A.C.C.O.S

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SUSTA.INNO

Abstract

A.C.C.O.S (Algae based carbon capturing facility on site)

We are three engineering students in different engineering disciplines from the inno.space design factory based at the University of Applied Sciences in Mannheim, Germany. Our team's name is "susta.inno" which stands for sustainable innovation. We are part of the design thinking Project "challenge-based innovation Australia, Asia, All others", short CBI A^3.

This challenge connects to the UN Sustainable development goal (SDG) 12, *Ensure sustainable consumption and production patterns*. The goal is to find a problem space and a solution for the SDG, which is supported by deep tech from CERN and the Attract-Academy, for a scenario in the year 2030.

In this whitepaper we present our idea and first concept for the solution. The solutions name is "Algae based carbon capturing facility on site" or short "A.C.C.O.S". Its goal is to help the producing industry to capture their produced carbon dioxide on the production site and to make CO_2 - Certificates and other "green" projects unnecessary.

This technology will have a big impact on the industry by 2030 because the price to emit CO_2 is going to more than doubled by then. Furthermore, carbon capturing is going to help the environment to recover from the high CO_2 concentration because nature can only lower that concentration if the emissions are lower than the natures capability to capture the carbon dioxide.

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1 Societal challenges

In an era marked by unprecedented global challenges, our world stands at a crossroad. We confront a range of complex issues, from economic inequalities and climate crises to health disparities and resource depletion. In this context, the United Nations has taken a decisive step by establishing the Sustainable Development Goals (SDGs) in 2015. The SDGs are a collection of 17 interlinked goals and a universal call to action. They are not just goals but a blueprint for a better and more sustainable future for all. Therefore, for each of the 17 goals, more precise sub targets are defined which are to be achieved.

In this chapter we will introduce you to the societal challenge we were assigned on. It is part of the SDG 12 which has the title *Ensure sustainable consumption and production patterns.* SDG 12 faces the topic of sustainable consumption and production from a wide range of perspectives such as the efficient use of natural resources, global food waste at the retail and consumer levels, chemical waste, or the encouragement of companies to adopt to sustainable practices [1].Especially the last perspective mentioned above caught our attention. The corresponding sub target of SDG 12 is the target 12-6. This target is particularly interesting as it aligns business operations with sustainable development, highlighting the critical role of transparency and accountability. It encourages companies to not only focus on economic success but also to consider their environmental and social impact, fostering a shift towards a more sustainable and responsible global economy. We think making the companies sustainable will be a key factor in solving environmental challenges. The next chapter will present the problem space we chose. A problem space that can be strongly influenced by a more sustainable corporate behavior.

2 Problem space

Figure 1 | Bathtub metaphor

Picture a bathtub, the water's surface is nearly touching the brim. Above this bathtub, there is a faucet, from which water continuously flows, never stopping, constantly adding to the already high water level. This image serves as a powerful metaphor for a complex environmental concept.

The level of water in this bathtub represents the current amount of CO_2 in our atmosphere. The faucet pouring water continuously into the tub symbolizes the ongoing CO_2 emissions that humanity contributes through various activities like burning fossil fuels, deforestation, and industrial processes.

If we look at the bathtub, it quickly becomes clear that the problem can be stopped by turning off the tap. The water level would still be high, but flooding would be prevented. The water is already running off through the drainage because there are processes in our environment (e.g. growth of plants) that bind CO_2. We can't see that right now because the amount flowing out is too small. Unfortunately, it is very difficult to turn off the tap (i.e. to stop CO2 emissions), because the tap consists of many small taps (emitters). That's why we want to minimize the problem and focus only on CO_2 emissions in Germany. Figure 2 shows the history of annual CO_2 emissions in Germany.

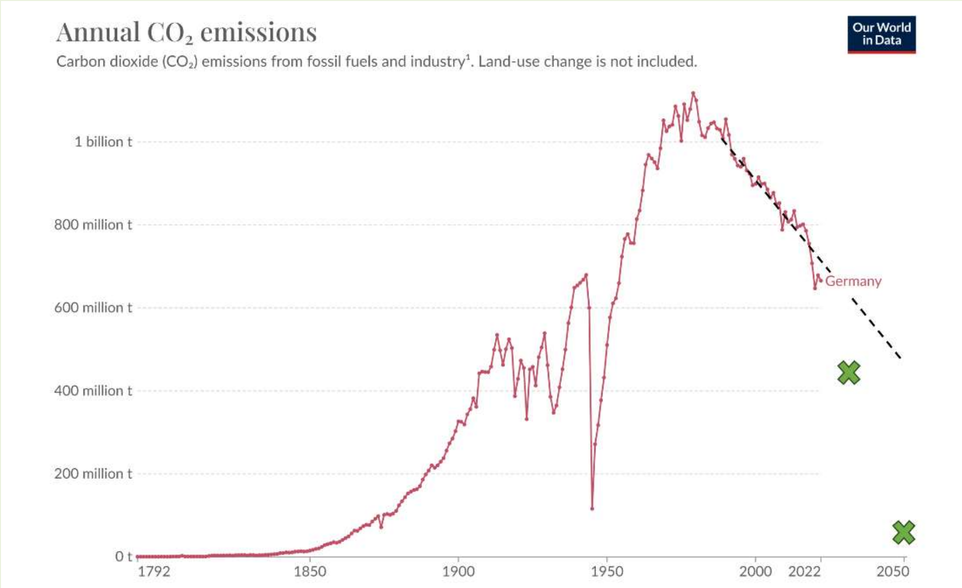


Figure 2 | Annual CO_2 emissions [2]

As you can see from the graph, annual CO_2 emissions have been falling for years. We are already turning off the tap, but are we doing it fast enough? The simple answer is no. For this purpose, an auxiliary line (black dashed line) has been drawn in the graph. In addition, the CO_2 emission levels for Germany for 2030 and 2050, which must be achieved to meet the Paris Agreement targets, have been drawn in too (green crosses) [3, 4]. This shows that we must reduce the amount of CO_2 emissions faster. But why?

If the limits set by the Paris Agreement are exceeded, it could trigger a series of climatic events. These events could be more severe and dramatic than any scenario depicted in fiction. For example, in a world where global warming is limited to 1.5°C, about 13.8% of the global population will face severe heat waves at least once every five years. If the temperature rises to 2°C, this percentage nearly triples to 36.9%, affecting an additional 1.7 billion people. By keeping global warming to 1.5°C, approximately 420 million fewer individuals will experience frequent extreme heat waves, and about 65 million fewer will be exposed to heat waves. [5, 6] In [7, 8, 2] other consequences of a warming of 1.5°C / 2°C are named. Including rising sea levels, declining biodiversity, almost complete destruction of coral reef, declining in global fishery, increase in poverty, a rise in diseases such as malaria and dengue fever expected. These are just to name some of the effects. In Figure 3 the differences between a 1.5 °C and a 2 °C warming is shown. Looking into Figure 3, the additional 0.5 degrees of warming causes enormous changes. It is therefore extremely important to keep the warming as low as possible.

In chapter 2 it is already mentioned that companies have a major influence on CO_2 emissions. To get an idea of the quantity, the German industry alone emits around 110 million tons of CO_2 per year. [9] That is a large quantity of emissions and therefore also a large potential for reduction. The aim is to neutralize all emissions. However, there are also processes in industry where the production of CO_2 is unavoidable or difficult to prevent. Therefore, a way must be found to compensate for these residual emissions. Currently companies buy CO_2 certificates to offset their emissions. For example, there are private providers who bind CO_2 through forest protection projects and then sell this bound CO_2 to other companies in the form of certificates. At the same time, these private providers then confirm the CO_2 compensation to the companies with a certification for their products. In this way, the companies can state that they are climate neutral, even though CO_2 was produced. [10] The problem with that is that a study [11] has shown that in over 90% of the forest protection projects examined, no CO_2 is saved. This is often because the project operators expect more deforestation than is realistic. This allows the private providers to sell certificates for forest areas that would not have been cleared anyway. In that way they just earn a lot of money. That being the case we came up with a how might we statement:

How might we support the industry in achieving net-zero emissions, without greenwashing?

We want to encourage companies to offset their CO_2 emissions themselves instead of buying fake certificates. We want to develop an in-place CO_2 compensation facility for the production site.

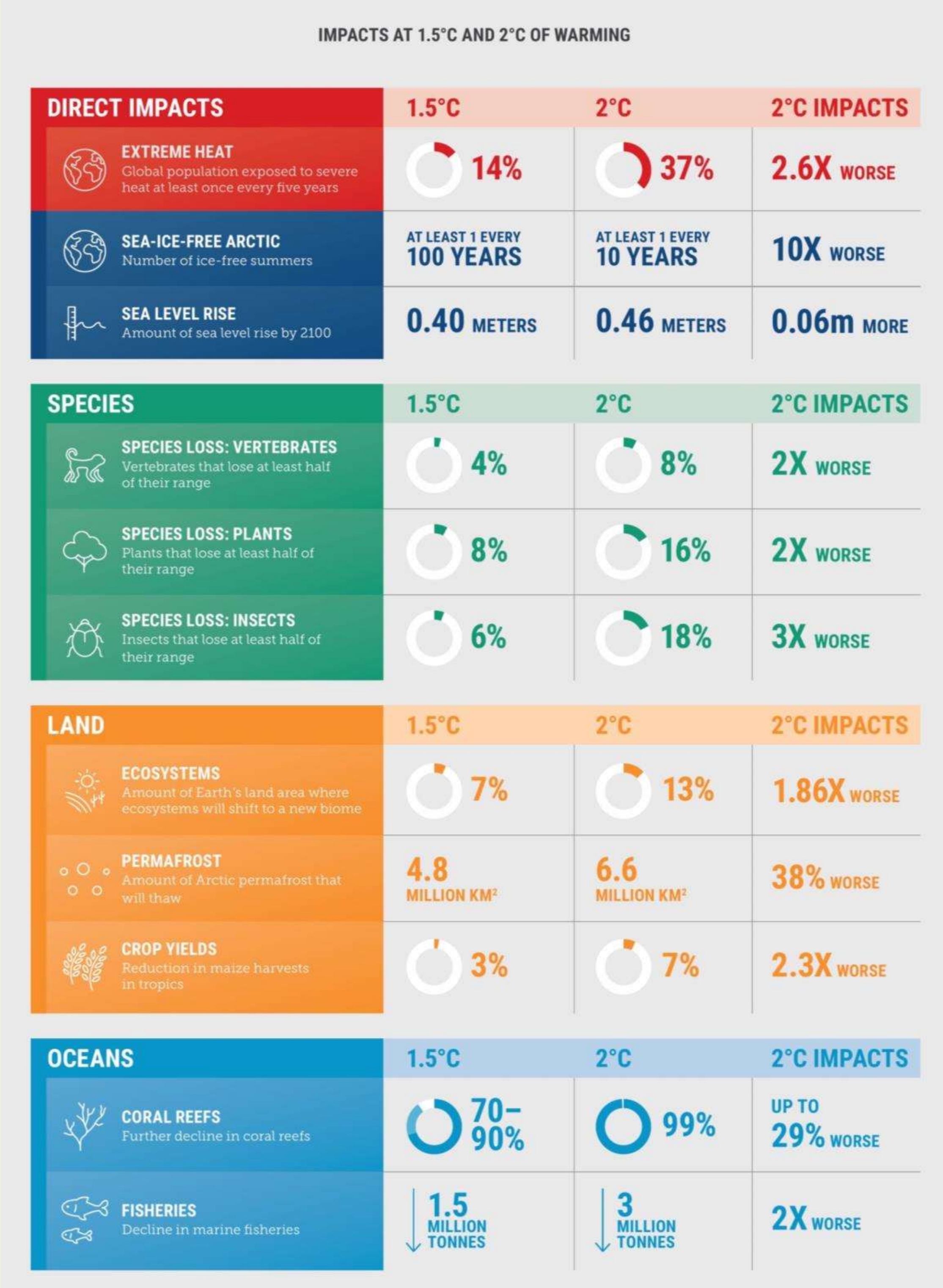


Figure 3 | Impacts of global warming [8]

3 Concept

3.1 Basic Concept

To encourage the companies, we created the on-site CO_2 compensation system A.C.C.O.S.

A.C.C.O.S is an advanced CO_2 capturing system, placed on the production facilities of the industry that uses microalgae to convert the CO_2 back into O_2 by growing through photosynthesis.

The concept of A.C.C.O.S combines a large pond, in which the algae culture can grow, a tubing system to increase the residence time of the CO_2 in the system, that the algae can consume almost 100 % of the CO_2 and a large filtration system to constantly purge some of the grown algae. The purge is going to control the density of algae in the system to create the best possible environment for the algae to grow as fast as possible.

The filtration system is connected to the HYGLIGHT analyzation system, which analyses the metabolic activity of the algae to give continuous feedback, which then allows us to know how much algae needs to be removed to ensure the best conditions for the algae.

To further help the system to be automated and efficient, the CO_2 concentration is measured both inside and outside the pond, to either increase or lower the residence time, depending on how much CO_2 is put into the system.

For increased safety, every A.C.C.O.S system has a second and third pond, in which the output of the first pond can be directed to. If the first pond does not have enough capacity to filter the aimed amount of CO_2, so the measured CO_2 level over the pond is higher than specified, then it is pumped into the second pond. Additionally, one pond works as a backup pond for maintenance work on the other ponds. For larger Facilities, more ponds could be needed as shown in

Furthermore, the A.C.C.O.S system is connected to the control-center of the facility and equipped with measuring equipment, that observes the nutrition level in the ponds. The system can inject new minerals such as Sodium chloride and urea. The control-center connects the filtration-, nutrition-, HYGLIGHT- and measuring systems.

In the future, the A.C.C.O.S concept shown in Figure 4 (built out of 3 similar systems as described above), will be capable to capture up to 18,000 t of CO_2 per year, which is an average CO_2 output of a medium sized facility [12].

This size is calculated out of the amount of CO_2 that the algae can consume, the scaling of the system, and efficiency of the system.

Now, algae can consume about 6.24 grams CO_2 per liter per day [13]. In the future, this number should be increased to up to 50 grams CO_2 per liter per day using the HYGLIGHT- and CRISPR-CAS9-technology.

By that, the needed pond volume can be calculated:

Now with 6.24 grams CO_2 per liter per day:

$$V = \frac{50 \cdot 10^6 \ \frac{g}{d}}{6.24 \ \frac{g \cdot d}{L}} = 8.012.000 \ L \rightarrow 8012 \ m^3$$

But in the future, that volume will decrease to:

$$V = \frac{50 \cdot 10^6 \frac{g}{d}}{50 \ \frac{g \cdot d}{L}} = 1.000.000 \ L \rightarrow 1000 \ m^3$$

Which means, in the future a pond with the volume of 1000 m^3 is needed.

That volume is calculated through:

$$V = \frac{\pi}{4} \cdot d^2 \cdot h = \frac{\pi}{4} \cdot (16 \ m)^2 \cdot 5 \ m \approx 1005 \ m^3$$

And shown in Figure 4 below.

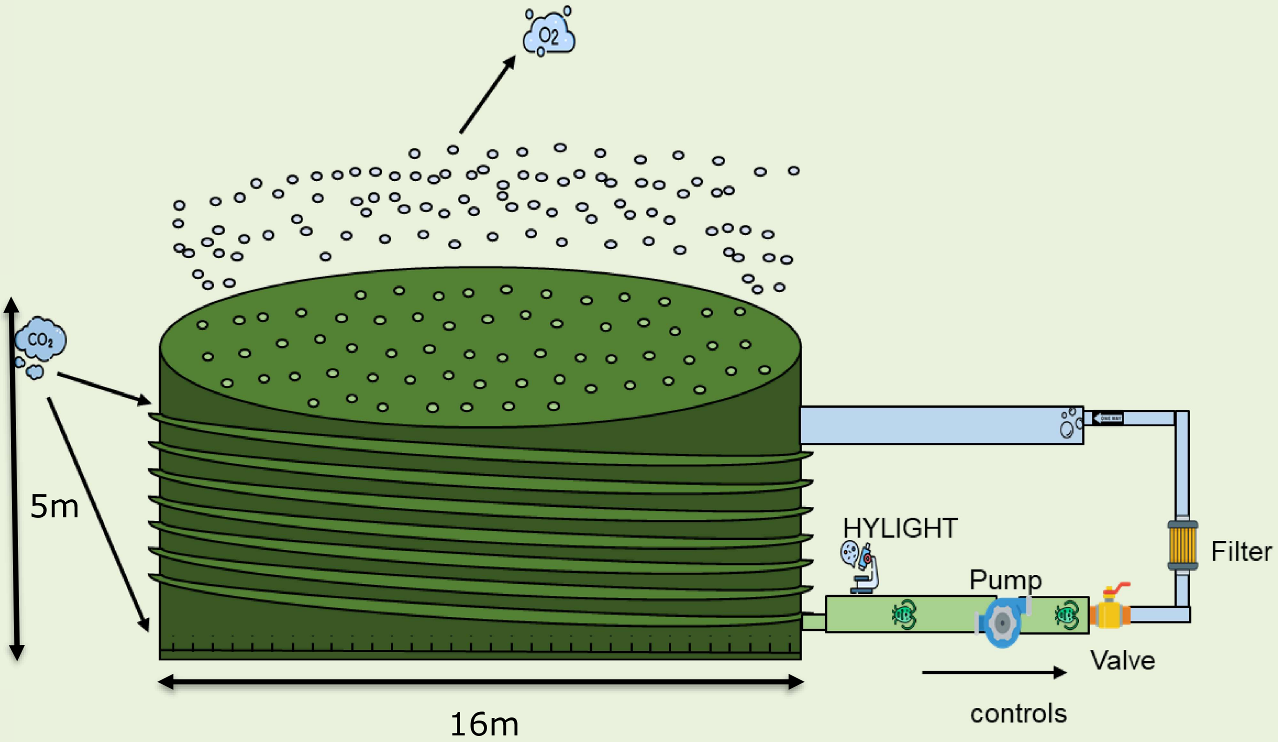


Figure 4 | Concept - A.C.C.O.S-pond system

Figure 5 | large amount of pond systems [14]

3.2 Network of A.C.C.O.S

As described in the previous chapter, A.C.C.O.S is implemented in an existing production facility and must be connected to the control room to operate all of the A.C.C.O.S systems.

In order for A.C.C.O.S to operate properly, A.C.C.O.S needs a lot of information. This information passes through the control room's data centre, where it is sent to systems that need specific data. First, A.C.C.O.S needs to know how much CO_2 is being emitted at the moment and how much is being pumped into the system. The system uses this information to decide whether to use one pond or to use the support pond for high CO_2 volumes. Secondly, the pumping rate has to be adjusted so that the residence time of the CO_2 is optimal. This ensures that the algae have enough time to consume all the CO_2.

Meanwhile, the data centre calculates the growth rate of the algae to give feedback to the filtration system on how much biomass needs to be removed from the system to ensure a good environment for the algae.

The information on the algae growth rate comes from the HYGLIGHT analysis and the analysis of the current metabolism of the algae.

To further control the residence time and CO_2 consumption in each pond, the CO_2 levels of the CO_2 feed (how much CO_2 is pumped into the system) and the output are measured. If the output is within specification, no action is required. If the specification is not correct, the retention time must be adjusted.

If the analysis of the algae and the CO_2 levels do not match expectations, the facility management will need to take manual action to keep the system in the correct operating window.

The relationships between the various parts of the A.C.C.O.S are illustrated in Figure 6.

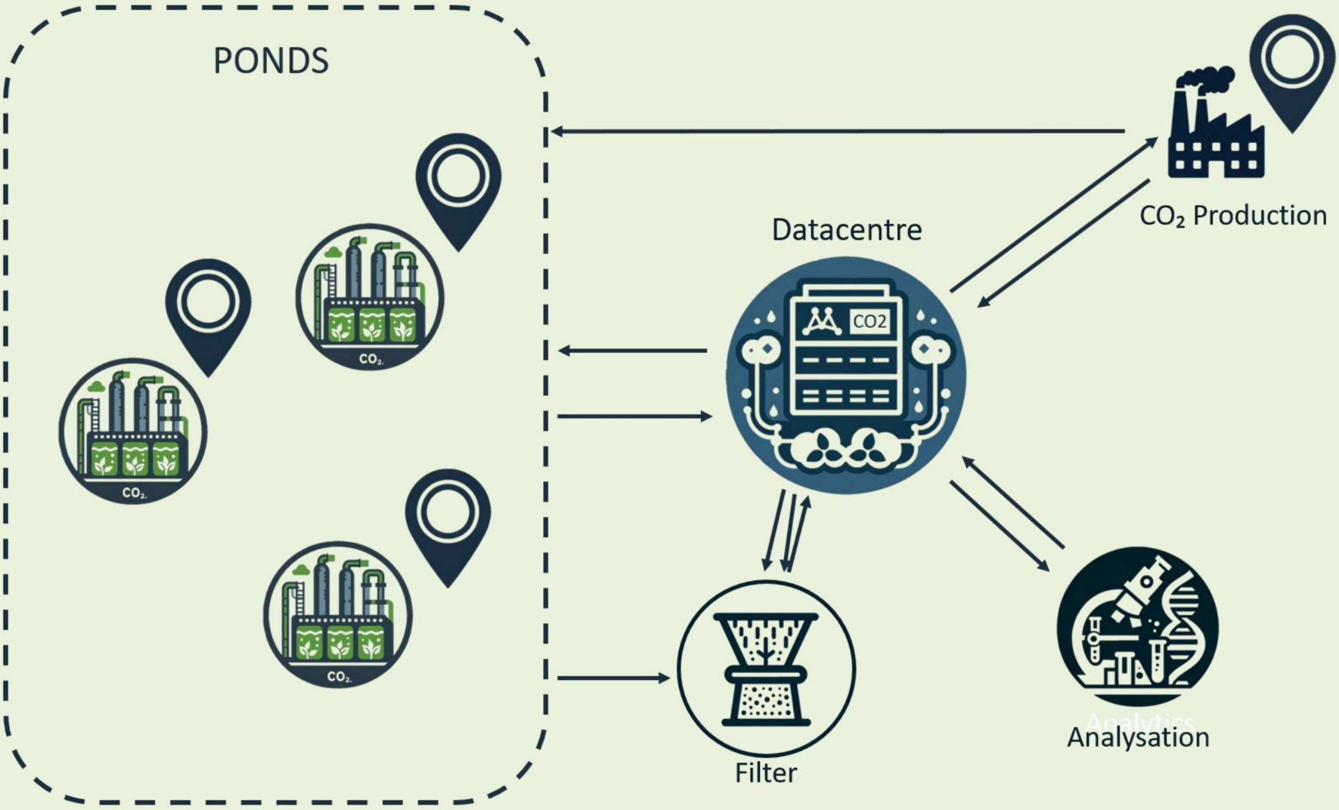


Figure 6 | Network of A.C.C.O.S

3.3 Why use algae instead of plants

You might think to yourself: "Why should we even use algae, why don't we just use trees and normal plants, like we currently do to try and fight CO_2 Pollution?". There are many reasons why Algae is superior, and we will highlight them here below.

Higher CO_2 binding

For the same amount of algae volume compared to terrestrial plants, some types of algae have been shown to be 10-50 times mor effective at binding CO_2 [15].

Easy to grow

Algae is easy to grow compared to trees or other plants. The require a lot less water and are not as picky about where you plant them [15].

Long term storage

When trees get cut down or die, they release the stored CO_2 back into the atmosphere. With algae, scientists have shown that by adding iron fertilizer to the ocean, algae will grow in an algae bloom and start to remove CO_2 from the atmosphere. When this algae begins to die, it sinks towards the ocean floor, still binding all the carbon it has consumed. Once sunk, it is estimated that it could stay there for centuries [16].

Useful side products

Algae can (depending on the species) be turned into fuel, food, energy and more. It does so while being more space efficient even, then common crops. A study has shown that algae can produce 27 times as much protein as soybeans in a single hectare of land / pond [17].

4 Users and touchpoints

Industry

Many industries, like chemical or steel smelting, simply cannot get rid of all the CO_2 in their production lines. Certain chemical reactions for example will always emit CO_2 and there is no way around it. Similarly in the steel production example, the melting and mixing of metals to form alloys will also emit CO_2 without a way to prevent it. We offer a solution for companies like these, by enabling them to capture the emitted CO_2 right on site where its being emitted. That way they don't have to rely on sketchy CO_2 certificates and can also save on CO_2 taxation for example. They can also earn some extra revenue with the side products which can be made from the algae.

Governments

Our solution can help governments achieve their goals for environmental protection. We believe that our solution will do so while also sustaining economic growth, without having to get rid of important industries and thus workplaces. This will also result in a positive opinion of the public.

Economy

This new industry of on-site carbon capture will create many new jobs and chances for investment. As more and more companies will be forced to comply to environmental regulations, the industry is bound to grow and thus also ensure economic growth.

Customers

Nowadays customers make way more conscious buying decisions with the products they want. By enabling all industries to go net zero and beyond, customers that care about the environmental impact their consumption creates will get more options to choose from.

Local communities

Air pollution can sometimes be a localized problem. With our on-site solution, areas with high air pollution can fight back and thus improve the living quality of the people living there.

5 Technology

A.C.C.O.S will be using technologies like CRISPR-Cas9 and HYLIGHT to achieve the above-described goals. HYLIGHT (Hyperspectral imaging for embryo selection) was originally developed to improve fertility quotes of in vitro fertilization. By measuring the light waves which are being emitted through natural auto-fluorescence of key cellular compounds of the egg cells, the egg

cell with the single highest reproductive potential can be selected to improve the chance of a successful pregnancy. As HYLIGHT is basically able to measure and compare the metabolic rates of cells, we aim to use this technology to measure and monitor the health of the algae in our system. With this monitoring system we will be able to control for example the concentration of algae in the water. This allows us to always ensure the peak efficiency for photosynthesis and thus algae reproduction and carbon capturing.
CRISPR-CAS9 is a technology that allows genome editing of genetic material of organisms. There are basically three different types of changes which can be made to a genome with CRISPR-CAS9. You can either Knockout a certain targeted gene to deactivate it or knock-in a new or modified gene at a certain position to activate it. The third option is called point mutation and refers to making precise alterations to bases of a genome to cause mutation and thus new traits. We want to use this technology to mutate our algae species to make it capture carbon at an even higher rate. We see this as a similar approach to how for example grain and other produce are being modified to increase their yield at harvesting.

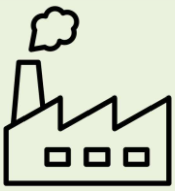
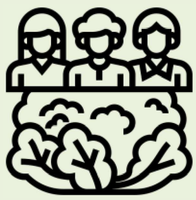
6 Value

Our benefit of the A.C.C.O.S system comes from the opportunity for companies to capture their carbon dioxide emissions on their production site or directly in the facility. This not only reduces the need of buying CO_2 certificates from the state, but also helps them achieve a visible green image. By not only implementing the A.C.C.O.S system to capture the carbon dioxide, but also using the produced biomass to generate revenue, companies can turn their CO_2 into revenue and have a great investment return.
Furthermore, from a corporate standpoint, this approach represents a significant step towards sustainability and responsible envi-

ronmental production. By capturing CO_2 emissions on-site through advanced technologies like photo-bioreactors with algae, companies can effectively mitigate their carbon footprint. This not only aligns with corporate social responsibility goals, but also enhances their reputation as environmentally conscious entities. Additionally, it allows these companies to comply with stringent environmental regulations and position themselves as leaders in sustainable practices within their industry.

Beyond the corporate benefit, the societal impact of A.C.C.O.S is immense. The reduction of CO_2 emissions at the source significantly contributes to combating climate change, which is one of the most pressing global challenges of today. By capturing emissions through A.C.C.O.S, companies actively participate in reducing greenhouse gas concentrations in the atmosphere, thus helping to mitigate the adverse effects of climate change, such as extreme weather events, rising sea levels, and destruction of habitats. This leads into a responsible production of goods and a responsible consumption of CO_2 emissions.

The reduction of up to 100% of CO_2 emissions

Industry	Society
	
Visible green image	Reduced air pollution
Revenue	Economic growth
Saving on CO_2 certificates	Cheaper products
Leading the market by innovation	Reducing the risk of extreme weathers

7 Conclusion

7.1 The next steps

For the next phase of the project, we need to build a test facility to research on algae behavior. We will need data on how much light they need, and how we can get the light into the pond without consuming too much energy.

Furthermore, we need to dive into CRISPR-CAS9-technology to find out, what exactly could be possible in the future and what the limitations are.

Additionally, we need to focus on different facility designs and how to implement those facilities in the best practical way possible for the industry.

On top of that, we will roughly calculate the investment costs for the companies to prove its feasibility.

7.2 Resumé

All in all, A.C.C.O.S will help the industry to fully compensate their carbon dioxide emissions by not only capturing the CO_2, but also consuming it and producing clean O_2 through photosynthesis. The system can not only filter CO_2 and additionally filter particles and other impurities.

By producing a lot of biomass, A.C.C.O.S also be profitable by either selling the biomass or further refining it for food ingredients as well as fuel.

To increase the efficiency to a feasible level, the algae need to be modified by CRISPR-CAS9-genetic-technology and monitored by the ATTRACT technology HYLIGHT. With this setup, the algae can capture more carbon dioxide and A.C.C.O.S can operate with the perfect setting for the environment of the algae.

The A.C.C.O.S system will be attractive to companies as it offers an on-site solution to handle CO_2 emissions. By that, the companies will not need CO_2 certificates or green projects to compensate for their emissions. A.C.C.O.S gives the industry the opportunity to have an authentic green image.

As a team, we are confident that we have a solution for the industry to create a genuine green image, which offers transparency for their customers. By reducing the CO_2 emissions, nature can focus on capturing the CO_2, that is already in the atmosphere.

8 Team

Nils Faulhaber

I'm Nils, 22 years old and I study chemical engineering for my master's degree at Hochschule Mannheim in Germany.
I love creating and developing processes to create a more efficient and sustainable industry. That's why I am already working in the project engineering. I also like sports and travelling. Combined I love sports like windsurfing or wave surfing in my vacation.
I am sure I can bring our project forward by thinking unconventional and well structured.

Daniel Rittershofer

My name is Daniel, I am 24 years old and I study Software Engineering for my Master's Degree at Hochschule Mannheim in Germany.
I am a tech lover at heart and thus interested in everything tech related no matter what it is. In my free time I am a rather relaxed person, as I enjoy hobbies like going fishing or fish keeping. With that said, my favorite hobby is still riding my motorcycle.
I am super excited to get this project going and to find out where this journey takes us as a team!

David Bitter

I'm David, 23 years old and I'm doing my Master's in information technology at Hochschule Mannheim. I did my bachelor's degree in electrical engineering, but I learned that I prefer programming to electrical circuits. I really enjoy tinkering - especially with individual solutions. Improvising, rethinking ideas and finding new ways to solve problems is great fun for me. I like to get creative when working on projects, so I am glad to work on the CBI A³ project. Some of my private interests are sports, photography and travelling/camping.

9 Partners

CERN Ideas

ATTRACT

Design Factory Global Network

SWINBURNE

DESIGN FACTORY MELBOURNE

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