# IDEA position paper – Microalgae growth

Within the Interreg NWEurope IDEA project, the enrollment of algae value chains in Europe was investigated. This document summarizes the views of the IDEA consortium on a number of questions related to microalgae growth in (NW)Europe.

**What are microalgae?**

- Microalgae are a diverse group of microorganisms known as phytoplankton. The majority of microalgae are unicellular, photosynthetic microorganisms producing oxygen and assimilating carbon dioxide by obtaining macro- and micronutrients from aquatic environments.
- Microalgae can be both eukaryotic microalgae or prokaryotic cyanobacteria. They are found in waste, ocean and brine waters and they have a high growth rate and productivity. Some species grow in salt water, while other species prefer fresh water.

**What is required for phototrophic microalgae cultivation at farm level**?

- Basic needs are water, light (sunlight can suffice), nutrients (NPK or other fertilizer, digestate, …), an inoculum (in case of consortia: only once) and $CO_2$. In times of strong light, $CO_2$ is necessary to keep photosynthesis running and avoid light stress; this can be used for targeted stressing. No $CO_2$ means lower productivity and possibly need for shading in times of very high or very low temperatures and high light exposure.
- Required equipment for algae growth comprises photobioreactors, harvesting equipment like centrifuge or membrane filters, pumps, compressor for air mixing, $CO_2$ supply and (cooled) storage vessels. Optional are climatization (greenhouse, cooling/heating, shading) and artificial light. Personnel is required to maintain the equipment regularly, e.g. to control biofilm formation on PBR surfaces where it is not wanted (generally after 1-2 weeks of culturing in a given vessel).
- Knowledge and personnel to use that knowledge are crucial. People need to develop a feeling for a growing culture enabling to realize 1) when the observed growth rate does not fit the conditions anymore and 1) when which action needs to be taken (harvest, feeding, shading, maintenance etc). This can be partly automated, but not completely yet.

**Which algae species to cultivate?**

- A variety of microalgae species can be cultivated in Europe, comprising *Spirulina, Chlorella, Nannochloropsis, Tetraselmis, Synechococcus, Pavlova, Dunaliella, Rhodomonas, Porphyridium, Scenedesmus, Chloromonas, Isochrysis*, etc.
- When selecting an algae for commercial cultivation, the envisioned application is a crucial element. Further, each algae species has specific growth requirements that need to be compatible with the climate and the available/envisioned infrastructure. It is important to take into account the expected growth rates of the algae species as well as the algae densities that can be reached.
- Within IDEA, the following species were considered: *Chlorella, Scenedesmus, Nannochloropsis, Porphyridium, Chloromonas* and *Spirulina.*
- Algae species & fractions that are accepted in food applications comprise a.o. *Chlorella* & *Spirulina*.

**Which type of photobioreactor to select?**

- Different types of photobioreactors are on the market that have each their advantages and points of attention in terms of costs, maintenance, illumination, optimal use of $CO_2$, co-contamination, algae densities that can be reached and suitability to cultivate specific species.

- A distinction can be made between open growth systems (like open ponds) and closed photobioreactors. Generally, open pond systems are lower prized but lower algae densities are reached (0.05-0.5 g/L), and the growth medium is in contact with the environment (higher chance for co-contamination). In closed bioreactors (tubular systems, bags, …) a higher cell density can be reached (0.5-2 g/L) and they are mostly used for growing pure strains. Both types of bioreactors can be installed in open air or in greenhouses.
- To select a photobioreactor type, the envisioned application field of the produced algae is to be taken into account as well as a.o. the envisioned algae species and the available budget.
- The size of the reactor can fluctuate from a few 100 L (used to produce inoculum) to more than 20 m³. At a large algae farm, reactors of different sizes are present. Because of risk management (contamination, culture crashes, stress factors), the closed reactor systems are often restricted to 10-20 m³. and it is opted to operate multiple reactors in parallel to increase the cultivation volumes and reduce downtime.
- Within IDEA three different types of closed bioreactors were used, being V-bags, vertical bag systems, and plastic tubular photobioreactors. In the IDEA capitalization part, also open ponds are considered.

V-BAG SYSTEM (NOVAGREEN GMBH)*

VERTICAL GREEN WALLS (PHYTOBAGS, PHYTOLUTIONS GMBH)*

TUBULAR BIOREACTOR**

(Pictures: * FZ Jülich GmbH, C. Kuchendorf: ** Sunbuilt-Belgium – Thomas More & VITO)

**How are the photobioreactors (PBRs) organized and functioning?**

- **IDEA-Example 1:** The V-bag systems were used within a greenhouse, where 33% of the roof is used for photovoltaic electricity production and the panels provide a measure of shade. The V-bags are approximately 1.5 m in length with a diameter of 0.15 m. Up to 144 V-bags can be connected here to one system (max. 3.6 m³). The culture circulated sequentially through all the V-bags and was sparged by 1.4 to 2% $CO_2$ with a gas flow rate of approx. 1.6 L per bag per minute.
- **IDEA-Example 2:** In the vertical bag system, tubes have a diameter of about 0.07 m and the culture height can be adjusted up to 1 m. A full bag is 10 m long and holds 320 L of culture in our setup. It can be run with a small pump as a single cultivation, or in this case connected to up to 8 bags (2.6 m³) with a larger pump setup. larger combinations are possible.. An air/$CO_2$ mixture is delivered by a sparging pipe running inside the bottom horizontal tube with a pH-dependent $CO_2$ control. The temperature in the greenhouse is modulated by automatic windows for cooling and a fan heater to avoid temperature peaks in summer or frost. The general temperature follows the outdoor conditions, slightly buffered. There is no additional light source except sunlight.
- **IDEA-Example 3:** The tubular reactors have a capacity of 300-1500 L. Guided Air bubbles ensure good mixing and gas exchange and are linked to a pH-controlled $CO_2$ dosing system. Different

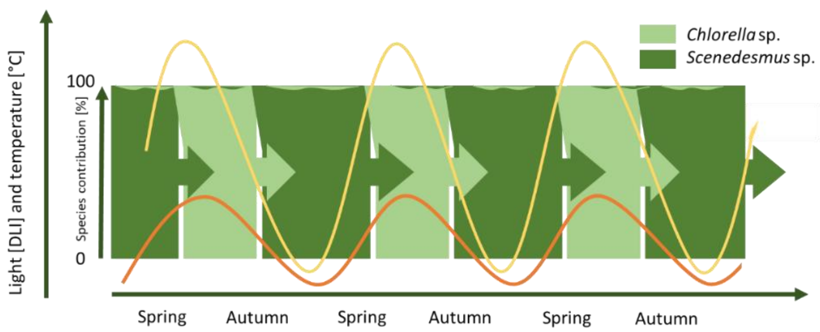
stock solutions are pumped in specific doses into medium preparation tanks to refill the photobioreactors and provide nutrients. The growth is computer controlled based on pH and cell density. Common horticulture equipment is present to prepare growth medium in an automated way. The PBRs are installed in a greenhouse equipped to control the temperature via cooling (shading, sprinklers, etc.) and heating, allowing year-round algae cultivation. Artificial light is used to prolong the daily lighting period in winter.

**How can algae harvest be organized?**

- Scalable harvesting technologies for microalgae comprise centrifugation, membrane filtration, coagulation, and sedimentation. Centrifugation is the most frequently used. Filtration is gaining more interest, especially for *Spirulina* (open mesh, vibrating sieves) and as a pre-concentration step for other microalgae species (membranes). Coagulation is possible for specific algae species and requires the use of additives.
- Within IDEA, centrifugation with and without membrane-based preconcentration (MAF-technology) was applied. Wet storage of algae at 8°C for up to 7 days was found to be an acceptable approach to bridge the time to further processing of the biomass that might be organized off-site.
- Batch harvesting and continuous harvesting are both possible. Batch harvesting refers to a process where at regular time-points a significant part of the reactor is harvested and new medium is added to dilute the culture.  Another approach is to extract continuously smaller amounts of algae culture while continuously re-adding new (recycled) medium. The latter approach allows to keep the culture in the most productive (late exponential) growth phase. IDEA findings indicated that a good algae productivity can be reached with continuous harvesting when nutrients (N/P) are dosed in sufficient amounts.

**Is year-round cultivation possible in NWEurope**?

- Algae cultivation is often associated with growth in summertime when days are long and temperatures high. Yet, also at moderate temperatures and in darker periods, algae growth is possible. A smart selection of algae species for each season is an approach that may enable at least a longer growth period and even year-round cultivation without excessive heating and artificial illumination.
- Within IDEA, two approaches were followed to realize year-round cultivation.  On the one hand, a set of three algae species was selected that were altered in the Sunbuilt growth facility (Belgium) along the seasons (*Nannochloropsis* in summer, *Porphyridium* in autumn/spring & *Chloromonas* in winter).  On the other hand, in the German growth facility, a mixed culture was used that shifts composition depending on the seasons (dominated by *Scenedesmus* in winter and by *Chlorella* in Summer) as illustrated in the enclosed figure.




- Productivity of algae cultivation is influenced by the seasons.

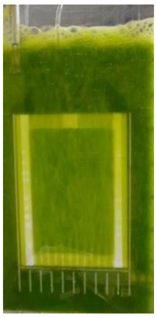
- Within IDEA, with the mixed algae consortium in Germany, the algae productivity averaged over 2018-19 (all seasons, including winter) to **13 g/m²d.** The summer months May-September 2018-2019 average over all cultures was between **25 and 32 g/m²d** with peak values of **60 g/m²d**. In **June 2021** the culture average productivity was **100.4 g/m²d** after $CO_2$ optimization**,** with growth rates between 0.3 to 0.99 $d^{-1}$ and max. productivity >0.68 g $L^{-1}$ $d^{-1}$.
- The following algae growth rates were recorded in Belgium (Sunbuilt):

| Algae species | Average specific growth rates (µ)* | Maximum specific growth rates (µ)* | Maximum productivity |
|---|---|---|---|
| *Chloromonas (B)* | *0.07 $d^{-1}$* | *0.15 $d^{-1}$* | *0.17 g $L^{-1}$ $d^{-1}$* |
| *Nannochloropsis (B)* | *0.17 $d^{-1}$* | *0.70 $d^{-1}$* | *0.37 g $L^{-1}$ $d^{-1}$* |
| *Porphyridium (B)* | *0.19 $d^{-1}$* | *0.60 $d^{-1}$* | *0.50 g $L^{-1}$ $d^{-1}$* |

* *Based on data from all seasons, during growth periods ranging from 2018 to 2020.*

**How sustainable is microalgae cultivation?**

- Phototrophic algae convert $CO_2$ and nutrients (N, P) into a variety of complex high-value compounds, hereby generating oxygen. This conversion process as such is sustainable.
- Large scale controlled algae cultivation does not require arable land, but water, nutrients/salts and energy are required. By reducing these inputs, the process can become more sustainable.
- Medium re-use can increase sustainability due to reduced use of chemicals and water, and by reduced discharges of (salty) medium. It is recommended to take care that medium is filtered well enough not to re-introduce too much cell debris into the culture, because this promotes bacterial and biofilm growth. Within IDEA, medium re-use using the MAF-technology (submerged membrane technology – see illustration) was evaluated in longer-term pilot-scale tests and > 95 % recycling of medium (water and salts) was shown to be feasible. The fact that the algae biomass is pre-concentrated simultaneously by the MAF-technology, reduces the required centrifugation capacity & associated energy use.



(Photo VITO)

- Algae cultivation becomes also more sustainable when non-petro-based $CO_2$ is used. Within IDEA, a technology was successfully demonstrated to capture $CO_2$ from the air for release in photobioreactors to stimulate algae growth, requiring per kg of $CO_2$ around 0.7 $kWh_{el}$ (electricity) and 2.9 $kWh_{th}$ (thermal, 100°C). Another approach may be to use $CO_2$-enriched residual gases from industrial plants (e.g. lignite plant, combustions gas) or biogas plants. The latter is being evaluated more in detail in the IDEA capitalization part.
- Also use of N/P-rich waste-streams can increase the sustainability of algae cultivation, especially in view of rising fertilizer cost. The impact on the quality of the algae biomass when using side/waste-streams is a point of attention.

**In conclusion**: Year-round algae growth is technically possible in (NW)Europe. To make algae production economic viable and more sustainable, a number of approaches were shown to be suitable. The development of a downstream market is crucial for algae farms to select suitable algae species and algae cultivation/harvest equipment.

Interreg North-West Europe IDEA
European Regional Development Fund

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Website: www.nweurope.eu/IDEA
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