TEAM SUSTA.INNO

FINAL WHITE-PAPER

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ABSTRACT

A.C.C.O.S (Algae-based carbon capture on site)
We are a team of three engineering students from different engineering disciplines at the University of Applied Sciences in Mannheim, Germany. Our team is known as "susta.inno," which stands for sustainable innovation. We are part of the design thinking project "challenge-based innovation Australia, Asia, All others," or CBI A3.
This challenge is aligned with the United Nations Sustainable Development Goal (SDG) 12, which aims to promote sustainable consumption and production patterns. The objective is to identify a problem space and a solution for the SDG, which is supported by advanced technology from CERN and the Attract Academy. This is to be achieved in a scenario in the year 2030.
This white paper presents our idea and the final concept for the solution. The solution, designated "Algae-based Carbon Capturing Facility on Site" (A.C.C.O.S.), is designed to assist the production industry in capturing their unavoidable carbon dioxide emissions at the source, thereby eliminating the necessity for CO_2 certificates and other "green" projects like tree plantings in rainforest areas.
This technology is poised to have a significant impact on the industry by 2030, as the price to emit CO_2 is projected to be more than doubled by then. Furthermore, carbon capture will assist in the recovery of the environment from the elevated CO_2 concentration, as the natural environment can only reduce this concentration if emissions from humanity are below the natural capacity of nature to capture carbon dioxide. By that, nature can reduce the amount of CO_2 which is already in the atmosphere.

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1 PROBLEMSPACE

THE CLIMATE CRISIS

Climate change represents one of the most critical and complex challenges currently facing the world. It is primarily driven by the increasing concentration of greenhouse gases (GHGs) in the atmosphere, with carbon dioxide (CO_2) being the most significant contributor [1]. Human activities, particularly since the onset of the Industrial Revolution, have dramatically escalated CO_2 levels through the burning of fossil fuels, deforestation, and various industrial processes [2]. These elevated CO_2 levels trap heat in the atmosphere, leading to global warming and a cascade of related impacts [3]. These impacts include rising global temperatures, melting polar ice and glaciers, ocean acidification, and ecosystem disruption [4]. These consequences pose significant risks to food security, water resources, human health, and economic stability [5], necessitating urgent action to reduce CO_2 emissions and mitigate climate change. It is imperative that the temperature rise does not exceed 2°C, as stipulated in the Paris Agreement, to prevent the climate change from entering an endless spiral of increasing temperatures. [5]
Figure 1 illustrates the necessity to eliminate greenhouse gas emissions by 2050 (cyan scenario, Figure 1) or by the latter part of the 21st century (blue scenario, Figure 1) to prevent an unacceptably high global temperature increase. As there are many CO_2 emitters, we will focus on one major emitter and look at how its emissions are produced and how they can be reduced.

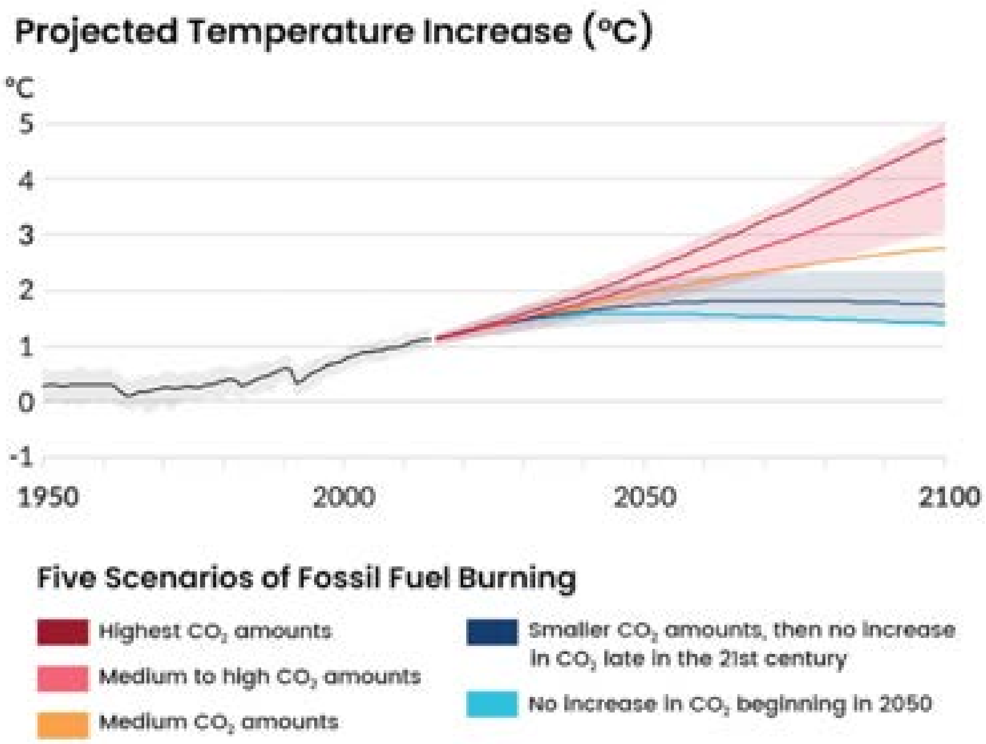

Figure 1: Projected Temperature Increase [6]

INDUSTRIAL CONTRIBUTIONS TO CO_2 EMISSIONS

One of the most notable contributors is the cement industry. The production of Ordinary Portland Cement (OPC) representing a significant source of CO_2 emissions. Cement is an essential material for construction, infrastructure, and urban development. However, its production is energy-intensive and inherently generates substantial CO_2 emissions. Cement production is responsible for approximately 8% of global CO_2 emissions, representing a critical area of concern for climate change. [1][7]

THE CHEMISTRY OF CEMENT PRODUCTION

The primary process in cement production is the transformation of limestone (calcium carbonate, CaCO3) into clinker, the key ingredient in cement. This process, known as calcination, involves heating limestone to high temperatures (approximately 1450°C) in a kiln. The calcination reaction can be summarized by the following chemical equation:
$CaCO3 \rightarrow CaO + CO_2$. This reaction releases CO_2 as a byproduct [1].

The process can be broken down into two main sources of CO_2 emissions:

Combustion of Fossil Fuels: The high temperatures required for calcination are typically achieved by burning fossil fuels such as coal, natural gas, or oil. This combustion process itself produces significant amounts of CO_2 [8].
Chemical Decomposition: The calcination reaction directly releases CO_2 from the breakdown of calcium carbonate into calcium oxide (lime) and CO_2. This source of CO_2 is unavoidable because it is intrinsic to the chemical transformation needed to produce clinker [7].

THE INEVITABLE NATURE OF PROCESS-RELATED EMISSIONS

In contrast to numerous other industrial processes where emissions can be reduced by transitioning to renewable energy sources, the CO_2 released during the calcination of limestone in cement production is unavoidable (Figure 2). This makes cement production one of the most challenging sectors to decarbonize. As global urbanization and infrastructure development continue, the demand for cement is projected to grow, resulting in an increase in emissions associated with its production unless innovative mitigation strategies are implemented [1].

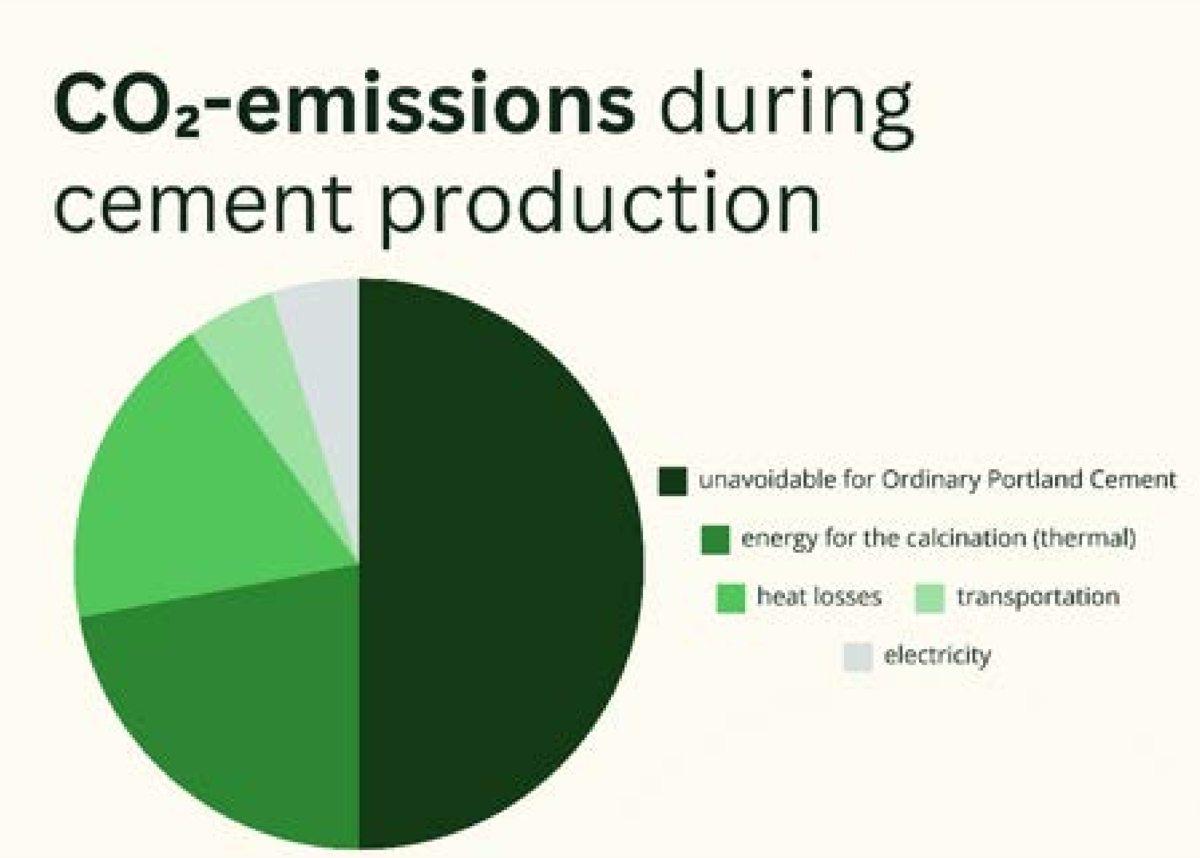

Figure 2: CO_2 emissions during cement production [8]

IMPACT ON CLIMATE CHANGE

The substantial CO_2 emissions from cement production contribute significantly to the global greenhouse gas inventory. The cumulative effect of these emissions accelerates global warming, leading to severe climate-related impacts. The consequences of this phenomenon include increased atmospheric CO_2 levels, enhanced greenhouse effect, and climate feedback loops. Warming temperatures can trigger feedback loops, such as the release of methane from thawing permafrost, which further exacerbates climate change [2].

Ordinary Portland Cement Production and Its Environmental Footprint
The production of OPC is exceptionally energy-intensive. The thermal energy required to achieve the high temperatures for calcination is primarily derived from the combustion of fossil fuels, which are significant sources of CO_2 emissions. The reliance on coal, natural gas, and oil for this energy exacerbates the carbon footprint of cement production [3].

Given the essential role of cement in construction and infrastructure development, the scale of its production is immense. Global cement production exceeds four billion tons annually, a figure that is expected to rise with ongoing urbanization and development projects. This vast scale of production results in correspondingly large quantities of CO_2 emissions, cementing the industry's position as a major contributor to global greenhouse gas emissions [10].

The chemical process of calcination, which converts limestone into lime and CO_2, accounts for a significant portion of the emissions. This process is intrinsic to the production of clinker, and consequently, OPC. The CO_2 released during calcination is a direct byproduct of the chemical reaction and is unavoidable with the current production methods [4].

Infrastructure development is critical for economic growth and societal well-being, but it also drives demand for cement. This demand is especially high in rapidly developing countries, where urbanization and industrialization are proceeding at a fast pace. Consequently, the environmental impact of cement production is particularly pronounced in these regions [5].

CONCLUSION

The CO_2 emissions from the production of Ordinary Portland Cement represent a significant challenge in the fight against climate change. Given the unavoidable nature of process-related emissions in cement manufacturing, the industry represents a significant source of global greenhouse gas emissions. As global demand for cement even continues to rise, addressing the emissions associated with its production is crucial for achieving global climate goals and ensuring a sustainable future. The cement industry's substantial contribution to CO_2 emissions highlights the pressing necessity for the implementation of comprehensive strategies that enables the cement industry to mitigate its impact on the environment and climate.

2 OFFSETTING EMISSIONS

This chapter addresses the problem of irreducible process-related emissions and identifies possible solutions. As previously stated in the Problem Space, emissions must be reduced to zero in order to keep global warming low enough. To this end, two scenarios were presented, which are shown in Figure 1.

The first and most important point is that emissions must be reduced as far and as fast as possible. However, the cement industry serves as an illustrative example. While emissions can be reduced through the use of green energy, process-related emissions cannot be reduced. The solution for these unavoidable emissions is to offset them. There are various methods of offsetting CO_2 emissions. As offsetting is not typically conducted independently by emitters, the purchase of CO_2 certificates is a popular option. The principle is based on the creation of certificates by various providers who carry out offsetting services (which bind CO_2). These certificates can be purchased by CO_2 emitters to offset their emissions. However, there are significant issues with the creation of these certificates, particularly the greenwashing of many of the certificates. One method of creating certificates involves defining rainforest areas as protected zones. By preventing deforestation in these regions, CO_2 emissions are reduced. However, there is a risk of fraud in this approach, as pseudo-protected areas may be used to greenwash projects. A recent study found that over 90% of rainforest projects do not result in the actual reduction of CO_2 emissions. [11,12] Alternatively, more transparent methods of compensation, such as direct air capture, can be employed. However, the issue with direct air capture is that it requires a significant amount of energy (1,000 kW/h for one tonne of CO_2 [13]). Despite the lack of efficacy demonstrated by the available carbon offset solutions, the cement industry is still required to offset its emissions in order to achieve zero emissions. This has led us to question how we might support the cement industry in achieving net-zero emissions without greenwashing.

3 DESIGN SOLUTION

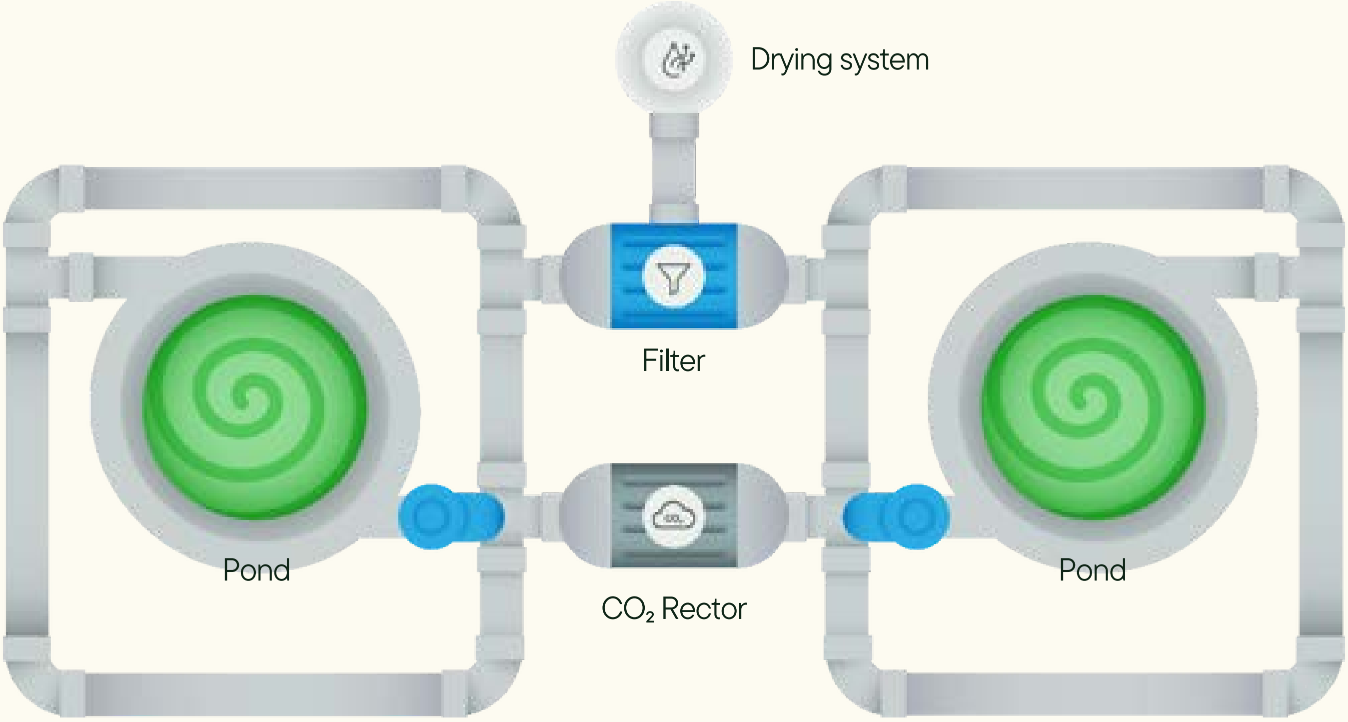

Figure 3: A.C.C.O.S Illustration

The following chapter introduces the design solution called A.C.C.O.S (Algae based Carbon Capturing on Site). Figure 3 shows the basic structure of an A.C.C.O.S system. The system consists of at least 2 tanks, a CO_2 reactor, a filtration system and a drying system. As you can see, the CO_2 reactor, filter and drying system are used by both ponds at the same time. More specifically, the system consists of seven essential parts, which are listed below and will be explained in detail.

1. CO_2 Reactor
2. Ponds
3. Pumps
4. Grow lights
5. Pollution and Sunblock Nets
6. Filter
7. Drying system

3.1 TECH PARTS

1 CO_2 REACTOR

DESIGN AND FUNCTION

The CO_2 reactor represents a fundamental component of the A.C.C.O.S. system, which has been designed to enhance the solubility of industrial CO_2 emissions into water (Figure 4). It employs a high-efficiency gas dispersion mechanism that breaks down CO_2 into microscopic bubbles (Figure 5). These bubbles are then introduced into the water with near-perfect solubility efficacy.

SCIENTIFIC BASIS

The efficiency of CO_2 dissolution is governed by Henry's Law, which states that the amount of dissolved gas is proportional to its partial pressure above the liquid [14]. By creating microbubbles, the CO_2 reactor maximizes the surface area-to-volume ratio, enhancing the gas-liquid mass transfer rate [15]. This method ensures that CO_2 is fully absorbed into the water, providing an optimal carbon source for microalgae [16].

The operation entails the introduction of CO_2 emissions into a reactor, where a series of diffusers create micro-bubbles [17]. These bubbles are then introduced into the water stream, which is subsequently circulated through the system [18]. The high solubility rate achieved in the reactor ensures that the water exiting the reactor is highly enriched with CO_2, thereby facilitating the uptake of this gas by the microalgae in the ponds [19].

Figure 4: Reactor closed

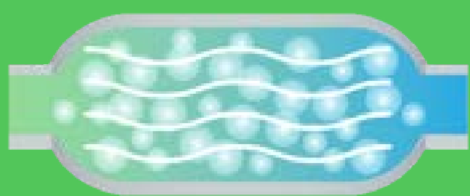
Figure 5: Reactor inside

2 PONDS

Figure 6: Pond

DESIGN AND STRUCTURE

The A.C.C.O.S. system comprises two principal cultivation ponds (Figure 6), each equipped with side inlets and bottom outlets to create a vortex flow pattern. The ponds have Klöpperboden (dished) bottoms, which enhance fluid dynamics, preventing sediment accumulation and promoting efficient drainage.

The vortex flow design increases the exposure time of the algae to the growlight, as the algae are perfectly agitated and constantly brought back to the water surface to perform photosynthesis. The dished bottom design aids in the circulation of the water, ensuring that the algae remain suspended and uniformly distributed, which is crucial for maximizing light exposure and nutrient uptake.

OPERATION

CO_2-enriched water from the reactor enters the ponds through the side inlets, creating a swirling motion. This vortex effect ensures thorough mixing, while the ponds are designed to maintain optimal conditions for photosynthesis and nutrient absorption, thus ensuring high productivity of the algae.

3 PUMPS

FUNCTION

The pumps in the A.C.C.O.S. system are responsible for maintaining a continuous flow of water throughout the entire setup (Figure 7). They are designed to handle the specific properties of the water-algae mixture, including its viscosity and particulate content [20].

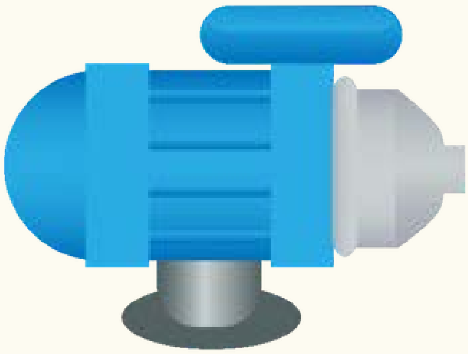

Figure 7: Pump

TECHNICAL SPECIFICATIONS

The pumps are high-efficiency, variable-speed units capable of maintaining consistent flow rates and pressure. These centrifugal pumps are constructed from corrosion-resistant materials to withstand the harsh conditions of industrial environments and the bioactive nature of the algae culture [21]. The energy requirement for these pumps is tailored to the system's needs, ensuring that energy consumption is optimized while maintaining the necessary flow rates for effective operation [22]. In maximum scales, the energy requirement is about 3kW per pump.

EFFICIENCY

These pumps are optimized for energy efficiency, utilizing advanced motor technologies and control systems to minimize power consumption while ensuring robust performance. The pumps' design ensures that the water flow remains stable, which is critical for maintaining optimal conditions in the ponds and other system components [23]. By maintaining a consistent flow, the pumps help in preventing sedimentation and ensuring uniform distribution of nutrients and CO_2 within the algae ponds, thereby maximizing the overall efficiency of the A.C.C.O.S. system [24].

4 GROWLIGHTS

FUNCTION

The installation of growlights above the ponds serves to ensure the continuous photosynthetic activity of the microalgae, thereby enabling 24/7 production (Figure 8). This is of particular importance for maintaining high rates of CO_2 absorption and biomass production [25]. The integration of solar panels to power the growlights not only ensures sustainability but also reduces operational costs by utilizing renewable energy sources [26].

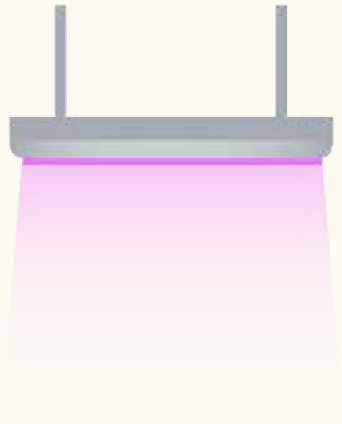

Figure 8: Growlight

TECHNOLOGY

The growlights utilize full-spectrum LEDs that closely resemble the natural sunlight spectrum. These LEDs are selected for their efficiency and capacity to provide the precise wavelengths required for photosynthesis, particularly in the blue (450-495 nm) and red (620-750 nm) regions [27].

SCIENTIFIC BASIS

The process of photosynthesis is dependent upon the absorption of light energy, which is utilized to facilitate the conversion of carbon dioxide and water into glucose and oxygen. The utilization of full-spectrum LEDs ensures that the microalgae are exposed to the requisite light quality and quantity, therefore optimizing their photosynthetic efficiency [28]. Furthermore, the lights are programmable to simulate natural diurnal cycles, which serves to further enhance the growth conditions.

5 POLLUTION AND SUNBLOCK NETS

POLLUTION NET:

A pollution net has been installed with the objective of protecting the ponds from external contaminants such as leaves, dust, and debris (Figure 9). This net serves to maintain the purity of the culture medium, thereby reducing the risk of contamination and ensuring consistent productivity of the microalgae [29]. The mesh size needs to be big enough, to not block sunlight while at the same time blocking the contamination. Therefore, we recommend a mesh size of around two centimeters [29].

SUNBLOCK NET

To prevent the microalgae from exposure to excessive natural sunlight, which can cause photoinhibition, a sunblock net is employed (Figure 9). This net regulates the intensity of sunlight reaching the ponds, preventing overheating and light stress. It is made from UV-resistant materials, and the mesh is fine enough to block around 80% of the incoming sunlight [29].

SCIENTIFIC BASIS

Photoinhibition is a phenomenon whereby light intensity exceeds the photosynthetic capacity of microalgae, resulting in reduced growth and efficiency [30]. By regulating light exposure, the sunblock net ensures that the microalgae operate within their optimal light range, maintaining high rates of photosynthesis and CO_2 absorption.

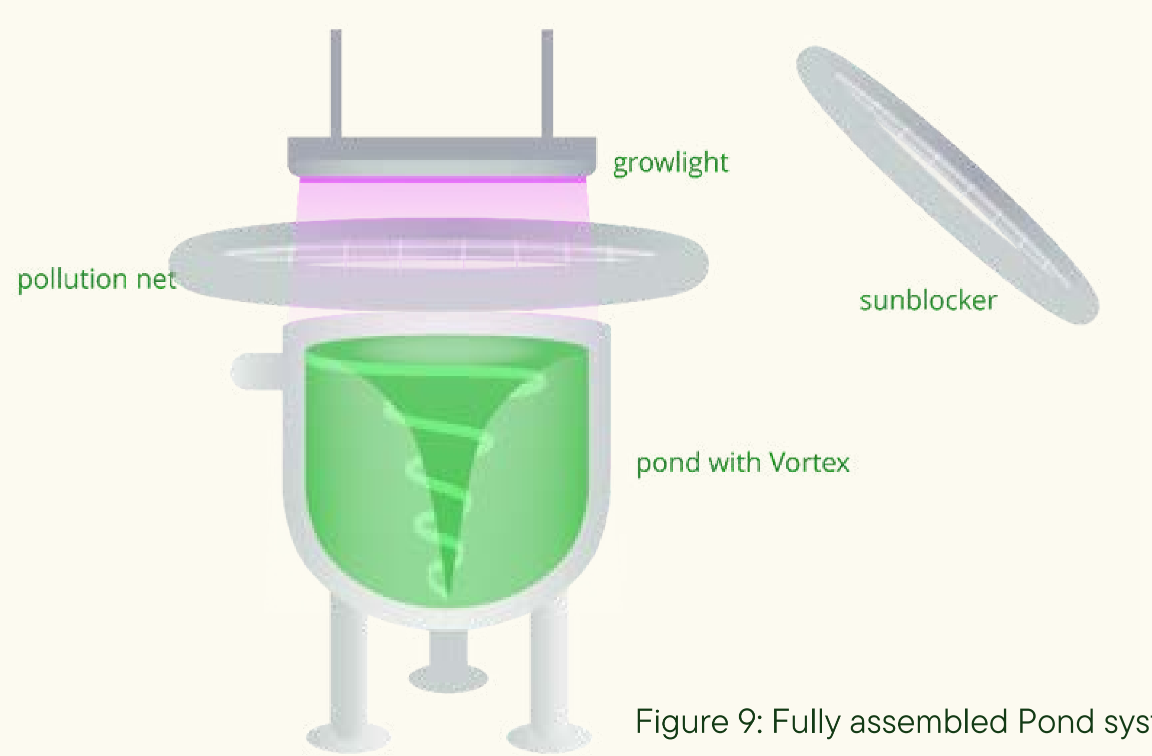

Figure 9: Fully assembled Pond system

6 DRUMFILTER SYSTEM

PURPOSE

The drum filter system is a fundamental component of the A.C.C.O.S. water recycling process (Figure 10). It serves to remove particulates and impurities from the water before it is recirculated back into the ponds, thereby ensuring a clean and stable environment for the microalgae.

MECHANISM

Water passes through a rotating drum filter equipped with fine mesh screens that capture solid particles. The filtered water is then reintroduced into the system, while the captured particulates are removed and processed separately (Figure 11). This process conserves water and maintains high water quality.

TECHNICAL SPECIFICATIONS

The drum filter system uses mesh screens with pore sizes optimized to retain even the smallest particulates, ensuring thorough filtration. The rotating mechanism ensures continuous operation, preventing clogging and maintaining efficiency.

Figure 10: Filter

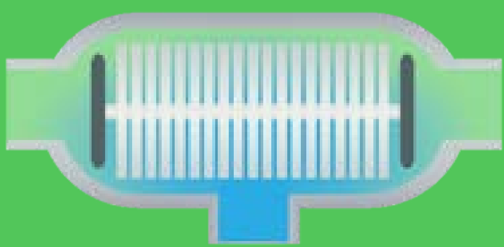

Figure 11: Filter inside

7 DRYING SYSTEM

FUNCTION

Once the microalgae have absorbed CO_2 and reached an optimal biomass concentration, they are harvested and transferred to the drying system. The drying process converts the wet algae biomass into a dry powder form, which facilitates easier transportation and storage.

PROCESS

The drying system utilises a combination of low-temperature heating and airflow to gently remove moisture from the algae biomass. This process is meticulously controlled in order to preserve the nutritional and biochemical properties of the algae, and thus ensure that the end product retains its value for applications such as biofuels and bioplastics (Figure 12).

TECHNICAL SPECIFICATIONS

The drying system includes temperature and humidity controls to optimize the drying conditions. The system is designed to prevent thermal degradation of the algae, maintaining the integrity of the bioactive compounds within the biomass.

Figure 12: Refining Process

✻ SCIENTIFIC BASIS

The low-temperature drying method employed in the A.C.C.O.S. system is a critical step in the process of converting harvested microalgae into a stable, usable form. Unlike traditional high-temperature drying methods, which can lead to the loss of volatile compounds and denaturation of sensitive molecules, the low-temperature approach preserves the integrity and quality of the dried algae powder [31]. This is essential for maintaining its value as a high-quality raw material for various industrial applications, including food, pharmaceuticals, cosmetics, and biofuels [32].

The low-temperature drying process involves carefully controlling the temperature and humidity levels to ensure gentle removal of moisture from the harvested microalgae. This is typically achieved using specialized drying equipment such as vacuum or freeze dryers, which operate at temperatures below 60°C [31]. By maintaining low temperatures, the risk of thermal degradation and nutrient loss is minimized, preserving the nutritional content and bioactive compounds of the algae [31]. Additionally, the use of vacuum or freeze drying techniques facilitates rapid moisture removal without subjecting the algae to excessive heat, further enhancing product quality and stability [31].

The preservation of volatile compounds, proteins, and other sensitive molecules through low-temperature drying ensures that the resulting algae powder maintains its nutritional value, flavor, and functional properties. This high-quality raw material can then be utilized in a wide range of industrial applications, including:

Food: as a nutrient-rich ingredient in functional foods, supplements, and snacks.

Pharmaceuticals: for the production of medicines, dietary supplements, and health products.

Cosmetics: as a natural source of antioxidants, vitamins, and moisturizing agents in skincare and beauty products.

Biofuels: for the extraction of lipids and sugars to produce renewable biofuels and biochemicals [31].

3.2 SCALING

The production of one ton of cement generates 600 kilograms of CO_2. Two thirds of this is process-related. This leaves 400 kilograms. The algae factor is 1.8, as CO_2 consists of 27 per cent carbon and the algae consists of 50 per cent carbon. This means that 220 kilograms of algae are required. The algae efficiency of 50 grams per litre means that five percent of the water mass absorbs CO_2.

Algae needed: 100 tons * 220 kg/ton = 22.000 kg
Water volume required: 22 tons / 0,05 = 440 tons = 440 m3
Thus, 4,4 m3 of water is needed per ton of cement per day.
For capturing 1 ton of CO_2 per day, 11 m3 of water is required.
The maximum size of each pond is 12 meters in diameter and 4 meters in height.
Given that the company Holcim produces 820 tons of cement per day:

Algae needed: 820 tons * 220 kg/ton = 180.400 kg
Water volume required: 180.400 kg / 0.05 = 3.608.000 liters = 3.608 m3
Therefore, 3.608 m3 of water is needed per day to capture CO_2 emissions from cement production.
Each pond has a maximum volume of 450 m3.
Thus, the number of ponds required is 3.608 m3 / 450 m3 per pond ≈ 8,02. (Figure 13)
Since ponds are typically available in pairs, the company would need to install 4 pairs of ponds to meet the CO_2 capture requirements for their cement production facility (Figure 13).

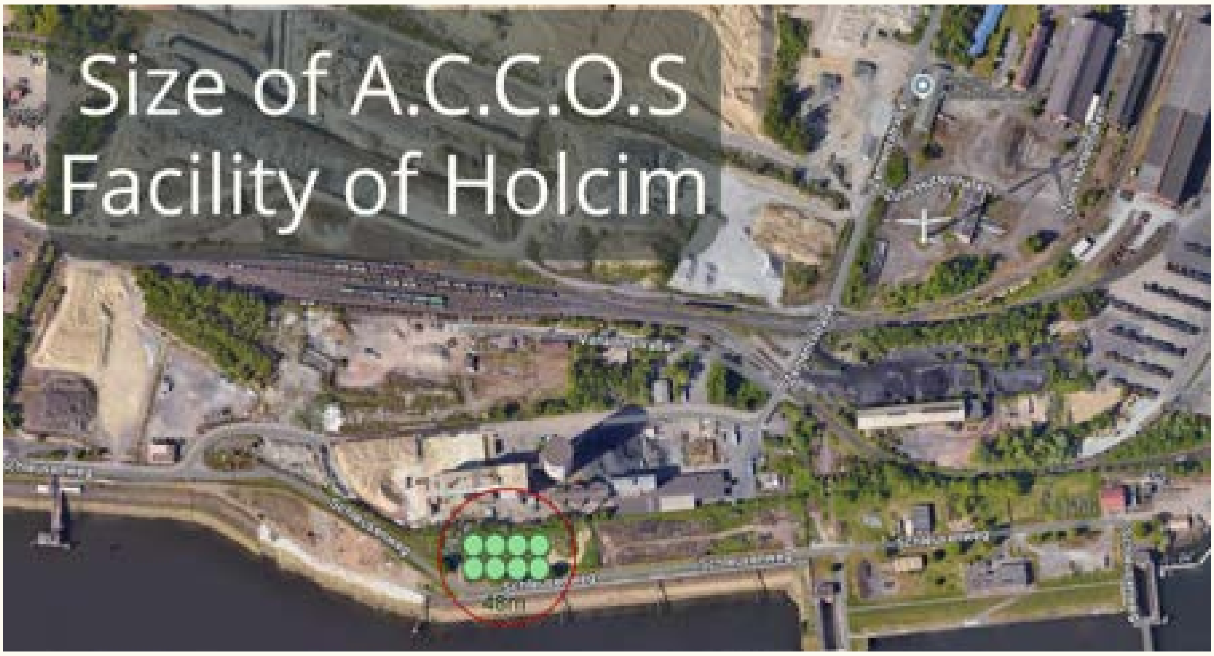

Figure 13: Size of A.C.C.O.S

In a scaling for the whole German cement industry, which is producing around 90.000 t [33], we can assume that 1 pond is capturing 100 tons of CO_2, Germany would need 900 A.C.C.O.S tanks at maximum size. To take that in perspective, the space needed is around 129.000 m2. This space equals around 18 footballfields (7000 m2).

3.3 ALGAE

You might be wondering, why we choose algae in the first place for our offsetting CO_2. Why didn't we choose trees or other plants for capturing the CO_2 emissions? There are many reasons for our decision so let's go over some of them.

FAST GROWING

Algae grows a lot faster, compared to trees or other plants. For Trees to capture a large volume of CO_2, they need to grow for many years, until they start to capture significant amounts of CO_2. With algae, the time it takes to double in volume is on average 26 hours, with some species doubling in just 8 hours [34]. Because of this, algae experience rapid growth and allows for quick deployment. Imagine you would be needing to wait multiple years at a capturing facility for trees to grow until it would be able to start capturing CO_2. That simply wouldn't be feasible.

HIGHER CO_2 BINDING & EFFICIENCY

We can also capture CO_2 way more effectively when it's dissolved in water, rather than in the air. With our CO_2-Reactor, nearly all the CO_2 is being dissolved into the water and then captured by algae, if we were to for example pump gaseous CO_2 into a greenhouse of some sorts, with plants in it, we would have a hard time, filtering out the pure oxygen while keeping the CO_2 inside the greenhouse. Dissolving the CO_2 makes it a lot easier to handle. Also, 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 [35].

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 [35].

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 [36].

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 [37].

Now that we have gone over the benefits of algae, we can go over the type of algae we ended up choosing.
With current estimations of around 70 thousand different species of algae in the world there is quite a variety to choose from. For now, we settled on "Chlorella Vulgaris" for being our species of choice, for a couple of reasons. Chlorella Vulgaris enjoys the typical climate of central Europe and thus requires little cooling or heating around the year. Secondly, it is a species that is already established in the industry, being used in everything from cosmetics and food coloring to fish-food and supplements. Finally, it was also cheap and easy to get and to care for, thus enabling us to use it in our many prototypes that we built over the project.
In the future we hope for new algae species to be researched, that thrive under more extreme temperatures. We also imagine the species to adapt and be able to bind other toxic gases that are being emitted like Nitrogen-oxides.

3.4 MEASUREMENTS

For the system to function optimally, it is essential to monitor and regulate a multitude of physical variables, as they exert a profound impact on the system's overall efficiency and effectiveness.

TEMPERATURE

The temperature plays a vital role in the growth rate of algae. For instance, Chlorella vulgaris is known to flourish best at temperatures above 25°C. As the temperature declines, the metabolic rate of algae slows significantly. Even among algae species that prefer lower temperatures, it is crucial to ensure that the water does not freeze. The freezing of water would result in the malfunction of the pumps and the potential rupture of the pipes and ponds due to the force exerted by the expanding ice.

LIGHT INTENSITY

The light intensity is of significance to the photosynthesis of the algae. In order for photosynthesis to be effective, it is necessary to maintain a high level of light. Therefore, if the light intensity is insufficient, it is necessary to supplement it with artificial light through the use of grow lamps in order to ensure that the algae are able to capture CO_2. The inclusion of multiple light sensors in the system allows for the estimation of the opacity of the water, which in turn allows for the estimation of the algae concentration of the water. It is important to be able to extract some of the algae if the concentration becomes excessive. For measuring light intensity, a normal lux meter is sufficient, although a PAR (Photosynthetically active radiation) meter should be used if possible. A PAR meter only measures the part of the light spectrum that is actually being used by photosynthesis, thus representing the light intensity more accurately in this case.

WATER HARDNESS

The water hardness is a significant factor in determining the capacity of the water to buffer the pH value. This in turn means that a harder water requires a greater quantity of CO_2 to achieve an increase in pH compared to a softer water. The water hardness is unlikely to undergo significant changes, as the water supply is typically characterised by a constant water hardness. Consequently, there is no need for constant monitoring of the hardness; rather, a scheduled manual measurement should be taken once a week. This measurement can be taken via a simple liquid drop tester, which will yield a value of dKH (Deutsche Karbonathärte / German carbonate hardness). The hardness value should then be entered into the system for proper calculations.

PH-VALUE

The pH value is required to calculate the current CO_2 saturation of the water. This is necessary as there is no direct method of measuring the CO_2 saturation automatically. To measure the pH value, a pH probe is inserted into the ponds. Prior to use, the probes must be calibrated. Once calibrated, they emit a voltage which can be combined with the water temperature to determine the appropriate pH value. The probes have a service life of approximately one year, necessitating annual maintenance by a service technician.

CO_2 CONCENTRATION

It is necessary to determine the CO_2 concentration of the water in order to ensure that the algae are provided with sufficient CO_2 for photosynthesis. As previously stated in the pH-value section, the pH-value can be used in conjunction with the water hardness and temperature in order to identify the actual CO_2 concentration of the water.
The basic formula for calculating the CO_2 concentration is CO_2=3*dKH*(10^(7-pH)), however, in our system, we would prefer to use the more complex but also more precise formula CO_2=12.839*dKH*10^(6.37-pH). A rationale for the use of this formula can be found at [38].

3.5 ECOSYSTEM

An A.C.C.O.S system produces enormous quantities of microalgae. In order to utilise these economically, it is necessary to consider the A.C.C.O.S system not only in isolation but also as part of an eco-system. An algae trading platform will enable companies that use an A.C.C.O.S system to sell the algae they produce to customers with ease. As a consequence of the ability to cultivate different types of algae in A.C.C.O.S systems, the trading platform should also assist the operators of the A.C.C.O.S systems in optimising the production of algae to meet the local needs of processing compa-nies. This helps to keep the transport routes of the algae as short as possible. In order to minimise transport distances, companies should be able to identify areas with high algae production. This can then help in the planning of new processing facilities.
In addition, as part of the ecosystem, operators of A.C.C.O.S. plants will be charged a fee that will be used to fund algae research aimed at optimising the plants by developing more efficient algae. The research also aims to improve the processing of microalgae in-to usable products, which should help to optimise the value chain.

4 DEEPTECH

CRISPR GENETIC RESEARCH

CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) technology has revolutionized genetic engineering by enabling precise modifications to the DNA of organisms. In the context of A.C.C.O.S., CRISPR is employed to enhance the genetic makeup of microalgae, which are key biological agents in the carbon capture process. Specifically, the enzyme RuBisCO which has the primary function of fixing the CO_2 has a lot of potential to be improved with CRISPR. RuBisCO catalyzes the first major step of carbon fixation. It combines CO_2 with ribulose-1,5-bisphosphate (RuBP) to produce two molecules of 3-phosphoglycerate (3-PGA), which are then used to synthesize sugars and other organic compounds. But RuBisCO has some problems. For one, it's a relatively inefficient enzyme, because its catalytic rate is rather low. On the other hand, as RuBisCO has a dual function as both a carboxylase (fixing CO_2) and an oxygenase (reacting with O_2), there is competition between CO_2 and O_2 at its active site. To compensate for the high inefficiency, RuBisCO is being produced at in very large quantities in plant and algae cells. RuBisCO can be seen as the bottleneck in photosynthesis, while at the same time having of the biggest potential for improvements. Because of that, it is easy to see why RuBisCO is a key focus that researchers today are already trying to improve with the help of CRISPR.
If successful, these genetically modified microalgae strains exhibit increased photosynthetic efficiency and enhanced carbon sequestration capacity. This way we will be able to absorb CO_2 from industrial emissions at an accelerated rate.

The application of CRISPR technology not only improves the performance of microalgae but also allows for the development of strains tailored to specific environmental conditions and industrial needs. This genetic customization ensures that A.C.C.O.S. can be deployed in diverse geographical locations and under various operational conditions, maximizing its impact on global carbon reduction efforts.

ATTRACT HYLIGHT TECHNOLOGY

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 metabolites of the egg cells, the egg cell with the single highest reproductive potential can be selected to improve the chance of a successful pregnancy. [39]

As HYLIGHT is basically able to measure and compare the metabolic rates of cells, we aim to use this technology to measure the photosynthetic activity of algae cells after gene modifications. This would allow us to compare the algae strains to determine whether the modification results in a significant improvement. An example for this could be to help evaluate the changes made to RuBisCO as described above.

Compared to other sensors or methods of comparing the metabolic rates, HYLIGHT has a couple of advantages.

For one, its able to compare individual Cells, rather than a whole batch of cells. One could argue that the metabolic rate could for example be compared based of weight, after a certain fixed growing time. But this would require separated growing media, while remaining under the same conditions in terms of nutrients, light and so on. With HYLIGHT we don not have to worry about such influential factors, as we can grow multiple different cells on the same media and compare them next to each other. For a higher number of tests in parallel, this also results in a reduction of space and equipment needed.

Another advantage is, that we would be measuring a direct indicator of the metabolic rate, compared to an indirect one. For example, if we were to compare metabolic rates based off the amount of CO_2 being turned into O_2, we would be monitoring a result of the metabolic function, rather than the metabolic activity itself. This again allows us to reduce the number of outside influences and thus get more accurate measurements.

5 SERVICE AS A PRODUCT AND LEASING

The deployment and operation of A.C.C.O.S present significant opportunities for innovative business models, such as service as a product (SaaP) and leasing arrangements. These models can make the adoption of A.C.C.O.S. more accessible and financially viable for industrial companies, fostering widespread implementation and maximizing environmental benefits.

SERVICE AS A PRODUCT (SAAP)

Service as a product is a business model where the provider offers comprehensive services to the customer, rather than simply selling a product. In the context of A.C.C.O.S., SaaP involves delivering a complete carbon capture and utilization solution, including installation, operation, maintenance, and product conversion services.

1. Comprehensive Solutions:
Under the SaaP model, companies do not need to purchase and manage the complex A.C.C.O.S. infrastructure themselves. Instead, they pay for the carbon capture service. This approach ensures that the customer benefits from the technology without the burden of ownership, capital expenditure, or technical expertise required for operation. The service provider manages the entire system, from installation to routine maintenance, ensuring optimal performance and efficiency.

2. Technical Expertise:
The SaaP model leverages the expertise of the service provider in operating and maintaining the A.C.C.O.S. system. This ensures that the system runs at peak efficiency, capturing maximum CO_2 and producing high-quality byproducts. The provider's specialized knowledge and experience reduce the risk of operational downtime and enhance the system's overall reliability.

3. Scalability and Flexibility:
SaaP allows industrial clients to scale their carbon capture capabilities according to their needs. As their production levels and CO_2 emissions fluctuate, they can adjust the service level, adding or reducing capacity without significant capital investment. This flexibility is particularly beneficial for industries with variable production rates or those undergoing expansion.

4. Performance-Based Contracts:
Service providers can offer performance-based contracts, where fees are tied to the amount of CO_2 captured or the volume of byproducts produced. This ensures that clients only pay for the actual benefits received, aligning costs with environmental impact reduction and providing clear financial incentives for both parties to maximize efficiency.

LEASING MODELS

Leasing is another innovative approach to making A.C.C.O.S. technology accessible to a broader range of industrial clients. Leasing arrangements allow companies to use the carbon capture system for a specified period, with the option to renew or purchase the system at the end of the lease term.

1. Lower Upfront Costs:
Leasing reduces the initial financial barrier to adopting A.C.C.O.S. by spreading the cost over the lease period. This makes it easier for companies, especially small and medium-sized enterprises, to implement advanced carbon capture solutions without substantial upfront investment.

2. Regular Upgrades:
Leasing agreements can include provisions for regular upgrades and updates to the system. This ensures that clients always have access to the latest technology and improvements in carbon capture efficiency, without the need to invest in new equipment.

3. Maintenance and Support:
Leasing agreements typically include maintenance and support services provided by the leasing company. This arrangement ensures that the A.C.C.O.S. system is consistently maintained and any technical issues are promptly addressed, minimizing downtime and operational disruptions.

4. Predictable Operating Expenses:
Leasing converts a capital expenditure into a predictable operating expense, simplifying budgeting and financial planning for industrial clients. Monthly or annual lease payments provide clear cost structures and avoid the financial uncertainty associated with large capital purchases.

5. End-of-Lease Options:
At the end of the lease term, clients can choose to renew the lease, purchase the system at a reduced cost, or upgrade to a newer model. This flexibility allows companies to adapt their carbon capture strategies to evolving business needs and technological advancements.

6 VALUE

The Algae based Carbon Capture On-Site System (A.C.C.O.S.) is poised to become a pivotal technology in addressing the global challenge of climate change. With a targeted production year of 2030, A.C.C.O.S. aims to align with the United Nations Sustainable Development Goal 12 (SDG 12), which focuses on ensuring sustainable consumption and production patterns. This innovative system combines the latest advancements in CRISPR genetic research and ATTRACT HYLIGHT technology to provide a robust, efficient, and scalable solution for on-site industrial carbon capture.

MODULAR ARCHITECTURE AND SCALABILITY

A.C.C.O.S. is designed with a modular architecture, allowing for easy integration into existing industrial infrastructures. This modularity ensures that the system can be scaled to meet the specific needs of different industries, from small-scale manufacturing plants to large industrial complexes. Each module can operate independently or in conjunction with others, providing flexibility in deployment and operation.

The modular design also facilitates maintenance and upgrades, as individual modules can be serviced or replaced without disrupting the entire system. This adaptability makes A.C.C.O.S. a viable solution for a wide range of industrial applications, enhancing its potential for widespread adoption.

CIRCULAR ECONOMY AND SUSTAINABLE RESOURCE USE

One of the key advantages of A.C.C.O.S. is its ability to convert captured CO_2 into valuable byproducts such as biofuels and bioplastics. This not only reduces the amount of carbon released into the atmosphere but also promotes a circular economy by creating sustainable alternatives to fossil fuels and conventional plastics. The production of these byproducts aligns with SDG 12 by reducing waste and promoting the sustainable use of resources.

The algae cultivated within the A.C.C.O.S. system can be processed to produce various types of biofuels, including biodiesel, bioethanol, and biogas. These biofuels are derived from the lipids, carbohydrates, and proteins present in the algal biomass. Biodiesel, for instance, can be produced through the transesterification of algal oils, providing a renewable substitute for petroleum diesel. Bioethanol, another potential product, can be generated by fermenting the carbohydrates in the algae.

Biogas, primarily composed of methane, can be obtained through the anaerobic digestion of algal biomass, offering a sustainable energy source that can be used for heating, electricity generation, and as a transportation fuel.

Additionally, algae can be used to produce bioplastics, which are biodegradable and have a significantly lower environmental impact compared to conventional plastics. The polysaccharides in algae, such as agar, alginate, and carrageenan, can be extracted and used as raw materials for bioplastic production. These bioplastics can be utilized in various applications, including packaging, agricultural films, and medical products, thereby reducing the dependency on fossil-based plastics and contributing to waste reduction.

Furthermore, algae-derived products extend beyond biofuels and bioplastics. The high protein content of algae makes it suitable for use in animal feed, offering a sustainable alternative to traditional feed ingredients. Algal proteins are not only nutritious but also have a lower environmental footprint compared to soy or fish meal. In the pharmaceutical and cosmetic industries, algae serve as a source of valuable bioactive compounds, including antioxidants, vitamins, and minerals, which can be incorporated into health supplements, skincare products, and other therapeutic applications.

The byproducts generated by A.C.C.O.S. can be used within the same industrial processes that produce the CO_2 emissions, creating a closed-loop system that minimizes environmental impact. For instance, biofuels produced by A.C.C.O.S. can be used to power industrial operations, reducing the reliance on external energy sources and further lowering the carbon footprint of these activities. This integration exemplifies the principles of a circular economy, where waste from one process becomes the input for another, thereby enhancing resource efficiency and sustainability.

By harnessing the potential of algae to capture CO_2 and convert it into a diverse array of valuable products, A.C.C.O.S. not only addresses the urgent need for carbon mitigation but also contributes to the development of a sustainable, bio-based economy. This innovative approach underscores the importance of leveraging biological systems to tackle environmental challenges while simultaneously creating economic opportunities.

ECONOMIC AND ENVIRONMENTAL IMPACT

The implementation of A.C.C.O.S. has significant economic and environmental benefits. By reducing carbon emissions, industries can comply with increasingly stringent environmental regulations and avoid potential penalties. Additionally, the production of valuable byproducts can create new revenue streams and reduce the cost of raw materials.From an environmental perspective, A.C.C.O.S. contributes to mitigating climate change by capturing and utilizing CO_2 that would otherwise be released into the atmosphere.

This helps to stabilize global temperatures and reduce the impact of climate-related disasters. Furthermore, the promotion of a circular economy reduces dependence on non-renewable resources and minimizes waste, leading to more sustainable industrial practices.

A.C.C.O.S represents a transformative approach to industrial carbon management. By leveraging the power of CRISPR genetic research and the advanced capabilities of ATTRACT HYLIGHT technology, A.C.C.O.S. offers an efficient, scalable, and sustainable solution for carbon capture and utilization. Its modular architecture, combined with its ability to produce valuable byproducts, positions A.C.C.O.S. as a key technology in the global effort to achieve SDG 12 and combat climate change. As industries worldwide seek to reduce their environmental impact and transition to more sustainable practices, A.C.C.O.S. stands out as a pioneering system capable of driving significant positive change.

INDUSTRY

* Visible green image
* Saving on CO_2 certificates
* Revenue
* Leading the market by innovation

SOCIETY

* Reduced air pollution
* Cheaper products
* Economic growth
* Reducing the risk of extreme weathers

7 ROADMAP

In order to gain a more comprehensive understanding of the system or solution as a whole, we have created a roadmap (Figure 14). The roadmap encompasses four phases, extending from the present day to the year 2070. As the solution evolves over time, the main purpose of our solution also changes. Initially, the goal is to achieve net zero emissions. In the future, however, the solution will be modified so that it not only enables the achievement of net zero emissions, but also the implementation of a sustainable economy. The roadmap also includes a timeline of events that we expect to happen. The four phases are explained in more detail below.

ROADMAP

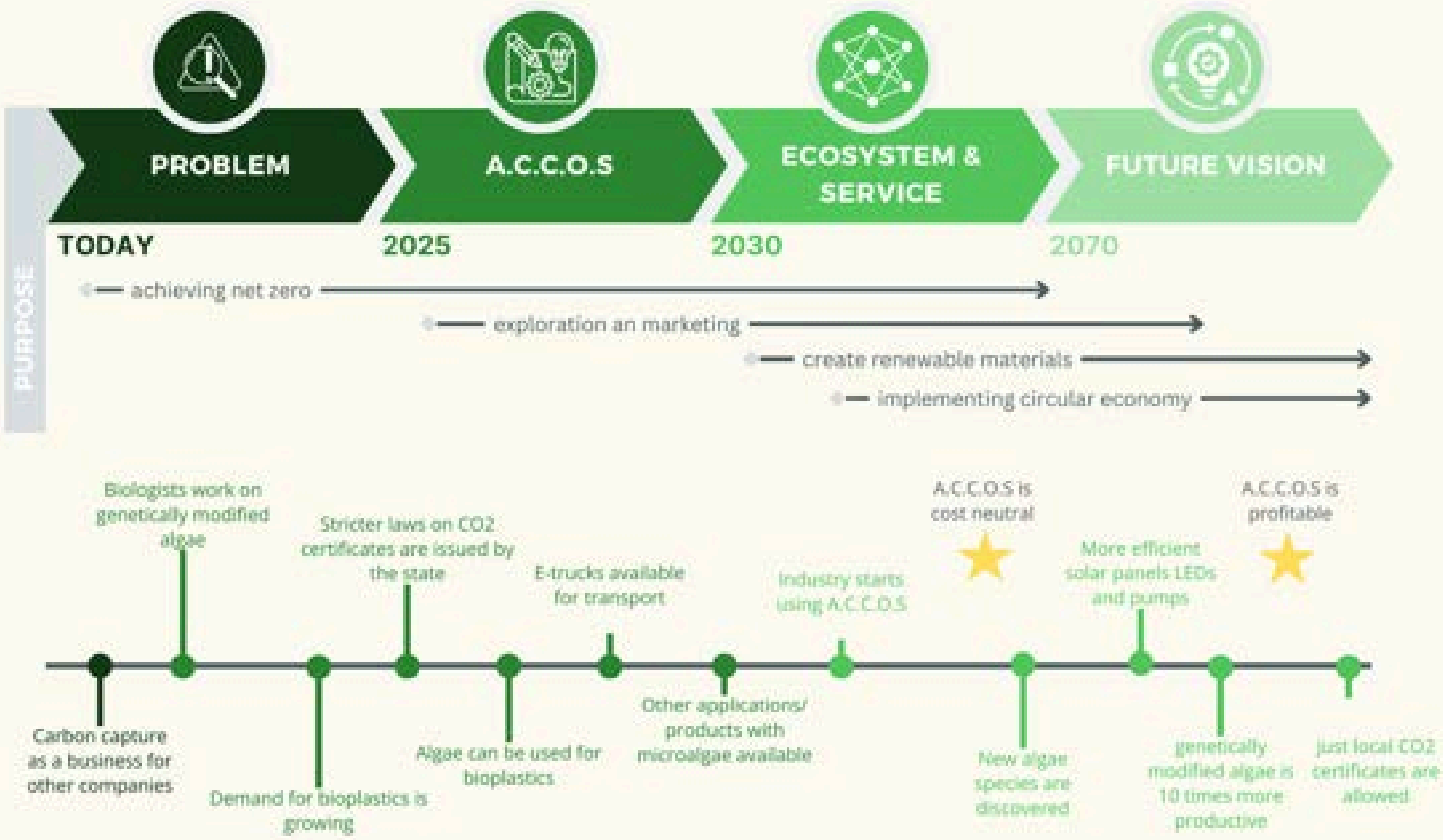

Figure 14: Roadmap

TODAY

An increasing number of countries are setting themselves the goal of achieving net zero emissions. However, the difficulty of imple-mentation often leads to greenwashing, as the certificates on offer often have no added value [11, 12]. We believe that microalgae could provide a way to help achieve net zero emissions.

2025

Further research into the efficiency and processing of microalgae will make microalgae an interesting raw material. As laws regarding CO_2 emissions become stricter, an A.C.C.O.S system will become a highly relevant technology. It is our 2025 prediction that the first A.C.C.O.S system will be constructed. The system's functionality will be demonstrated by the establishment of the initial A.C.C.O.S. pilot facility on a industrial site. At the same time, the system will be promoted through a combination of marketing measures.

✻ 2030

In order to establish A.C.C.O.S in the industry, a marketplace for trading the algae produced by A.C.C.O.S systems is to be set up from 2030. A.C.C.O.S will also be offered as a leasing service, mak-ing the system easier to scale. Furthermore, the system becomes even more sustainable through the reuse of leasing returns. It is our belief that, thanks to genetically modified algae and technologi-cal advances in solar panels and LEDs, A.C.C.O.S. systems will first achieve cost neutrality and subsequently generate a profit by cap-turing CO_2.

✻ 2070

Demand for the conventional A.C.C.O.S. system is expected to decline in the future as priority is given to reducing emissions before offsetting them. Therefore, fewer A.C.C.O.S systems will be needed to achieve net zero emissions. In order to maintain the use of the system and meet the demand for microalgae due to sustainable algae products, a new transformation of the system into A.C.C.I.P will be necessary. A.C.C.I.P is presented in the following section.

8 FURTHER IDEAS

Another concept that emerged was the transition from A.C.C.O.S to A.C.C.I.P (Algae-based Carbon Capturing in Parks). The goal of this transformation is to establish a circular economy, which implies that the systems should be utilized for as long as possible. As A.C.C.O.S is offered as a leasing service to enable companies to scale up and down their carbon offsetting performance, systems will also be re-turned for renewal and reuse. The transformation to A.C.C.I.P. will take place as soon as the need for A.C.C.O.S. systems has de-creased. The modification is optical in nature and enables the sys-tems to be installed in parks, where they filter CO_2 from the ambi-ent air and produce algae.

9 CONCLUSION

A.C.C.O.S addresses a critical issue in the industrial sector, particularly within the cement industry, where significant CO_2 emissions are an unavoidable byproduct of production. Cement manufacturing is a major contributor to global greenhouse gas emissions, with each ton of cement produced emitting approximately 600 kilograms of CO_2. Two-thirds of these emissions are process-related and cannot be eliminated through traditional means. This underscores the necessity for innovative solutions to mitigate the environmental impact of such essential industrial processes. The design of the A.C.C.O.S. system is a sophisticated response to this challenge, integrating multiple components to ensure effective CO_2 capture and utilisation. Central to this system are the algae ponds, which are carefully engineered to maximise the absorption of CO_2. Each pond, with a maximum capacity of 450 cubic metres and dimensions of 12 metres in diameter and 4 metres in height, is designed to support optimal conditions for algae growth. The ponds feature side inlets and bottom outlets to create a vortex, enhancing the mixing and distribution of CO_2 within the water. The positioning of the grow lights above the ponds ensures continuous algae production, while the pollution nets protect the ponds from debris and the sunblock nets regulate sunlight exposure to prevent overexposure.

A critical component of the system is the CO_2 reactor, where process-related CO_2 is dispersed into tiny bubbles. This maximises the dissolution of CO_2 into the water, achieving nearly 100% efficiency. Subsequently, the algae-laden water undergoes filtration through a drum filter system, which recycles the water and separates the algae. The algae are then dried using a drying system, converting them into a powder form that is easier to transport and can be used in various applications such as biofuels or fertilisers.

The filtration system has been designed to accommodate the considerable volume of water required for the algae to capture CO_2. For instance, with a production rate of 100 tons of cement per day, the system processes 440 cubic metres of water to sustain the algae. The filtration system operates continuously, filtering 220 cubic metres of water per day at a rate of 10 cubic metres per hour, thus ensuring that the ponds remain in optimal condition for CO_2 absorption.
In conclusion, the A.C.C.O.S. system represents a comprehensive and innovative approach to addressing the problem of industrial CO_2 emissions. The A.C.C.O.S. system harnesses the natural carbon-capturing capabilities of algae and integrates advanced technological components to provide an effective solution for mitigating the environmental impact of cement production. This system exemplifies the potential for combining biological processes with engineering ingenuity to create sustainable industrial practices, paving the way for a future where economic growth and environmental stewardship coexist harmoniously.

10 THE TEAM SUSTA.INNO

David Bitter
Information Technology
"Synergy – the bonus that is achieved when things work together harmoniously."

Nils Faulhaber
Chemical Engineering
"Any idiot can build a bridge that stands, but it takes an engineer to build a bridge that barely stands."

Daniel Rittershofer
Software Engineering
"The science of today is the technology of tomorrow"

SUSTA.INNO

SUSTA.INNO
David Bitter, Nils Faulhaber, Daniel Rittershofer
inno.space - Design Factory Mannheim

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