BEST PRACTICES ON THE PRODUCTION AND SUSTAINABILITY OF MICROALGAE IN EUROPE

22 October 2024

Auto- and heterotrophic microalgae production – from side streams to high-value products:

Experience from MULTI-STR3AM & CIRCALGAE projects

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Agenda

- About A4F
- Multi-Str3am & CIRCALGAE
- Phototrophic production, technology choices, scale-up and optimization
- Heterotrophic production and harvesting choices
- CAPEX and OPEX reduction results under MULTI-STR3AM
- Impact on process sustainability

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A4F Group

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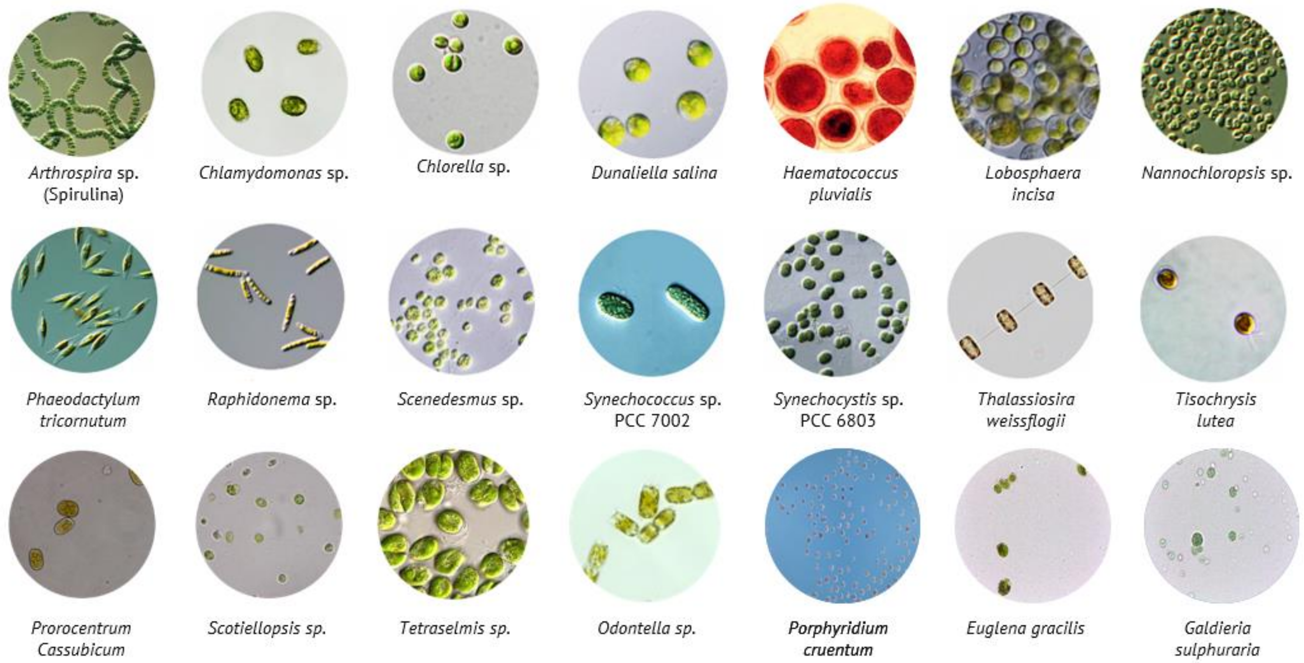
The A4F Group of companies provides services in the microalgae, macroalgae, fermentation and biorefinery sectors, specializing in the development of bioprocesses and in the design–build–operate–transfer (DBOT) of commercial scale algae production facilities.

Microalgae production expertise at pilot and industrial scale



Macroalgae production expertise at pilot and industrial scale

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Technological process overview

A4F aims to develop, scale-up, optimize and implement tailor-made industrial production facilities for algal biomass.

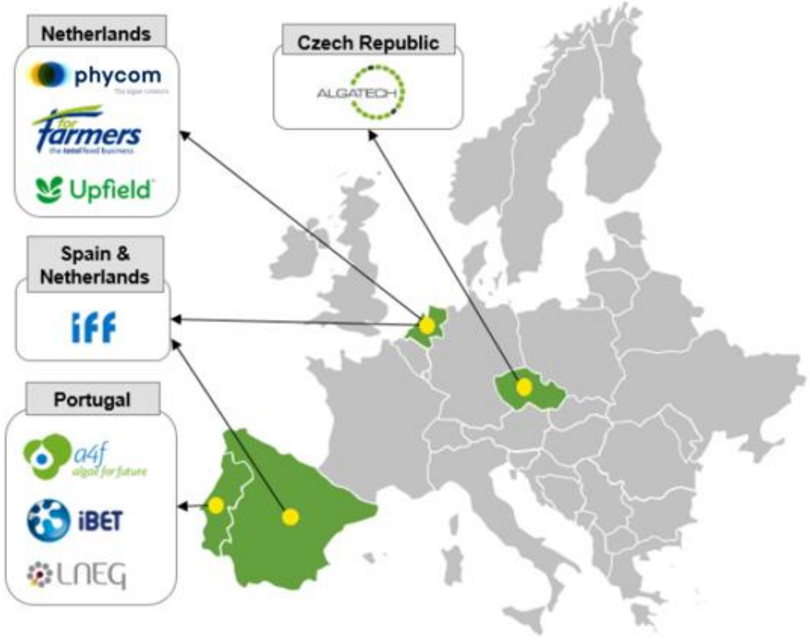
Depending on the aim of the final application and biorefining process, the production process should be selected, adjusted and optimized. Sometimes, the target compound production in the cells must be induced.

Common technology choices for phototrophic production

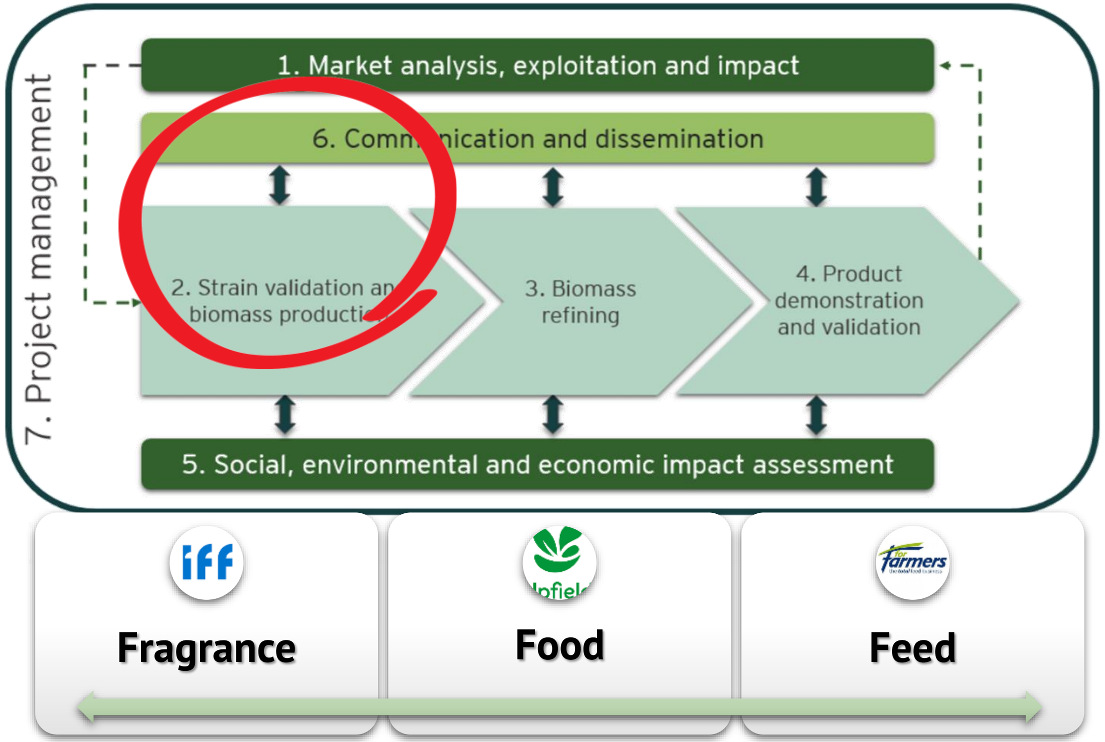
Tubular PBRs | Flat panel PBRs | Cascade Raceways | Raceways

A sustainable **multi-strain, multi-method, multi-product** microalgae biorefinery integrating industrial side streams to create high-value products for **food, feed** and **fragrance**.

Consortium



May 2020 - April 2025



BBI JU
Bio-based Industries Consortium
Horizon 2020
European Union Funding
for Research & Innovation

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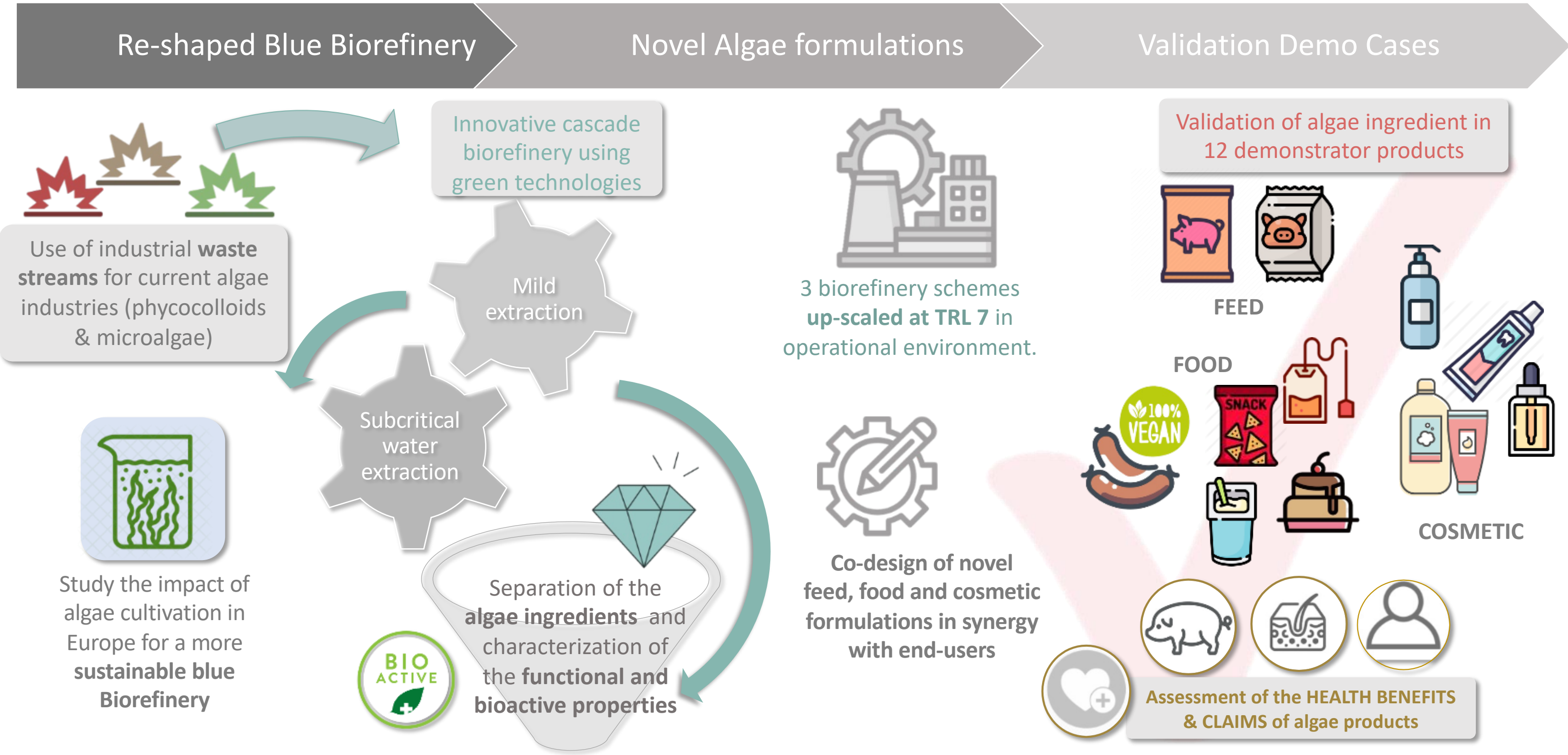
CIRCular valorisation of industrial ALGAE waste streams into high-value products to foster future sustainable blue biorefineries in Europe.

Consortium



October 2022 - September 2026

Co-funded by the European Union

Goals for microalgae biomass production

- **(Re-)design, install and commission production units at A4F and Phycom**, to produce *Chlorella* (heterotrophic), *Nannochloropsis*, *Dunaliella*, Spirulina, among others.
- Establish the **optimal biomass production conditions**, including **harvesting and storage** conditions, for each strain to produce sufficient quantities of the targeted products, informed by chemical analysis (both in real time and near-real time) during cultivation and following harvesting.
- Determine the **biochemical composition of the microalgae biomass** and any potential changes to this arising from drying, storage and transport, and use these dates to determine optimal handling conditions.

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- To evaluate different cultivation parameters in order to obtain high biomass production yields and high production of microalgae ingredients (within the biorefinery).

Phototrophic cultivation | Biomass production

Cultivation pilot (1-10 m^3) and demonstration scale (100 m^3).
Species: *Nannochloropsis*, *Dunaliella*, Spirulina

FP-PBR ***up to 45 m^3***
Production of all 3 species

UHT-PBR ***1560 m^2/ 35 m^3***
Production of all 3 species

CRW ***2500 m^2 / 70-120 m^3***
Production of all 3 species

Monitorization of cultures in production.
Growth parameters and composition; focus on components relevant for the valorization of biomass, e.g. EPA, beta-carotene, phycocyanin, soluble protein.

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Microalgae cultivation and optimization parameters

- *Dunaliella*

- Growth under nutrient-replete conditions → High biomass productivity
- Growth under nutrient-depleted conditions and high solar irradiance → High β-carotene accumulation

- *Nannochloropsis*

- Growth under nutrient-replete conditions → High EPA accumulation
High biomass productivity
- Growth under nutrient-depleted conditions and high solar irradiance → High TAGs accumulation

- Spirulina

- Growth under nutrient-replete conditions → High phycocyanin accumulation
High biomass productivity

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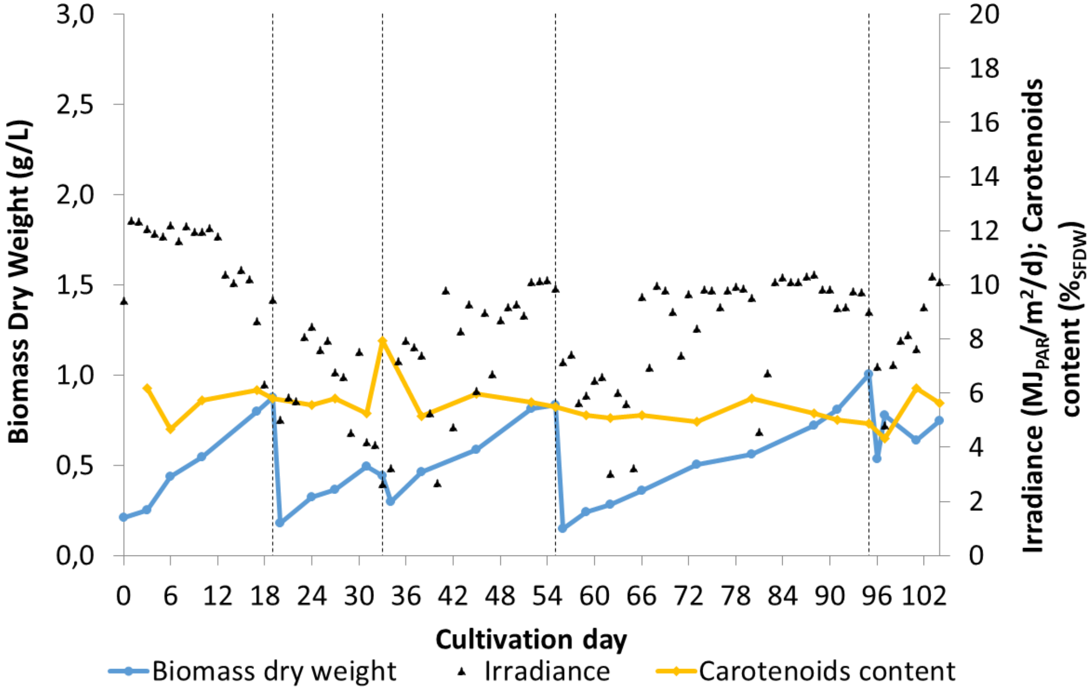
Microalgae cultivation and optimization parameters

Dunaliella in carotenogenic stage

Production



Dunaliella

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Harvesting

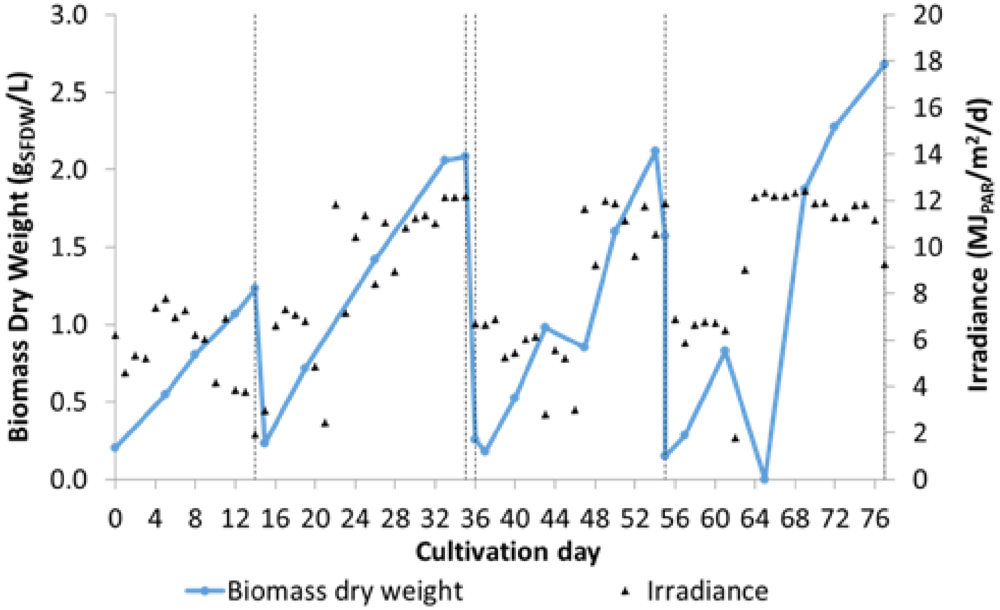
↓

Biorefinery

- Carotenoids Extract
- **Exhausted Pellet**

Microalgae cultivation and optimization parameters

Dunaliella in green stage



Characterisation:

- Compositional differences depending on cultivation parameters
- Slight differences between batches due to density and moisture differences

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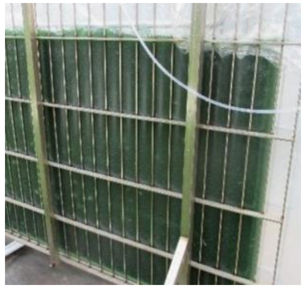
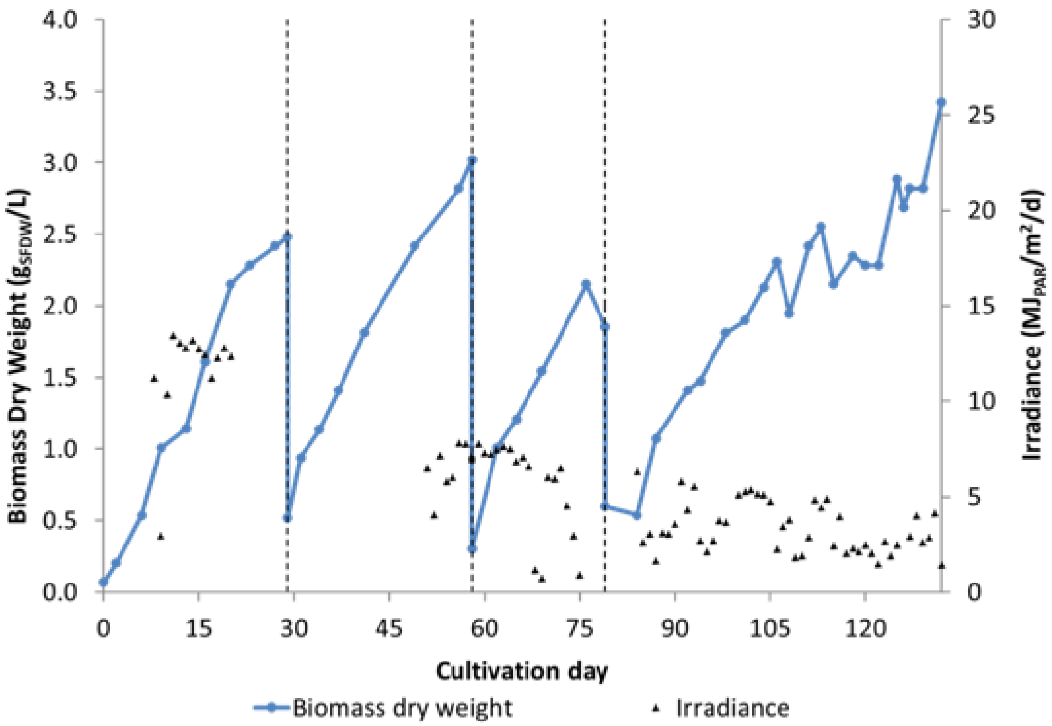
Microalgae cultivation and optimization parameters



Spirulina

Production



- Spirulina

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Harvesting

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Biorefinery

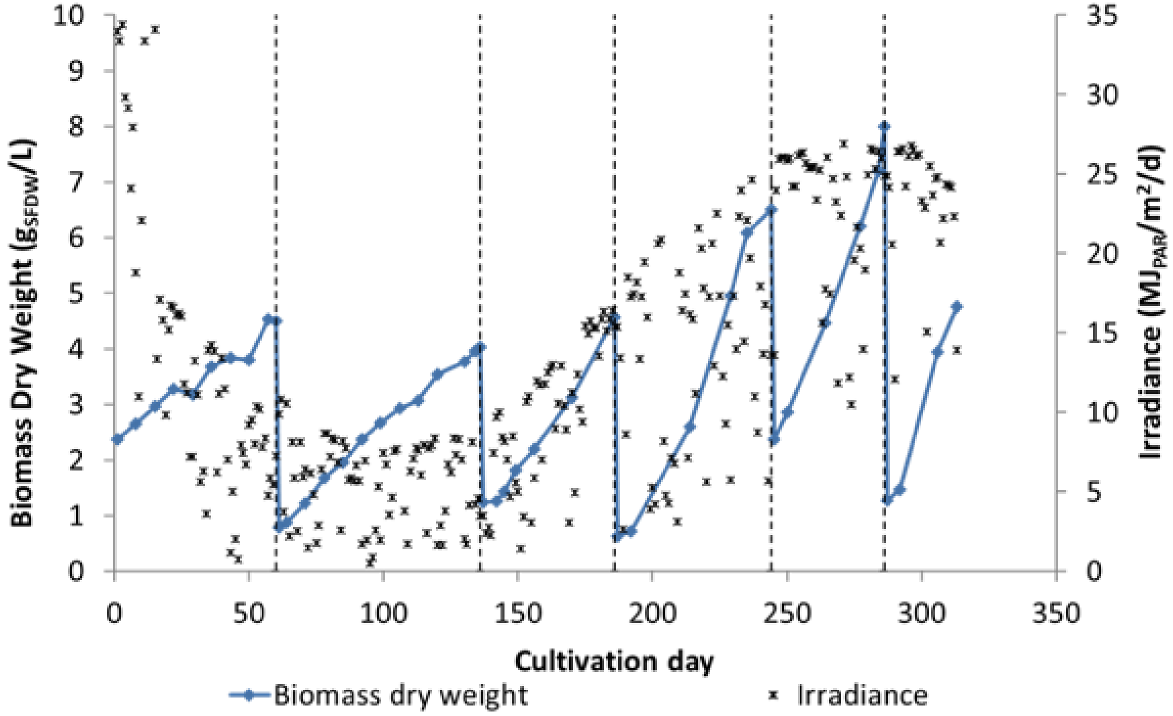
Phycocyanin

Exhausted Pellet

Microalgae cultivation and optimization parameters

Nannochloropsis

Production



Nannochloropsis

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Harvesting

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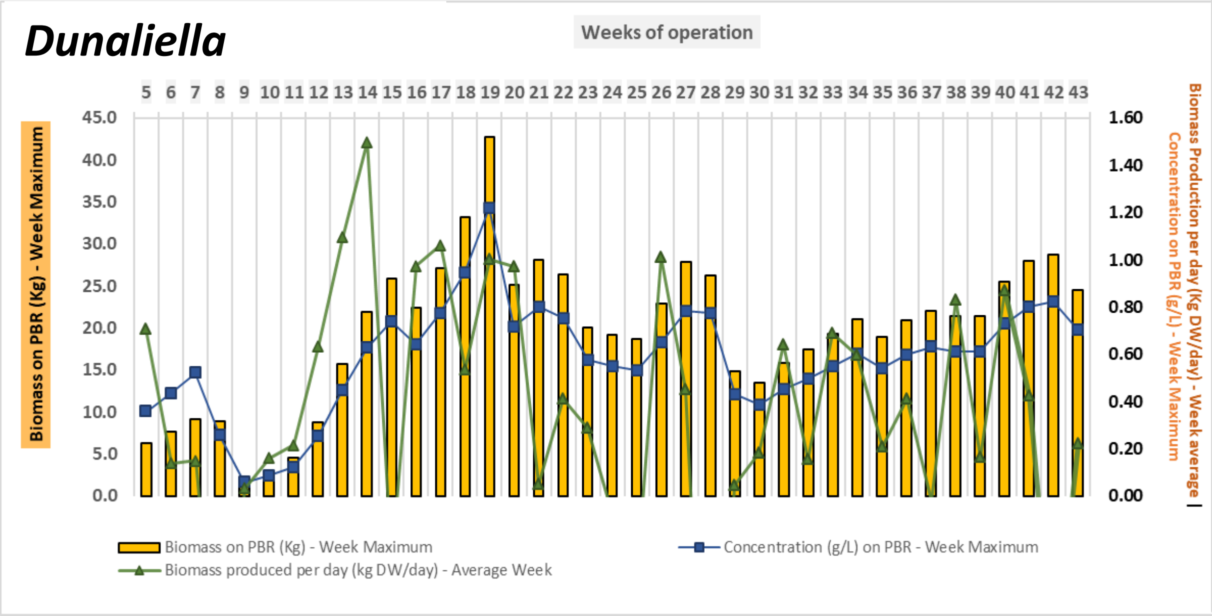
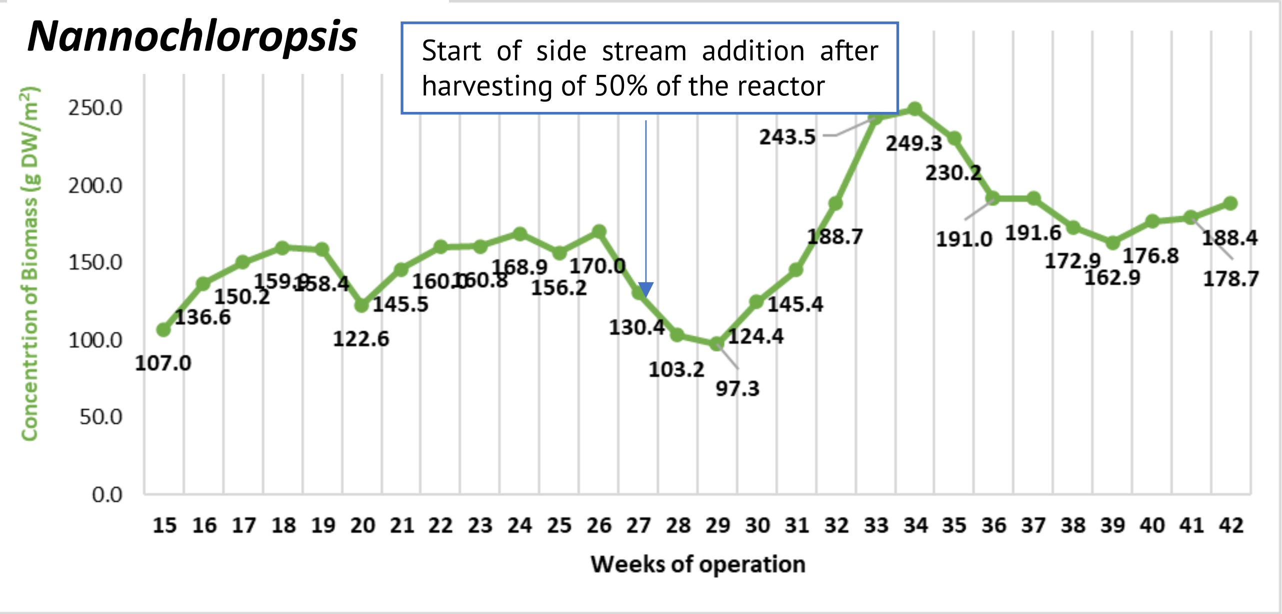
Biorefinery

Lipid Extract	**Exhausted Pellet**
	

Phototrophic cultivation | industrial side streams as feedstock

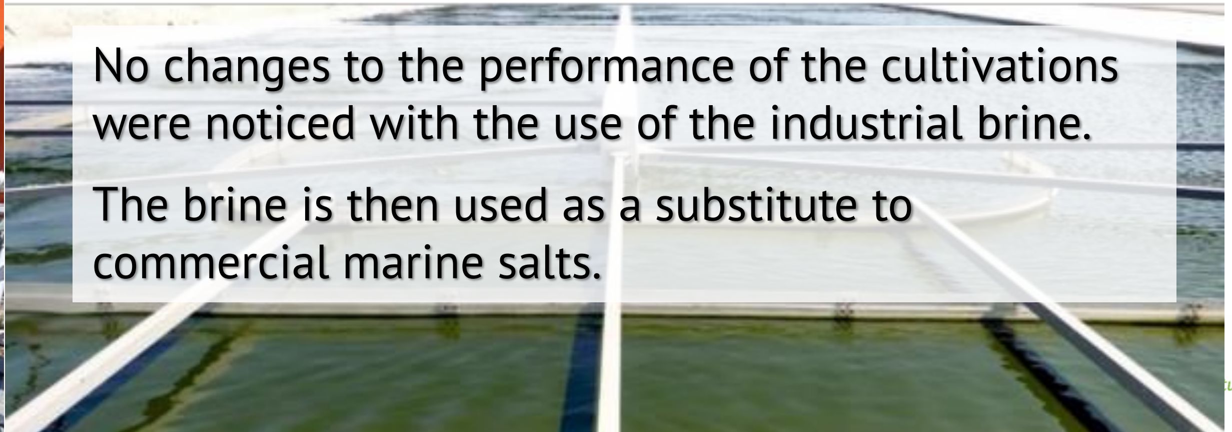




An average intake of NO_3 was found to be between 1-2 mM per day.

Integration of industrial side streams as feedstock for microalgae cultivation:

1. Effluent rich in nitrogen;
2. Industrial brine effluent.



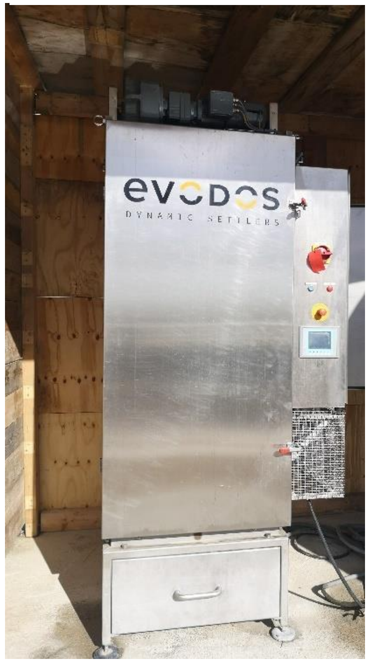
No changes to the performance of the cultivations were noticed with the use of the industrial brine.

The brine is then used as a substitute to commercial marine salts.

Phototrophic cultivation | Harvesting

Filtration
0.5 - 2 m^3/h

Centrifugation
0.5 - 2 m^3/h



Filtration
10 - 20 m^3/h

Harvesting technologies:

1. Membrane microfiltration (cross-flow inside-out and fluidized bed outside-in);
2. Centrifugation (spiral plate);
3. Combination of both.

Heterotrophic production | *Chlorella*

Heterotrophic productivity improvement

- Heterotrophic production reached a 5-fold increase in productivity for *Chlorella vulgaris* and *sorokiniana,* from ~500 kg DW/m^3/y to 2500 kg DW/m^3/y.
- Dry weight biomass harvesting for these strains exceeds 200 kg/day as more than 50 kg/ h has already been achieved several times for *Chlorella vulgaris* and 35 kg/ h for *Chlorella sorokiniana*.
- The production capacity objective of >10 ton/y at Phycom, for both species under heterotrophic conditions, has been achieved.

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phycom

Vibrating membrane filtration system for harvesting

Multiple functions in algae cultivations:

1. Water, medium and recycled water pre-treatment
   - reduces filter cartridges dramatically
   - removes microorganisms
2. Harvesting
   - high product concentration (25-30% DW)
   - buoyancy independent

Properties:

- Easy maintenance and cleaning
- Very low overall energy use:
  - homogeneous and very low TMP → low pump energy required
  - no cooling required
- Sharp cut-off and uniform TMP
- Several membrane types, among PES and PVDF

In contrast to centrifugation, no loss of biomass or cell fragments in the residual water.

Membranes are capable of recovering ~100% of the produced biomass.

- Energy costs per kg biomass, investments & other costs are similar; space use is similar.

CAPEX and OPEX reduction

- Microalgae cultivation and harvesting are still associated with high CAPEX and OPEX, even at industrial scales.
- Following cultivation, harvesting and dewatering can account for 3-15% of biomass production costs.
- Depending on the type and location of the unit, OPEX can represent more than 50% of the biomass production cost.
- To ensure microalgae products are economically attractive, A4F and Phycom are introducing design improvements to both cultivation and harvesting systems to reduce CAPEX and OPEX .

OPEX reduction | Phototrophic production at pilot and demo scale

OPEX reduction was obtained through:

1. Culture media recycling: this allowed to decrease costs with culture media preparation by 78%;
2. Water management integration with local industries;
3. Optimization of growth conditions;
4. Increase management processes robustness and data analysis for increase performance: additional sensors and flow meters will be installed to accurately measure specific improvements being achieved in the microalgae production and biorefinery units;
5. Introduction of the usage of side streams as feedstocks: it was possible to substitute the use of prepared saltwater by the use of brine coming from a nearby industry, which prevented costs associated with water and marine salts consumption, decreasing the cost by 89-90%.

Optimisation of the operation conditions continue with:

- optimization of thermoregulation of the reactors,
- reduction of the levels of dissolved O_2.

Heterotrophic CAPEX and OPEX reduction

Reduction of CAPEX for heterotrophic production processes can be accomplished by:

1. Scaling. Increasing the bioreactor content saves investments in both the bioreactor as well as the attached infrastructure such as valves, piping, sensors, etc.
2. Alternative processing can reduce investments. Medium preparation, harvesting, drying, milling and packing are part of such processes.

- At Phycom the drying and milling are combined in a new technology.
- A first series of tests have been executed with success and are continued.

Reduction of OPEX for heterotrophic production involves:

- Maximizing conversion efficiency, increase of algae biomass density in the bioreactors;
- Reduce cycle time between start and harvest;
- Automation of the processing steps.

Sustainability improvements are coupled to the process improvements

1. **Utilization of side-streams:**
    1. Decreases impact at the origin of side-streams
    2. Reduces consumption of water
    3. Reduces consumption of marine salts
    4. Reduces consumption of fertilizer / conventional sugar source
2. **Intensification of processes, working with higher biomass concentrations in cultivation and downstream:**
    1. Reduces energy consumption per kg of product
    2. Reduces water consumption per kg of product
    3. Reduces infrastructure per kg of product
3. **Improvements in productivity, by producing the same amount of biomass in a shorter time:**
    1. Reduces energy consumption per kg of product
    2. Reduces water consumption per kg of product
    3. Reduces infrastructure per kg of product

Thank you

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