Layman's Report

Advanced Material from Algae

A project co-funded by the LIFE Program of the European Commission

LIFE Project Number
LIFE17 CCM/SE/000050

LIFE PROJECT NAME or Acronym
SUNALGAE for LIFE

www.swedishalgaefactory.com

In Brief

Project title	SUNALGAE – Innovative process of enhancing the efficiency of solar panels through the use of algae
Project acronym	SUNALGAE for LIFE
LIFE Reference	LIFE17 CCM/SE/000050
Project place	Sweden
Sector	Solar energy
Duration	July 2018 – December 2023
LIFE budget	€4,052,787
EU contribution	60% of total eligible cost
Partners	Swedish Algae Factory AB and Fastighetsbolaget Swedish Algae Factory AB
Website	https://www.swedishalgaefactory.com/projects/life-sunalgae

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Situation

Developments of solar energy systems

Solar power is one of the main sources of energy that we need to be able to supply the world with clean renewable energy.

The theoretical maximum conversion efficiency of a silicon solar cell is 33.7%, according to the Shockley-Queisser limit. However, the silicon solar panels that are available on the market today rarely achieve efficiencies of over 22% [1]. An increase of the efficiency would make solar energy viable in more places due to a quicker ROI, which would speed up our energy transformation. Solar panel producers invest heavily in efficiency increases of only 0.1%. An efficiency enhancement of 0.1% is worth €141M/year for the solar energy industry[1].

There are different ways of achieving higher efficiencies, e.g. through increased anti-reflection, wavelength shifts, the right light dispersion, and anti-soiling properties. To achieve these properties new unique materials are needed. The materials that are being researched for these purposes today have issues with stability and sustainability.

Silicon solar panels are still by far the dominating solar energy technology on the market today, but new technologies are picking up the pace in the race for the future of solar energy technologies. These new technologies aim to solve the problems of the current silicon-based technology. They can be used to develop more flexible, transparent, effective, and/or sustainable solar energy systems. These new technologies include CIGS, DSSC, perovskite, and organic solar cells.

To solve the issue of the world's increasing need for renewable energy, the production of renewable energy is not enough; the storage of energy is just as necessary. Lithium-ion batteries (LIBs) are one of the most common ways of storing energy today. As the world transitions from a fossil-based energy market to an energy market that is renewable, LIBs will become even more important [2].

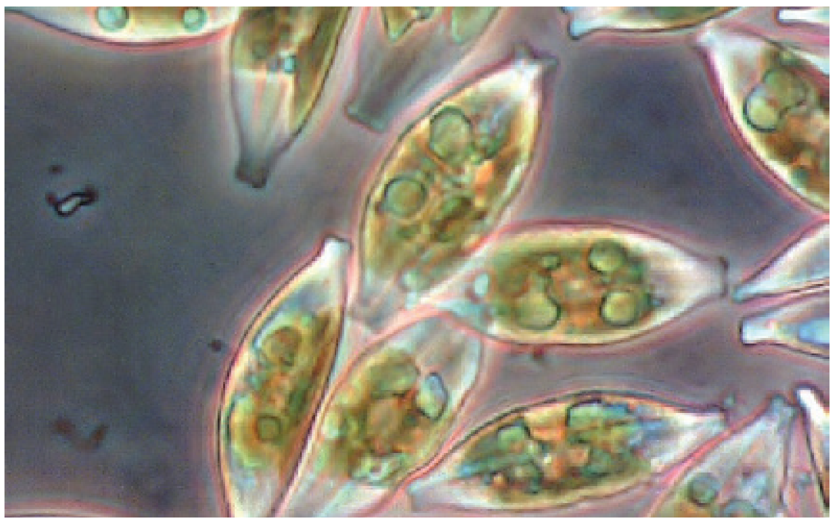
[1] The global production of solar panels in 2021 is estimated to 174GW. At €814/kW the total market for solar energy 2021 was €141B/year. A 0.1% enhancement would thereby be worth €141M/year.

◆ The Algae Material

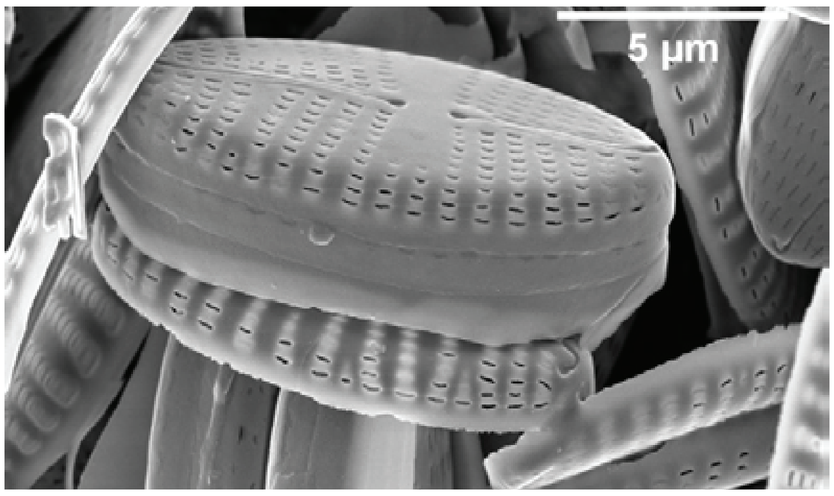
We grow the world's only natural nanoporous silica with excellent properties.

Diatoms in the wild

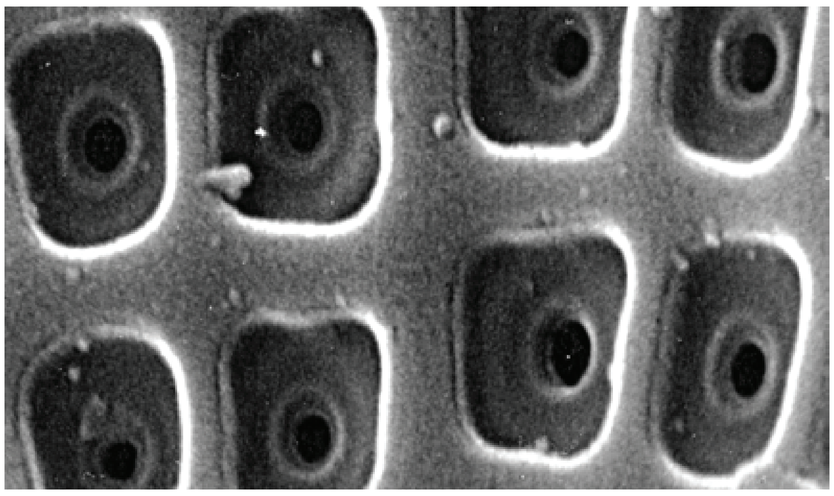
Algae are a diverse group of photosynthetic, eukaryotic organisms. Diatoms are one of the most common algae groups in the world, producing a fifth of the oxygen we breathe. Diatoms can thrive in tropical areas as well as in cold and dark climates. One reason for diatoms being so successful is their amazing shell (scientifically called "frustules").



The biomass rich in oil and proteins, encased by the silica shell.



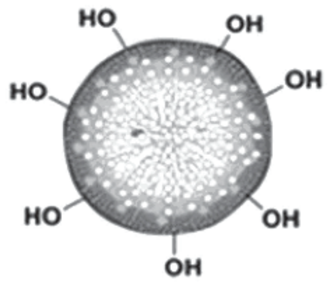
A cleaned nanoporous shell.



Regular nanoporous structure with two layers of pores visible.

Properties

Diatom shells consist of pure silica with hydroxyl groups on the outside (see image to the right). Diatom shells have a transparent nanoporous structure with one-three layers of pores in decreasing size, from 800 to 15 nm. The sizes depend on the species, but within a single species the pores are perfectly regular. This enables the creation of a unique funnel structure.



This structure, developed through evolution, can:

- Efficiently trap visible light in order to make sure that the algae photosynthesize even when there is not much light present [3].
- Efficiently block UV light, but also manipulate UV light into visible light (wavelength down-conversion), which protects from DNA damage [4] [5].
- Efficiently absorb and release chemical substances, such as nutrients and carbon dioxide, essential for growth.
- Block harmful chemical substances from entering the algae cell, such as air pollutants.
- Efficiently bind water through hydroxyl groups on the surface of the shell, so the diatom maintains a good water level in the cell.
- Provide efficient physical protection by being extremely durable and stable [6].

◆ The Algae Material

Industrial production and use

All these properties are valuable in a variety of industrial products. A whole new research field around this material has emerged during the last years with a wide range of applications being studied, including cosmetics, sensors, drug delivery vehicles, solar panels, UV filters, batteries, catalysts, and advanced filters.

Positive environmental and health impacts of Algica

The algae material is natural and non-toxic. After all, diatoms exist in most of our waterways. It is not only the properties of this material that we brand under the name Algica that are amazing, but also how it is produced. In the production process carbon dioxide is absorbed instead of released. Customers that purchase this material can also contribute to a healthier food supply chain through the recycling of the life-sustaining nutrients nitrogen and phosphorous. Read more in the Production section.

Through our operations, we contribute towards several of the Sustainable Development Goals. We mainly have an impact on these five:

The technology behind the use of Algica in solar and competing solutions

We offer a stable, natural nanoporous material without the negative health and environmental effects associated with the use of synthetic nanomaterials. The unique hierarchical nanoporous structure creates a double layered anti-reflective effect that is not seen elsewhere on the market today. The combination of anti-reflective properties along with light diffusion, UV light blocking, and wavelength down-conversion creates a unique value offering to the market.

There is no direct competition to Algica today that provides the same combination of traits. Future research may lead to alternatives, but in most cases, Algica will remain a complementary add-on material that further enhances the efficiency of solar panels.

There have been attempts to produce synthetic nanoporous materials and nanomaterials for efficiency enhancement of silicon solar panels, but these materials have been expensive and not durable enough for commercial use. Below we explain the four underlaying technical principles that are the foundation for how Algica can be used to increase solar panel efficiency.

SWEDISH ALGAE FACTORY

Double layer anti-reflective coating and light diffusion

Algica is a hierarchical nanoporous material. The material is built of two layers of different porosities. This layered structure increases transmission of light into the solar panel glass (see figure below). Depending on the thickness of each porous layer, the transmission of one wavelength will be favored. The wavelength that is favored by Algica is around 700nm, which is in the region where silicon solar panels have a high efficiency and where the number of photons from the sun is at its highest. As light is transmitted through Algica, the light is also diffused, which means that the direction of the light is changed when passing through our Algica material. The changed light direction hinders light that is reflected from deeper layers in the solar panel from escaping out from the solar panel.

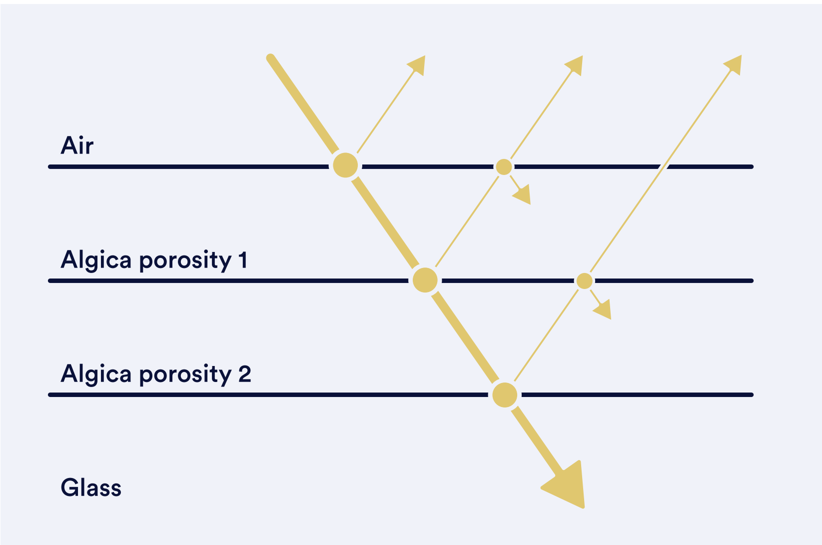


FIGURE A. Algica has a hierarchical nanoporous structure. This layered structure improves transmission of light into the solar panel. As light is transmitted into the solar panel, it is also diffused and the increased angle of the light makes it difficult for reflected light to escape.

FIGURE B. The solar panel without an Algica coating. Only one reflection occurs when light is transmitted. However, the amount of reflected light in FIGURE B is larger than the sum of reflected light in FIGURE A.

There have been attempts to synthesize ordered nanoporous materials for efficient anti-reflection in solar panels, but it has been hard to make them durable enough. Silica nanoparticles have a proven durability and are used today in antireflective coatings to enhance the efficiency of solar panels. However, these anti-reflective coatings only have a single porosity and cannot reach the potential of the double layer porosity that Algica possesses. Silica nanoparticles also have questionable effects on our environment and health [7].

UV light blocking

UV light is causing degradation of encapsulants, solar cells, and backsheets over time. The UV light blocking property, seen in our research published in Nature in 2018 [8], is believed to be caused by the periodic pattern of pores in the diatom shells. These periodic patterns create photonic band gaps that block UV light with an energy level matching that of the band gap. Visible light, on the other hand, is allowed to pass through since the energy level of visible light is lower than the band gap. The theory is supported by simulations for some diatom species that have shown band gap structures for UV light [9]

Wavelength down-conversion

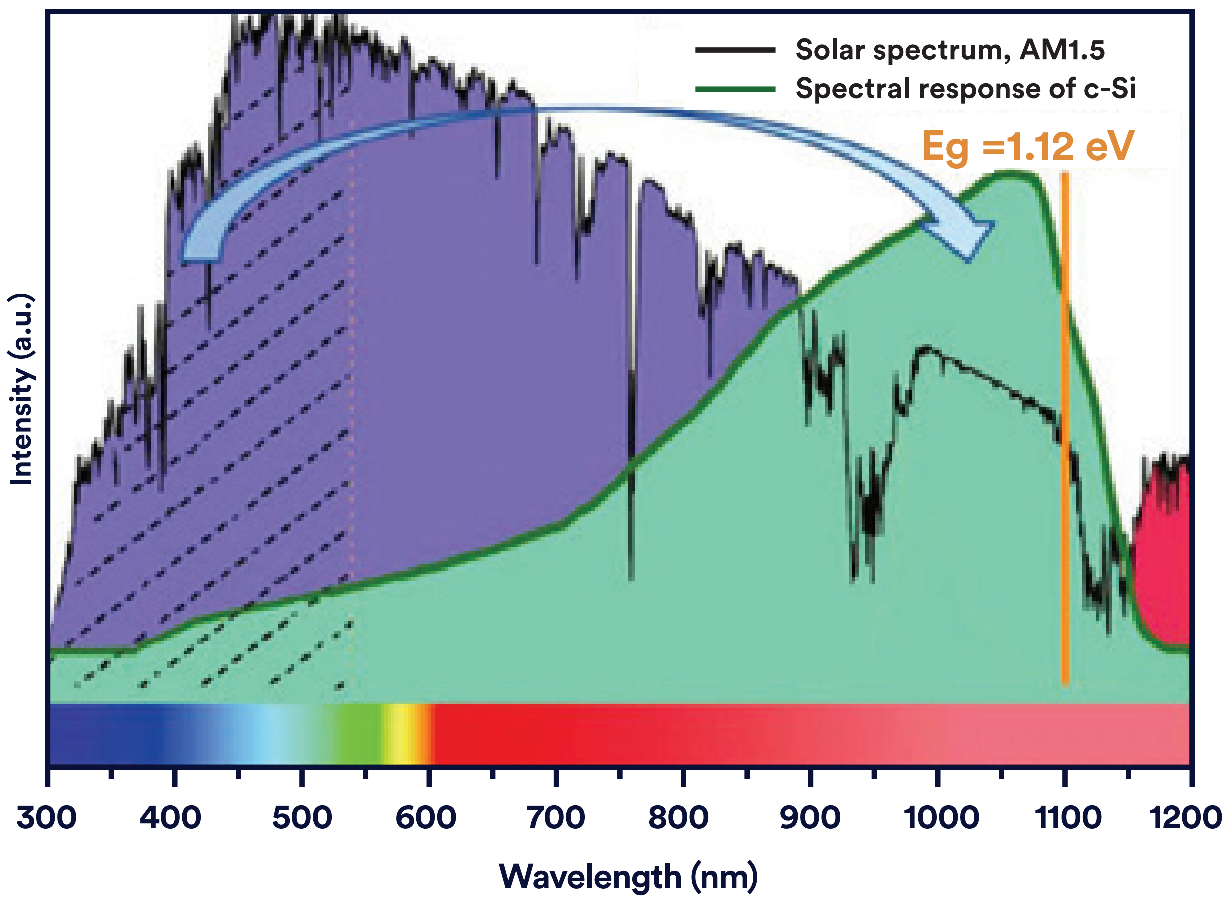


FIGURE: Picture showing the AM1.5 solar spectrum and the spectral response of a crystalline silicon (C-Si) solar cell. Arrow showing the promise of wavelength down-conversion.

Sunlight consists of many wavelengths, but solar cells work best at longer wavelengths of visible light. By manipulating the wavelength of the incoming light, a larger portion could be transferred into useful energy through e.g. a wavelength down-conversion process, illustrated in the figure to the right [10].

Algica has in research been proven to have this effect, but the effectiveness of this effect is yet to be determined [11]. The other attempts so far have utilized nano particles such as (Ba,Sr)2SiO4Eu2+ or compounds of rare earth metals such as Ce, Yb or Cd [12]. However, this type of light manipulating material is not used today, mainly due to problems with thermal and chemical stability [13].

Main objectives

The main objective of the **SUNALGAE for LIFE** project was to demonstrate a new, highly innovative algae material that leads to significant enhancements in the efficiency of silicon based and thin film solar panels. The project aimed to build up a larger pilot facility to produce the innovative algae material where SAFAB´s algae cultivation also is utilized to recycle nutrients from a land-based fish farm. Thus, a circular economy could be created. Tests in small scale, conducted since 2016 in a small prototype facility, had shown that the concept should be possible in a larger scale. The **SUNALGAE for LIFE** project included the following sub-objectives:

- To demonstrate the algae concept in a pilot production facility for up to 12 months.
- Verifying a minimum 4 % enhancement of the power output from a silicon solar panel and up to 60 % efficiency enhancement of a future transparent type of solar cell (DSSC).
- To successfully disseminate the outcome of the project to potential stakeholders and target groups in Europe. Interested parties will be invited to the pilot facilities to observe the functionality of the innovative process as well as to receive information on the potential environmental and energy savings it offers.
- Perform a fast replication and commercialization, based upon the results of the demonstration.

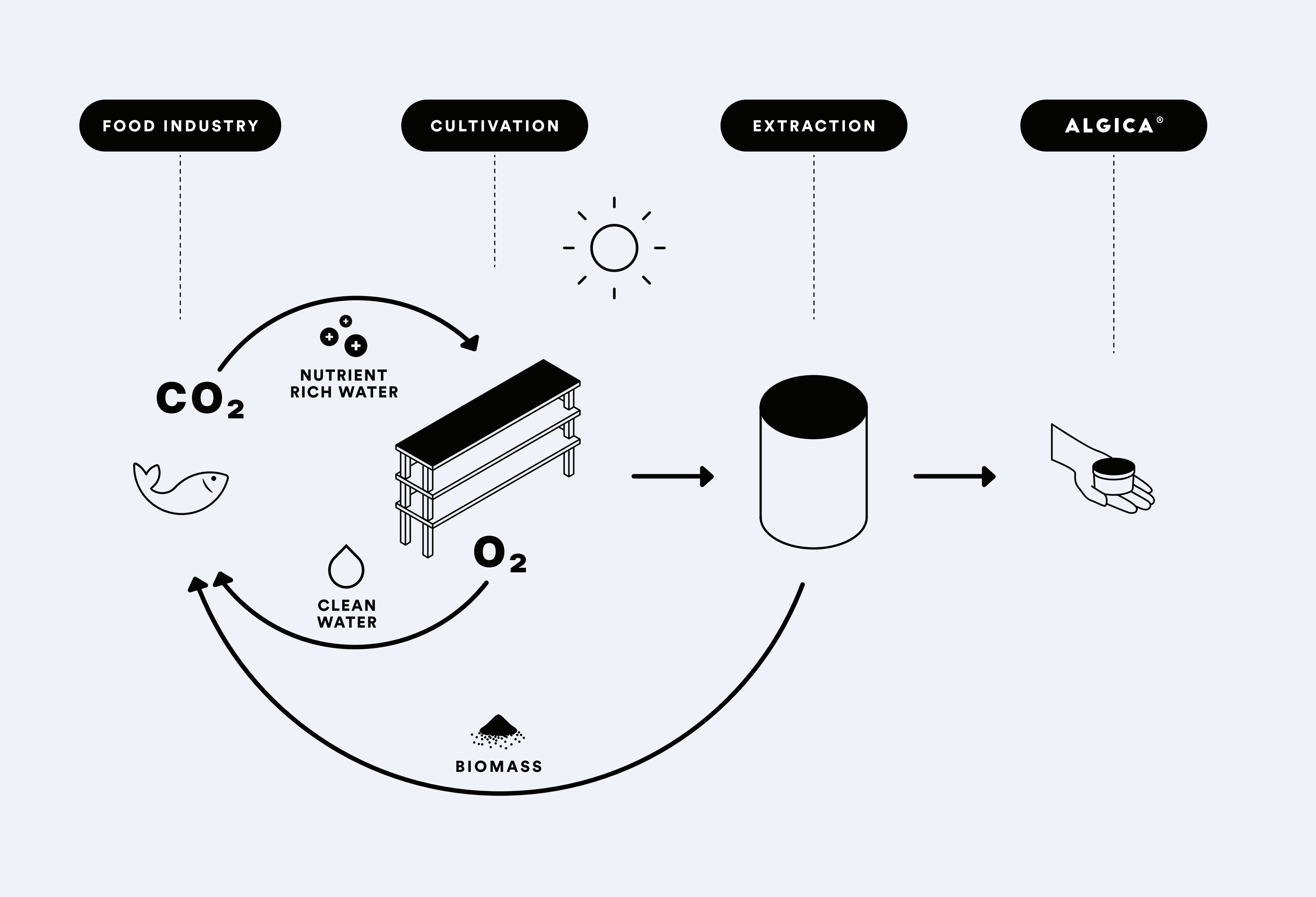
Demonstration of the algae cultivation

Algae need sunlight, carbon dioxide (CO2), water, and nutrients such as nitrogen (N) and phosphorous (P) to grow. We grow the algae in biofilm systems, which means that the algae are attached on horizontal surfaces, where water is running over the biofilms to provide the algae with the nutrients they need. By growing algae in this way, less water and energy is needed for growth, which is good both for the planet and for our profits. The algae biomass is harvested by being scraped of the horizontal surfaces every other week. After the harvest, we extract and clean the Algica from the organic biomass.

From mid-2018 until mid-2022 we operated a small prototype facility on the west coast of Sweden in a city called Kungshamn. This facility allowed us to learn a lot about optimal algae growth and high quality Algica material. This facility was operated in symbiosis with a prototype-sized land-based fish farm. The nutrient-rich water derived from the land-based fish farm was used to grow our algae, as well as the CO2 the fish exhales. By using wastewater as our feedstock, we could create a more environmentally friendly production process. After

the water had benefitted the growth of our algae, the water was returned to the fish farm with reduced levels of N, P and CO2. In that way, our algae can play an important role in the fish farm's water treatment process and reduce the costs of their process. In the production of 1 kg of Algica, at least 1,1 kg of N and 0,3 kg of P can be recycled according to data from this prototype plant and the larger pilot plant.

The water will also contain increased levels of oxygen that is needed for the fish to survive, which will limit the need of pumping in oxygen in the fish farm water, resulting in decreased costs for the fish farm. This industrial symbiotic relationship is a win-win from both a sustainability and profitability aspect, but also from a production stability aspect, as shown by the operations of this prototype. After the extraction of Algica, an organic biomass remains that is rich in nutrients and carbohydrates. With some extra investments, the omega 3s can also be harnessed from this biomass. This biomass can be used to produce feeds, fertilizers, energy, and possibly even food for humans in the future.



The Project

The aim of the **SUNALGAE for LIFE** project was to scale the algae cultivation and extraction of Algica in a larger pilot facility. This facility started to be built in 2020 and was inoculated with the first algae March 2022. In January 2023, this plant consisted of a greenhouse of 2300 m2 with an adjacent process and office building. At the first stage, this facility will produce 250 kg of Algica/year.

During the **SUNALGAE for LIFE** project we have been able to successfully prove that we can cultivate diatom algae all year around and extract their shells efficiently at a good quality for the use of the material in solar efficiency enhancement, but also in other applications.

During the project, this factory was operated as a stand-alone unit without the coupling to our fish farm partner, SmögenLax, since they are still in the process of receiving an environmental permit. Until they receive their permit and build their larger plant, we aim to use recycled nutrients from different sources.

The biomass that remains after the extraction of Algica was during the project processed in a biogas facility close to our plant and produce heath back to our factory as well as eco-fertilizers. The fertilizer product is one of the sources of recycled nutrients we can utilize to grow our algae. The CO2 was during the project sourced from emissions from a vodka plant and transported to us. We have been looking into the use of more local CO2 emissions for the future.

Demonstration of the use of Algica in solar panels

The objectives of verifying a minimum 4 % enhancement of the power output from a silicon solar panel and up to 60 % efficiency enhancement of a future transparent type of solar cell (DSSC) was reached within the **SUNALGAE for LIFE** project.

Our algae material has been evaluated for efficiency enhancement of silicon solar panels by 3 commercial actors with good results. In pilot tests with one actor efficiency enhancements of over 4 % could be seen. Simulations also showcase that shells from diatoms should be able to increase the efficiency of solar panels significantly. It has however been proven more difficult to incorporate our algae material in silicon solar panels in a repeatable way at scale than expected, which will delay a commercialization in this industry.

Our algae material work more as a drop-in product for DSSC and organic solar cells. A 38 % efficiency enhancement was proven and published (Bandara, T. M. W. J., Furlani, M., Albinsson, I., Wulff, A. Mellander B.-E, 2020 Diatom frustules enhancing the efficiency of gel polymer electrolyte based dye-sensitized solar cells with multilayer photoelectrodes, Nanoscale Advances) together with Chalmers University of Technology and the University of Gothenburg for DSSC. During the end of the project, we started to generate interest for start of tests from commercial actors within DSSC and organic solar cells.

More research, pilot tests and large-scale commercial tests needs to be conducted before a commercialization can be achieved in the solar application.

Dissemination of the project

The **SUNALGAE for LIFE** project has been successfully disseminated through press, web page, conferences, study visits and other information materials. See some examples below.

Media and advertisement: Swedish Algae Factory and thereby the project has been featured in several Swedish articles (e.g. https://www.affarsvarlden.se/bors-ekonominyheter/har-ar-alla-vinnarna-pa-33-listan-20196958489 and https://www.dn.se/nyheter/vetenskap/algerna-ska-gora-framtiden-ljusare-for-svensk-solenergi) and won the prestigious international competition Postcode Lotteries Green Challenge in October 2019 (https://www.greenchallenge.info/info/winners/swedish-algae-factory).

We expect that the number of persons that have been reached through notices in press is well over 5000.

Conferences and exhibitions: We have e.g. attended both the InterSolar (https://www.intersolar.de/en/home) on 15/05/2019-17/05/2019 and EU PV-SEC (https://www.photovoltaic-conference.com) on

The Project

07/09/2020-10/09/2020 since the start of the project to learn more about the solar industry with the aim to increase our value offering. Our project was also exhibited through the Postcode Lotteries Green Challenge (see above). We have reached more than 2000 people through conferences and exhibitions.

Study visits to the pilot facility: We have been hosting several study visits during the project to both the prototype facility and the pilot facility. We have been hosting visit for potential future fish farm partners potential investors (e.g. Aqua-Spark in high school and university student groups and decision makers (national and local politicians). 1st of September 2022 we hosted over 100 guest for the inauguration of our pilot plant where we went through our activities in relation to the EU LIFE project.

Other information material: During the course of the project several presentations about Swedish Algae Factory and the **SUNALGAE for LIFE** project has been held at start-up pitching events and general events around sustainable business.

Replication and commercialization

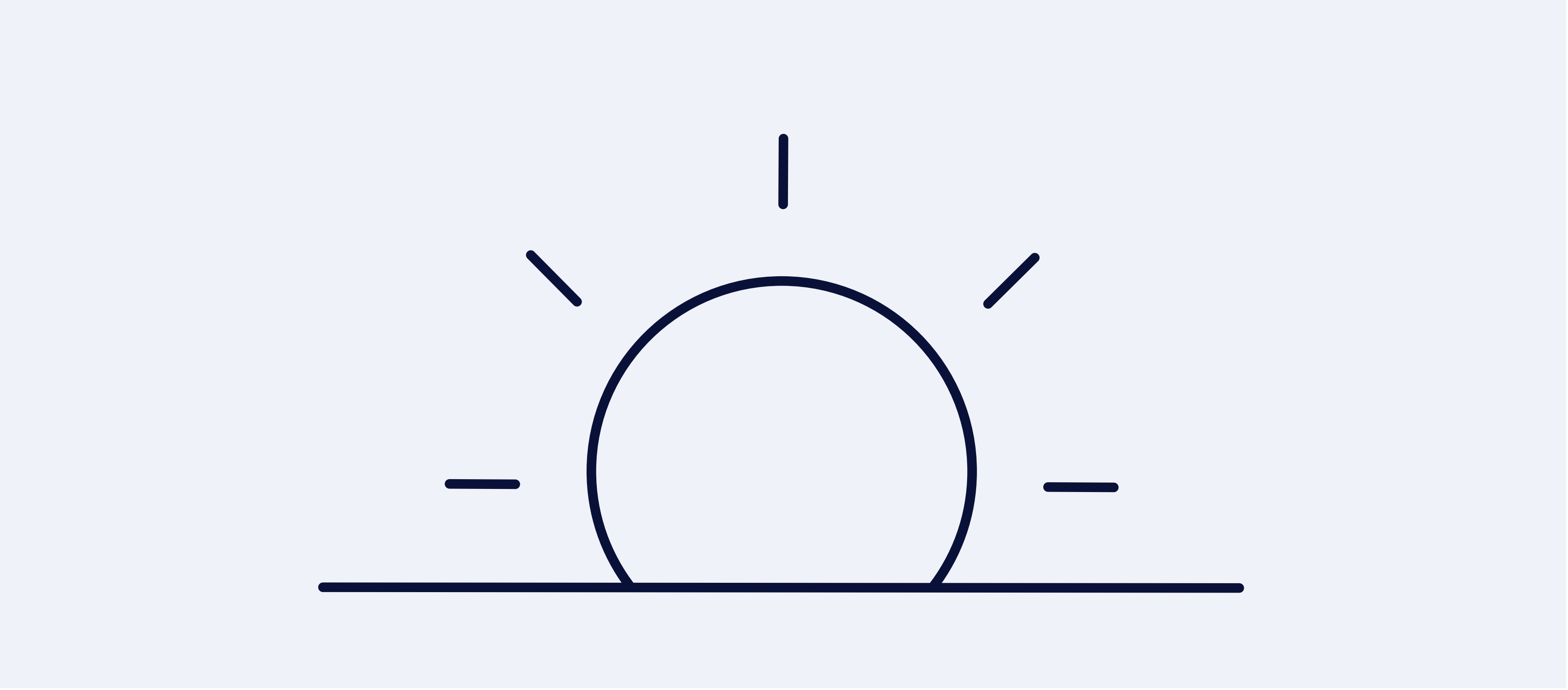
Based on the results from demonstrations of the use of our algae material for efficiency enhancement of solar panels, we see great potential for our material in this sector. More research and pilots though needs to be conducted before an effective commercialization can be initiated in this sector. The risk of a long commercialization time of our algae material in the solar industry was already identified in the project application and was acted upon during the project in line with the Grant agreement.

To be able to perform a fast replication and commercialization, based upon the results of the demonstrations, tests of our algae material was also performed in other industries with an expected shorter time to market. By these measures we have been able to start sales of our algae material in the personal care industry where we contribute with up to 1 821 kg reduction of carbon dioxide emissions/kg algae material as well as the reduction of use of up to 27,6 kg of harmful substances per kg/algae material that are causing damage to life in water as well as our health according to conservative LCA figures. We have by these measures been able to secure a continuation of the project and realized that the total potential impact of our algae material extends far beyond the solar application. The goal of achieving a fast replication and commercialization based on the results of the project has thereby been achieved.

Our algae material has also during the project been tested by commercial actors for increasing the energy storage capacity of batteries, more efficient and greener wound care, biofiltration and catalytic support.

We are confident that the results of this LIFE project will contribute with a positive environmental impact in several industries.

◆ The Future



Based on the activities and positive results of the **SUNALGAE for LIFE** project, the aim is to build more facilities like the one demonstrated in the project, enabling even more sustainable products as well as jobs in a more sustainable industry. One potential long-term strategy is to scale up the concept of combining land-based fish farms and algae cultivation in collaboration with actors like SmögenLax. The organic biomass of the algae will then mainly be utilized as locally produced energy, fertilizers and fish feed. To enable this we need to find the right partners and model for upscaling to ensure both a good IP situation and fast upscaling of our technology.

The sale of algae silica shells will drive the business growth since this more ”high value product” is a prerequisite for achieving an economically sustainable production. Sales of algae silica shells also generate significant value even when sold in smaller volumes. Larger production will enable a more cost-efficient recycling of nutrients and the organic biomass will start to generate a more significant impact.

We see great potential of our algae material in the solar, personal care, battery, wound care, biofiltration and catalytic support industry based on results from this project.

To be able to harness this potential we need to make sure that our material works in customers products at a commercial scale. Timing of production scale up vs. needed volumes for customers to go from proof of concept to order is also crucial for growth.

We will continue to disseminate the results from the project in oral and written presentations of the project and through study visits at the pilot plant to support the growth of our business.

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