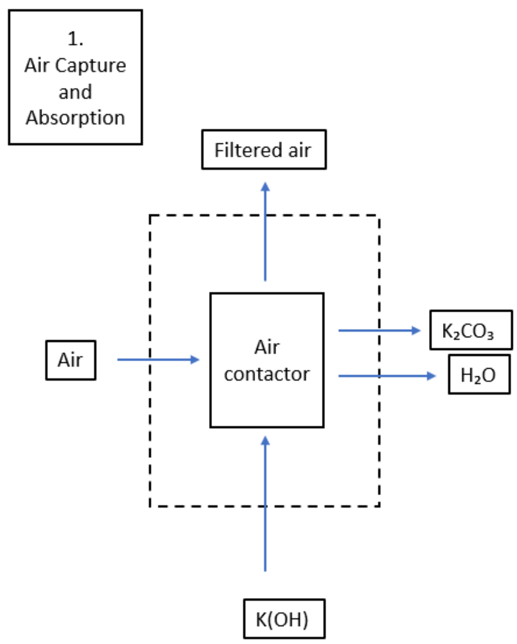
CONCEPT DESIGN

Functional Analysis

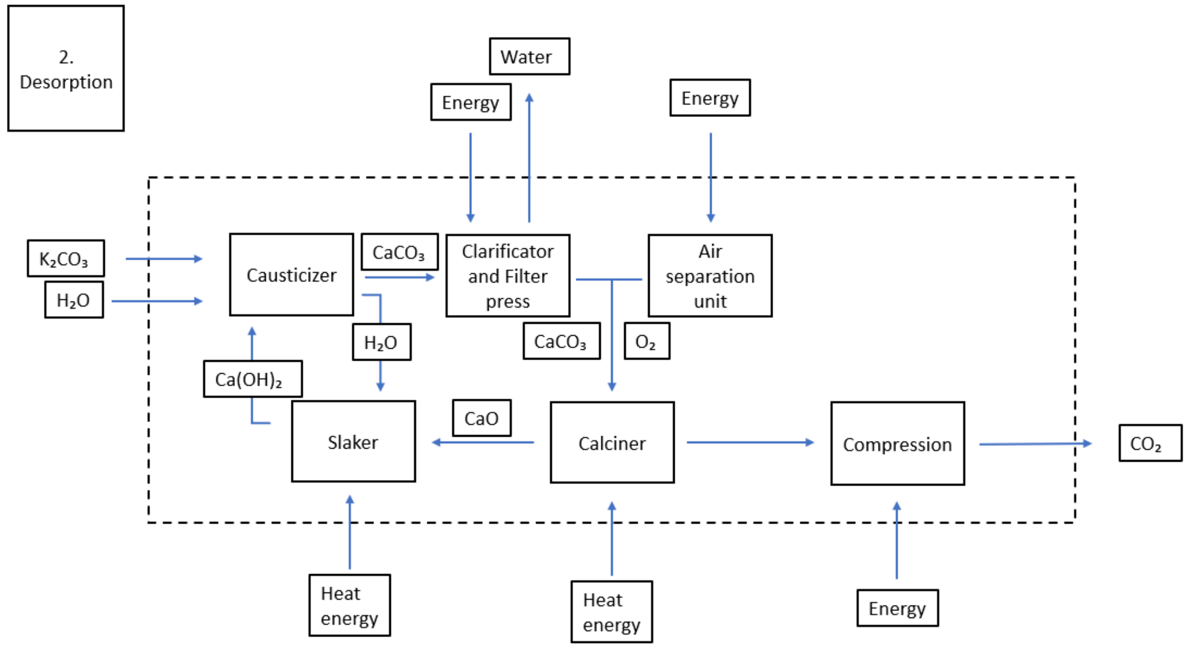
0.0 Overall Functional Flow Diagram for the facility



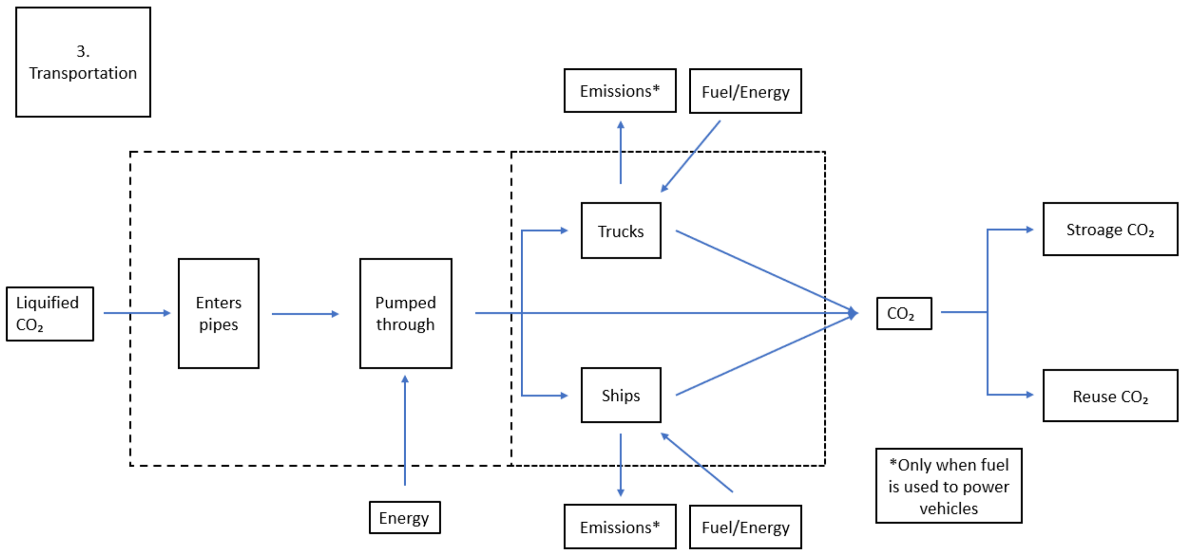
1,0 Air capture and CO2 Absorption



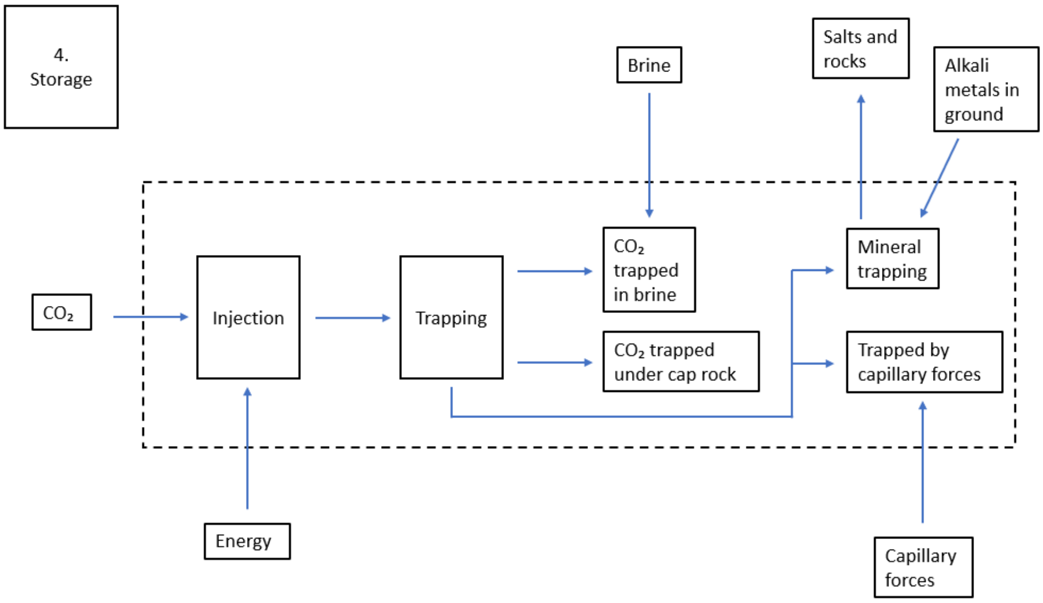
2.0 CO2 Desorption



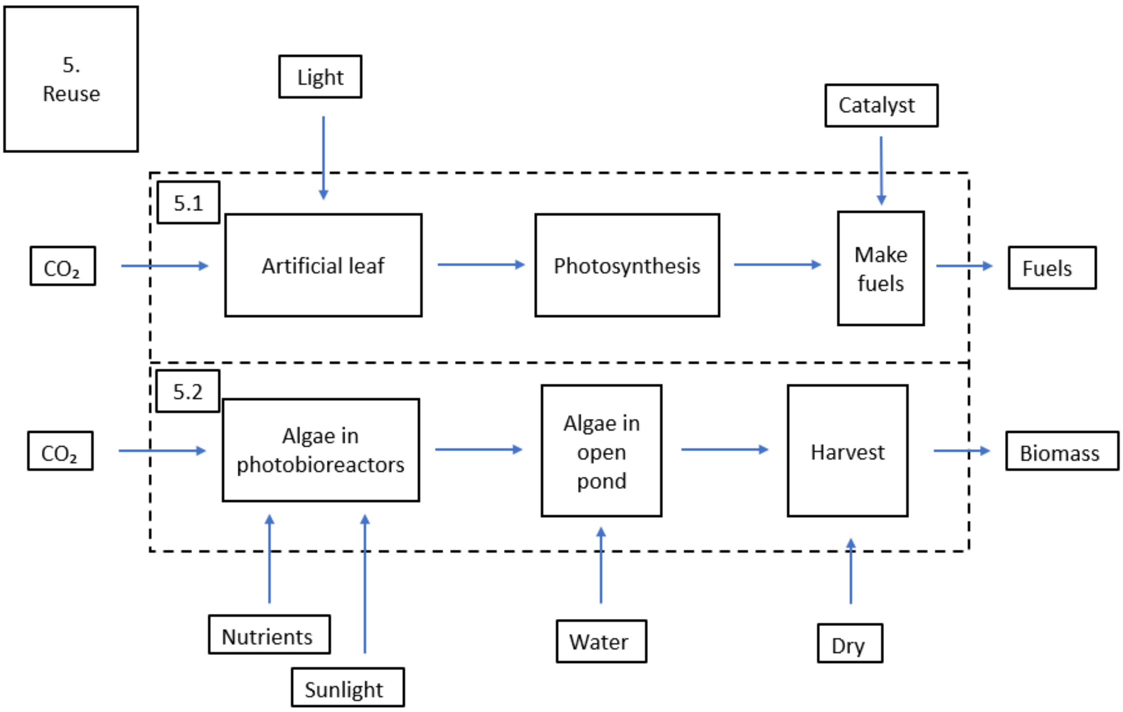
3.0 CO2 Transportation



4.0 CO2 Storage

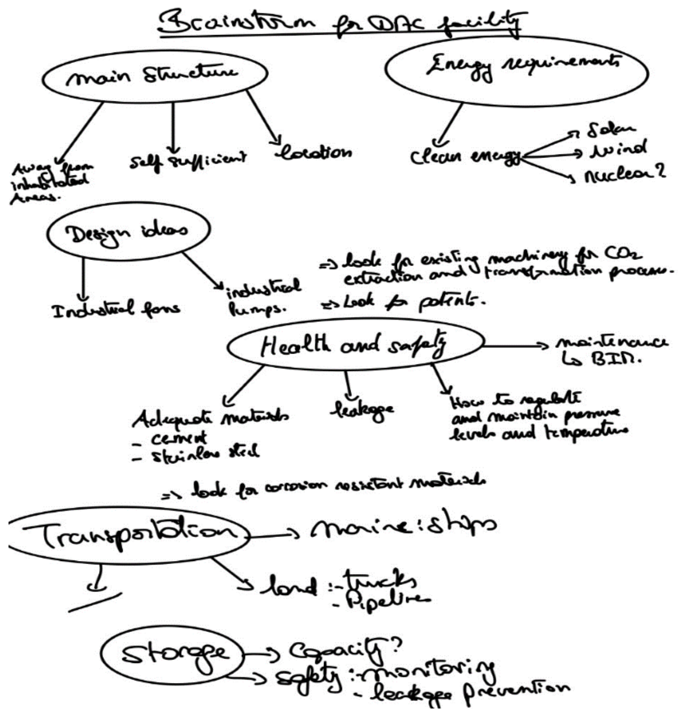


5.0 CO2 Reuse

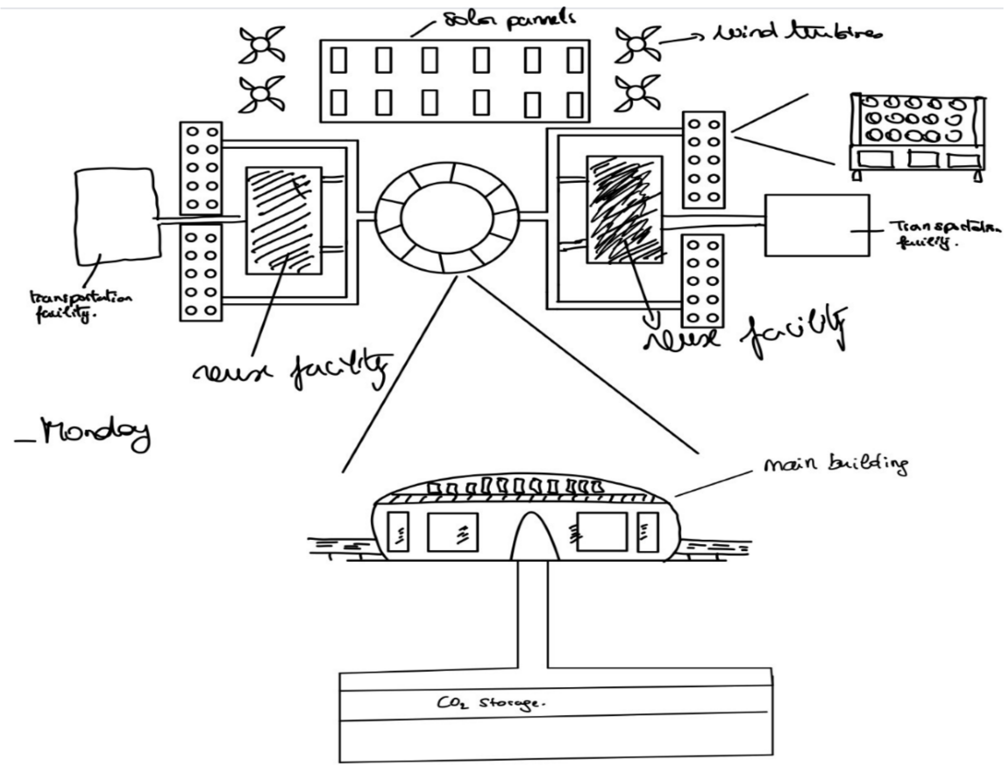


Design Ideas

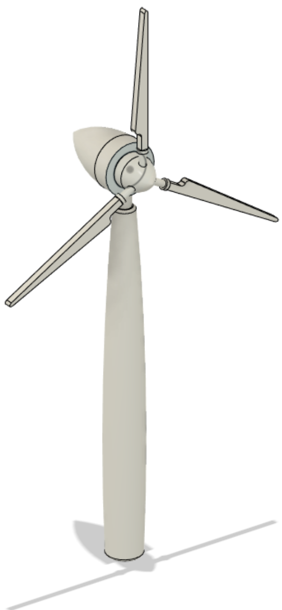
Brainstorming – initial concepts



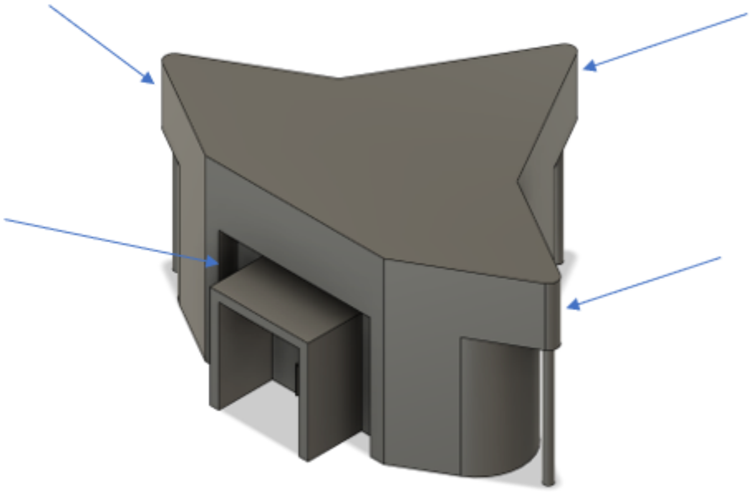
An initial brainstorm was constructed based on each group members' general knowledge. A general idea of the main aspects of the facility was developed which allowed us to focus our research on specific ideas such as clean energy for the energy requirements of the facility. In addition, the brainstorm allowed us to understand what was required from the project.



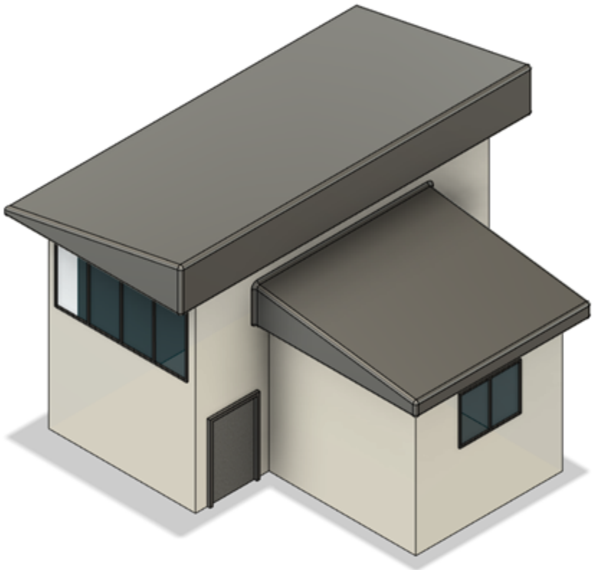
A schematic conceptual design was then developed to have a basic idea of the overall structure of the facility as well as a layout of the different elements. In the initial layout, it was agreed that two transportation facilities and two reuse facilities would be required, as well as four wind turbines and a solar farm to power the facility. It was later decided that only one reuse and transportation building would be necessary.



The above picture shows the final design for the wind turbine which, combined with the solar panels, is responsible for the power generation of the facility. With additional research, it was decided that the dimensions of the wind turbines would need to be reconsidered to get an optimum efficiency.



An example of an initial CAD design is provided above. The initial idea of this design was to be multi-functional and cover a lot of responsibilities. The main function of this building was to have a general control system of the DAC facility. In addition, it was initially agreed that the building would be situatable for the storage of chemicals. Finally, due to its central position in the site, the building was considered as an ideal location for the managers' offices. The design and layout were finally rejected due to its conceptual complexity and safety reasons. As shown by the arrows, the building includes several complex and unnecessary features. Finally, it was agreed that storing hazardous chemicals next to offices would bring health and safety concerns to the facility. This design and layout were therefore rejected, and other conceptual designs were adopted.



This conceptual design was prioritized for a warehouse. The solar panels would be placed at the roof of the building taking advantage of the space provided. However, it was rejected because of the roof design which has two separate roof tops with initiated angles. This will make the solar panels difficult to place while on the bottom roof they would not be functional as at some point of the day they would be covered from the sunlight. Thus, the operational time would be reduced and as a result it would not supply the calculated amount of energy for keeping the facility sustainable.

Morphological Chart

Feature	Means		
Clean energy	Solar panels	Wind turbines	No carbon fuels
Sustainability	Clean energy	Safe site for local ecosystems	CO_2 reuse
Health and safety	Pressure gauge	Temperature gauge	Corrosion prevention
CO_2 storage	Pressurized stainless-steel tanks	Adequate temperature	Leak proof
Longevity of CO_2's storage	Monitoring	Leakage prevention system	Reserve sealed by cement
Construction site	Away from any endangered ecosystems	Away from public infrastructures	Adequate geological site for CO_2 storage

Maintenance	Building Information Model	Daily Inspections	Adequate on-sit equipment
CO2 transportation	Specialized vehicles	Pipelines	Long-lasting road infrastructure

In the final process of designing the DAC facility, we used the morphological chart shown above to improve and conclude our design thinking. Initially, some crucial factors related to health and safety, or the longevity of the carbon dioxide's storage were not taken into consideration. The chart allowed us to make some additional changes such as the material used for the tanks or pipelines. Furthermore, additional measures have been taken to guarantee a complete health and safety policy within the facility. Thus, daily inspections of the facility will be needed as well as monitoring systems to allow a complete control of critical parameters such as temperature and pressure. A close loop monitoring system was therefore adopted within the main building of the facility.

TRIZ Contradiction Matrix

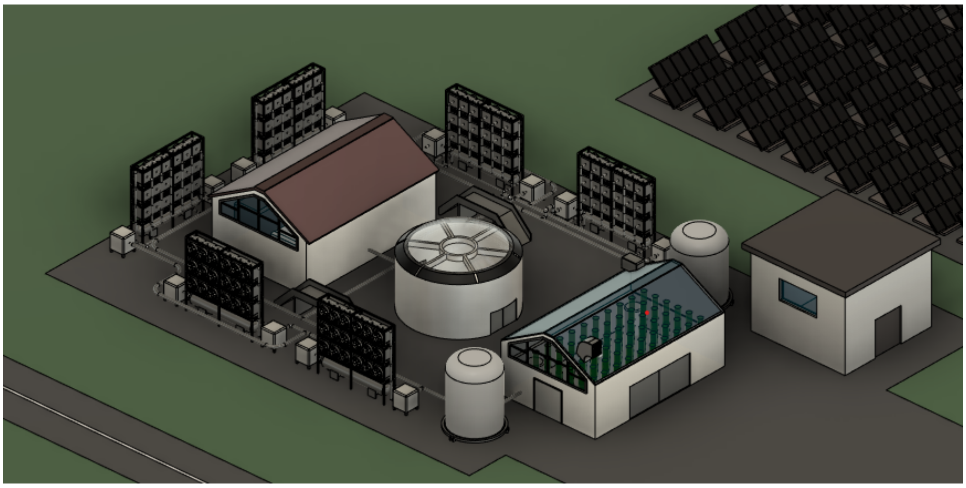
Number	Improving parameter What do we want to make better?	Undesirable result What gets worse as a result?	Inventive principle
1.0	Area of stationary object	Productivity	7. Nested Doll 10. Prior Action 15. Dynamics 17.Another dimension
2.0	Temperature	Stress or pressure	2. Taking Out 19. Periodic action 35. Parameter changes 39. Inert atmosphere
3.0	Shape	Ease of manufacture	1. Segmentation 17. Another dimension 28.Mechanics substitution 32. Colour changes
4.0	Loss of energy	Device complexity	7. Nested Doll 23. Feedback
5.0	Power	Difficulty of detecting and measuring	16. Partial or excessive action 19. Periodic action 35. Parameter changes
6.0	Productivity	Shape	10. Prior action 14.Spheroidality-curvature 34. Discarding and recovering 40.Composite materials
7.0	Length of stationary object	Productivity	7. Nested doll 14.Spheroidality-curvature 26. Copying

			30. Flexible shells and thin films
8.0	Speed	Reliability	11. Cushion in advance 27. Cheap short living objects 28.Mechanics substitution 35.Parameter changes
9.0	Volume of stationary object	Productivity	2. Taking out 10. Prior action 35. Parameter changes 37. Thermal expansion
10.0	Use of energy by stationary	Productivity	1. Segmentation 6. Universality
11.0	Reliability	Loss of time	4. Asymmetry 10. Prior action 30. Flexible shells and thin films
12.0	Device complexity	Ease of repair	1. Segmentation 13.The other way around

TRIZ Design Patterns Realised:

When designing the DAC facility, we used a Triz Contradiction Matrix to help us ensure that our structure was safe and operational in regards of the energy production and consumption of the facility (point 4.0). For instance, we wanted to optimize the energy production and consumption of the facility and avoid any loss of energy during the different processes while keeping our design simple and not excessively complex. A solution proposed by the Triz Contradiction Matrix was to add a central building to our design to allow the control of all the various aspects of the processes, such as the temperature and pressure of the carbon dioxide inside the pipelines (Element A in figure). This solution was also used for point 5.0 to control the power of the facility using a closed loop control system incorporated in the main building (Element A in figure). Using this system, we were able to ensure that our facility was safe.

Element	Name
A	Main building



Final Design

Design Rationale

The DAC facility was designed to capture CO2 and store it underground. Part of CO2 are reused in algae production to produce biomass or transited to the other companies for various utilizations.

For CO2 capture, 108 fans units with the diameter of 1.3m and air take-in velocity of 1.5m/s make it possible to capture 4923.6 tons CO2 every year. The mixture of KOH and $\mathrm{Ca(OH)_2}$ is pumped into the fans unit by the pipeline system from the chemical storehouse for absorption. Then the heater inside the unit decomposes the sediment into pure CO2 and the condensers in the bottom of the fans compress it to the supercritical state. After that the CO2 are pumped to the tanks for storage.

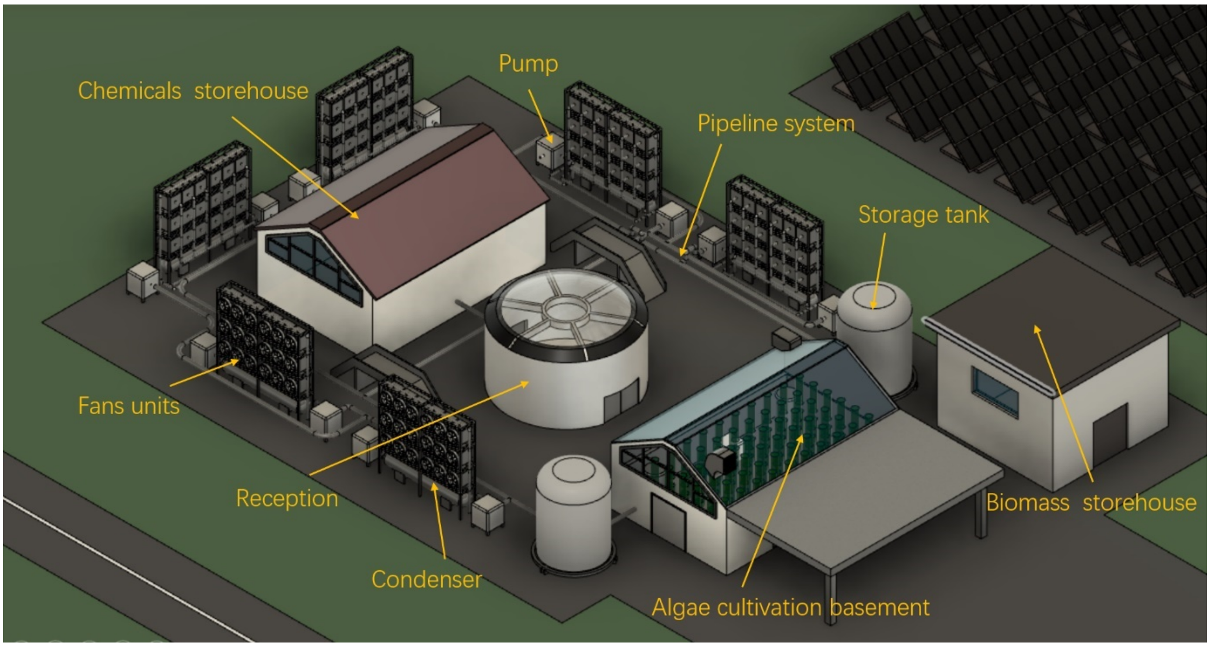
The algae cultivation basement can reuse 965.04 tons of CO2 each year and produce 16.91 tons of biomass. And three-fifths of CO2 are stored underground by the injection well, while 1000 tons of CO2 remained are planned to transport to some enterprises for further utilization.

The total power required for the whole system is 6.943MW, which exceeds our expectations a lot. That means we need 3 wind turbines of 2MW and a 1.3 hectares of solar panels farm to meet the energy consumption.

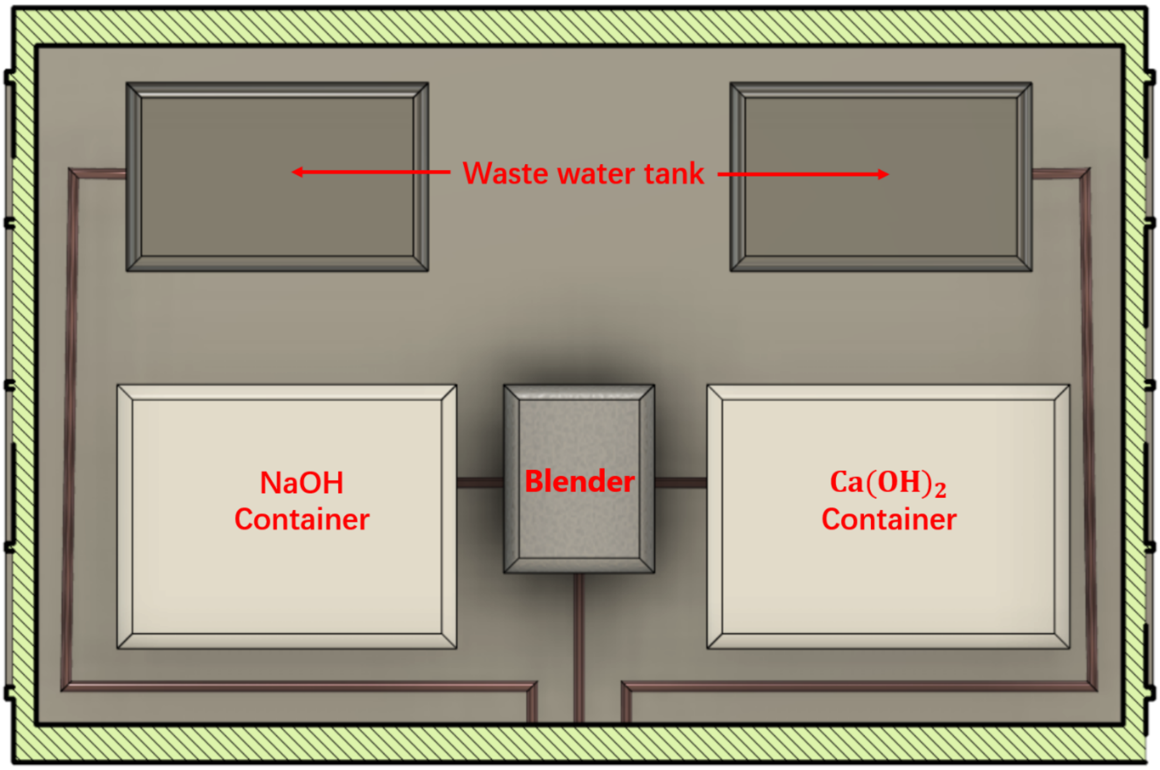
Calculation process is shown in the Appendix E.

Design Schematic

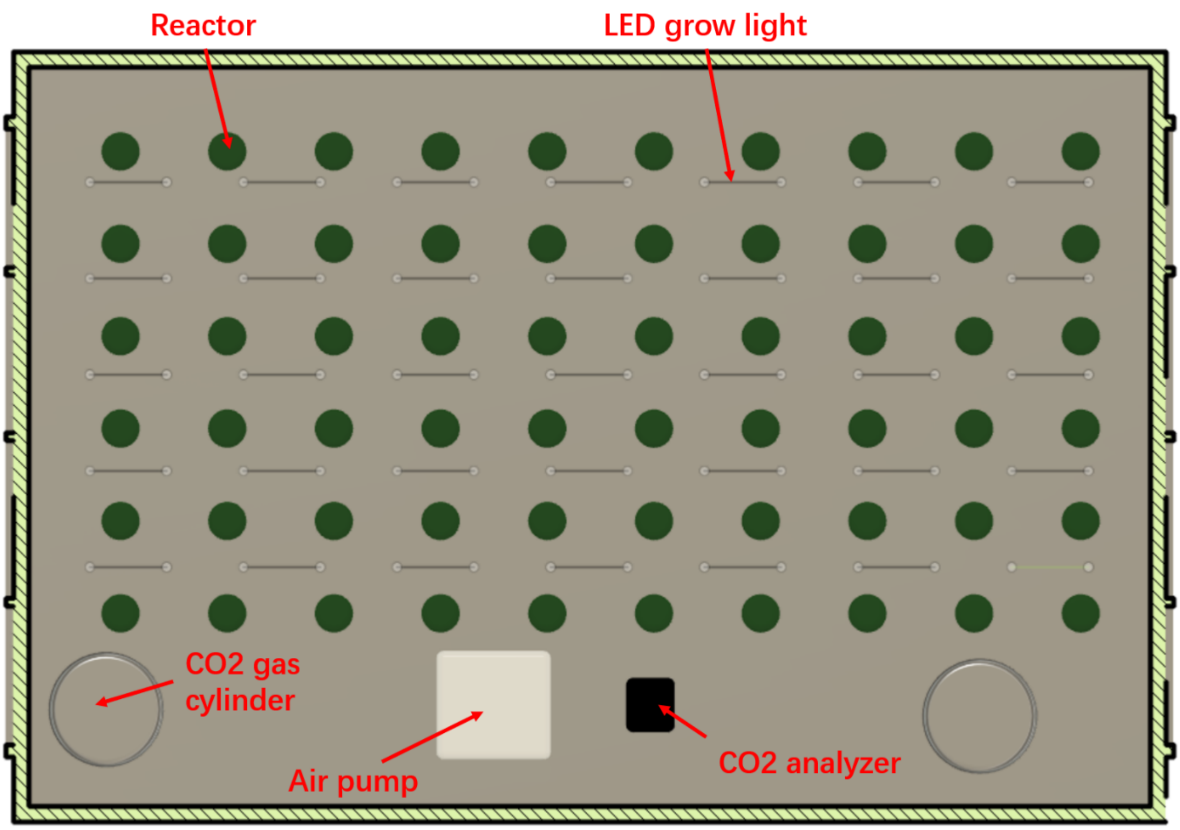
Main Body



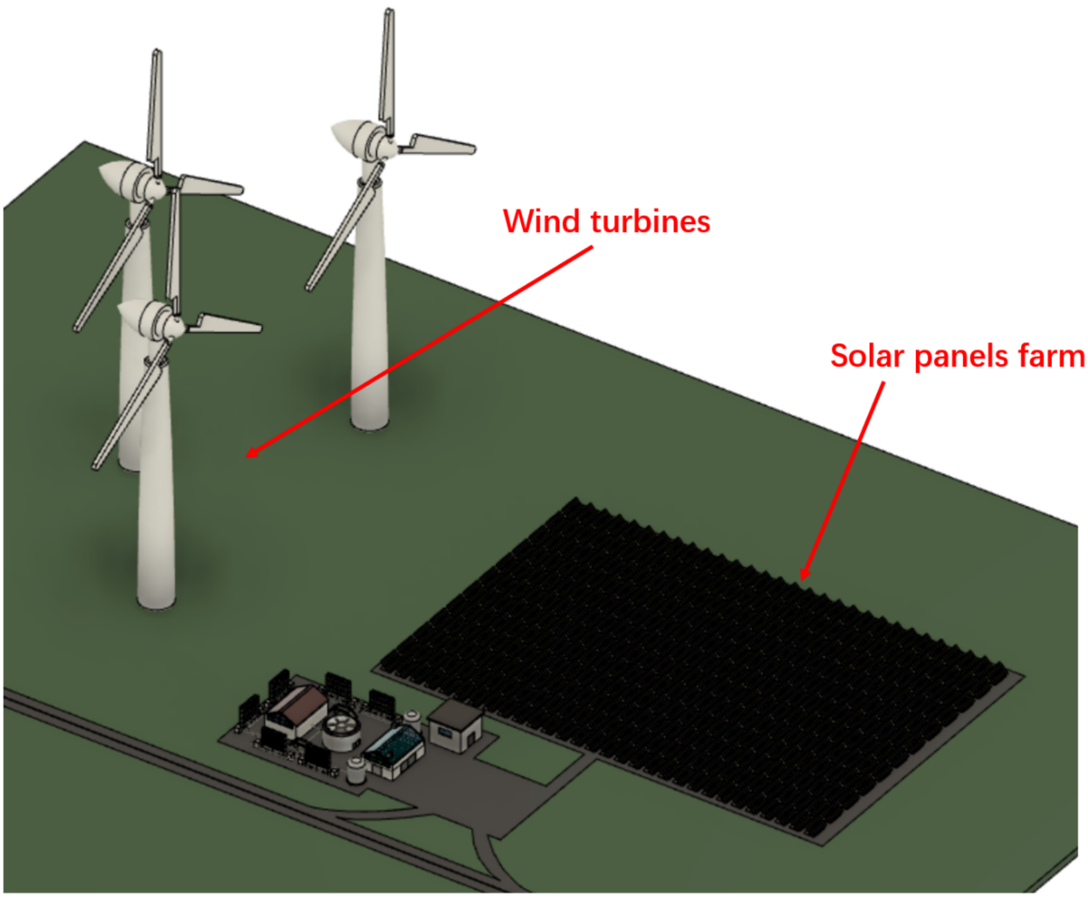
Chemical Storehouse



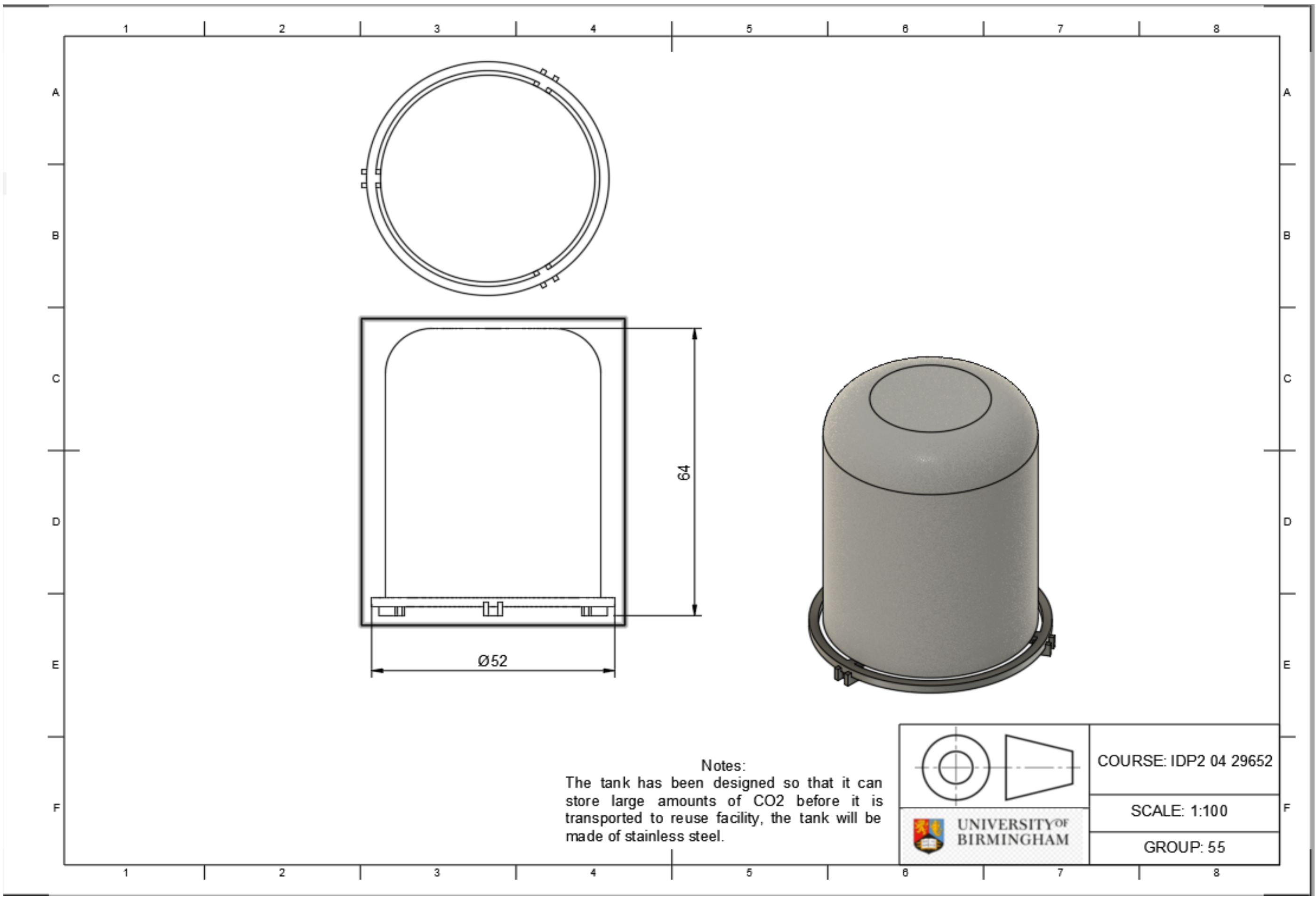
Algae Cultivation Basement



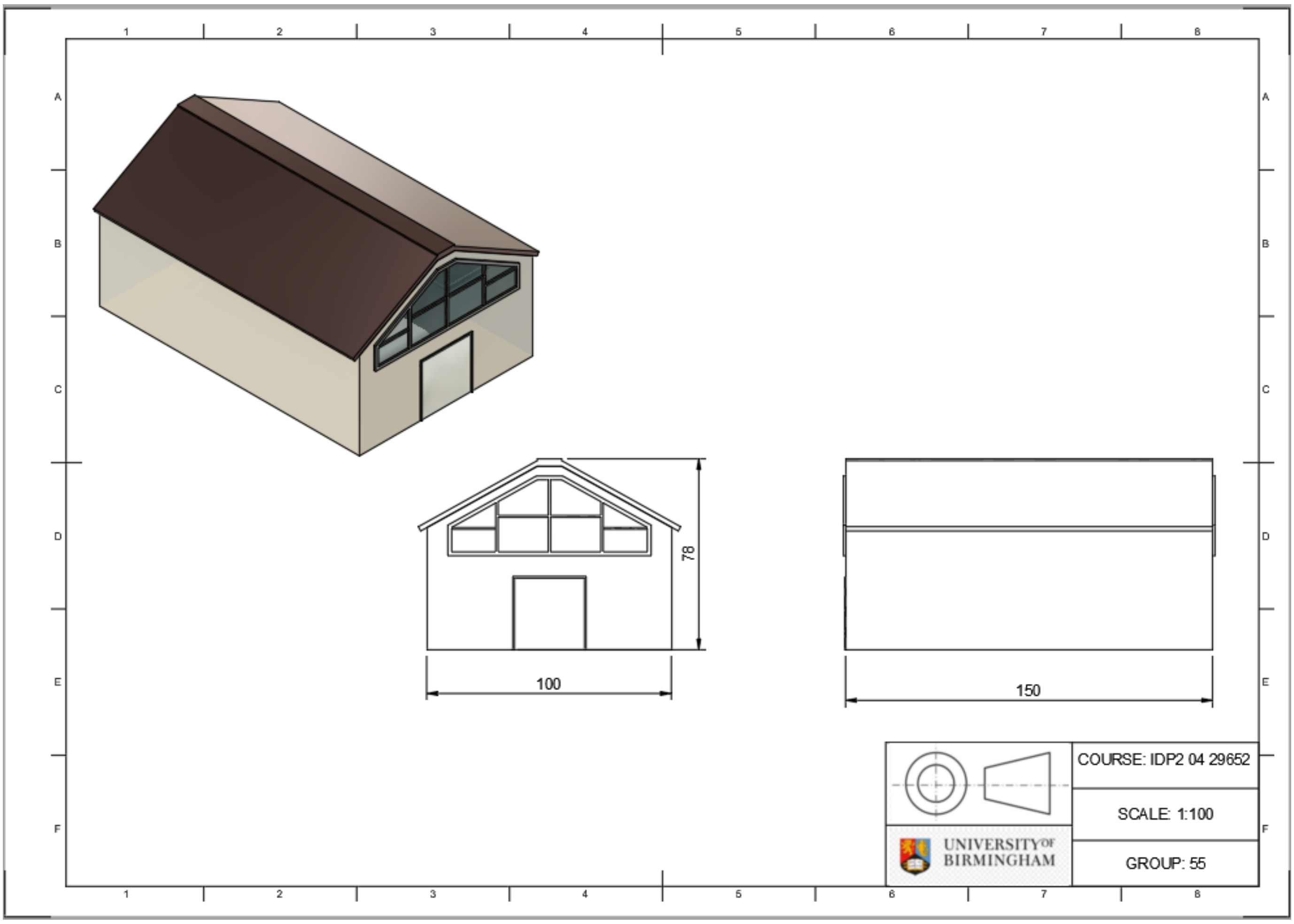
Energy Supply Structure



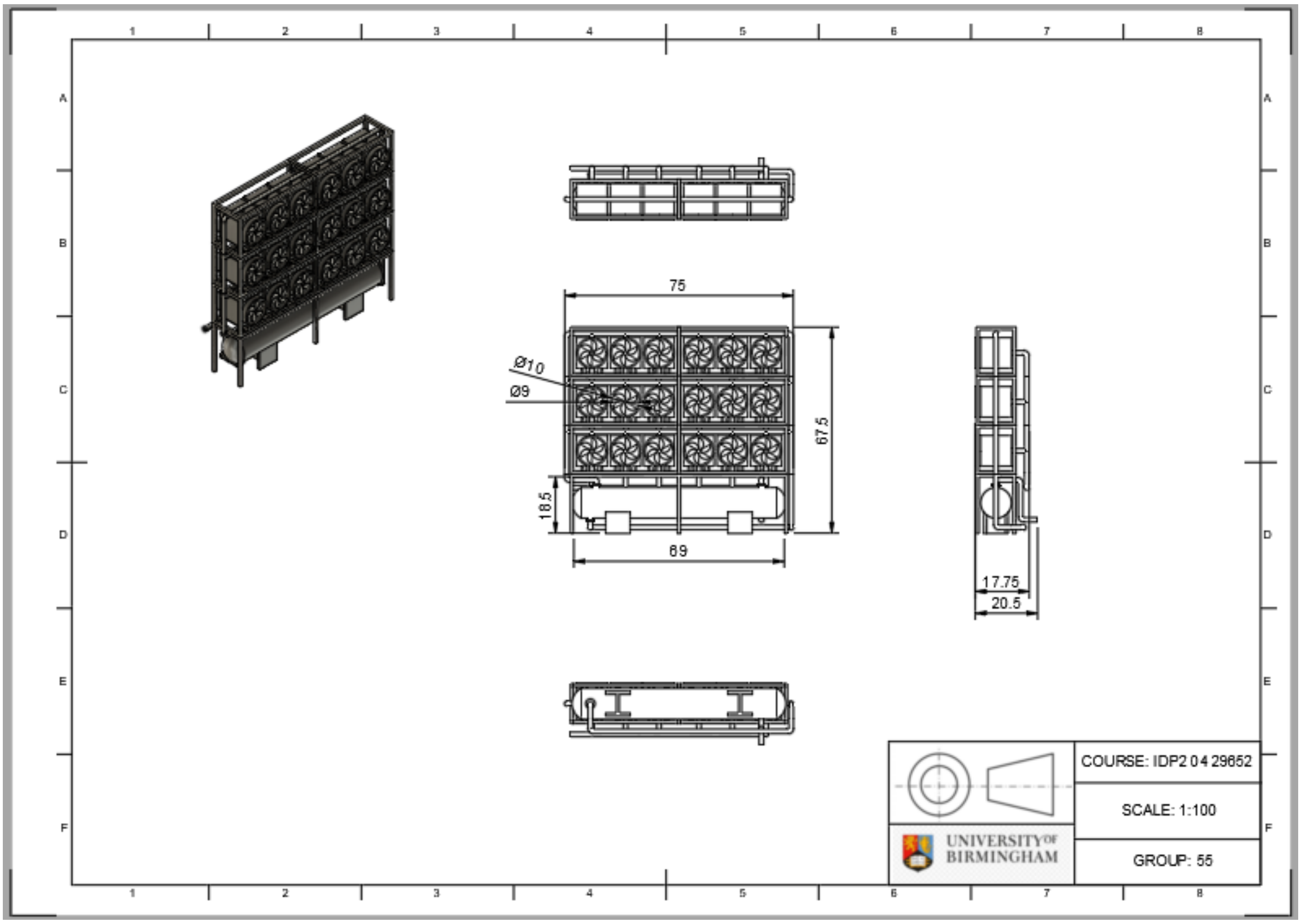
Injection Well



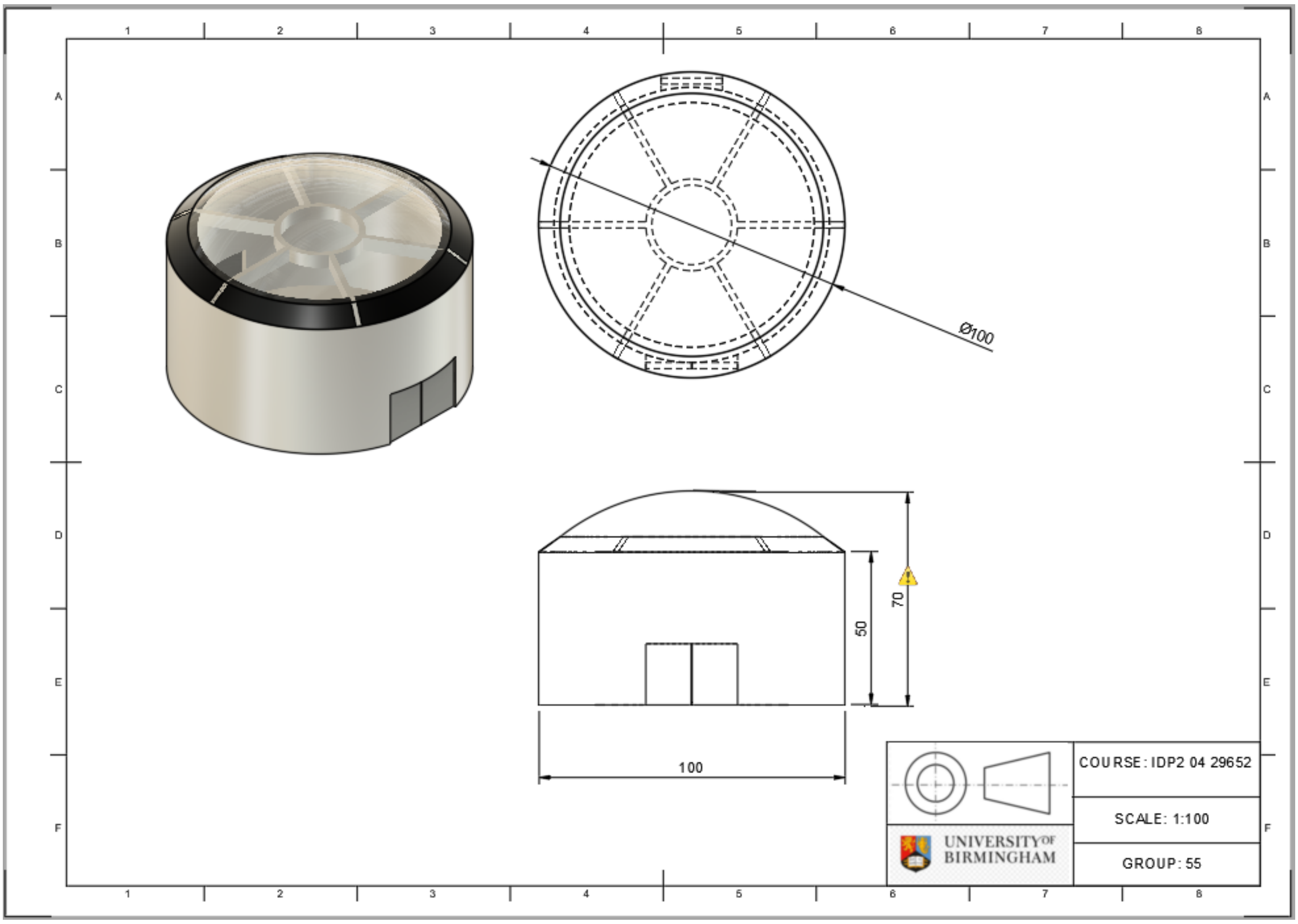
Engineering drawing for carbon dioxide tank



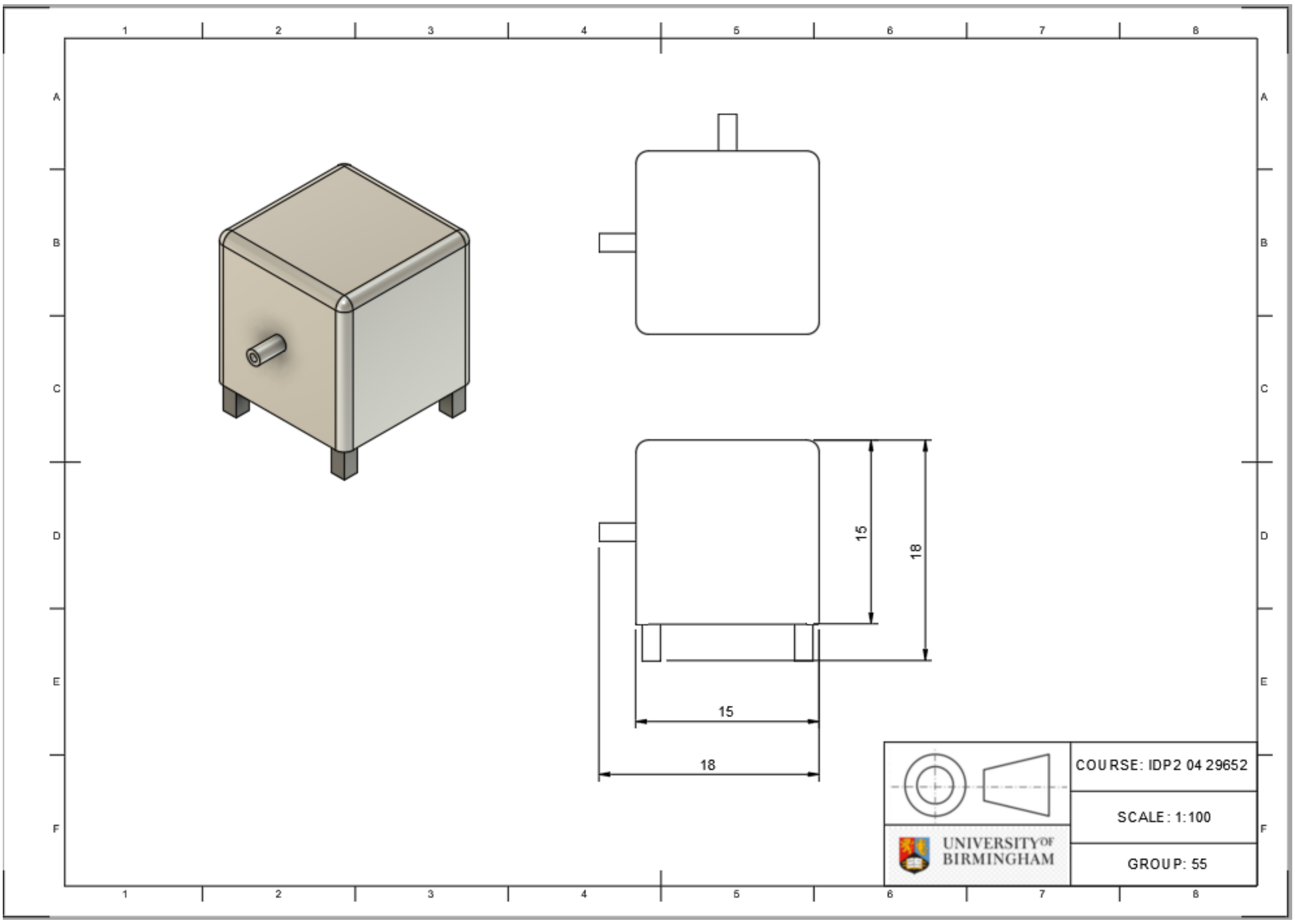
Engineering drawing for chemicals storehouse



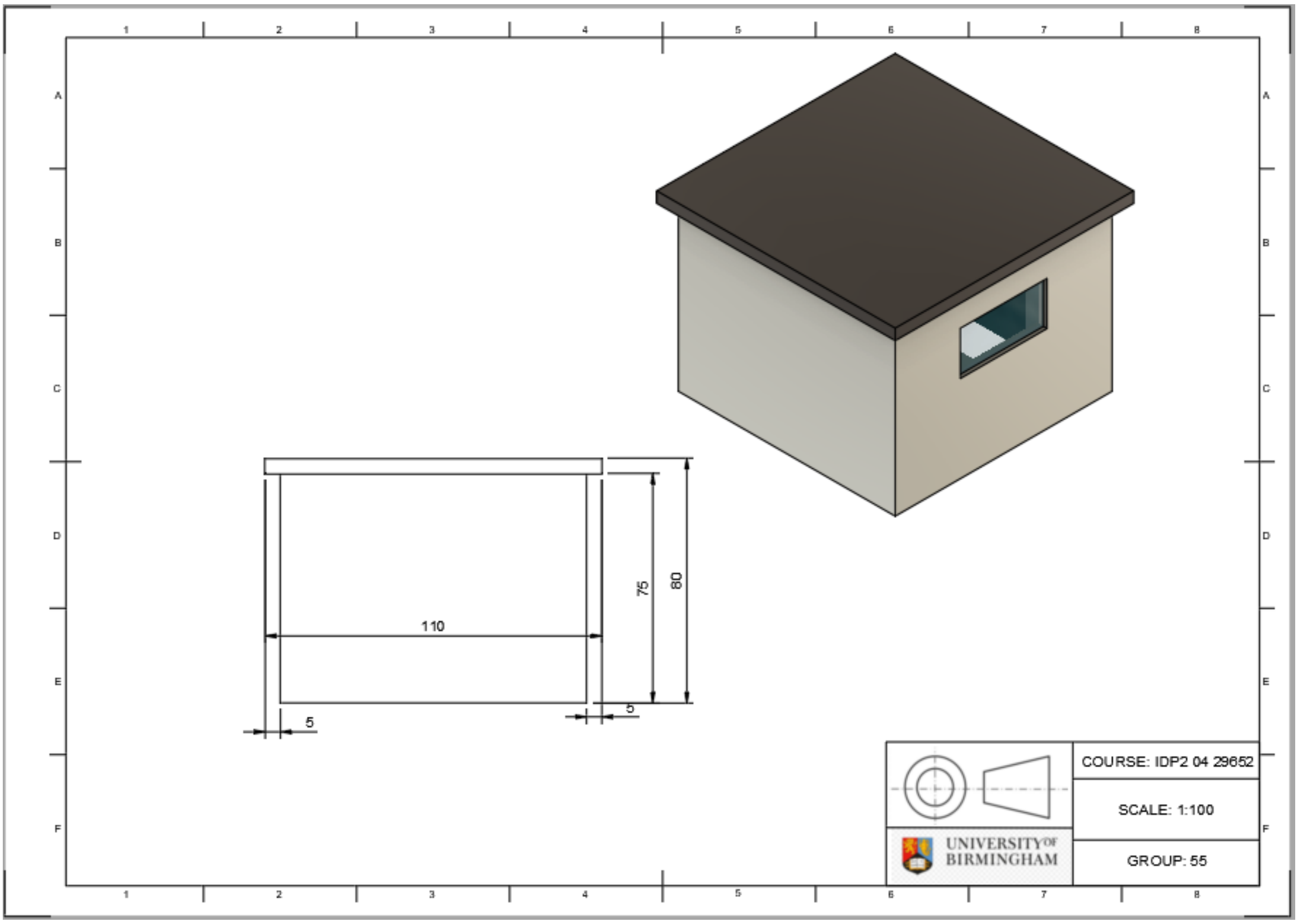
Engineering drawing for fan units



Engineering drawing for reception



Engineering drawing for pump



Engineering drawing for biomass storehouse

Patent Search:

Patent 1.

Patent Number: US2017/0106330A1

Patent Title: Direct air capture device

Patent Holder: 1) Christoph Gebald

2)Werner Meier

3)Nicolas REPOND

4)Tobias RUESCH

5)Jan André Wurzbacher

Patent date: Apr.20,2017

Patent Description:

On the one hand, it is an object of the present invention to provide a new vacuum chamber for a direct air capture process device with as low a thermal mass as feasible while maintaining as high a mechanical stability as possible to enable for the application of flow vacuum pressures.

On the other hand, and as a different invention from the above, the current invention aims to provide a new vacuum chamber closure mechanism. Suitable for a direct air capture process that allows for a wide flow cross-section to be available in the open position while also allowing for tight and robust sealing in difficult environmental conditions while maintaining high mechanical stability at low thermal mass

Patent 2.

Patent Number: US009095813B2

Patent title: CARBON DIOXIDE CAPTURE METHOD AND FACILITY.

Patent Holder: DavidKeith,Calgary(CA);Maryam Mahmoudkhani,Calgary(CA);

AlessandroBiglioli,Calgary(CA); BrandonHart,Okotoks(CA);Kenton

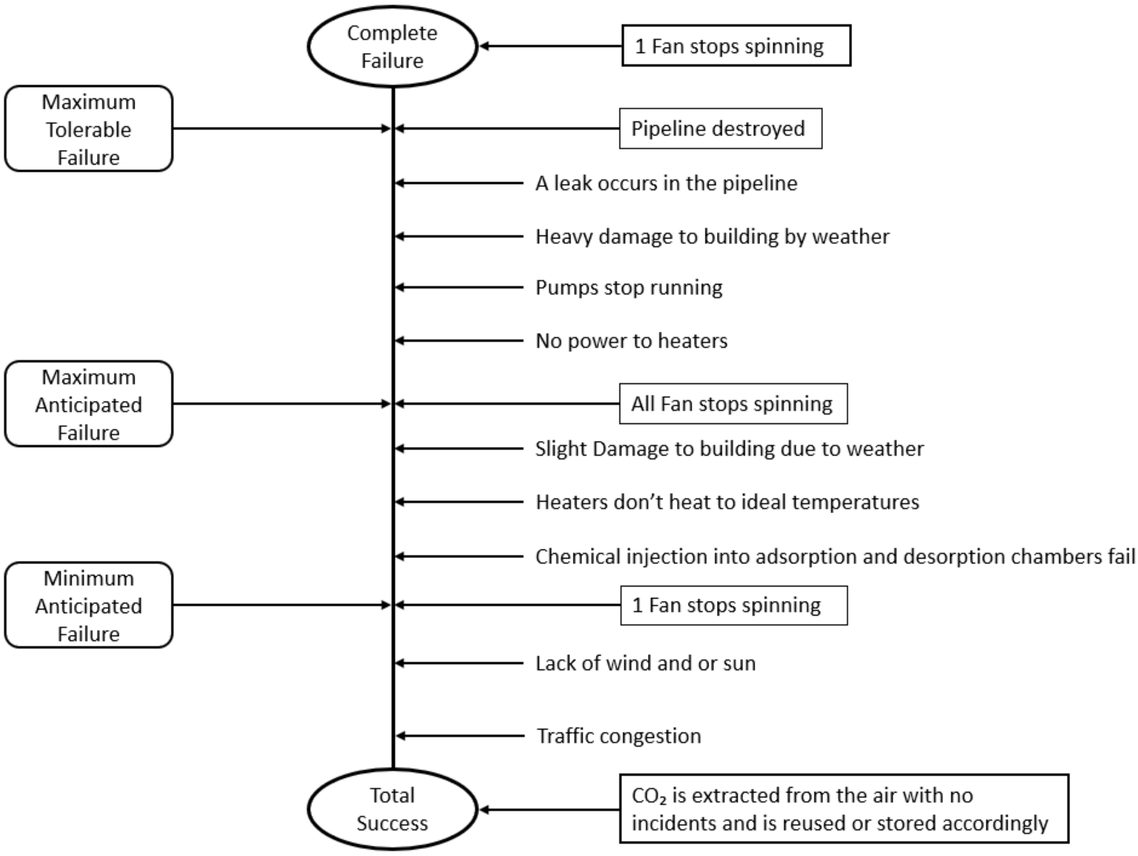
Heidel,Calgary(CA);MikeFoniok, Calgary(CA)

Date of Patent: Aug.4,2015

Patent Description: A carbon dioxide capture facility with packing formed as a slab and at least one liquid Source has been disclosed. The slab has opposed dominating faces, which are at least somewhat wind penetrable to allow wind to flow through the packing. The at least one liquid source is aimed at directing carbon dioxide-absorbent liquid into the packing and through the lab. Theslabislocatedinawindflowwithanon-zeroincidentanglewithoneoftheopposeddominantfaces. A carbon dioxide capture method is also closed. A carbon dioxide-absorbing liquid is used to pack a series of pulses. A gas containing carbon dioxide is circulated through the packing to at least partially absorb the carbon dioxide from the gas into the carbon dioxide absorbing liquid.

RISK MANAGEMENT

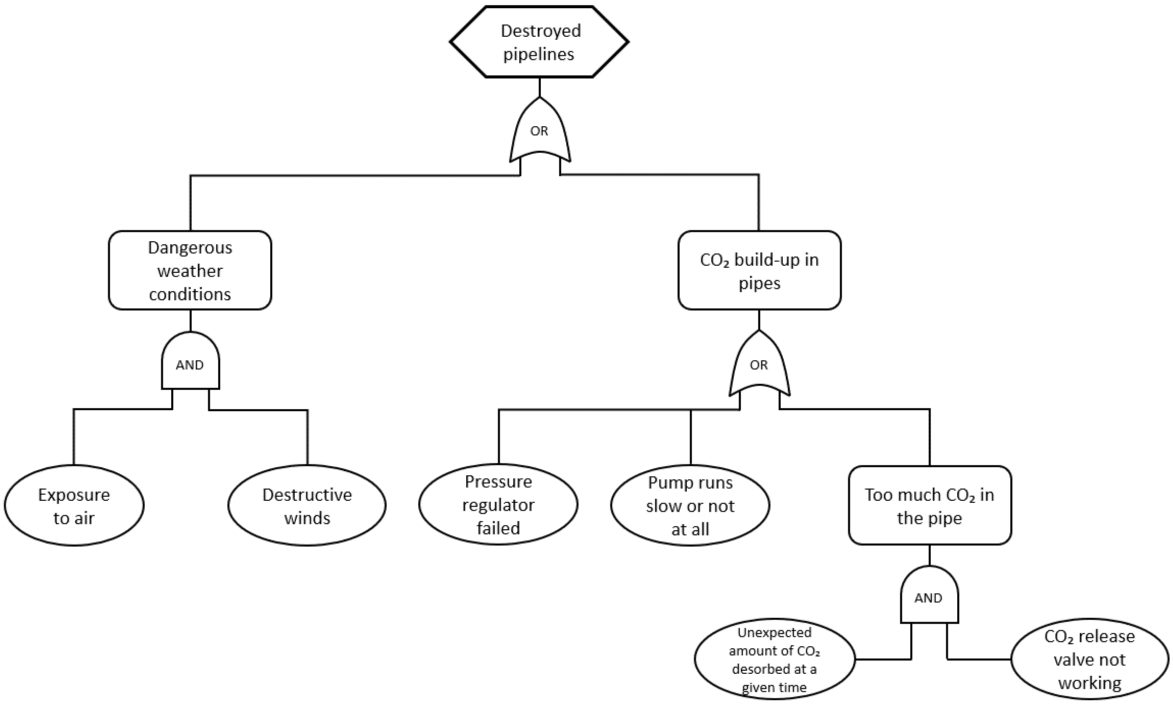
Failure space – Success Space



Hazop

Intents	**Guidewords**	**Causes**
Air capture	No	Broken fans? Leak in pipe?
CO_2 extraction	No	Pump failure? Chemicals not released?
Transportation of CO_2	No, Reverse	Leak in pipe? Pump failure? No power?
Storage	Less	Incorrect pressure?
Power	No	No power? Power source failure?
Reuse	Opposite	No opportunities to reuse?

FTA



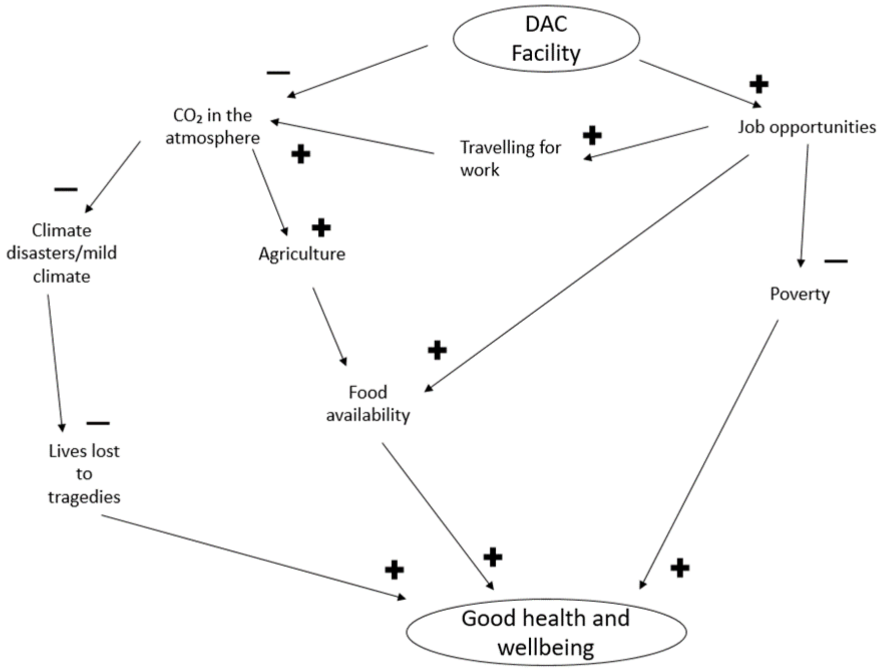
Looking at the failure space – Success space diagram for the facility we see that the maximum tolerable failure is a leak being in the pipes. This event is, therefore, wanted to be avoided as much as possible. It is also shown by the HAZOP table that a leak in the pipes will prevent the air from being captured and the CO_2 from being extracted. These intents being the main function of the facility means that with a leak in the pipes the entire facility stops running until it is fixed.

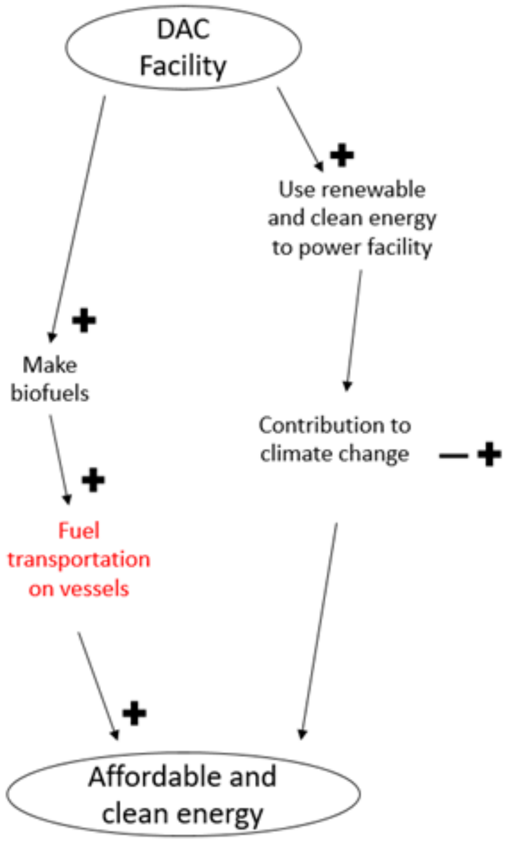
Breaking the event down into smaller issues that can add up using the FTA, or failure tree analysis, we can see various events which are much simpler to prevent. Since the pipes can be damaged by the weather if not properly protected a decision was made to either have the pipes inside or, when traveling out of the main buildings, underground to eliminate the 'exposure to air' where possible. If not, the pipe will be short to reduce the surface area exposed.

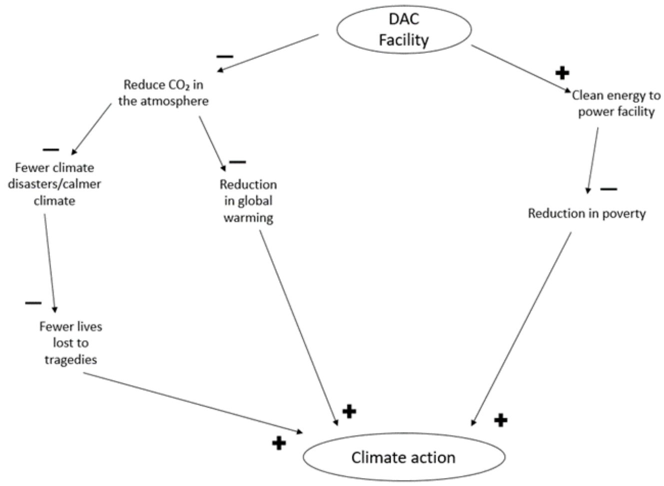
We can also see lots of failure events related to power being lost or no power being generated by the solar panels and wind turbines. This event cannot be avoided if the weather does not do what we want. However, we can get around these issues by having back-up generators/power for when we are not getting enough power to the system for it to run properly.

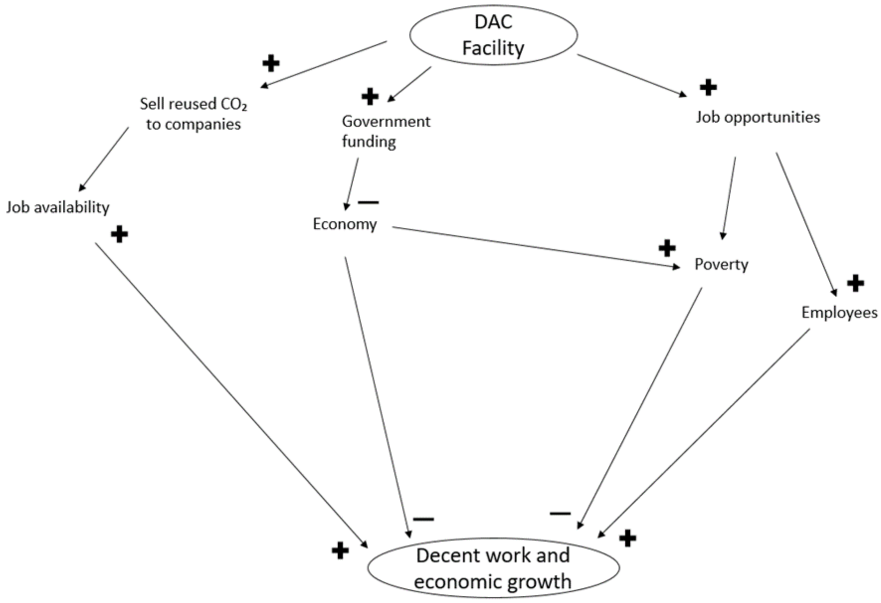
SUSTAINABILITY

Progression of the United Nations Sustainable Development Goals (SDG)









Life Cycle Analysis:

Requirements for material of facility:

The materials required for the facility must be thought about critically. The facility should be designed to last if possible but consideration for how components of the facility will be dealt with at the end of their life i.e., how they will be recycled or disposed of, must be thought about. The materials selected should also have a low carbon footprint in their manufacture and transport, hence CES Edupack will be used to obtain information for different materials.

Fans:

The fans and the compressor will be placed outside the facility. Therefore, we must consider not only rain, where certain metals can rust but also the impact of heavy hail and relatively hot days with direct sunlight, both of which can be extreme in Sydney, Australia. re, the two major materials the fans will be made from are plastic and of course, metal for the casing, below is a bubble diagram which helps justify which material we chose:

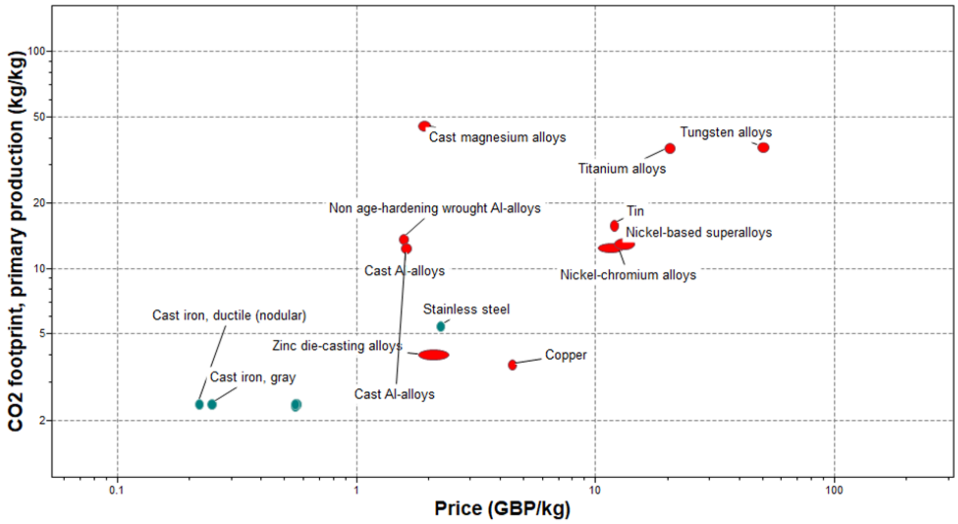


Figure 1 shows the relationship between price and CO2 produced from production for various metals and alloys

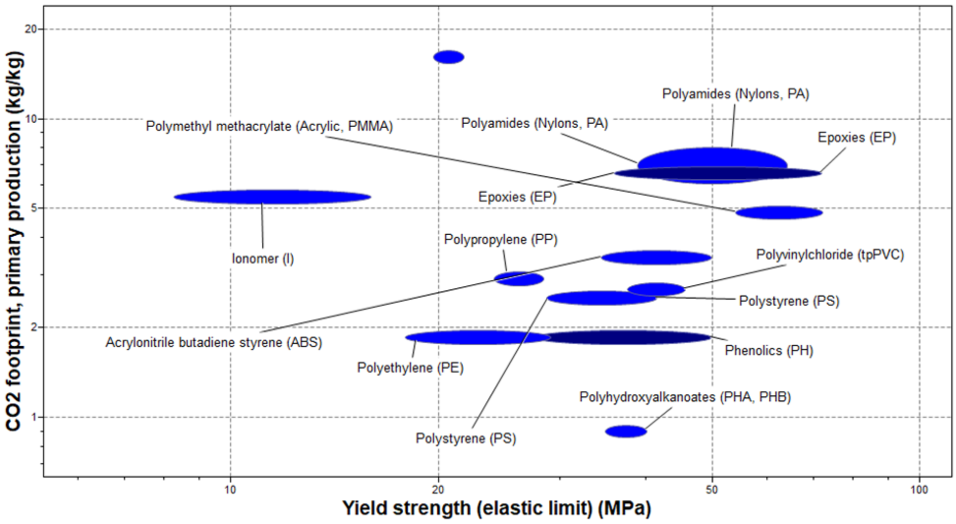
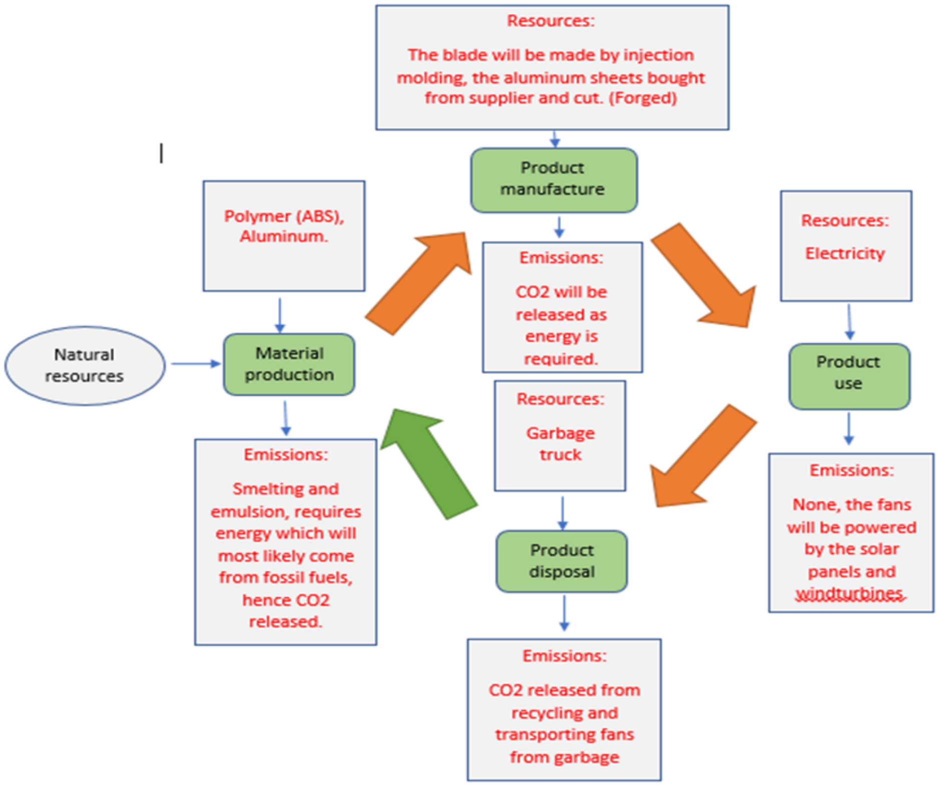


Figure 2 shows the relationship between CO2 released from production and yield strength for polymers

From figure 1 we can see that the irons and its alloys are the best when it comes to a good balance of CO2 production and price, followed by aluminium and stainless steels. However, unlike aluminium and stainless steel, the iron alloys are prone to rusting and corroding much quicker than aluminium and stainless steel. Stainless steel is also a lot more difficult to recycle when compared to aluminium, therefore for the main casing of the aluminium would be more ideal. As for the polymers, we have chosen ABS plastics as though it may not be as strong and green as the other polymers, it is a lot easier to manufacture in terms of making the fan blades and is not biodegradable, which in this case helps it be a more all-weather material.

Life cycle analysis of fans:



Compressor, storage tanks and pump:

The compressor, storage tanks, and pump need to be made from a very strong material, with a very low young modulus as we do not want any sort of deflection from the high pressures in the tank or the high pressures generated from the compression. They must also be durable and long-lasting and should not corrode in all weather conditions. Below are 2 figures which give details of the most relevant metals and alloys and their properties.

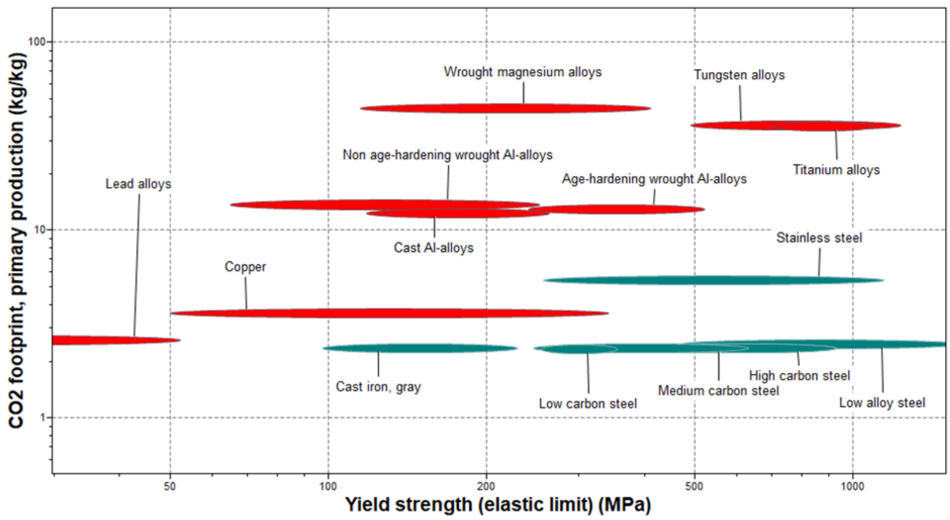
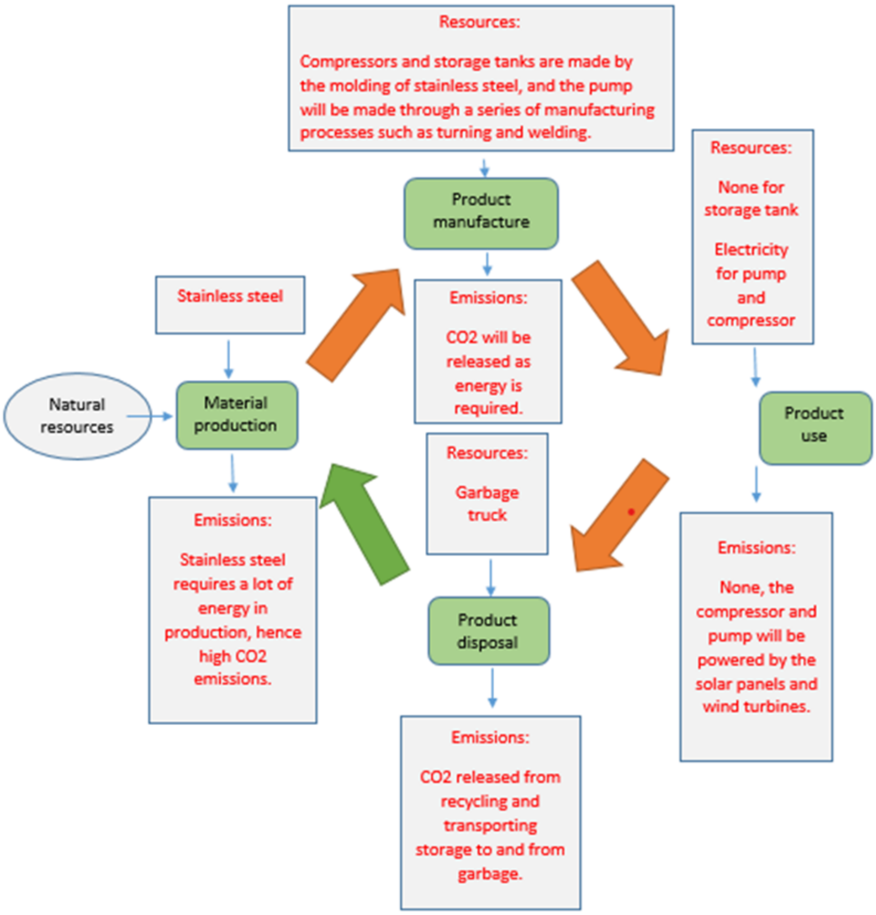


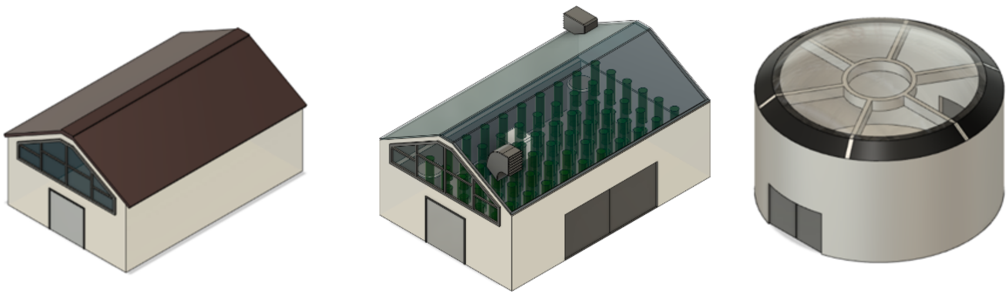
Figure 4 shows the relationship between the thermal expansion coefficient and price

From figure 3 we can see that the four steels perform the best when it comes to a good ratio between yield strength and CO2 produced form their manufacture. However, in figure 4 we can see that titanium and tungsten alloys were the best when it came to resistant thermal expansion which is crucial in a hot climate like Australia. However, the cost and strength of stainless steel outweighs the other factors, and stainless steel's resistivity to corrosion is very advantageous in this case, hence stainless steel would be used for the storage, compressor tanks and pump.

Life cycle analysis of pump, compressor and storage tanks:



<u>Buildings:</u>



The buildings will be made from materials that are as simple as possible to minimize the transport of goods and keep carbon emissions as low as possible. The materials we have chosen for the main body of these buildings involve concrete, glass, steel rods (for the structure), and metal sheets for the roof – type of metal will be discussed and backed below. The reason why we have chosen steel rods is that they are cheap and readily available; they are also manufactured in large amounts which keeps the carbon emissions relatively low (per rod). We have chosen concrete because one of the processes in the reuse stage involves using CO2 to create calcium carbonate, which is then used in the production of concrete – hence we can aim to offset the concrete we have used, further pushing for carbon neutrality. Below is figure 6 which shows the relationship between cost and CO2 released from production for various metals; this data can be used to find suitable materials for the metal sheet roof.

Primary material production: energy, CO2 and water

Embodied energy, primary production	0.779	-	0.859	MJ/kg
CO2 footprint, primary production	0.116	-	0.128	kg/kg
Water usage	* 3.23	-	3.57	l/kg

Figure 5 shows the CO2 footprint to produce concrete as well as other information

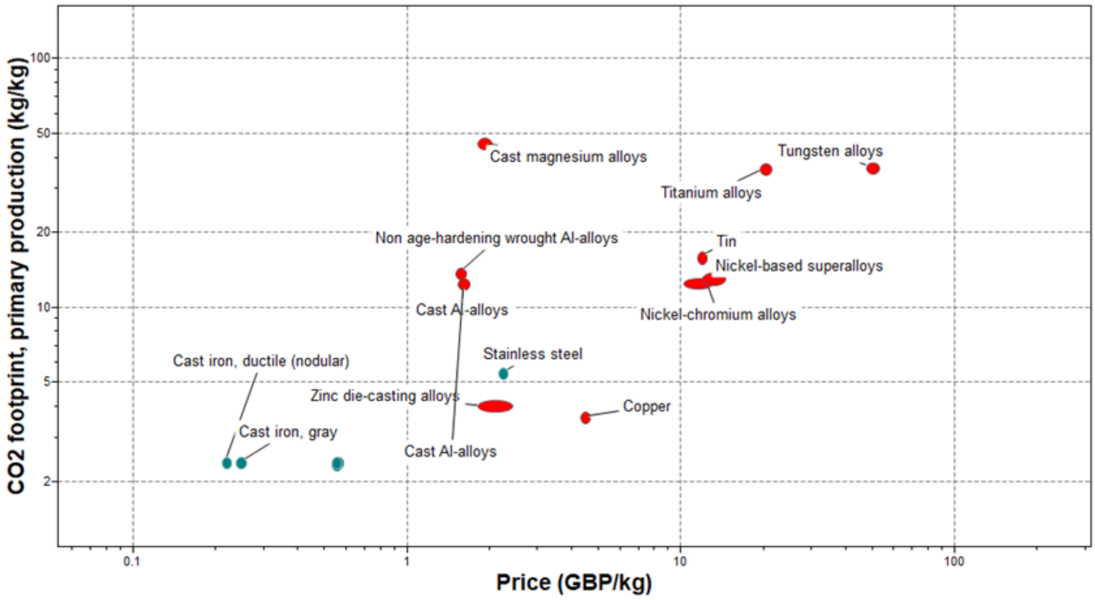
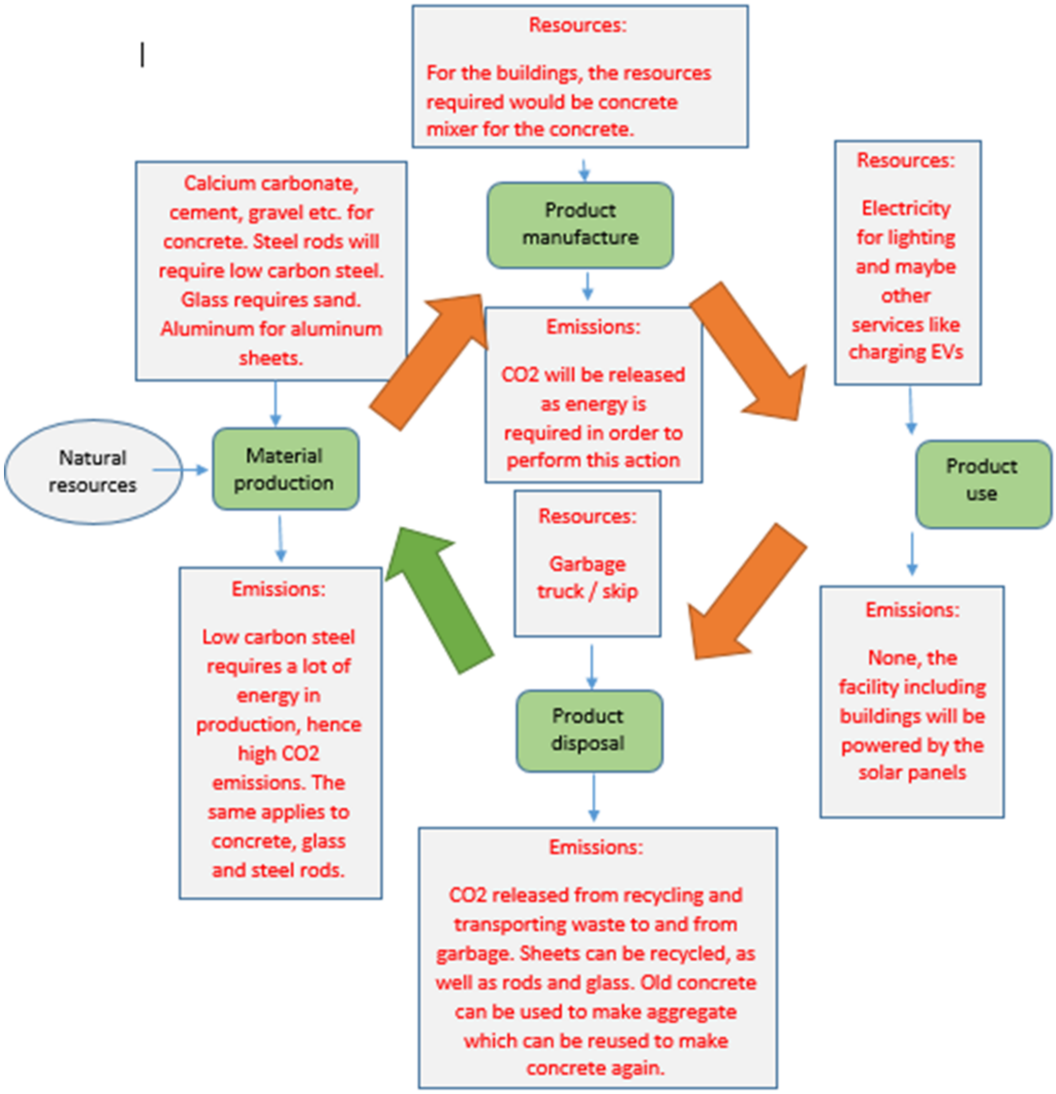


Figure 6 shows the relationship between CO2 from production and price, for various metals and alloys

From figure 6 we can see that iron, zinc die-casting alloys, stainless steel, copper and aluminium have a great price to CO2 footprint ratio. However, there are more factors to consider for example, of these metals only stainless steel and aluminium are resistive to corrosion and are relatively unreactive. We must also consider ease of manufacture and CO2 released from the manufacture of these sheet metals – aluminium is very easy to work with and shape (easier than stainless steel) therefore aluminium sheets will be used.

Life cycle analysis for buildings:



<u>Wind turbines and solar:</u>

The lifecycle analysis below shows how much carbon dioxide is released from the production of wind turbines and solar panels. It is better to buy solar panels and wind turbines from the manufacture than to create them hem we, as it will be a lot more cost efficient and environmentally friendly.

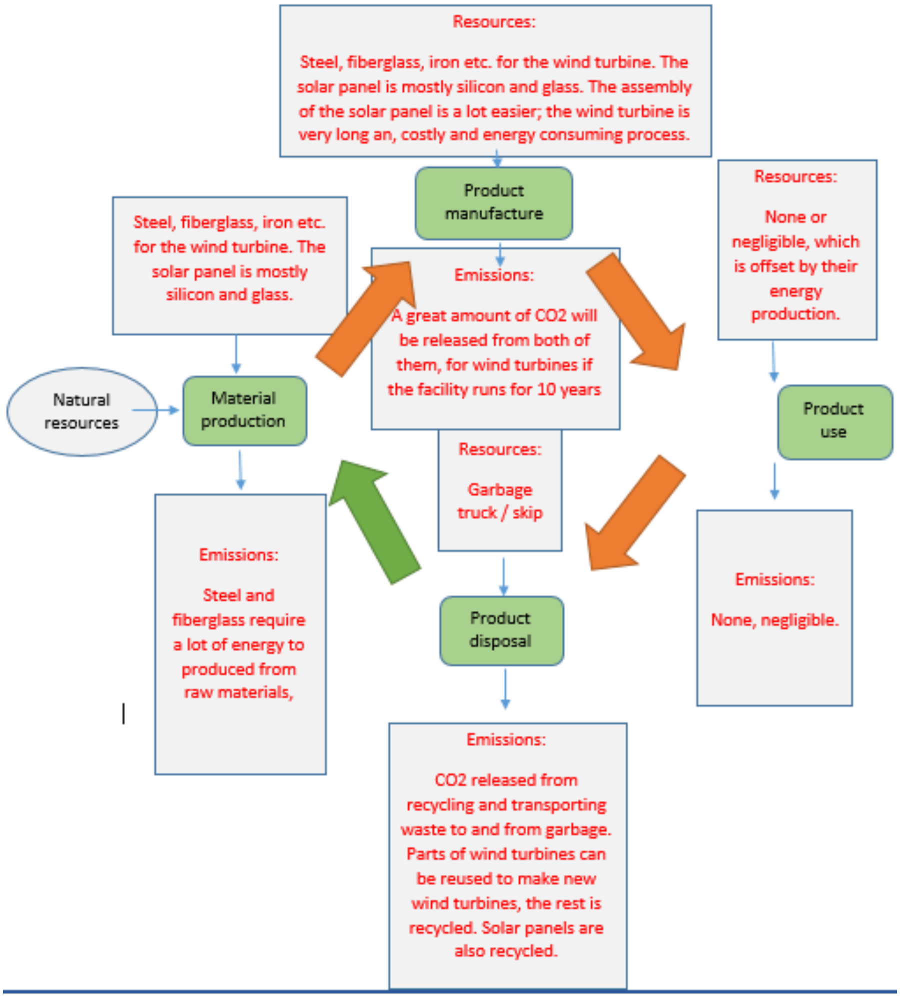
Wind turbines:

The wind turbines will use energy from wind to generate power for the DAC facility. However, despite emissions being negligible when in use, wind turbines cost a lot of money and cause a lot of CO2 release from their manufacture and their disposal. For the average wind turbine, 11 grams of CO2 will be released per kWh of energy it produces. Assuming only the wind turbines alone, for 10 years, power the plant (which has an energy consumption of approximately 62 million kWh), the total amount of CO2 released from the turbine would be 682,000 kg of CO2 released from all three wind turbines – however, we have assumed that the life of the wind turbines is only 10 years which is not true.

Solar panels:

Solar panels are a major source of renewable energy, especially in a place like Australia. Australia, Sydney has a high number of daylight hours per year and relatively more sunny days than cloudy days. We can expect 6 grams of CO_2 released per kWh of energy produced from the solar panel. The solar panels will be used as more of backup or to power processes that do not relate to the main processes, as the three turbines are already sufficient; so, the wind is an unreliable variable; hence it is good to have a backup.

Life cycle analysis for solar panel and wind turbine:



References:

1. Angelika Spyroudi, "The race to reduce the carbon footprint of wind energy", *ore.catapult* catapult, 14/04/2021. Available from: https://ore.catapult.org.uk/blog/race-reduce-carbon-footprint-wind-energy/#:~:text=When%20considering%20a%20wind%20turbine's,from%20a%20natural%20gas%20plant.
2. Simon Evans, "solar, wind and nuclear have 'amazingly low' carbon footprints, study finds", *carbonbreif*, 08.12.2017. Available from: https://www.carbonbrief.org/solar-wind-nuclear-amazingly-low-carbon-

footprints#:~:text=The%20study%20finds%20each%20kilowatt,wind%20is%20also%204gCO2e%2FkWh.

BUSINESS CASE

PEST Analysis

1) **Political:**

Australia follows a federal constitutional monarchy and liberal democracy model of administration. The government holds a high degree of transparency that allows foreign investors to operate according to local laws and regulations which can vary between different states and territories. We will therefore need to work with local specialists who have an advanced knowledge on construction practice and regulations to avoid any legal action against our organization. In addition, we will need the government's approval for the use or purchase of the plot of land located in a national park in the surroundings of Sydney.

2) **Economical:**

Australia holds the 13th spot for being the largest economy in the world. The favorable economic climate of Australia makes it an exciting choice for investors. In addition, Australia has had a prosperous industrialization which makes it one of the countries that produce the most carbon dioxide emissions. This factor can bring substantial opportunities in the carbon dioxide capture facilities in the region. Furthermore, the DAC facility will play an important role in improving the economy of the country as locals will get job opportunities in all aspects of the project and will attract a considerable number of investors. An economic analysis of the project will be required before the initiation of the construction process. An accurate estimate of the overall cost of the project will have to be determined including the cost of the patents, research and initial designs. Salaries and maintenance cost will also need to be considered for the near future. Finally, the DAC facility is a business that will need cash intakes and provide profits in the long term. The exchange rate of the local currency will need to be analyzed. The carbon dioxide collected will also need to be sold to companies that will reuse the product in a responsible way. Therefore, a developed analysis of the carbon dioxide market will need to be made, with all the companies and sectors that might be involved with the facility.

3) **Sociological:**

Climate change has become a growing concern amongst populations around the world. Groups of activists can put a considerable amount of pressure on the government as well as our organization. It is therefore crucial that the public understands the nature of the facility and its main objective. We are aware that the technology and the general concepts behind the DAC facility are very recent and not known by the public yet. Therefore, we will need to come up with an advertisement campaign to promote our facility and bring a positive opinion of our project to the public. An example of the ways by which this can be achieved is the Building Information Model (BIM) of the project which will allow the public to have a realistic idea of the DAC facility. The public opinion will be key to the success of the project.

4) **Technological:**

We are aware that the technology involved in the facility is still very recent. It will therefore be very hard to maintain a high efficiency of the facility and avoid any risk related factors that may affect the process of capturing and storing the capture of the carbon dioxide. A very little amount of this kind of facility is operational today. Therefore, we will need to increase the amount of research by providing the government with a research program in order to allow the facility to constantly improve throughout the years. This will also help us guarantee the health and safety of everyone involved in the project.

APPENDICES

APPENDIX A: MEETING LOG

Week	**Agreed Actions**	**Attendees**
1	//	Khalil, Andrew, Udayan, odysseas, Pinyu, Hassan
2	//	Andrew, Udayan, odysseas, Pinyu, Hassan
3	Provide more work to mentor	Khalil, Andrew, Udayan, odysseas, Pinyu, Hassan
4	//	Khalil, Andrew, Udayan, odysseas, Pinyu, Hassan
5	Make drawings and add to CAD, add annotations to the drawings	Khalil, Andrew, Udayan, odysseas, Pinyu, Hassan
6	//	Khalil, Andrew, Udayan, odysseas, Pinyu

APPENDIX B: ACADEMIC MENTOR MEETING FORMS

IDP2 2021/22: Weekly academic mentor meeting record	
Stage-Gate *(you should have a meeting form for each week/stage-gate) Numbers refer to weeks.*	
☐1 INTRO to Plan stage-gate ☐2 PLAN to Research stage-gate ☐3 RESEARCH to Requirements stage-gate ☐4 REQUIREMENTS to Design stage-gate ☐5 DESIGN to Assignment 1 stage-gate	☐7 INTRO to Plan stage-gate ☐8 PLAN to RESEARCH stage-gate ☐9 RESEARCH to Requirements stage-gate ☐10 REQUIREMENTS to Design stage-gate ☐11 DESIGN to Assignment 2 stage-gate
Stage Progress: *(The group should complete this before the meeting). LIST the work you will present to your mentor. Your academic mentor is NOT a subject-matter expert on your challenge. They will discuss and facilitate your group's progress, and provide formative feedback on the work you bring them each week)* In week 1, we have learned what we have to do individually, i.e., we have assigned each other tasks and have decided on a module leader. The Belbin tests allowed us to understand our team members and assign them roles related to their skills. The first task as a group was to list hopes and fears, we did this using the IBM project management tool. The hopes and fears exercise gave us a good insight into what we are trying to achieve and what complications we are expecting to encounter. Generally, our hopes are to have the project finished on time, with equal contribution from everybody. Our fears include lack of participation and effort from team members, as this will hinder the project a lot.	
Group functioning issues: *(The group should complete this before the meeting) Specific non-technical issues hindering group performance. These may include punctuality, attendance, lack of preparation, disruption, dominant personalities, work quality, and what can be done to improve matters.* As it is only week 1, we have not had any major issues yet, meeting with everyone was not an issue. Everyone knows what they are doing and will proceed to research their topics relating to the direct air capture facility at home.	
What is being done well in this stage and what could be improved *(The academic mentor should complete this). This is your group's formative feedback you should use to improve your work.* We have efficiently assigned everyone work relating to the skills they have, which were calculated from the Belbin tests. So far as it is only week 1, there are no issues.	
Initialled Present: Hassan, Khalil, Uduyan, Odysseas, Pinyu, Andrew Absent: Group number: 55	
Initialled Academic mentor:	

Date:

IDP2 2021/22: Weekly academic mentor meeting record	
Stage-Gate *(you should have a meeting form for each week/stage-gate) Numbers refer to weeks.*	
☐1 INTRO to Plan stage-gate ☐2 PLAN to Research stage-gate ☐3 RESEARCH to Requirements stage-gate ☐4 REQUIREMENTS to Design stage-gate ☐5 DESIGN to Assignment 1 stage-gate	☐7 INTRO to Plan stage-gate ☐8 PLAN to RESEARCH stage-gate ☐9 RESEARCH to Requirements stage-gate ☐10 REQUIREMENTS to Design stage-gate ☐11 DESIGN to Assignment 2 stage-gate
Stage Progress: *(The group should complete this before the meeting). LIST the work you will present to your mentor. Your academic mentor is NOT a subject-matter expert on your challenge. They will discuss and facilitate your group's progress, and provide formative feedback on the work you bring them each week)* Week 2 was an introduction into how we are all (apart from the group coordinator) are expected to find sources and write research journals onto the templates provided onto canvas. We are expected to do about 5-10, and the research will be about the topic assigned to each person. The other part of this week was for the Grant chart, the group coordinator has taken on the responsibility to make sure it is completed to a suitable degree.	
Group functioning issues: *(The group should complete this before the meeting)* *Specific non-technical issues hindering group performance. These may include punctuality, attendance, lack of preparation, disruption, dominant personalities, work quality, and what can be done to improve matters.* A few issues that we had were not understanding the deliverables for this project, specifically the research part. As a group, we were not sure whether we were required to do just journal templates and a summary, or also a report as well as the other 2 things. We were also unsure about the size that our research journals should be, as the example provided was quite small and basic, which we feel would not be enough information to get across. Luckily, in the end, the lecturer was able to help us with this.	
What is being done well in this stage and what could be improved *(The academic mentor should complete this). This is your group's formative feedback you should use to improve your work.* Everyone is happy with their part, despite the hardship in deciding how to write up the research, nobody has a problem with the difficulty of their part, which is a good sign of progress.	
Initialled Present: Hassan, Khalil, Uduyan, Pinyu, Andrew, and Odysseas. Absent: Group number: 55	
Initialled Academic mentor: Date:	

IDP2 2021/22: Weekly academic mentor meeting record	
Stage-Gate *(you should have a meeting form for each week/stage-gate) Numbers refer to weeks.*	
☐1 INTRO to Plan stage-gate ☐2 PLAN to Research stage-gate	☐7 INTRO to Plan stage-gate ☐8 PLAN to RESEARCH stage-gate

☐3 RESEARCH to Requirements stage-gate ☐4 REQUIREMENTS to Design stage-gate ☐5 DESIGN to Assignment 1 stage-gate	☐9 RESEARCH to Requirements stage-gate ☐10 REQUIREMENTS to Design stage-gate ☐11 DESIGN to Assignment 2 stage-gate

Stage Progress: *(The group should complete this before the meeting). LIST the work you will present to your mentor. Your academic mentor is NOT a subject-matter expert on your challenge. They will discuss and facilitate your group's progress, and provide formative feedback on the work you bring them each week)*

Week 3 involved a lot of work beside the research journals, the week was about sustainability. Sustainability is one of the most important things to think about, as the whole point of the DAC facility is to offset the amount of CO2 released from creating the actual site and running the site. We did find the workload a bit hard however, from week 3 we have decided to assign each member activities, for instance, Hassan, Odysseas will do the first activity from now on, while Pinyu and Uduyan would do the second activity. Khalil would develop the objective tree and the sustainability diagrams.

Group functioning issues: *(The group should complete this before the meeting)* Specific *non-technical issues hindering group performance. These may include punctuality, attendance, lack of preparation, disruption, dominant personalities, work quality, and what can be done to improve matters.*

Only difficulty was that we did not properly assign the group members relevant work, so we had fallen behind a tiny bit, however now we have agreed on a suitable approach to tackle the lab exercises weekly.

What is being done well in this stage and what could be improved *(The academic mentor should complete this). This is your group's formative feedback you should use to improve your work.*

The actual worksheets are straightforward so there are no problems in understanding the work, which is good, however as said before, we need to improve how we all tackle these lab exercises as a group.

Initialled Present: Hassan, Khalil, Odysseas, Pinyu, Andrew, and Uduyan.
Absent:
Group number: 55

Initialled Academic mentor:
Date:

IDP2 2021/22: Weekly academic mentor meeting record	
Stage-Gate *(you should have a meeting form for each week/stage-gate) Numbers refer to weeks.*	
☐1 INTRO to Plan stage-gate ☐2 PLAN to Research stage-gate ☐3 RESEARCH to Requirements stage-gate ☐4 REQUIREMENTS to Design stage-gate ☐5 DESIGN to Assignment 1 stage-gate	☐7 INTRO to Plan stage-gate ☐8 PLAN to RESEARCH stage-gate ☐9 RESEARCH to Requirements stage-gate ☐10 REQUIREMENTS to Design stage-gate ☐11 DESIGN to Assignment 2 stage-gate
Stage Progress: *(The group should complete this before the meeting). LIST the work you will present to your mentor. Your academic mentor is NOT a subject-matter expert on your challenge. They will discuss and facilitate your group's progress, and provide formative feedback on the work you bring them each week)*	

The activities in week 4 included the risk and reliability exercise and lab enterprise exercise. Through these exercises we gained an insight into some of the key financial aspects of the project that included factors such as the business organisation, business structures, the PEST analysis, the marketing and the financial accounting aspects involved in a direct air capture project working.
Group functioning issues: *(The group should complete this before the meeting) Specific non-technical issues hindering group performance. These may include punctuality, attendance, lack of preparation, disruption, dominant personalities, work quality, and what can be done to improve matters.* Minor problems in assigning roles for each member arose in the start of the week but were soon resolved and the roles of each member were assigned to them respectively. The tasks given to each member were carried forth well and the progress made was to a satisfactory remark.
What is being done well in this stage and what could be improved *(The academic mentor should complete this). This is your group's formative feedback you should use to improve your work.* There currently are no problems whatsoever and each member is progressing well with their respective given tasks. Looking at the current progress it is an indicator of things running smoothly and on track and we expect to wind up our work on schedule
Initialled Present: Hassan, Khalil, Uduyan, Odysseas, Andrew and Pinyu. Absent: Group number: 55
Initialled Academic mentor: Date:

IDP2 2021/22: Weekly academic mentor meeting record	
Stage-Gate *(you should have a meeting form for each week/stage-gate) Numbers refer to weeks.*	
☐1 INTRO to Plan stage-gate ☐2 PLAN to Research stage-gate ☐3 RESEARCH to Requirements stage-gate ☐4 REQUIREMENTS to Design stage-gate ☐5 DESIGN to Assignment 1 stage-gate	☐7 INTRO to Plan stage-gate ☐8 PLAN to RESEARCH stage-gate ☐9 RESEARCH to Requirements stage-gate ☐10 REQUIREMENTS to Design stage-gate ☐11 DESIGN to Assignment 2 stage-gate
Stage Progress: *(The group should complete this before the meeting). LIST the work you will present to your mentor. Your academic mentor is NOT a subject-matter expert on your challenge. They will discuss and facilitate your group's progress, and provide formative feedback on the work you bring them each week)* **Work to show:** -Conceptual design -Risk Reliability exercise -Sustainability 2 (completed) -Objective tree (Storage) -Journals club completed **To be discussed:** -Business case -Schematics required for storage and reuse	

-Conceptual design (drawings?)
Group functioning issues: *(The group should complete this before the meeting) Specific non-technical issues hindering group performance. These may include punctuality, attendance, lack of preparation, disruption, dominant personalities, work quality, and what can be done to improve matters.* Lack commitment and independent skills from certain group members significantly impacts and hinders progression, I.e., incomplete tasks cause further tasks from being completed.
What is being done well in this stage and what could be improved *(The academic mentor should complete this). This is your group's formative feedback you should use to improve your work.*
Initialled Present: Khalil, Hassan, Odysseas, Udayan, Pinyu, Andrew Absent: Group number: 55
Initialled Academic mentor: Date:

IDP2 2021/22: Weekly academic mentor meeting record	
Stage-Gate *(you should have a meeting form for each week/stage-gate) Numbers refer to weeks.*	
☐1 INTRO to Plan stage-gate ☐2 PLAN to Research stage-gate ☐3 RESEARCH to Requirements stage-gate ☐4 REQUIREMENTS to Design stage-gate ☐5 DESIGN to Assignment 1 stage-gate	☐7 INTRO to Plan stage-gate ☐8 PLAN to RESEARCH stage-gate ☐9 RESEARCH to Requirements stage-gate ☐10 REQUIREMENTS to Design stage-gate ☐11 DESIGN to Assignment 2 stage-gate
Stage Progress: *(The group should complete this before the meeting). LIST the work you will present to your mentor. Your academic mentor is NOT a subject-matter expert on your challenge. They will discuss and facilitate your group's progress, and provide formative feedback on the work you bring them each week)* There were no activities set this week, hence we used this time to finish all our lab exercises and we have started to finalise our CAD. It appears all journal templates have been finished, and now we have sustainability to complete, which requires the energy consumption of everybody's part.	
Group functioning issues: *(The group should complete this before the meeting) Specific non-technical issues hindering group performance. These may include punctuality, attendance, lack of preparation, disruption, dominant personalities, work quality, and what can be done to improve matters.* The issues were are facing include running out of time as a lot of uncertainties about certain exercises and work has caused some members to dwell too long on things, however we can see us finishing before the deadline.	
What is being done well in this stage and what could be improved *(The academic mentor should complete this). This is your group's formative feedback you should use to improve your work.* Right now we believe the CAD is at a very proficient level, we have both initial designs and final designs, and we have thought deeply about practicality such as location and energy demands. We could improve now by spending our last few days to structure the report at a good level.	

Initialled Present: Hassan, Khalil, Uduyan, Odysseas, Andrew and Pinyu. Absent: Group number: 55
Initialled Academic mentor: Date:

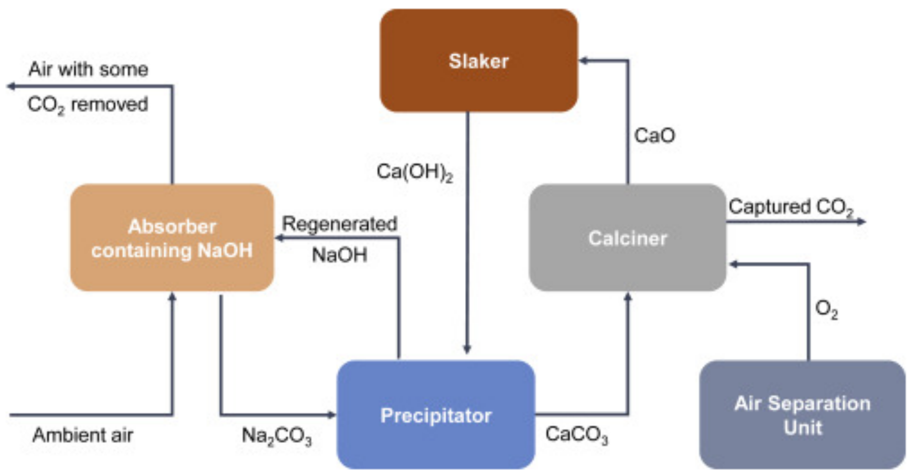
APPENDIX C: RESEARCH JOURNAL CLUB REPORTS

Air Capture:

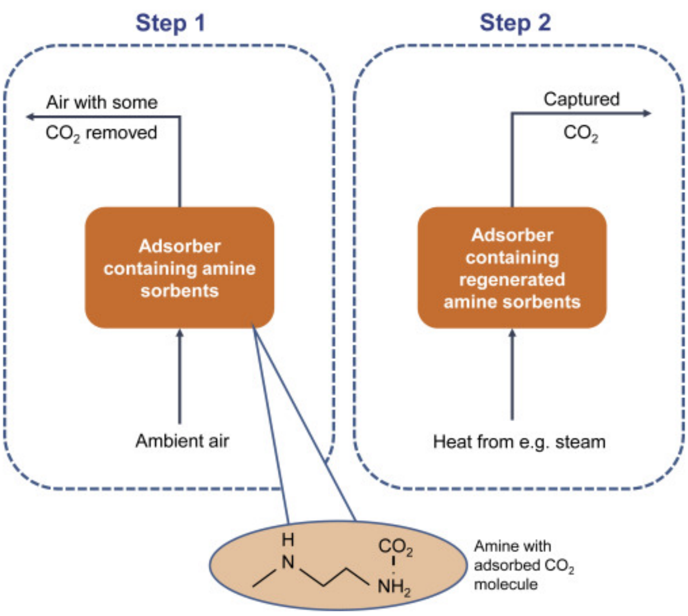
Journal Paper / Book Chapter / Article citation: Ajay Gambhir, Massimo Tavoni, Direct Air Carbon Capture and Sequestration: How It Works and How It Could Contribute to Climate-Change Mitigation,

https://www.sciencedirect.com/science/article/pii/S2590332219302167

Summary: This journal explains what direct air capture and sequestration is and how it works, focusing on the two major processes.
Questions (Aims): • Why Direct air carbon capture and sequestration (DACCS) is important? • How does (DACCS) work in general? • How does DACCS work using base sorbents? • How does DACCS work using solid sorbents?
Answers (Knowledge): • The primary premise of DACCS is that, even though CO2 is not substantially concentrated in the atmosphere (it occurs at little over 400 parts per million by volume (ppmv)), significant amounts may be removed each year by exposing huge volumes of air to chemicals known as sorbents. • The sorbents function in essentially two ways. The first is absorption, in which CO2 is absorbed by the sorbent material. Adsorption is the second process, in which CO2 molecules cling to the surface of the sorbent substance. • Placing ambient air in contact with a strong liquid base, such as potassium hydroxide (KOH) or sodium hydroxide (NaOH), which dissolves CO2, is the most technically mature method for capturing atmospheric CO2. This also causes a chemical interaction between the CO2 and the base, resulting in the formation of a carbonate solution, from which the CO2 can be extracted using a different method that involves mixing the carbonate solution with a calcium hydroxide (Ca(OH)2) solution in a precipitator. This regenerates the base and precipitates solid calcium carbonate (CaCO3) out of the base solution. The precipitate is then transferred to a calciner, where it reacts with oxygen (O2) from an air-separation unit at extremely high temperatures (about 800°C), yielding pure CO2 and calcium oxide (CaO). In a slaker, CaO is mixed with water to generate (Ca(OH)2), which can then be reused.



- The most common alternative design to the strong base variety of DACCS is to use solids (made of chemical compounds called amines) that adsorb (rather than absorb) atmospheric CO2 in a two-step process: step 1 involves adsorption of ambient CO2, while step 2 involves separation of the CO2 using low-temperature heat (around 100°C or less), pressure or humidity changes, or some combination of these to regenerate the sorbent (figure 2). Because adsorption results in a weaker link between the CO2 and the sorbent than absorption into a strong base, less energy is required to remove the CO2 from the amine sorbent.



Impact:
A general description of how DACCS work is given and different methods to consider for the air captured such as using liquid or solid sorbent. Design decisions are going to be made by the selection of the sorbent.

Actions:
- Further research upon the liquid and solid sorbents to decide which fits the best.
- Further research on other DAC plants to gain knowledge and inspiration on how to begin the conceptual design

Journal Paper / Book Chapter / Article citation: Stephen A. Rackley, 6 - Absorption capture systems,

https://www-sciencedirect-com.ezproxyd.bham.ac.uk/science/article/pii/B9780128120415000064

Summary: This chapter gives a description of chemical and physical absorption-based processes for removing CO_2 from gas streams.
Questions (Aims): • What are the different processes to capture CO2 based on absorption? • How does chemical absorption work? • How does the sodium hydroxide-based absorption work? • How does physical absorption processes work?
Answers (Knowledge): • There are two types of CO2 absorption procedures, depending on whether the solvent reacts chemically with the sorbate (CO2) to produce chemical compounds from which the CO2 is recovered or is chemically inert and absorbs the sorbate without a chemical reaction. These two processes are referred to as chemical and physical absorption. • Chemical absorption for CO2 collection is based on an exothermic interaction of a sorbent with CO2 contained in a gas stream, preferably at low temperature. In a process known as stripping, or regeneration, the reaction is then reversed at a higher temperature. Chemical absorption is especially well suited to CO2 capture at low partial pressures, with amine or carbonate solutions being the most common solvents. • The synthesis of carbonic acid from CO2 and water, as well as the formation of sodium bicarbonate or carbonate from sodium hydroxide (NaOH) and carbonic acid, are the key processes involved in the absorption of CO2 by sodium hydroxide. ➢ H2CO3 + NaOH → NaHCO3 + H2O ➢ NaHCO3+ NaOH → Na2CO3 + H2O • Rather of reacting chemically with acid gas components, physical absorption techniques use organic or inorganic physical solvents to absorb them. The amount of CO2 absorbed by a physical solvent at a given temperature is determined by the vapor–liquid equilibrium of a mixture, which states that the amount of a gas dissolved in unit volume of a solvent at a given temperature is proportional to the partial pressure of the gas in equilibrium with the solvent.
Impact: A general description of the two main processes to capture CO2 based on absorption is given. It can affect the selection of the method used in the plant.
Actions: Compare it with the adsorption process and decide which one fits best.

Journal Paper / Book Chapter / Article citation: Stephen A. Rackley, Adsorption capture systems,

https://www-sciencedirect-com.ezproxyd.bham.ac.uk/science/article/pii/B9780128120415000076

Summary: This chapter gives a description of chemical and physical adsorption while also gives examples for sorbents that could be applicable.
Questions (Aims): • How does adsorption work and what are the different processes? • What is the most appropriate temperature for each process? • What low temperature CO2 sorbents can be used? • What high temperature CO2 sorbents can be used?
Answers (Knowledge): • Adsorbed atoms or molecules (known as adparticles) remain on the surface of the sorbent, in contrast to absorption. However, similar to absorption, the sorbate can adhere to the surface by a chemical link (chemical adsorption or chemisorption) or a lesser physical attractive attraction (physical adsorption or physisorption). • Physical sorbents are used at low temperatures because of their weaker binding forces and lower heat of adsorption, whereas chemical sorbents, which have greater heats of adsorption, may maintain high capacity at higher temperatures. Low-temperature sorbents are commonly used at temperatures ranging from ambient to 100°C, whereas high-temperature CO2 sorbents are used at temperatures ranging from 400°C to 600°C. • Activated alumina, Activated carbon, Ion-exchange resins, MOFs, and Zeolites. • Metal oxides, Hydrotalcites, and Lithium zirconate
Impact: An explanation of adsorption and its' different processes is given. Examples of sorbents to be used in our plant are provided. It can have an impact at the total cost by choosing which sorbent is going to be used and in the design of the plant
Actions: Comparison between absorption and adsorption and choose what fit best.

Journal Paper / Book Chapter / Article citation: H. Hikita, S. Asai, T. Takatsuka, Absorption of carbon dioxide into aqueous sodium hydroxide,

https://www.sciencedirect.com/science/article/pii/S0300946776800354

Summary: This part gives an overview of the rates of absorption of pure carbon dioxide into aqueous sodium hydroxide

Questions:

- In what conditions did the reaction take place?
- What is the absorption rate of the chemical reaction between aqueous NaOH and CO2?

Answers:

Water and aqueous NaOH were utilized as absorbents. At atmospheric pressure, the gas phase was pure CO2 saturated with water vapor. The experiments were conducted out at a temperature of 30 degrees.

In the graphic below, the CO2 absorption rate NA is plotted versus exposure time t in logarithmic coordinates.

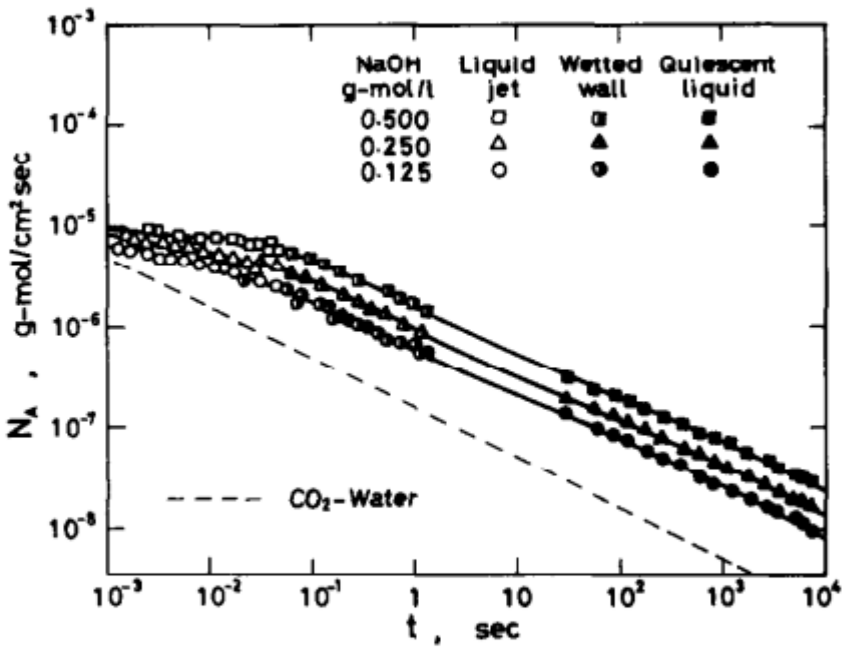


Fig. 6. Absorption rate of CO_2 into aqueous NaOH solutions at 30 °C.

Impact:

The chemical reaction between sodium hydroxide and pure carbon hydroxide is an effective way to extract the CO2 from the air and it could be used in the facility as the main method of clearing the air.

Actions: The usage of the sodium hydroxide as a liquid solvent is going to be considered for the use at the DAC facility.

Journal Paper / Book Chapter / Article citation: Tom Terlouw, Karin Treyer, Christian Bauer and Marco Mazzotti Life Cycle Assessment of Direct Air Carbon Capture and Storage with Low-Carbon Energy Sources

https://pubs.acs.org/doi/10.1021/acs.est.1c03263?fig=abs1&ref=pdf

Summary:

a comprehensive life cycle assessment of different DACCS systems with low-carbon electricity and heat sources required for the CO_2 capture process

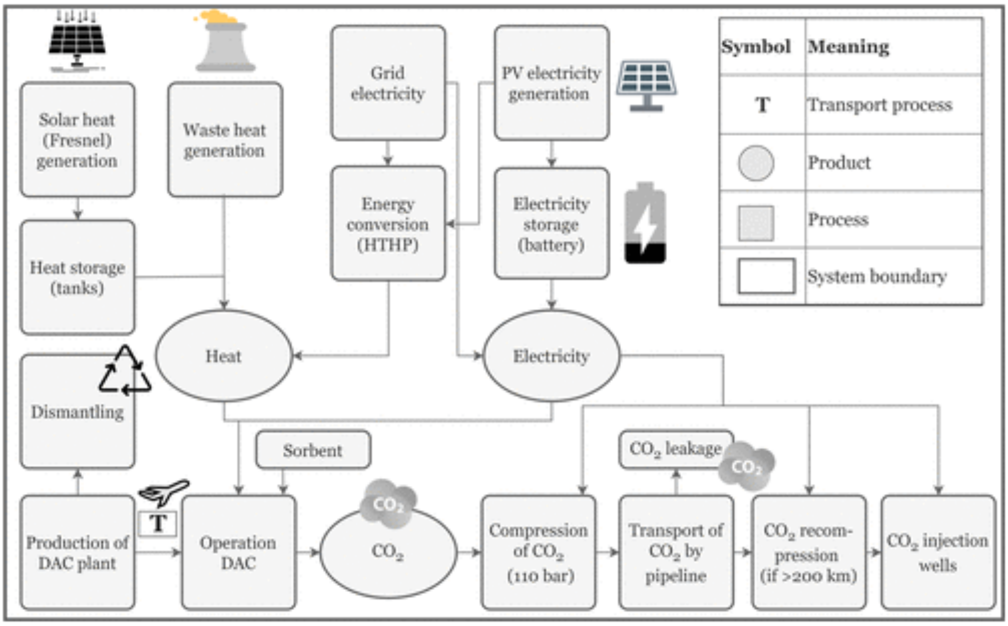
Questions:

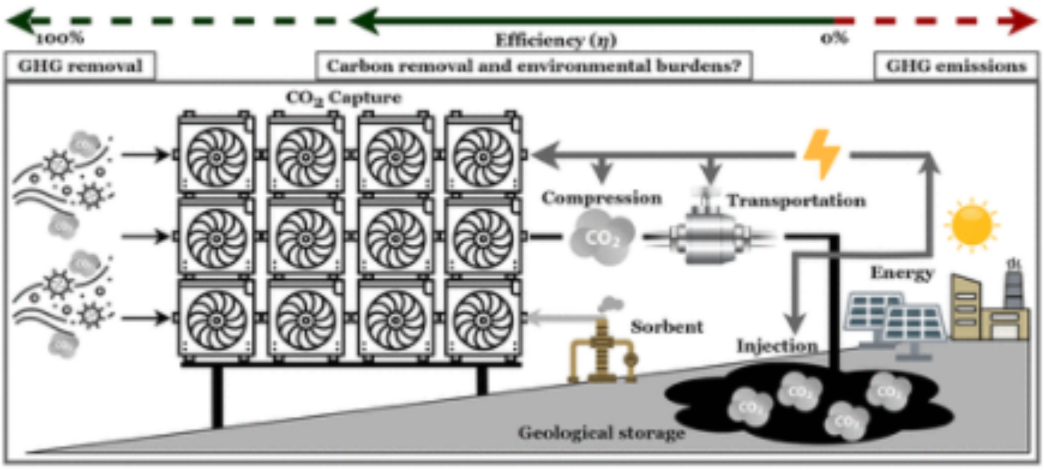
- How does a DAC facility operate?

• What is the main drawback of a DAC facility? • What are the two main methods for extracting CO2 from the air? • What is the main factor that determines the efficiency of a DAC facility? • How the electricity for the operation of the DAC facility is going to be acquired and the heat for the absorption process?

Answers:

- The two diagrams below show the operation of a DAC facility





- One disadvantage of direct air capture (DAC) is the high energy demand for CO2 extraction from the atmosphere.
- Aqueous solutions with high-temperature regeneration (up to 900 °C) or solid sorbents with low-temperature regeneration (less than 100 °C) are the most common DAC systems.
- climate benefits are influenced by energy sources used for CO_2 capture.
- Heat from a Fresnel solar-thermal heat collector and electricity from a PV installation. When there is enough sun irradiation, solar heat can be generated using Fresnel solar collectors. Fresnel solar collectors may generate steam temperatures of up to 400°C, making Fresnel solar heat an ideal heat source for industrial

applications as well as DAC systems. A temperature of 100 °C is necessary for CO_2 desorption.
Impact: It gives an overview of the whole process for the operation of the DAC facility
Actions: Consider following the recommended process or adopt some of the main ideas

Journal Paper / Book Chapter / Article citation: Negative Emissions Technologies and Reliable Sequestration: A Research Agenda (2019) Chapter: 5 Direct Air Capture

https://www.ncbi.nlm.nih.gov/books/NBK541435/

Summary: In this chapter an explanation of the operation of the DAC facility is given as well as the procedure needed to calculate energy requirements.
Questions: • What attributes does the design of a DAC facility need? • What would be the process of a liquid solvent-based direct air capture system? • How does the air contactor work? • What considerations do we need to take for the pressure drop? • How can we calculate the work of the fun? • What happens in the slaker? • What happens in the causticizer? • What happens in the calciner?
Answers: • An air contactor and a regeneration facility were built into the design of both direct air collection approaches. In general, a practical process necessitates the following five characteristics: Because the low concentration of CO_2 in air necessitates passage of large gas volumes through the contactor, a low-cost air contactor is required; (2) optimal CO_2-sorption thermodynamics, which entails having a sorption isotherm with suitably high CO_2 uptake at CO_2 partial pressures below 500 ppmv to minimise sorbent inventory and overall process size. Because of the need for high CO_2 uptake at low partial pressures, sorbents must have strong chemical interactions with CO_2, as opposed to separation processes that operate at higher CO_2 partial pressures, which can use sorbents with lower physical contacts. (3) quick sorption/desorption kinetics, resulting in rapid sorption and desorption, faster cycling, and hence less sorbent being required for the same output; (4) low sorbent regeneration energy, such that the CO_2 binding energy is high enough to obtain a decent uptake capacity but not so high that endothermic sorbent regeneration energy necessitates unacceptably high regenerator costs. Furthermore, effective process designs will minimise the thermal mass of equipment that is repeatedly thermally cycled between sorption and desorption—

that is, the process's sensible heat should be minimised; and (5) low capital costs, which applies to virtually any process but is especially relevant for direct air capture systems, where the lifetime of sorbent media can be a significant capital cost in some designs.

- The air contactor and regeneration facility are the two main components of a liquid solvent direct air capture method. In this procedure, CO2 from the air combines with an aqueous potassium hydroxide solution (KOH) to form water and potassium carbonate (K2CO3) in an air contactor. The potassium carbonate aqueous solution is then sent through a causticizer, where it reacts with calcium hydroxide (Ca(OH)2) to produce calcium carbonate (CaCO3). The CaCO3 slurry is then filtered and clarified before being fed to a calciner, where the CaCO3 precipitate is heated to around 900°C in an oxy-fired kiln with natural gas, generating solid calcium oxide (CaO) and high-purity CO2 gas that can be compressed and transported for long term sequestration.

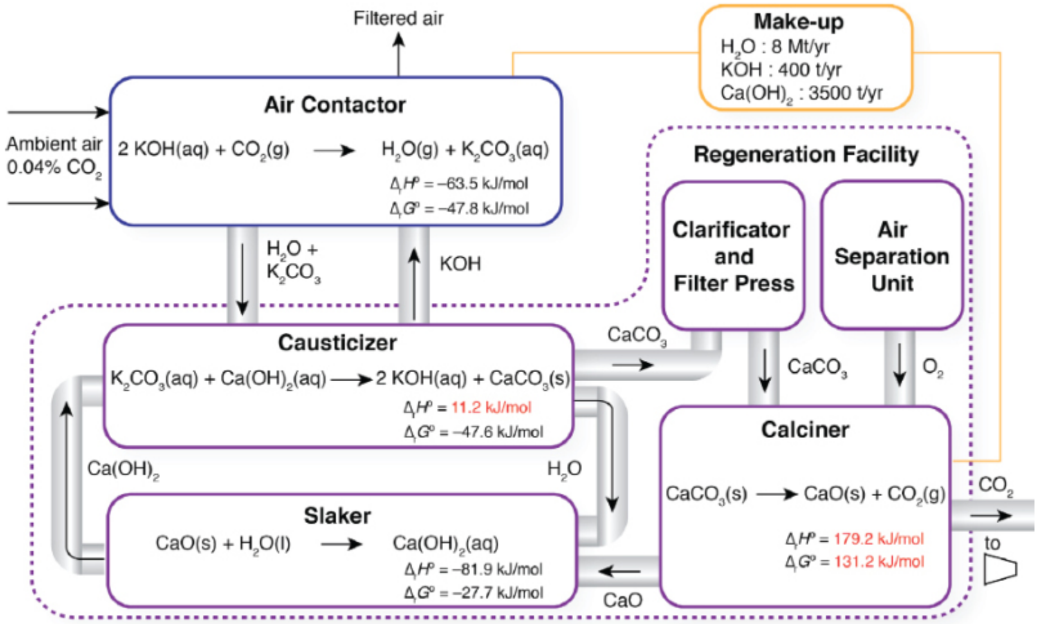


FIGURE 5.1 Simplified process flow diagram of a generic liquid solvent–based direct air capture system

- The air contactor is used to contact the air with a KOH aqueous solution such that CO_2 reacts to produce K_2CO_3:

  2KOH + CO_2 → H_2O + K_2CO_3

  At 400 ppm, ambient air reaches the contactor, and 75 percent of the CO2 is trapped in the solvent as K2CO3. Due to the high stability of this product species, a caustization step is required to convert K2CO3 to calcium carbonate CaCO3, regenerating the KOH solution for use in the contactor.

- The packing material composition (e.g., metal, plastic, ceramic) as well as the nature of the air flow through the wetted packing material must be considered when calculating the pressure drop. The flow is frequently approximated as counter-current in post-combustion applications.

$$\Delta P=7.4*D*u^{2.14}$$

• Fan Work: From the pressure drop, the fan power (MW) can be calculated from: $$\omega'_{fan}=(V'\ \Delta P)/\varepsilon$$ where V denotes the volumetric flow rate (m3/s) and ε is the electrical efficiency of the fan (60 percent assumed). • CaO interacts exothermically with H2O in the slaker to regenerate Ca(OH)2, which is then reused in the causticizer: $CaO + H_2O \rightarrow Ca(OH)_2$ • An aqueous solution of K2CO3 is pumped from the air contactor's exit stream into the causticizer, where it reacts with Ca(OH)2 to produce CaCO3 and regenerate KOH for reuse in the air contactor: $H_2O + K_2CO_3 + Ca(OH)_2 \rightarrow 2\ KOH + CaCO_3$ • CaCO3 must be burned to high temperatures (900°C) in a calciner after filtration, clarifying, and drying to generate calcium oxide (quicklime) and highly concentrated CO2: $CaCO_3 \rightarrow CaO + CO_2$ The quicklime is reintroduced to the slaker after calcination, where it exothermically combines with water to regenerate Ca(OH)2 and heat the slaking solution to around 95°C.
Impact: Gives a good overview of the entire process of a DAC facility for capturing and extracting the CO2 from the ambient air.
Actions: Acquired the knowledge of the entire process which leads to create a solid design for the project

Desorption Process:

Journal Paper / Book Chapter / Article citation: Shinying Lin, Takashi Kiga, Yin Wang, Katsuhiro Nakayama. (2011) Energy analysis of $CaCO_3$ calcination with CO_2 capture

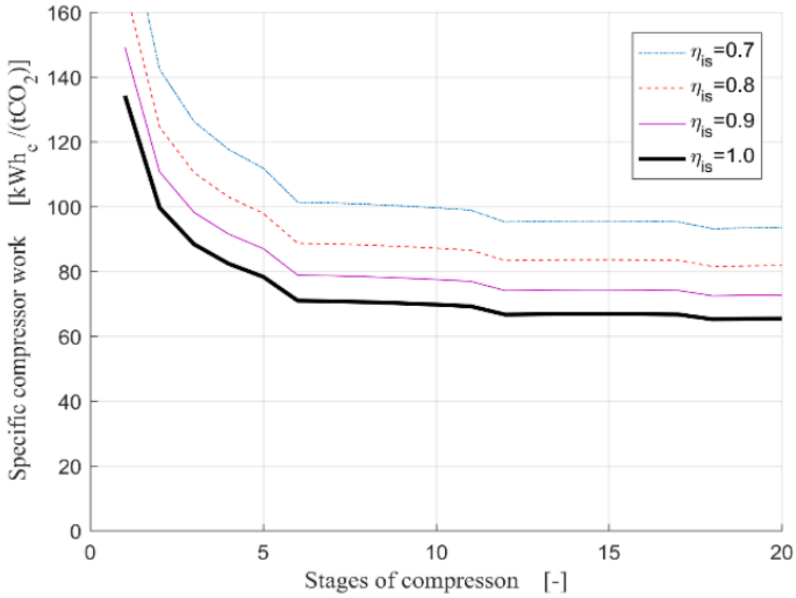
Summary: *Provide a brief overview of this text.* This article provides and insight into the energy consumption of the calcination of $CaCO_3$ during CO_2 capture
Questions (aims): *Skim read the text and diagrams. Identify questions could help you progress your project. You can revise these while you try to answer them.* 1. What temperature does calcination take place at

2. How much energy is required to achieve this
Answers (knowledge): *Read the text more carefully and answer your questions.* 1. For calcination of $CaCO_3$ requires that the calciner is heated to roughly 900^oC 2. The whole of the calcination process is shown to take 220.36 kJ/mol-$CaCO_3$ 3. The air separator unit which supplies the oxygen to the uses 889 kWh/tO_2 of energy. The slaker consumes 32kWh/tCO_2 of energy. 4. The Compressor responsible for making the CO_2 Applicable for the pipes uses 89.2kWh/tCO_2 of energy. 5. All of the energy consumptions, given a minimum of 5000 tonnes of CO_2 a year, add up to 25,000,000 kWh of energy consumed pe year.
Impact: *Consider which elements of the text can be directly incorporated into your project. Are you still missing something?* 1. The energy consumption can directly be fed into the research aspect of the report

Journal Paper / Book Chapter / Article citation: : S Jackson and E Brodal 2018 IOP Conf. Ser.: Earth Environ. Sci. 167 012031

Summary: *Provide a brief overview of this text.* This article looks at the energy requirements for the compression of the CO_2 post desorption
Questions (aims): *Skim read the text and diagrams. Identify questions could help you progress your project. You can revise these while you try to answer them.* 1. What method for compression should be used for the facility 2. How many stages should be used for this process 3. What are the specific energy consumptions for the compression of CO_2 4. What other energy is needed for the process of desorption
Answers (knowledge): *Read the text more carefully and answer your questions.* 1. By the *conventional* method of compression using a multi-stage integrally geared compressor 2. Using the method described above, we see that there is a large reduction in specific compressor work when we increase the number of stages form 1 – 5. This trend then

levels out when adding the 6th and 7th stages. Therefore, 7 stages will be used.



3. With 7 stages and an isentropic efficiency of 0.8 the optimum specific power is 89.2 kWh/tCO_2.
4. Heating the stripper takes 0.52 kWh of energy and the reboiler 0.55kWh. These two components will be running all the time.

Journal Paper / Book Chapter / Article citation: David W. Keith, Geoffrey Holmes, David St. Angelo, Kenton Heidel. (2018) A Process for Capturing CO_2 from the Atmosphere

Summary: *Provide a brief overview of this text.*
This article details the process for capturing CO_2 from the air

Questions (aims): *Skim read the text and diagrams. Identify questions could help you progress your project. You can revise these while you try to answer them.*

1. What is the process for desorption
2. What are the energy consumptions for the slaker and calciner stages
3.

Answers (knowledge): *Read the text more carefully and answer your questions.*

1. As the air enters the facility it comes in contact with KOH which reacts with the CO_2 in the air in the air contactor. This produces K_2CO_3 and H_2O. $CA(OH)_2$ is then added in the causticizer to regenerate the potassium hydroxide and to produce $CaCO_3$. This is separated and sent to a calciner which, at 900^{o}C, decomposes the calcium carbonate into CaO and CO_2. This CO_2 is the output of the facility and is sent of to the compressor.
   The CaO, however, I sent to a slaker in which it mixes with the water from the absorption reaction to regenerate $Ca(OH)_2$ for the causticizer to continue reacting with the potassium carbonate produced by absorption.
2. The calciner consumes 1391 kWh/tCO_2. The slaker consumes 32 kWh/tCO_2 however, as the reaction that takes place here is exothermic is also produces 77 kWh/CO_2 in heat energy.

Impact: *Consider which elements of the text can be directly incorporated into your project. Are you still missing something?*

1. This process will be used for absorption and desorption
2. The energy will be directly incorporated

Group: 55 Reviewer: ...

Journal Paper / Book Chapter / Article citation: Banaszkiewicz, T., & Chorowski, M. (2018). Energy Consumption of Air-Separation Adsorption Methods. *Entropy (Basel, Switzerland)*, *20*(4), 232. https://doi.org/10.3390/e20040232

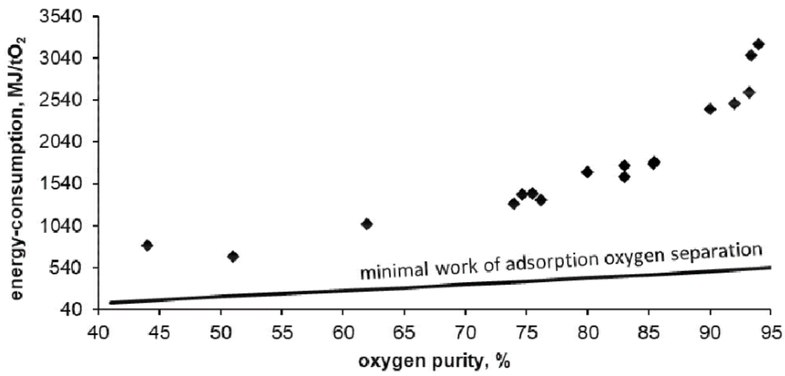
Summary:
This article discusses how air separation is achieved and the energy it consumes

Questions (aims): *Skim read the text and diagrams. Identify questions could help you progress your project. You can revise these while you try to answer them.*

1. How does it work
2. What is it used for
3. How much energy does it consume

Answers (knowledge): *Read the text more carefully and answer your questions.*

1. At ambient temperature a zeolite is exposed to the air at a high pressure. Then the air is released form the zeolite sponge and a film of oxygen is produced.
2. This process is necessary for producing the oxygen required to run the calciner stage of desorption. The oxygen is used to burn an heat the calciner to its 900^{o}C temperature to release the CO_2
3. The air separator consumes 889 kWh/tO_2 in order to produce the oxygen at a purity of 94%. A lower purity can be produced with less energy consumption as shown in the diagram below:



However, this would affect the efficiency of the calciner process causing it to produce less pure CO_2 at a higher energy cost.

Group: 55 Reviewer: ...

Journal Paper / Book Chapter / Article citation: Noah McQueen *et al* 2021 *Prog. Energy* **3** 032001

Summary: *Provide a brief overview of this text.*

This article talks through two commercial direct air capture processes. Looking at solvents and sorbents and various chemical kinetics.
Questions (aims): *Skim read the text and diagrams. Identify questions could help you progress your project. You can revise these while you try to answer them.* 1. What are the climate goals of the global agreements 2. What chemicals are used in direct air capture processes 3. How much does the process cost
Answers (knowledge): *Read the text more carefully and answer your questions.* 1. The goal of the Paris Climate Agreement is to reduce the global temperature increase to 2^{o}C above preindustrial levels. Above this there is an extra goal of 1.5^{o}C if possible. As of 2020 we had a temperature level increase of 1^{o}C. 2. When absorbing the carbon dioxide from the air potassium hydroxide (KOH) is used to extract the CO_2. An addition of calcium hydroxide ($Ca(OH)_2$) is used to produce calcium carbonate ($CaCO_3$) which is broken down to release CO_2. 3. The process of capturing carbon dioxide this way cost between \$94 and \$232 per tonne of CO_2 produced
Impact: *Consider which elements of the text can be directly incorporated into your project. Are you still missing something?* 1. Knowing what chemicals are needed to produce the CO_2 will be directly incorporated into the procedure of direct air capture used in the facility

Group: 55 Reviewer: ...

Journal Paper / Book Chapter / Article citation: Colloide (2020) *Lamella separator – How does it work* 09/03/2022 {https://www.colloide.com/lamella-separator-how-does-it-work/}

Summary: *Provide a brief overview of this text.* The page describes how a lamella separator works
Questions (aims): *Skim read the text and diagrams. Identify questions could help you progress your project. You can revise these while you try to answer them.* 1. What is the use of a clarifier in the DAC facility 2. How does it work
Answers (knowledge): *Read the text more carefully and answer your questions.* 1. A clarifiers job is to remove sold particles from suspension for further processing 2. Lamella settlers are used to greatly increase the clarifier capacity with maximum efficiency. The aqueous solution with soldi suspension passes over a series of flat plates inclined at an angle causing the heavier solids to separate from the solution and collate at the bottom plate. The remaining solid free solution is removed and the soldi is taken by water to a press to be dried.
Impact: *Consider which elements of the text can be directly incorporated into your project. Are you still missing something?*

1. This process will be used to separate the solid calcium carbonate ($CaCO_3$) from the aqueous potassium hydroxide (KOH).

Carbon Dioxide Transportation:

Journal Paper / Book Chapter / Article citation: A Process for Capturing CO2 from the Atmosphere.

David W. Keith, Geoffrey Holmes, David St. Angelo, Kenton Heidel.

Published by Elsevier Inc.

https://doi.org/10.1016/j.joule.2018.05.006

Summary: Provide a brief overview of this text. **This article gives a brief overview about Carbon Capture and the chemical processes involved in taking carbon dioxide from the atmosphere and facilitating it for transport and storage.**
Questions (aims): *Skim read the text and diagrams. Identify questions could help you progress your project. You can revise these while you try to answer them.* 1. How can we take carbon dioxide directly from the atmosphere and utilize it for transport and storage? 2. What are the chemical processes involved in diluting the carbon dioxide taken from the atmosphere? 3. What is the compression process involved in liquefaction of carbon dioxide? 4. How can we develop this process at an Industrial scale?

Answers (knowledge): *Read the text more carefully and answer your questions.*

1. In the process of capturing carbon dioxide we use a contractor to bring ambient air in contact with an alkali capture solution. Carbon Dioxide is captured from the air occurs on a film of about ~50micrometers thick film of solution
2. The chemical process is comprised of two loops that are connected with each other. In the first loop carbon dioxide is captured using an aqueous solution with ionic concentrations of about 1.0 M OH^-, 0.5 M CO_3^{2-}, and 2.0 M K^+.

3. There are two processes that are connected to each other. The first process captures CO_2 from the atmosphere by using an aqueous solution and given specific ionic concentrations of 1.0 M OH^-, 0.5 M CO_3^{2-}, and 2.0 M K^+. In the second process, CO_3^{2-} is precipitated. This is done by Ca^{2+} that forms $CaCO_3$ and the Ca^{2+} gets replenished. This is done by dissolution of $Ca(OH)_2$. $CaCO_3$ undergoes calcination process liberating CO_2 to give CaO, which is hydrated or "slaked" to produce $Ca(OH)_2$.

4. CE has developed a process which helps in the conduct of this process at the industrial scale. At it's full capacity, the plant is able to capture 0.98 Mt-CO_2/year from the atmosphere as well as produce 1.46 Mt-CO_2/year stream of dry CO_2 at 15 MPa. An addition of 0.48 Mt-CO_2/year is generated by the combustion of natural gas that is done on the site in order to meet all the plant thermal as well as the electrical requirements.

…

Impact: *Consider which elements of the text can be directly incorporated into your project. Are you still missing something?*

The report in this segment gives an introduction to the chemical processes needed in order to make the carbon dioxide captured from the air as a liquid to further enable and facilitate its transportation. The energy requirements needed in order to carry out these processes will be covered further in the next segments.

Actions: How are you going to follow-up to progress your project work?

1. Explore emerging technological as well as civil engineering aspects in order to facilitate a deeper understanding of the transportation process.
2. Explore the economical aspects of the infrastructure required to propagate the implementation of the process to the advanced stages.
3. Further explore means of transportation such as tanker trucks, pipelines etc.

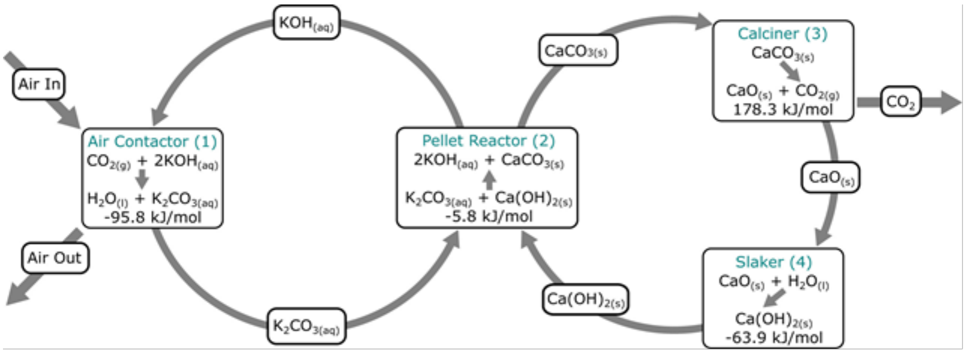
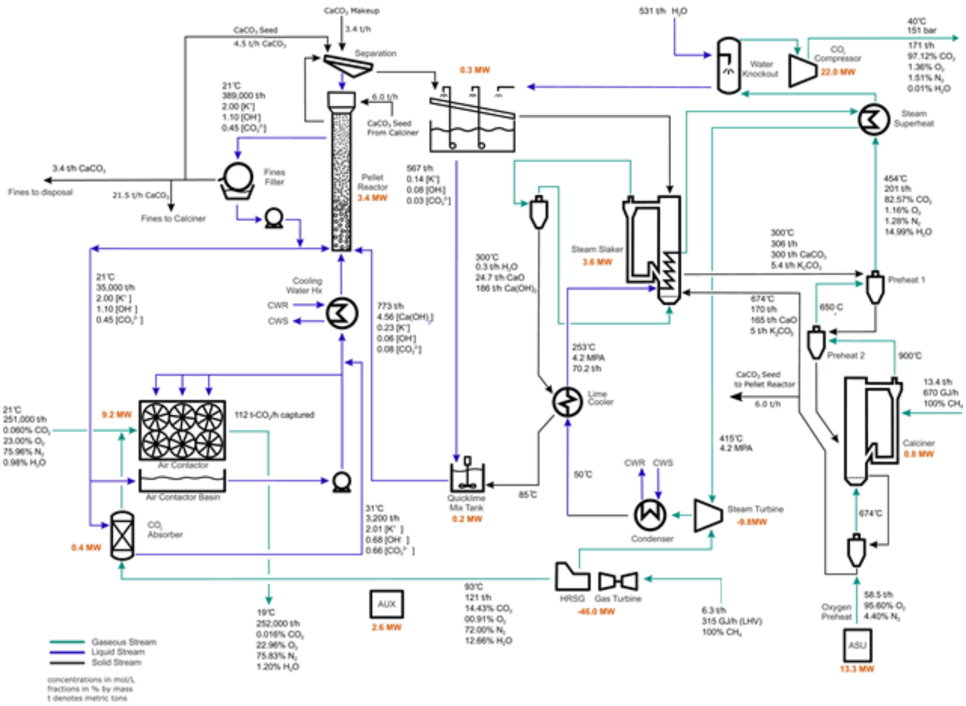


Figure 1: Process Chemistry and Thermodynamics



Journal Paper / Book Chapter / Article citation: A review of direct air capture (DAC): scaling up commercial technologies and innovating for the future

Noah McQueen1, Katherine Vaz Gomes1, Colin Mc Cormick2, Katherine Blumanthal3, Maxwell Pisciotta1 and Jennifer Wilcoxc 4,1 ....

Citation Noah McQueen *et al* 2021 *Prog. Energy* **3** 032001

[Progress in Energy](), [Volume 3](), [Number 3]()

https://iopscience.iop.org/article/10.1088/2516-1083/abf636

Summary: *Provide a brief overview of this text.*

This article gives an insight to the energy required in the transportation process of carbon dioxide after being captured from the air by the DAC facility and compressed into the liquid state for transportation as well as storage purposes.

Questions (aims): *Skim read the text and diagrams. Identify questions could help you progress your project. You can revise these while you try to answer them.*

1. What is the type and general energy requirement for transporting the liquid carbon dioxide to and from the DAC facility to the storage facility?
2. What is the purpose of additional heat pumps for transportation of liquid carbon dioxide?

3. Why is the DAC facility also known as a refinery for the sky?

4. What equipment is needed for both the approaches in the compression and transportation processes?

Answers (knowledge): *Read the text more carefully and answer your questions.*

1. Both the processes in the DAC facility have a general requirement of 80% thermal energy and 20% electricity. The sorbent DAC process is found having a thermal energy requirement nearing 6 GJ tCO2 −1 and electricity requirements of approximately 1.5 GJ tCO2 −1. For sorbents having lower regeneration energy requirements cause a reduction in thermal energy requirement on the order of 3 GJ tCO2 −1 with some sorbents said to be having low regeneration energies near 1 GJ tCO2 −1. The solvent process is said to be having thermal energy requirements ranging from 5.25 to 8.1 GJ tCO2 −1, chiefly depending on the heat integration from the calcination process and having an electricity requirement for 1.3–1.8 GJ tCO2 −1.
2. The overall energy requirement between both the solvent and sorbent processes do not differ greatly from each other. The quality of thermal energy needed differs as the solid sorbent process needs thermal energy on the order of 80 °C–130 °C, which may be met via industrial waste heat or other sources of lower quality thermal energy. These temperatures also lie in the range of an electrically powered heat pump which consume >20% electricity beyond the DAC system. The liquid solvent process needs heat near 900*C or the decomposition of CaCO3 into CaO and CO2.
1. The DAC facility exhibits similar characteristics as a petroleum refinery chiefly since refineries also consume 20% electricity and 80% thermal energy breakdown in their operations as well. The electricity requirements for refining include energy needed for pumping, motors, and instrumentation in which the thermal energy requirements mainly are used for steam production and process heating.
2. For the solid sorbent approach contractor fans are used to overcome the system pressure drop. The vacuum pumps are used to remove the residual air from the contactor during regeneration process. For the liquid solvent process electricity is needed for the contactor in order to overcome the system pressure drop as well as the pellet reactors, steam slaker and filtration units.

Impact: *Consider which elements of the text can be directly incorporated into your project. Are you still missing something?* The report in this segment gives an idea about the energy requirements needed for making the carbon dioxide available for transport as well as storage purposes. The data incorporated in the segment can be used to facilitate a formal report as well. Furthermore, methods of transportation will be incorporated in the further stages of the report.
Actions: How are you going to follow-up to progress your project work? 1. Energy requirements for the DAC process to transport carbon dioxide have been covered fully in this report. 2. The equipment and methodology undertaken to transport carbon dioxide over great distances will be covered in the next segments of the journal reports by citing articles and journal reports on the equipments required for carrying liquefied carbon dioxide over large distances. 3. The specifications on the means of transport and infrastructure needed will be included in the latter part of this report by further citing articles and research journals needed for getting the required specifications for them.

Journal Paper / Book Chapter / Article citation: MATERIAL SELECTION FOR SUPERCRITICAL CO2 TRANSPORT.

by Dr Shiladitya Paul, Richard Shepherd, Amir Bahrami, and Paul Woollin TWI, Abington, UK
https://www.twi-global.com/technical-knowledge/published-papers/material-selection-for-supercritical-co2-transport

Summary: *Provide a brief overview of this text.* *This report gives an overview of the materials used in constructing the pipelines required for the transportation of liquefied carbon dioxide from the DAC plant as well as aims to look at the problems that are caused over a period of time while using these materials in the pipelines.*
Questions (aims): *Skim read the text and diagrams. Identify questions could help you progress your project. You can revise these while you try to answer them.* What are the two chief materials used in pipeline construction used in transportation of carbon dioxide? What is the phase condition required to transport liquid carbon dioxide by using pipelines? What are the factors affecting carbon dioxide corrosion in pipeline systems? What methods are used to prevent or reduce carbon dioxide corrosion in pipelines?

Answers (knowledge): *Read the text more carefully and answer your questions.*
The two chief materials used in pipeline construction are as follows:

A. Metallic materials such as steel.

B. Polymeric materials such as elastomers and plastics.

2. The phase temperature and pressure used is above the critical temperature and pressure of carbon dioxide. Beyond this phase carbon dioxide exists in the supercritical phase with the temperature being 31.1*C and the pressure being 73.9 bar. In this phase the density of carbon dioxide ranges from 50-80% of the density of water. The viscosity in this phase is similar to that in the gaseous phase and can be up to 100 times lower in the liquid phase. This is one of the key factors needed in pipeline transportation as it implies a lower drag.

3. The chief materials used are metallic as well as polymeric materials. Corrosion in steel pipes is caused due to the fact that the material is subjected to contact with high pressure carbon dioxide. Primarily, wet carbon dioxide has a greater corrosion effect than dry carbon dioxide. The three main factors that are responsible for carbon dioxide corrosion are as follows:
(i) water chemistry
(ii) operating conditions
(iii) material type.

4. The presence of chromium (Cr) in steel can greatly reduce the corrosion rate in steel pipelines. Cr forms stable oxides when put in the pipeline systems containing liquid carbon dioxide. Some publications have implied using 13% Cr steel either in homogeneous ('solid') form or cladding on carbon steel for corrosion mitigation. If low chromium steel alloy is to be selected the influence of steel microstructures is of less significance. Now glass reinforced epoxy (GRE) lined tubing which is a form of tubing that comprises of an internal fibreglass liner or sleeve that is bonded bonded to the inside of a steel pipe is used. Some carbon dioxide pipelines are constructed using an epoxy-coated and polyethylene-lined carbon steel. Internally plastic coated (IPC) tubing that has a sprayed coating (phenolics, epoxies, urethanes or novolacs) on the inside of the steel pipes are also used.

Impact: *Consider which elements of the text can be directly incorporated into your project. Are you still missing something?*
This report incorporates the basic materials needed in pipeline construction used to transport liquid carbon dioxide over long distances .
This report also incorporates aspects of corrosion resistance in the pipeline infrastructure that is used for liquid carbon dioxide transportation.
Further aspects of pipeline infrastructure will be looked upon in the latter stages of the report.

Actions: How are you going to follow-up to progress your project work?
Explore further into the pipeline infrastructure that is used to transport liquid carbon dioxide over large distances.
Further research into the design as well as dimensioning of pipeline construction.
Further research on the distance as well the terrain of transport of the liquid carbon dioxide.

Journal Paper / Book Chapter / Article citation: CARBON DIOXIDE PIPELINES:

A PRELIMINARY REVIEW OF DESIGN AND RISKS

J. Barrie1*, K. Brown2, P.R. Hatcher1 and H.U. Schellhase

http://ccs-info.org/onewebmedia/Pipeline_material.pdf

CO2 Pipeline Design: A Review

Suoton P. Peletiri, Nejat Rahmanian, Iqbal M. Mujtaba.

https://doi.org/10.3390/en11092184

Summary: *Provide a brief overview of this text.*

This article gives an overview of the pipelines needed for transporting liquified carbon dioxide over long distances from the Direct Air Capture(DAC) facility. the report also incorporates the design as well as methods of construction of these pipelines.

Questions (aims): *Skim read the text and diagrams. Identify questions could help you progress your project. You can revise these while you try to answer them.*

1. What are the design considerations to be kept in mind when designing the pipelines?
2. What is required to determine and design the pipeline diameter?
3. What are the safety measures that need to be taken into consideration while designing a pipeline?
4. Why is it necessary to have a pipeline control system in place?

Answers (knowledge): *Read the text more carefully and answer your questions.*

1. *Carbon dioxide being an acidic gas has the tendency to react with water in the pipelines which in turn leads to the formation of carbonic acid. This is a recognized problem over many years in pipeline construction as it leads to corrosion of carbon steels and is commonly called 'sweet gas corrosion.' Thus, in piping environments with turbulent flows operating with high concentrations of carbonic acid corrosion resistant stainless steel is needed. The correct technology to separate water from carbon dioxide is essential for the transportation process. Maintaining a single phase flow for transportation is a necessity as the pipelines experience a wide range of ambient temperatures. Apart from these the pressure conditions that are most widely used are 7.4 and about 21 MPa. Above 7.4 MPa, CO2 exists as a single dense phase over a wide range of temperatures. Typical pipeline-engineering considerations for CO2 include:*

- operating pressure;
- operating temperature;
- Gas mixture composition;
- corrosivity;
- ambient temperatures; and
- pipeline control (SCADA).

2. An optimum pipeline diameter is the smallest pipe diameter large enough so that the volume of fluid is transported without reaching an excessive range of velocities. For an adequate pipeline diameter it should avoid excess of pressure loss as well as try to reduce the no of boosting stations to optimize the cost. The following are the criteria that affect building of a pipe diameter:

a) flow rate
b) pressure dropp
c) density
d) viscosity
e) pipe roughness
f) topographic differences
g) bends

The final equation to calculate pipe diameter was McCoy and Rubin by holding the upstream and downstream pressures constant. Velocity is assumed to be constant and compressibility averaged over the pipeline length.

3. An experienced risk assessment team must be put to the task of thorough assessment of the pipeline infrastructure as a whole. All equipments such as the:

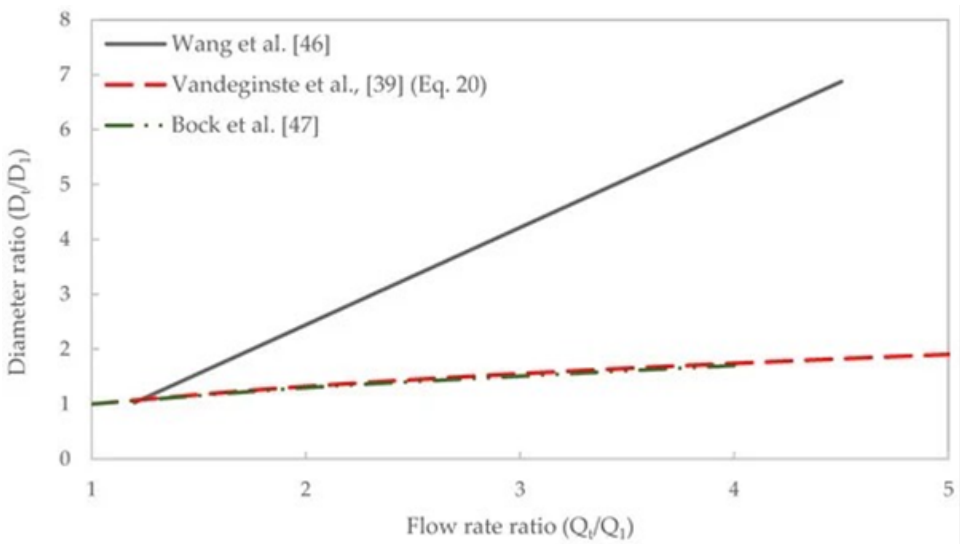
1. Pipe
2. Compressors
3. Control valve

4. Valves purchased in bulk

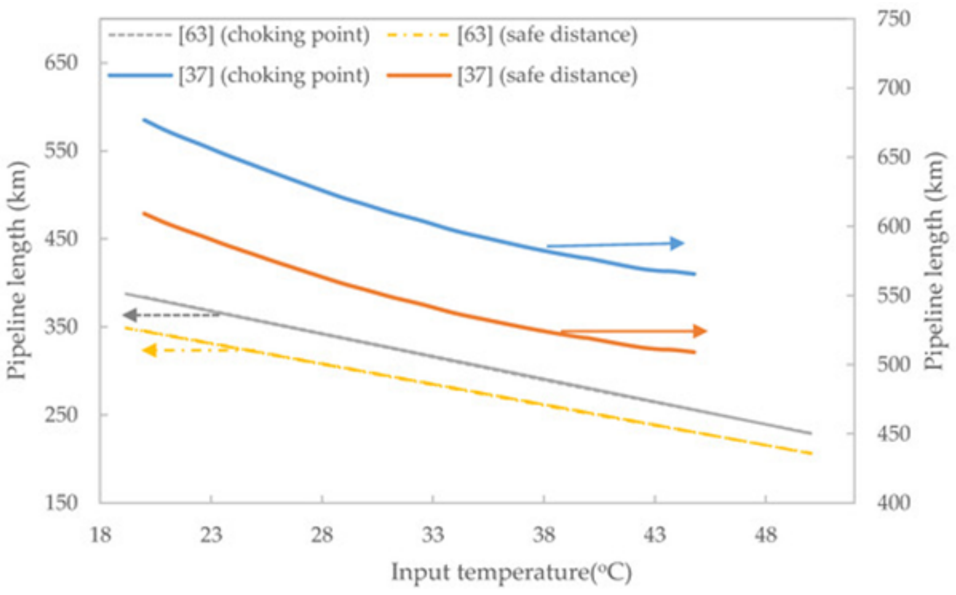
must undergo sufficient quality checks to avoid any major mishap. Apart from these there must be an Emergency Response Planning team (ERP) trained and prepared for any form of catastrophe that may occur on site.

4. A pipeline control system should be one that can keep a real time monitoring on the key parameters such as pressure, temperature and flow rate. It is in place to ensure timely intervention if large swings in values occur.

Impact: *Consider which elements of the text can be directly incorporated into your project. Are you still missing something?* This article incorporates the main aspects of pipeline Construction that is taken into account when constructing pipelines needed for transportation of liquid carbon dioxide from the DAC facility over long distances. Pipeline transportation is the main form of transportation of liquid carbon dioxide today.
Actions: How are you going to follow-up to progress your project work? 1. The main aspects of pipeline construction are covered in this article. Further details such as specification of general pipeline diameters and terrain over which the carbon dioxide is transported will be incorporated over the next stage of this report. 2. To further the aspect of pipeline transport similar articles will be cited and researched upon.



The relationship between diameter ratio and flow rate ratio



Variations of maximum safe CO_2 pipeline length and choking point for different input temperatures

Journal Paper / Book Chapter / Article citation:

Transport of CO2.

Coordinating Lead Authors

Richard Doctor (United States), Andrew Palmer (United Kingdom)

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David Coleman (United States), John Davison (United Kingdom), Chris Hendriks (The Netherlands), Olav Kaarstad (Norway), Masahiko Ozaki (Japan)

Contributing Author

Michael Austell (United Kingdom)

https://www.ipcc.ch/site/assets/uploads/2018/03/srccs_chapter4-1.pdf

Summary: *Provide a brief overview of this text.* This article gives an overview of the distance over which carbon dioxide is transported by the use of pipeline infrastructure. This article also incorporates the various terrains over which pipelines are set up by looking at existing pipeline infrastructure in various parts of the world as well as the challenges involved in setting these over the different forms of terrain. Finally, the report also incorporates the basic pipeline dimensioning needed for construction and briefly mentions the specified minimum toughness value of the pipeline constructed.
Questions (aims): *Skim read the text and diagrams. Identify questions could help you progress your project. You can revise these while you try to answer them.* How are the underwater pipelines constructed? What are the existing pipeline connections currently used to transport carbon dioxide? What are the distances, terrains as well as the capacity of these pipelines that are laid out?

Answers (knowledge): *Read the text more carefully and answer your questions.*

1. The underwater pipelines are primarily constructed by the lay-barge method. This involves laying down 12m or 24m long pipelines that are brought to a dynamically positioned or anchored barge and then are welded each to the end of the pipeline. The barge moves forward at a slow pace and the pipeline then leaves the barge when it is over the stern. It then further passes over the support structure (stinger) and then down to the water in a suspended span till it reaches the seabed. There are a pipelines that are upto 450mm in diameters which are constructed by the reel method. The reel method involves welding the pipeline together on the shore, wound onto a reel on a ship later then unwound from the reel to the final position of the pipeline. For the construction of some short pipelines the tow and pull method is incorporated into the construction process.

2. The following list gives the location of about the existing carbon dioxide pipeline connections that are in use today:

Canyon Reef (USA)
Bravo dome pipeline(USA)
Cortez pipeline(USA)
Sheep Mountain(USA)
Val Verde(USA)
Bati Raman(Turkey)
Weyburn(USA and Canada)

3. Below listed is the distance, terrain and capacity respectively of the above mentioned carbon dioxide pipelines:

a) Canyon Reef.
Length of pipeline: 225Km
Type of terrain: Grassy terrain with light to dark loam surface.
Capacity: 5.2 $MtCO_2/yr$

b) Bravo Dome pipeline.
length of pipeline 350 Km
Type of terrain: High plains
Capacity: 7.3 $MtCO_2/yr$

c) Cortez.
length of pipeline 808Km
Type of terrain: Canyon and flat grass covered plains.
Capacity: 19.3 $MtCO_2/yr$

d) Sheep Mountain.
length of pipeline: 660 Km
Type of terrain: Mountainous.
Capacity: 9.5 $MtCO_2/yr$

e) Val Verde.
length of pipeline: 130Km
Type of terrain: Desert.
Capacity: 2.5 $MtCO_2/yr$

f) Bati Raman.
length of pipeline: 90Km
Type of terrain: Plateau
Capacity: 1.1 $MtCO_2/yr$

g) Weyburn.
length of pipeline: 328Km
Type of terrain: Slight elevation
Capacity: 5 $MtCO_2/yr$

Impact: *Consider which elements of the text can be directly incorporated into your project. Are you still missing something?* This text summarises the incorporation of the final aspects of pipeline construction. Detailed explanation and detailed dimensioning as well as specification will be looked upon in the final stages of this report.
Actions: How are you going to follow-up to progress your project work? Explore further modes of transportation of liquid carbon dioxide by researching and citing articles related to these. Alternate modes of transport such as tankers and ships and the conditions under which these operate will be taken into account in the next stages of this report by citing articles for the same.

Ship type	Number of ships 2000	Serious incidents 1978-2000	Frequency (incidents/ship year)
LPG tankers	982	20	0.00091
LNG tankers	121	1	0.00037
Oil tankers	9678	314	0.00144
Cargo/bulk carriers	21407	1203	0.00250

Table 4.2 Statistics of serious incidents, depending on the ship type.
189

Pipeline	Location	Operator	Capacity	Length	Year finished	Origin of CO2
			(MtCO2 yr-1)	(km)		
Cortez	USA	Kinder Morgan	19.3	808	1984	McElmoDome
Sheep Mountain	USA	BP Amoco	9.5	660	-	Sheep Mountain
Bravo	USA	BP Amoco	7.3	350	1984	Bravo Dome
Canyon Reef Carriers	USA	Kinder Morgan	5.2	225	1972	Gasification plants
Val Verde	USA	Petrosource	2.5	130	1998	Val Verde Gas Plants

Bati Raman	Turkey	Turkish Petroleum	1.1	90	1983	Dodan Field
Weyburn	USA & Canada	North Dakota Gasification Co.	5	328	2000	Gasification Plant
Total			49.9	2591		

Journal Paper / Book Chapter / Article citation:

CO2 capture in ethanol distilleries in Brazil: Designing the optimum carbon transportation network by integrating hubs, pipelines and trucks.

Fabio T.F. da Silva Francielle M.Carvalhoa Jorge Luiz G.Corrêa Jr nPaulo R. C.MerschmannbIsabela S.Tagomorian Alexandre Szkloa Roberto Schaeffera

https://doi.org/10.1016/j.ijggc.2018.02.018

Transportation systems for CO2—application to carbon capture and storage.

Rickard Svensson Mikael Odenberger Filip Johnsson Lars Strömberg

https://doi.org/10.1016/j.enconman.2003.11.022

...

Summary: *Provide a brief overview of this text.*

This text gives a brief overview of the role of tanker trucks in the transportation of liquid carbon dioxide as well as talks about the process necessary for converting the carbon dioxide (air) into the liquefied state for it to be able to get transported via trucks and tankers.

Questions (aims): *Skim read the text and diagrams. Identify questions could help you progress your project. You can revise these while you try to answer them.*

1. What is the optimal sugarcane ethanol bio-CCS CO2 network?
2. What are the on-shore and off-shore methods of transportation of liquid carbon dioxide?
3. What are the two main technologies used for intermediate storage?
4. What is the safety aspect involved in these alternative means of transportation?

Answers (knowledge): *Read the text more carefully and answer your questions.*

1. As suggested by its name, the sugarcane ethanol method involves the fermentation of the carbon dioxide captured from the direct air capture facility by using a solution comprised of a mixture of ethanol and sugar. This method is currently in use in a group of ethanol distilleries in the Central-South of Brazil to transport the carbon dioxide to an oil field in the Campos basin via tankers.

2. As of now pipelines are the only remaining on-shore means of transportation for liquid carbon dioxide due to the fact that railway and motor carriers are both expensive and lack the capacity to transport liquefied carbon dioxide. In addition to these factors, pipeline construction is both reliable and cost effective in terms of mass scale liquid carbon dioxide transportation.Pipelines are used in off shore transportation of liquid carbon dioxide as well but they are in heavy competition against water carriers such as ships, fuel tankers etc. These alternatives differ from each other in terms of suitability a each alternative has its own suitable use. This greatly affects the cost/tonne of the carbon dioxide in terms of long distance transportation of carbon dioxide. Water carriers have a greater degree of flexibility than pipelines in terms of adaptability of capacity and transportation route. Water Carriers however, require intermediate storage capacity. [16]. Pipelines are able to handle large quantities with less complex coordination because of steady flow and thus eliminate the need for intermediate storage.

3. Storage of liquid carbon dioxide is similar to that of LPG. There currently exist two ways to store LPG. It can be stored underground in great rock and salt caverns. At present this method is not in usage but can be applied to the storage of LPG or liquid carbon dioxide. At present the steel tank technology is in use for storing LPG or liquid carbon dioxide. Existing rock caverns for LPG currently hold the storage capacity of up to 500,000 m^3 off LPG that approximately is equal to 500,000 tonnes of CO_2. Salt caverns hold a storage capacity similar to the rock caverns of LPG yet do not get included in this work due to uncertainties with respect to the dissolution behaviour of CO_2. Steel tanks hold the storage capacities of up to 3000 tonnes of liquid carbon dioxide.

4. There arise chiefly two issues with carbon dioxide. These are as follows:

a) Though not toxic in nature, carbon dioxide can still prove to be fatal due to asphyxiation if its concentration exceeds 10% by volume. Such a level can be achieved by due to the discharge of carbon dioxide as it is heavier than air.

b) The problem of public acceptance arises when people do not wish to have storage plants. On shore storage faces this difficulty which in turn causes hinderance to the transportation process of carbon dioxide. This problem is also referred to as Not In My

Back Yard (NIMBY) problem. It also poses a threat of leakage near public dwellings which is the reason off shore storage is considered to be a safer and more viable option.

Impact: *Consider which elements of the text can be directly incorporated into your project. Are you still missing something?* This report gives a brief idea of the various alternate modes of carbon dioxide transportation other than pipeline infrastructure. More specifically, it dwells on the roadway or tanker truck method of transport of liquid carbon dioxide and the process involved to make carbon dioxide feasible for carriage via roadways. Further detailed analysis of the specifications regarding construction, storage capacity and usage of these technologies as well as the cost will be incorporated in the latter segments of this report.
Actions: How are you going to follow-up to progress your project work? 1. Explore further alternate means of liquid carbon dioxide transportation by citation of articles for the same. 2. Explore further into waterways transport with regard to ship transportation. 3. Explore further into alternate modes of land transportation.

Table 1 Module combinations evaluated in the different scenarios

Scenario	Module combinations	Distance [km]	Amount [Mt/y of CO_2]
S1-1	Pipeline on shore	110	1.0
S1-2	Railway	100	1.0
	Intermediate storage		
	Water carrier	500	
S1-3	Pipeline on shore	100	1.0
	Intermediate storage		
	Water carriers	500	
S1-4	Pipeline on shore	100	1.0
	Pipeline off shore	500	

S2-1	Pipeline on shore	110	10.0
S2-2	Pipeline on shore	100	10.0
	Intermediate storage		
	Water carriers	500	
S2-3	Pipeline on shore	100	10.0
	Pipeline off shore	500	
S3-1	Pipeline network on shore	230	40.0
	Pipeline network off shore	550	
S3-2	Pipeline network on shore	230	40.0
	Intermediate storage		
	Water carriers	500	

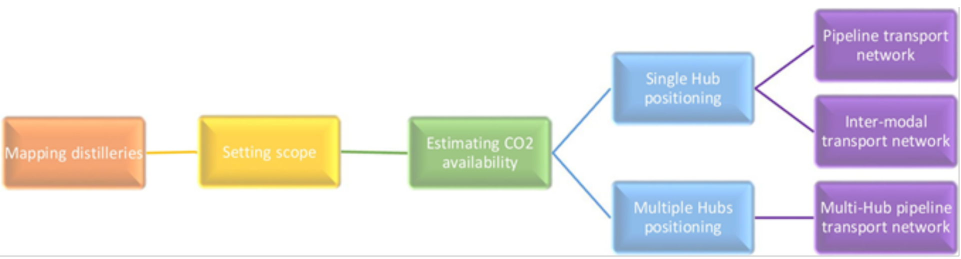


Fig. 1. Methodological scheme of the CO2 transport networks design.

Carbon Dioxide Storage

Journal Paper / Book Chapter / Article citation: Wang, Pengfei, Teng, Ying, Zhao, Yusheng et al. Experimental studies on gas hydrate-based CO storage: state of the art and future directions. Energy Technology. [Internet] [2021 May 3] [Cited 14/02/2022] Vol.9. 1-2. Available from: https://doi-org.ezproxye.bham.ac.uk/10.1002/ente.202100004

Summary:

The source give a good concise insight introduction to CO_2 storage methods, and talks about the differences between them and why some have been rejected internationally. Different methods of storage have their advantages and disadvantages, and it is important to consider these when selecting a site. Ideally, we want to find a site which will enable all four stages of CO2 storage, including structural trapping, mineral trapping, solubility trapping and capillary trapping.

Questions (aims):

1) What considerations must be taken when considering a CO_2 storage method?

2) Why are a few others storage methods banned, and do the "allowed" methods pose any uncertain risk?

3) What are the safety concerns and how are they prevented?

4) Will trapped CO2 stay trapped for a relatively long and reasonable time, and is any maintenance required to make sure that the CO2 that is trapped is not prone to leaking or escaping?

Answers (knowledge):

1. A few considerations that need to be taken when thinking of CO_2 storage are: site location; not only does the site have to be big enough to store reasonable amounts of CO_2 but it must be so that the climate does not cause any of the trapped CO_2 to be released.
2. Some storage methods are banned, in particular, ocean trapping. This is because the CO_2 increases acidity in the ocean, which can lead to drastic changes in marine life.
3. The safety concerns would be the one above which is damaging wildlife and marine life, however if the CO_2 is stored properly, then there is negligible risk of the CO_2 escaping unless a big natural disaster hits that area (which again why site location is important). CO_2 should remain trapped for thousands of years if done right.
4. There is minimal risk of CO2 escaping, however this does depend on how the CO2 is stored, for example, with structural trapping, if there is damage or a crack in the cap rock, CO2 is likely to be released.

Impact:

CO2 must not migrate to other parts of the site for where it was not intended to be, including bodies of water, even if it does not escape into the atmosphere due potential damage to marine life in the ocean. The source does states that maintenance or check-ups are required, however does not state how this is actually done.

Actions: How are you going to follow-up to progress your project work?

1. Further research into why some storage methods are deemed better than others, and try to find a reasonable balance between longevity (how long the CO2 will remain trapped for), cost and energy requirement for each process and compare the costs/energy and longevity to how much CO2 can actually be stored, to see if it is worth doing the process.
2. Research examples of potential threats DAC storage poses to its environment and learn what measures are taken in order to prevent them.

Journal Paper / Book Chapter / Article citation: CCP, co2captureproject [internet], BP group, 2015. Available from: https://www.co2captureproject.org/co2_trapping.html

Summary:

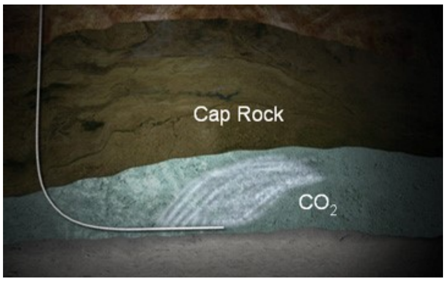
The page on the website gives a fairly detailed explanation of 4 of the major phases of storing CO_2 and also provides diagrams to help illustrate this. It talks about structural trapping as the primary source of CO2 trapping. It talks about the basic procedures of each trapping phase and the science behind how it works.

Questions (aims):

1) What complications are to be encountered when trying to store CO_2 when using structural trapping?
2) How long is the CO_2 likely to be trapped for with structural trapping?
3) Once stored, do these sites have to be monitored/maintained?
4) Are there any disadvantages of structural trapping compared to other methods of trapping?

Answers (knowledge):

1. Complications that are encountered depend on the type of storage practiced, for example, with structural trapping you must ensure that the cap rock is big enough to hold the CO_2 in its place otherwise the CO_2 would leak out. Some storage methods are banned, in particular, ocean trapping. This is because the CO_2 increases acidity in the ocean, which can lead to drastic changes in marine life. The image below is from the source, and shows how CO2 is trapped underneath the cap rock:



2. With structural trapping, CO_2 is likely to remain trapped for thousands of years, in fact, the longer the CO_2 remains trapped, the more and more secure it is said to be. That said, any damages to that area or land, can cause fractures in the cap rock, ultimately causing the CO2 to escape, hence why site location is very important.
3. After the CO_2 is injected, the injection pipe must be sealed with steel and concrete to ensure no CO_2 escapes, similar to how natural gas is collected. However, the source does not talk about how the site will be monitored.

Impact:

The primary source of CO_2 capture is structural trapping. It works by injecting CO_2 deep into the ground, the CO_2 will travel upwards until it meets a low permeability cap rock. The source does not talk much about monitoring these sites after CO_2 has been injected. The source only talks about the actual method, and not about longevity or detail of complications involved in these trapping processes.

Actions: How are you going to follow-up to progress your project work?

1. Further research into how these sites are monitored after the CO_2 has been injected, the source above has a hyperlink which discusses a lot more detail of each process and also site screening, which is helpful.
2. Try to find out whether natural disasters are likely to occur at these sites and if they do, will it result in all CO_2 being leaked into the atmosphere.
3. Try to find the differences in the amount of CO2 that can be stored for each different phase.

Journal Paper / Book Chapter / Article citation: Stefan Iglauer. International journal of greenhouse gas control. Edith Cowan University, School of Engineering. 15/08/2018. Volume 77. P 82-87. https://doi.org/10.1016/j.ijggc.2018.07.009

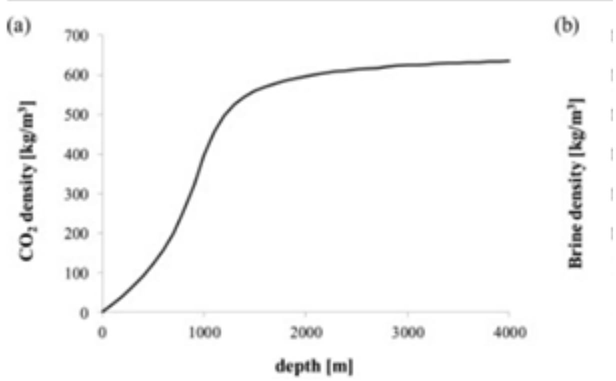
Summary: The source talks about some issues with structural trapping, it helps give a good insight into why structural trapping is the primary source of CO2 trapping but due to its limitations, other phases are also being researched further and used today. The source talks about how the cap rock is not the only thing which stops the CO2 from escaping, but how capillary forces stop the CO2 from escaping, there is resident brine below the CO2, and the CO2 travels upwards as it is less dense, some of this CO2 would be absorbed into the brine (solubility trapping) but the escape of some CO 2(from the brine) is inevitable, luckily the cap rock is enough to stop the CO2 from escaping the site.

Questions (aims):

1) Why, in some cases, are different phases of CO_2 storage/trapping preferred instead of structural trapping?
2) What are these limitations and can these limitations be bypassed?
3) What stops the CO2 from escaping in the structural trapping process?

Answers (knowledge):

1. Despite structural trapping being the primary method of CO2 trapping, there are limitations for example, when CO2 is trapped, engineers must make sure the pressure of the CO2 gas is not too great so that it actually starts flowing through the cap rock despite the cap rock being impermeable. Fortunately, capillary forces also help stop this from happening, and the only way for CO2 to leak out, is when there is a fracture in the cap rock.
2. The only thing to avoid this is to make sure the pressure is not high enough, even then with enough time there is still risk of CO_2 leakage. This can be caused by factors which cannot, with current technology, be avoided, such as tectonic compression.
3. The cap rock and the capillary force, when both combined, are sufficiently enough to stop the CO2 from escaping, they are what keeps the CO2 trapped in the site. The concentration of CO2 also increases with depth in the site, which is ideally what we want:



Impact:

Despite the cap rock being strong enough to prevent CO2 from traveling through, if pressures become too high or even over a large period of time, there is risk that some CO_2 can still leak, this can be caused by injecting too much CO2 or by a tectonic compression. This is why we must look further into other phases of CO2 storage. This source also has not gone over what needs to be monitored after the CO2 has been stored.

Actions: How are you going to follow-up to progress your project work?

1) Compare the problems and complications of different methods, a good balance between costs, difficulty of the method, longevity (how long the CO_2 can remained trapped for) should be found.
2) Find out further how these sites should be monitored to ensure no CO2 is leaking.

Journal Paper / Book Chapter / Article citation: Maria Rasmusson. Residual and solubility trapping during geological CO2 storage. Uppsala Universitet. Available from: http://www.diva-portal.org/smash/get/diva2:1187364/FULLTEXT01.pdf

Summary: The source talks about the generic way of capillary trapping. It broadly talks about the procedure and how it can be compared to other methods of trapping. The source not only talks about capillary trapping, but also how injected CO2 and resident brine will mix with each other depending on various factors in the field of thermodynamics. When the CO2 is injected into the area/site, almost always CO2 is less dense than the resident brine, and hence rises. The CO2 then meets the cap rock. While some CO2 escapes to the bottom of the cap rock, some becomes trapped due to capillary forces, this is known as capillary trapping.

Questions (aims):

1) What is capillary trapping?
2) Are there any problems with this method of trapping?

Answers (knowledge):

1. In this method, right after the carbon dioxide is injected, it travels upwards due its relatively lower density than resident brine and buoyancy, until it is met by the cap rock. The CO2 which manages to reach the cap rock will be trapped by structural trapping which has been discussed recently, some of the CO2 however will be trapped between the brine, and this due capillary forces. (Capillary forces help with solubility trapping).
2. The CO_2 will only flow to our area of interest if other fluids in that area can easily be displaced by the CO_2. Otherwise, the procedure would not work, hence finding the densities and other physical properties of fluids that are already present there is critical, typically information about the temperatures, pressures etc. of the resident brine will be taken.

Impact: *Consider which elements of the text can be directly incorporated into your project.* Are you still missing something*?*

As this mechanism requires the CO2 to flow through these porous rocks, it is critically important to understand the viscosity and fluids originally in these porous rocks, to make sure that the CO2 will remain trapped and not leak out. However, it is even more important to find the permeability of these rocks, as this will have a huge effect on the flow rate.

Actions: How are you going to follow-up to progress your project work?

1) Continue to compare capillary trapping with other methods of trapping, so in my report I can write a small summary of the best method trapping while taking account of factors such as complication and the amount of CO_2 that can be stored.

Journal Paper / Book Chapter / Article citation: Andrew C. Mitchell, Knud Dideriksen, Lee H. Spangler, Alfred B. Cunningham, Robin Gerlach. Microbially Enhanced Carbon Capture and Storage by Mineral-Trapping and Solubility-Trapping

Environment Science Technology. 2010, 44, 13, 5270–5276. Available from: https://doi-org.ezproxyd.bham.ac.uk/10.1021/es903270w

Summary: The source gives a detailed explanation for capillary and mineral trapping, by not only explaining the process but also providing annotated diagrams and chemical equations. When CO2 is injected into the brine, once it has stayed there for a very long time from the previous 2 stages (structural trapping and capillary trapping), the CO2 will start to decompose as shown:

equation involved are:

Journal Paper / Book Chapter / Article citation: Andrew C. Mitchell, Knud Dideriksen, Lee H. Spangler, Alfred B. Cunningham, Robin Gerlach. Microbially Enhanced Carbon Capture and Storage by Mineral-Trapping and Solubility-Trapping

The equations on the left show how the CO2 changes phases, it will then, under large enough pressures, react with the brine and other minerals (this is mineral trapping) essentially storing it forever (unless disturbed). Mineral is different though, as the carbonate ions react with other minerals present to form salts.

$CO_2(g) \rightarrow CO_2(aq)$

$CO_2(aq) + H_2O \rightarrow H_2CO_3$

$H_2CO_3 \rightarrow HCO_3^- + H^+$

$HCO_3^- \rightarrow CO_3^{2-}\ H^+$

Questions (aims):

1) What is solubility trapping?
2) Are there any problems with this method of trapping?
3) What is the difference between this method trapping and mineral trapping?

Answers (knowledge):

1. In this method, carbon dioxide is dissolved into salt water, this increases the density of the salt water, and the brine (saltwater) with the CO2, will sink to the bottom due to its density and essentially trap the CO2. The CO_2 will only flow to our area of interest if other fluids in that area can easily be displaced by the CO_2. Otherwise, the procedure would not work, hence finding the densities and other physical properties of fluids that are already present there is critical.
2. In order for this method to go wrong, there needs to be a drastic change in pressure in the water, and as this is very unlikely, mineral and solubility trapping are seen as the safest methods of CO2 trapping.
3. Mineral trapping has the same steps as solubility trapping, however has more steps afterwards which will be discussed in the next journal.

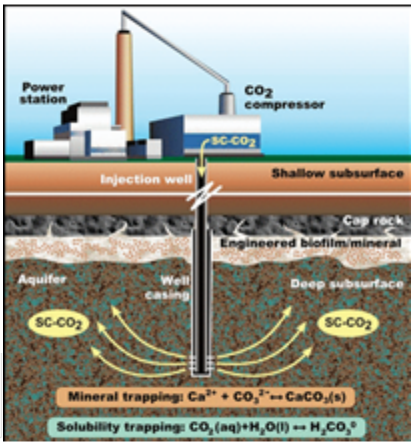


Figure 1 - diagram showing mineral trapping and solubility trapping [5]

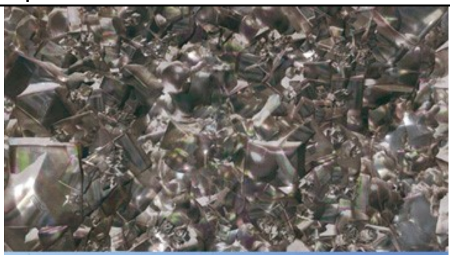
Journal Paper / Book Chapter / Article citation: CCP, co2captureproject [internet], BP group, 2015. Available from: https://www.co2captureproject.org/co2_trapping.html

Impact: The CO2 will be absorbed into the brine (saltwater) and thus will sink to the bottom essentially trapping. Risk of leakage is minimal compared to other methods of trapping as a huge change in pressure occurring randomly is very unlikely. The source does not talk about whether this type of trapping poses any risk to life in and around that environment.
Actions: As both mineral trapping and solubility trapping involve the CO2 complexly changing states and even as the molecule itself, what do engineers aim for more, mineral trapping (where the carbonate ions react with minerals to form salts, or to react with the brine to form carboxylic acids?

Journal Paper / Book Chapter / Article citation: CCP, co2captureproject [internet], BP group, 2015. Available from: https://www.co2captureproject.org/co2_trapping.html

Summary: The source gives a good insight into mineral trapping. From the previous journal we say that CO2 can form carbonate ions when in a solution such as brine. The source gives a good explanation but also an easy to understand diagram of how the minerals form.
Questions (aims): 1) What is mineral trapping? 2) How does the CO2 become trapped in this method of trapping? 3) IS there any risk of leakage and what are the complications?
Answers (knowledge): 1. Mineral trapping is where carbonate ions which are formed when carbon dioxide is dissolved in a solution such as brine for a very long period of time, starts to react with other metals, typically alkali metals For example, dissolved carbon dioxide may form carbonic acids, which then undergoes a neutralisation reaction with am alkali metal such as calcium to calcium carbonate.

Journal Paper / Book Chapter / Article citation: National Energy Technology Laboratory. U.S department of energy. 2020. Carbon capture FAQs. Accessed 05/03/2022. Available from: https://netl.doe.gov/coal/carbon-storage/faqs/carbon-storage-faqs#:~:text=Carb



2. In this process, the product is a salt or a rock, the carbon dioxide essentially does not even exist anymore, and the rocks will remain at the bottom of the basin.
3. As they are now rocks, there is practically no risk of leakage or the minerals decomposing back into CO2, hence the only complication involved is that it takes a very long time.

Impact: Once CO2 is trapped in water, it may form weak carbonic acid, these acids may react with minerals in the surrounding rock to from solid carbonate minerals.

Actions: Now that I have knowledge on all four mechanisms of carbon dioxide trapping, I need to start researching how the actual trapping is done, where it is done, energy required etc.

Journal Paper / Book Chapter / Article citation: National Energy Technology Laboratory. U.S department of energy. 2020. Carbon capture FAQs. Accessed 05/03/2022. Available from: https://netl.doe.gov/coal/carbon-storage/faqs/carbon-storage-faqs#:~:text=Carbon%20dioxide%20(CO2)%20can,critical%20point%20for%20CO2.

Summary: The source talks about the different geological sites which can be used for carbon storage. It also gives a graph for the density of carbon dioxide at different depths, as this information will be used later to help find how much CO2 can actually be stored in certain sites.

Journal Paper / Book Chapter / Article citation: National Energy Technology Laboratory. U.S department of energy. 2020. Carbon capture FAQs. Accessed 05/03/2022. Available from: https://netl.doe.gov/coal/carbon-storage/faqs/carbon-storage-faqs#:~:text=Carb

Questions (aims):

1) At what level is CO_2 typically stored in carbon trapping?
2) What should we look for when trying to find a good site?

Answers (knowledge):

1. The level CO_2 is stored at depends on which site you are storing it at, for example structural trapping can take place at any site provided that there is a cap rock, however in order to ensure that all four stages work at their optimums, carbon dioxide is injected at its super critical stage at a depth of 800-1200m.
2. The site chosen for the storage of carbon dioxide depends on the major phase you are after. However, since it is ideal to use all stages of carbon trapping; an oil and gas reservoir would be ideal. Whether it is better to use an oil and gas reservoir that has been depleted or not depends on how it was done For example, if an oil and gas reservoir has been used and sealed, but sealed by sand, the sand is not enough to stop CO_2 from leaking out hence that site cannot be used.

Impact:

Oil and gas reservoirs make very good places for carbon capture and storage, the reason being is as these sites have stored oil and gas for millions of years, hence they can do the same thing for carbon dioxide. There is also a lot of research on these sites meaning engineers who will be familiar with the process and problems if any are to occur. For the information I needed, this site has been sufficient, the last thing to do is to use this research to find a suitable location in Sydney.

Actions:

The last thing to do now is to find a suitable location in Sydney. The plant will be powered by renewable energy sources; wind turbines and solar panels however, the priority is to make sure the site can be used for CO_2 storage, as there will not be huge variations in climate around the city of Sydney.

Journal Paper / Book Chapter / Article citation: National Energy Technology Laboratory. U.S department of energy. 2020. Carbon capture FAQs. Accessed 05/03/2022. Available from: https://netl.doe.gov/coal/carbon-storage/faqs/carbon-storage-faqs#:~:text=Carb

IDP2 Research Journal Club Report

Group: 55 **Reviewer:**

Journal Paper / Book Chapter / Article citation: Martin Blunt. Gratham institute for climate change. Carbon dioxide storage. Imperial college London. [Online]. Vol 4. P. 5. 2010. Available from: https://www.imperial.ac.uk/media/imperial-college/grantham-institute/public/publications/briefing-papers/Carbon-dioxide-storage---Grantham-BP-4.pdf

Summary: It is important to think about factors which affect the amount of CO2 we can store in certain sub surface geological sites. The more obvious factors include size of the basin chosen, depth of where CO2 will be stored, (depth affects density and temperature of CO2 which will affect how well it is absorbed) but also permeability and porosity need to be thought about as these variables control the amount of CO2 which can be stored in certain rocks etc.

Questions (aims):

1) How does porosity relate to the amount of CO2 that can be stored and why does it matter and then can we estimate storage capacity by estimating the total water-filled pore volume in a rock foundation?
2) Why does permeability matter?

Answers (knowledge):

1. Porosity is essentially the amount of space in something. As CO2 will be stored and trapped in these rocks, it is important to consider the porosity of the rocks we may be encountering in our chosen basin. The source suggests that porosity is about 10%-30% of the total volume of rocks. The reason for the range is as porosity depends on several factors, e.g. the type of rock, the depth the rock is at (density increases with depth). The source also talks about even when the porosity is the same, the structure of the rock can also play a huge role in how it will hold and absorb CO2. The CO2 will be injected at a depth of 1000m near the gas rich shale, from the well it will enter at a temperature and pressure of roughly 31 degrees Celsius and 7.9MPa, from journal 7 we know that at depth of around 1000m, the density of the carbon dioxide will be roughly 625 kg/m^3, hence assuming the porosity is 20%, we can aim to store 125kg of carbon dioxide per metres cubed of rock (estimate).
2. Permeability affects the rate at which the whole process can take place, however in some cases a low permeability may decrease the flow rate of CO2, which would significantly slow down all stages, hence it would be ideal to find a location with a high porosity but also a high permeability.

Impact: The porosity of the rocks is relevant to its depth, however typically ranges from 10% to 30% porosity. However this is not the only factor which must be considered as typically there is oil and gas or resident brine in these rocks already, and the CO2 will displace these gases, oil or brine or get further absorbed by these gases and liquids. The source does not talk about how to find a good location for CO2 capture and storage.

Actions: I will further need to research what makes a good location for a carbon capture facility but also further sources to find a good location in Sydney to choose where to make our DAC facility.

Journal Paper / Book Chapter / Article citation: Australian Government. Sydney Basin. Ga.gov.au. Accessed: 05/03/2022. Available from: https://www.ga.gov.au/scientific-topics/energy/province-sedimentary-basin-geology/petroleum/offshore-eastern-australia/s

Journal Paper / Book Chapter / Article citation: Australian Government. Sydney Basin. Ga.gov.au. Accessed: 05/03/2022. Available from: https://www.ga.gov.au/scientific-topics/energy/province-sedimentary-basin-geology/petroleum/offshore-eastern-australia/sydney#heading-2

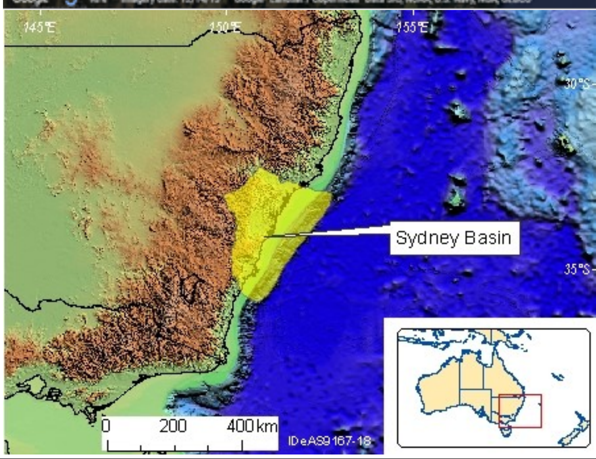
Summary: This source is backed by the Australian government, it holds information relating to geoscience. The information that I needed from the source was showing areas of Basin in and near Sydney.

Questions (aims):

1) What is a suitable location for the DAC facility?

Answers (knowledge):

1. 

2. 

Journal Paper / Book Chapter / Article citation: Hussein Hoteit, Marwan Fahs, Mohamed Reza Soltanian. 2019 Assessment of CO2 injectivity during sequestration in depleted gas reservoirs. Geosciences MDPI. Departments of Geology and Environmental Engineerin

The images above shows the areas of gas and oil basins in the Sydney. Using google satellite images, we can see that this is Jerrawangala national park, it resides over a large basin area for oil and gas, and if permission was granted by the government, who are responsible for this park, a DAC facility which would be no more 700x700m could be built. The design may require the chopping down of some trees, but a DAC facility would quickly offset the CO_2 released due to the cut down of the trees.
Impact: The picture showing the map of oil and gas basins was all I needed from this source.
Actions: This is the last journal. (Journal 9 for Storage)

Journal Paper / Book Chapter / Article citation: Hussein Hoteit, Marwan Fahs, Mohamed Reza Soltanian. 2019 Assessment of CO2 injectivity during sequestration in depleted gas reservoirs. Geosciences MDPI. Departments of Geology and Environmental Engineering, University of Cincinnati. Available from: https://www.mdpi.com/2076-3263/9/5/199

Summary: The source talks about how CO_2 must be heated and compressed before it is injected for storage. CO_2 in this state is called supercritical carbon dioxide.
Questions (aims): 1) What is the energy consumption of the injection well?
Answers (knowledge): 1. The injection well will have to both heat up the carbon dioxide but also compress it, from journal 7 we know the carbon dioxide is at its supercritical state at 7.9Mpa and 31 degree Celsius. However in order to do this, a lot of energy will be required. This energy will be supplied by the renewable energy facility in our DAC facility hence it is important to know how much energy will be required. From journal 7 in the desorption part of this report, we know that the compression of CO_2 into the critical state will require 89.2kWh/tCO_2. The CO_2 must also be heated and the energy required for this is 65 kWh/tCO_2 at a constant pressure, hence we had to calculate both these results differently. Therefore, combined we will expect roughly 144.2kWh/CO_2 to be used for the storage.

Journal Paper / Book Chapter / Article citation: Hussein Hoteit, Marwan Fahs, Mohamed Reza Soltanian. 2019 Assessment of CO2 injectivity during sequestration in depleted gas reservoirs. Geosciences MDPI. Departments of Geology and Environmental Engineerin

Impact: The required energy is a function of initial pressure … for a constant pressure the required enthalpy difference is 100 Btu / Ib which corresponds to 65 kWh per metric tonnes of CO2.
Actions: I will use this information and add it to the energy consumption part of this report.

Carbon Dioxide Reuse:

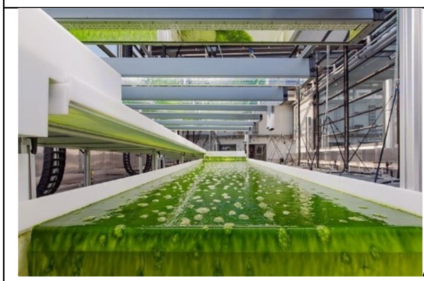
Journal Paper / Book Chapter / Article citation: Reinforced Plastics / Volume 64, Issue 1, January–February 2020, Pages 50-53 / Algae to sustainably produce carbon fibre and simultaneously take CO2 out of the atmosphere. Django Mathijsen

https://www.sciencedirect.com/science/article/pii/S0034361719301717

Summary: CO2 can be used to fed to algae to make carbon fibre and some chemicals.

Questions (aims):

1. How is carbon fibre produced in this way?
2. What are the challenges and requirement of this method?
3. What are the benefits?
4. The market of this method? The price of the carbon fibre produced by the algae? Are there existing product lines and plants?
5. What can algae produce except carbon fibre?



Answers (knowledge):

1. First, using ammonia to turn the glycerin into acrylonitrile. Next, a polymerization reaction produces polyacrylonitrile (PAN), which is the precursor for ninety percent of carbon fibre production. Last using solar power to heat up the fibres in a furnace to 2000 or 3000 degrees Celsius, which turns PAN into carbon fibre.
2. The process is preferably implemented in warm climates because algae grow best where there is lots of sun. And industrial grade CO2 is required for the process.
3. The algae are not competing with agriculture for the same land because they grow in salt water. And using manure in algae cultivation for carbon fibre production could reduce the

Journal Paper / Book Chapter / Article citation: Hussein Hoteit, Marwan Fahs, Mohamed Reza Soltanian. 2019 Assessment of CO2 injectivity during sequestration in depleted gas reservoirs. Geosciences MDPI. Departments of Geology and Environmental Engineerin

problems of manure overproduction. Water consumption is not a issue as well because fresh water is not used in algae cultivation.

4. There is already a pilot plant of up to 500 liters in Garching, Germany, proving that the process works and delivering first economics data. And the price of the carbon fibre produced by the pilot plant has to come down for it to become competitive with regular carbon fibre production. But it still takes time to improve the efficiency, and it is believed that these algae produced carbon fibres can be very fast to market once the efficiency goals are met.
5. The algae can produce two product streams: bio-fuel from the fatty acids and carbon fibre from the glycerin. Polymers (e.g. Polyhydroxyalkanoates (PHA)) and even hydrogen are possible to be product by algae though it is less efficient now, and need more process engineering to make it viable.

Impact:

The algae can take in CO2 and turn it into carbon fibre, it is a novel and advanced technology. The process is absolutely green though needing some improve commercially.

It is also worth mentioning that carbon fibre can be joined into natural stone to replacing comment. This is very relevant because cement accounts for up to 7 percent of all CO2 emission.

Actions:

1. We can cooperate with such company, and built the plant in Sydney cause there are lot of solar power here and salt water, which make it easier for transportation.
2. Find some information about the plant cited above, and research the progress of this technology in the coming years.
3. Find more method for CO2 reusing.

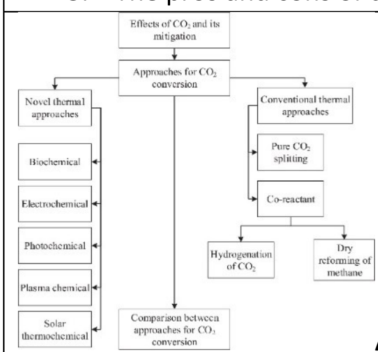
Journal Paper / Book Chapter / Article citation: Journal of Energy Chemistry / Volume 49, October 2020, Pages 96-123 / Current technology development for CO2 utilization into solar fuels and chemicals: A review. Azeem Mustafa, Bachirou Guene Lougou, Yong Shuai, Zhijiang Wang, Heping Tan

https://www.sciencedirect.com/science/article/pii/S2095495620300383

Summary: CO2 utilization into solar fuels and chemicals.

Questions (aims):

1. What technologies are used?
2. What kinds of fuels or chemicals are product?
3. The pros and cons of different technologies?



Answers (knowledge):

1. There are conventional technologies such as CO2 decomposition (direct splitting of CO2 into chemicals CO using carbon (C), and then the carbon monoxide can be reacted with

Journal Paper / Book Chapter / Article citation: Hussein Hoteit, Marwan Fahs, Mohamed Reza Soltanian. 2019 Assessment of CO2 injectivity during sequestration in depleted gas reservoirs. Geosciences MDPI. Departments of Geology and Environmental Engineerin

hydrogen, to create fuels such as CH3OH, CH2O and even carboxylic acids. Hence applications which use this fuel can now be carbon neutral.

There are some novel technologies such as Photochemical conversion, Biochemical conversion (algae), Electrochemical conversion, Plasma technology, and Solar thermochemical conversion.

2. Direct oxidative route produces short-chain olefins (C2H2, C3H6), oxygenated products (CH3OH, CH2O, HCOOH) and hydrocarbons. And indirect oxidative route produces syngas which can be further processed into almost any kind of fuel or chemical.
3. Shown in the table 10. (And can be found in the summary part of the article, the content is too long to write on the journal.)

Table 10. Comparison of different technologies used for CO_2 conversion.

Technology	Use of earth metals	Renewable energy	Turnkey process	Conversion and yields	Products	Investment cost	Operating cost	Flexibility
Traditional	Yes	–	No	High	Yes	Yes	High	Low
Photochemical	Yes	Direct	Yes	Low	Yes	Low	Low	Low
Biochemical	No	Direct	No	Medium	Yes	H/L	High	Low
Electrochemical	Yes	Indirect	No	High	Yes	Low	Low	Medium
Plasma chemical	No	Indirect	Yes	High	Yes	High	Low	High
Solar Thermochemical	Yes	Direct	Yes	High	No	High	Low	High

And the separation of products when all the feed is transformed is notable as well. Electrochemical and solar thermochemical CO2 transformations are the only two approaches capable of producing separated products and the products in plasma technology are in one feed, their separation is possibly the biggest drawback of plasma technology.

Impact:
Fuels and chemicals production is the main part of CO2 utilization, this article gives us a clear review in this aspect and lists many technologies and productions which can be written in our report.

Actions:

1. Make some further research on one or two technologies shown in this article.
2. Find some information about the application of this technology, are there some progresses from the companies or labs aiming on it?
3. Find more method for CO2 reusing in light industry (carbonating drinks etc.)

Journal Paper / Book Chapter / Article citation: Engineering and Technology/ Tuesday, February 19, 2019/ Six ideas for CO2 reuse: a pollutant or a resource? Tereza Pultarova

https://eandt.theiet.org/content/articles/2019/02/six-ideas-for-co2-reuse-a-pollutant-or-a-resource/

Summary: Introduction of six ideas for CO2 reuse.

Questions (aims):

1. What are these six ideas?
2. How can they reuse CO2? (The process)
3. The advantages of the ideas?

Answers (knowledge):

1. i) Turning CO2 into rocks (limestone). This technology is developed by Blue planet.
ii) Making cement out of CO2.
iii) Feeding CO2 to algae to make carbon fibre, developed by scientists from the Technical University of Munch. (This idea is cited in my first journal club)
iv) Turning CO2 into insulation for housing from Econic Technology.

Journal Paper / Book Chapter / Article citation: Hussein Hoteit, Marwan Fahs, Mohamed Reza Soltanian. 2019 Assessment of CO2 injectivity during sequestration in depleted gas reservoirs. Geosciences MDPI. Departments of Geology and Environmental Engineerin

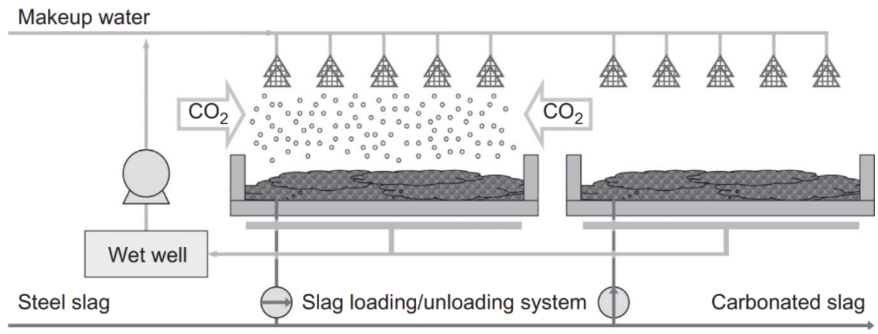
v) Feeding CO2 to algae to revive oyster reefs. vi) Turning CO2 into fuels, promoting by researchers from the US Department of Energy's Idaho National Laboratory 2. i) The process takes flue gas from a natural-gas-fired power plant and turns it into calcium carbonate, essentially artificial limestone. ii) Combining CO2 with calcium to form calcium carbonate, which is dried to make cement. iii) Glycerol from algae can converse into acrylonitrile which is the precursor of polyacrylonitrile fibres. And pyrolising polyacrylonitrile fibres, carbon fibres are formed. iv) Replacing up to 43 percent of the propylene oxide with CO2 in the polyols production. v) Using CO2 to grow algae in special photobioreactors which could then be fed to baby oysters. iv) Specialised liquid materials are used to make the CO2 more soluble and allow the carbon-capture medium to be directly introduced into a cell for electrochemical conversion to synthetic natural gas 3. i) Using CO2 without having to purify it, which can save a lot of energy. ii) same as i) iii) Algae-based carbon fibres are as strong and lightweight as the current commercially available carbon fibres but would be at least 10 times cheaper. And carbon fibres can be used to replace concrete and metals which generates a lot of CO2. iv) Propylene oxide is made from oil, and the process generates CO2. The product is more environmental-friendly, cheaper and perform as well as conventional polyurethane. v) This idea can revive the ecosystem when isolating the CO2. vi) More energy efficient than previous technology.
Impact: This article gives us 6 good ideas for CO2 re- utilization. And some of them have already been put in the market. It also gives us some examples of the application of the CO re-utilization technology and makes comparisons.
Actions: 1. List some ideas as example. 2. Find some information about the details of the ideas. 3. Find more method for CO2 reusing in light industry (carbonating drinks etc.)

Journal Paper / Book Chapter / Article citation: Rackley, S. A. (2017). Carbon capture and storage Part 3 Chapter 22 - CO2 utilization and other sequestration options https://www.sciencedirect.com/science/article/pii/B9780128120415000222

Summary: This article demonstrates some processes for CO2 utilization and the technologies used in them.
Questions (aims): 1. What is the traditional utilization of CO2? 2. What are the two processes in CO2 utilization? 3. Why CO2 utilization is important? 4. What can CO2 be used for? And what technologies are used for CO2 utilization? 5. What are the advantages and challenges of the technologies?
Answers (knowledge):

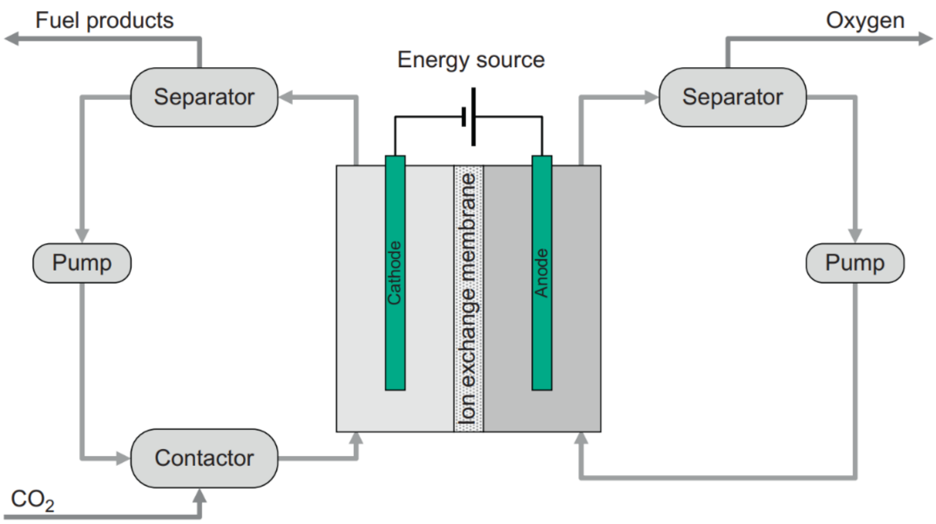
1. CO2 has traditionally been used in a wide range of industrial processes, from the carbonation of soft drinks to the production of fertilizers.
2. There two processes for CO2 utilization: low-energy processes(C-O) for the production of chemicals such as urea, carbonates, and polycarbonates and high-energy processes(C-H) for the production of fuels.
3. There are perceived risks of other options for the long-term storage of captured CO2.
4. i) Generating high-value products such as PCC from these wastes, while also capturing CO2. There two schemes:

- Mineral carbonation of alkaline wastes by direct air or flue gas capture
- Calcium and magnesium carbonate precipitation from seawater by flue gas capture

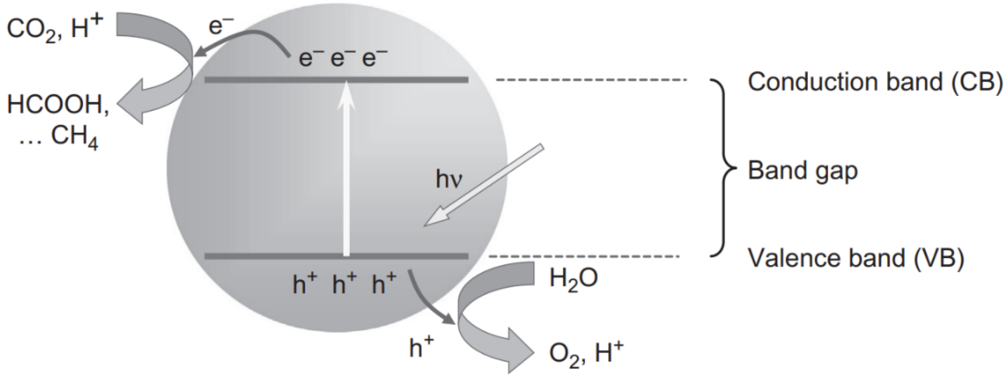


ii) CO2 can be used to accelerate CO2 curing of concrete products in the cement industry. Curing in a CO2-rich atmosphere is a viable and faster alternative to steam curing, which eliminates this energy cost and offers a route for the cement industry to significantly reduce its net emissions. And the use of magnesium oxide (MgO) as the intermediate cement product, based on a magnesium silicate (talc) feedstock, results in a significant reduction in the CO2, while absorption during hydration and curing is increased significantly, giving an overall negative emission of ~0.6 t-CO2/t-cement produced and used.

iii) Electrochemical CO2 conversion into fuels. CO2 can be converted to a range of fuels and fuel precursors by this means, including CO, formic acid (HCOOH), methane (CH4), and ethylene (C2H4).



iv) Reduction of CO2 using semiconductors as photocatalysts for artificial photosynthesis.



v) Using CO2 in algae production. Algal biomass can be used without further processing as a feedstock for fish farming (aquaculture) or as a solid fuel for power generation, the main organic components can also be processed into high-value products: proteins can be used as animal feed, carbohydrates can be fermented to produce bioethanol, and lipids (oils and fats produced for energy storage) can be used for biodiesel production.

5. i) In the pulp and paper industry, the capture of CO2 emissions from a paper plant could be achieved producing an otherwise energy-intensive feedstock (PCC) while also consuming waste from other industries.
   Water consumption, as a result of evaporation and droplet loss through entrainment in the wind, would be a significant proportion of the overall operating cost of such a system.
   ii) Limited carbonation increases strength and makes concrete less permeable and more resistant to shrinkage and cracking, while excessive carbonation reduces the pH of water in the cement pores, potentially leading to corrosion of steel-reinforcing bars.
   iii) A major drawback of electrochemical conversion is the cost of electricity required to drive the reaction, and this process will only ever be economically viable if the energy input comes at near-zero cost.
   iv) Significant technical challenges need to be overcome to achieve the conversion efficiencies that would enable commercial deployment.
   v) The aqueous cultivation has a number of advantages that can lead to higher productivity per unit of land usage. These advantages are balanced by the cost of systems to supply CO2 and for continuous cultivation and harvesting. And contamination is particularly problematic in a algae farm system.
   Many companies have started on this scheme to product biomass. A two-stage algae production system that combines closed photobioreactors with open ponds has been developed by Cellana which achieves the main advantage of the closed photobioreactor in eliminating contamination while also minimizing cost through use of the open pond system.

Impact:
This article gives me some details in the CO2 utilization and contains. It is worth mentioning that the article also lists some examples in the application of these technologies and demonstrates the theory of each method.

Actions:
1. Find more method for CO2 reusing in light industry (carbonating drinks etc.)
2. Find some articles to do with the policy of CO2 reuse.

Journal Paper / Book Chapter / Article citation: Hussein Hoteit, Marwan Fahs, Mohamed Reza Soltanian. 2019 Assessment of CO2 injectivity during sequestration in depleted gas reservoirs. Geosciences MDPI. Departments of Geology and Environmental Engineerin

Journal Paper / Book Chapter / Article citation: Carbon Capture Journal / January 2017 /CO2 Utilization: A Look Ahead. Fatima Maria Ahmad

https://www.c2es.org/document/co2-utilization-a-look-ahead/

Summary: The benefits and challenges of carbon dioxide enhanced oil recovery (CO2-EOR) in technology, market and policy.
Questions (aims): 1. What are benefits of CO2-EOR? 2. What are challenges of CO2-EOR? 3. How can we solve the challenges?
Answers (knowledge): 1. The climate benefits of CO2-EOR are clear. Last fall, the International Energy Agency concluded that for every barrel of oil produced using manmade CO2, there is a net CO2 storage of 0.19 metric tons. CO2-EOR is the “most immediate, highest value opportunity to utilize the greatest volumes of anthropogenic CO2. And a major benefit of reusing manmade CO2 is creating a revenue stream to offset the costs of capturing carbon dioxide. 2. Technical challenges: ● Processes need to be efficient in light of thermodynamic constraints. There is an energy penalty associated with the conversion of CO2 to other substances. The CO2 molecule is stable and breaking the bonds through a chemical or catalytic method often requires a large amount of energy, which affects the lifecycle analysis of emissions reduction. Innovators have explored using renewable energy for this task. If renewable energy prices continue to drop, that would enable greater use of such energy for conversion of CO2 through chemical or catalytic methods. ● Due to the cost of transport, the re-use of CO2 will need to take place near sources of captured CO2, which is a geographic constraint. ● Due to the volume of manmade CO2, re-use options need to be possible in many seasons and in various climates and on a commercial-scale. Market challenges: ● Options for re-use of CO2 are highly diverse and it is not easy to compare their performance and benefits. ● The potential economic benefits of CO2 conversion for re-use are largely unquantified because the technologies are in early stages of development. The climate benefits of re-use of CO2 are also not fully quantified. ● Utilities are not able to take on the technological or financial risk of investing in CO2 re-use options. Legal and regulatory obstacles prevent testing of promising technologies on operating power plants. As a result, utilities are also not regularly communicating with CO2 re-use innovators to inform the R&D process. ● Regulations on CO2 emissions are not stringent enough to independently drive the creation of a commodity market for CO2. Policy challenges: The international ASTM standards for materials like concrete may need to be revised to reflect new approaches. CO2-EOR and other geologic storage technologies should be recognized under law for their emissions reduction benefits. 3. First, policymakers should implement a price on carbon, increase mandates for renewable products and fuels, and incentivize continued emissions reductions.

Second, research should be funded to decrease the cost of CO2 utilization. Third, production can be scaled-up through collaborations among researchers, entrepreneurs, governments and businesses for process integration of carbon capture, CO2 conversion, and hydrogen generation. Fourth, infrastructure is needed to link generators of CO2 with users of CO2 to ensure a reliable source of CO2. Finally, funders should explore applied research into long-shot technologies and applications with high CO2 abatement potential.
Impact: This article gives us the demonstration of CO2-EOR and depicts the market and policy overview of it. Which can be added to the report for supplementary.
Actions: 1. Find more method for CO2 reusing in light industry (carbonating drinks etc.) 2. Added the commercial and policy aspect into the report. 3. Find some examples about the cooperation of company and government in CO2 utilization.

Journal Paper / Book Chapter / Article citation: Hussein Hoteit, Marwan Fahs, Mohamed Reza Soltanian. 2019 Assessment of CO_2 injectivity during sequestration in depleted gas reservoirs. Geosciences MDPI. Departments of Geology and Environmental Engineerin

APPENDIX D: Lab exercises

<include all Lab worksheet/exercises you completed>

APPENDIX E: DESIGN EVIDENCE

Calculation Process:

Mass of captured CO2

$$Diameter of the fans: d = 1.3m$$

$$CO2\ taken\ in\ velocity: v = 1.5m/s$$

$$Volume\ of\ CO2\ taken\ in\ per\ second: V = 108 \times \frac{\pi d^2}{4} \times v$$

$$Density\ of\ the\ air: \rho = 1.21kg/m^3$$

$$Mass\ of\ air\ taken\ in\ per\ second: V \times \rho$$

$$Mass\ of\ CO2\ taken\ in\ per\ second: V \times \rho \times 0.06\% = 0.177kg/s$$

$$Mass\ of\ CO2\ taken\ in\ per\ hour: 0.562t/h$$

$$Mass\ of\ CO2\ taken\ in\ per\ year: 4923.057t/year$$

Energy consumption

CO2 capture

$$Column\ depth: D = 7m$$

$$Electricity\ effeciency: \varepsilon = 0.6$$

$$The\ pressure\ drop: \Delta P = 7{,}4 * D * v^{2{,}14}$$

$$The\ volumetric\ flow\ rate: V = \frac{plant\ capture\ rate\ from\ the\ air}{capture\ fraction\ of\ CO_2\ from\ air * concentration\ of\ CO_2\ in\ air\ by\ mass}$$

$$Total\ work\ from\ fans\ per\ year: W_{fan} = \frac{(V * \Delta P)}{\varepsilon} = 5256MWh/y$$

$$Total\ work\ from\ pump\ per\ year: W_p = 15\% * W_{fan} = 788.4MWh/y$$

$$Total\ work\ done\ per\ year: W_{fan} + W_p = 6044.4MWh/y$$

$$Total\ power: P = 690\text{KW}$$

CO2 desorption

Desorption Journal 1 shows 25,000,000 kWh for 5000 tonnes of CO2

$$Total\ Energy\ per\ ton: 5000KWh/t$$

$$Total\ power: 0.562t/h \times 5000KWh/t = 2810KW$$

CO2 storage

Storage Journal 10 shows 144.2 kWh per tonne of CO2

$$Total\ energy\ per\ ton: 144.2KW/t$$

Only 3/5 of CO2 are stored underground.

Journal Paper / Book Chapter / Article citation: Hussein Hoteit, Marwan Fahs, Mohamed Reza Soltanian. 2019 Assessment of CO2 injectivity during sequestration in depleted gas reservoirs. Geosciences MDPI. Departments of Geology and Environmental Engineerin

$$Total\ power: 144.2KW/t \times\ 0.562t/h \times \frac{3}{5} = 48.62KW$$

CO2 transportation

Transportation journal 2 shows

$$Total\ work\ per\ ton: 21.4\ \mathrm{GJ/t} = 5944.44\mathrm{KWh}$$

$$Total\ power: P = 3340.78\mathrm{KW}$$

CO2 reuse

70 red led grow light (720W) and 70 pump (50W) are used for algae production

$$Total\ power: P = 70 \times (720\mathrm{W} + 50\mathrm{W}) = 53.9KW$$

Total power of the system shown in the table ?

Process	POWER(KW)
CO2 capture	690
CO2 desorption	2810
CO2 storage	48.62
CO2 transportation	3340.78
CO2 reuse	53.9
In Total	6943.3

Table ?

$$P_{total} = (690 + 2810 + 48.62 + 3340.78 + 53.9)KW = 6.943MW$$

The energy produced from a single turbine in Australia is about 1256 / 527 = 2.83MW

(https://selectra.com.au/energy/guides/renewable/wind-energy)

That means we need at least 3 wind turbines for energy consumption.

The mass of reused CO2

Algae strain: Chlorella ZY-1

The data used below are based on the best condition for this algae strain.

(https://doi.org/10.1016/j.enconman.2004.10.010)

$$CO2\ \ concentration: 10\%$$

$$Flow\ rate\ of\ 1L\ bioreactor: 0.25L/min$$

$$Volumeofonebioreactor: V = \left(\frac{\pi \times 5^2}{4} \times 20\right)L = 392.7L$$

$$Flowrateofthesystem: Fr = (0.25 \times 392.7L) = 98.175L/min = 9.818 \times 10^3 m^3/min$$

The system working for 24 hours without stopping.

$$\rho_{CO2} = 1.87kg/m^3$$

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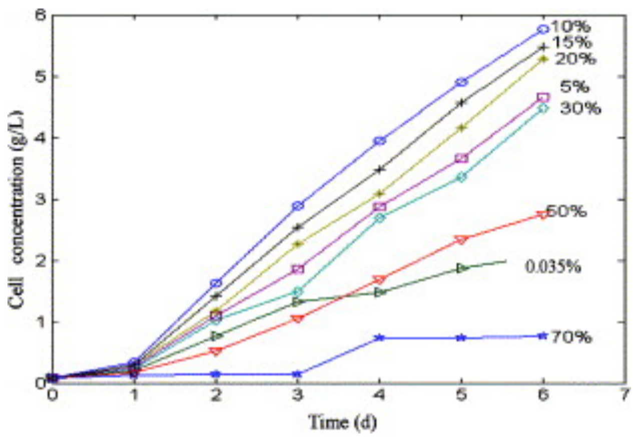
$$Mass\ of\ \ CO2\ captured\ per\ year\ for\ each\ bioreactor: Fr \times \rho_{CO2} = 9340.22kg/y = 9.34t/y$$

$$The\ number\ of\ the\ bioreactor: 120$$

$$Mass\ of\ \ CO2\ captured\ per\ year\ for\ the\ whole\ system =\ 1120.8t/y$$

The mass of the product/biomass

Figure ? shows the amount of the cell concentration in different days and CO2 concentration.



$$When\ the\ CO2\ concentration = 10\%, the\ cell\ concentration\ = 5.9g/L\ in\ the\ day\ 6$$

$$Mass\ of\ biomass\ produced\ per\ year: \left(5.9 \times 392.7 \times 120 \times \frac{365}{6}\right) = 16.91t/y$$