Project Title:

REDUCTION OF MICROALGAE HARVESTING COSTS VIA THE DEVELOPMENT OF AN ULTRASOUND FLOW CELL TO PROVIDE PRE-CONCENTRATION

Project Acronym: ALGAEMAX

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Final Report
Publishable Summary

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Executive Summary

The worldwide production of microalgae is currently around 15,000 tons/year of dry algal biomass, used for a wide variety of applications including livestock feed, aquaculture, functional foods, cosmetics or pharmaceuticals. In addition, microalgae contain around 30% by weight of lipids, being regarded as a highly promising feedstock for biofuels, primarily biodiesel.

Microalgae are commercially grown in open ponds of bioreactors, and then harvested using a centrifuge separator. However, the centrifuge step requires a high capital investment and is highly **energy intensive** (up to 50% of the total processing energy) due to the properties of microalgae and their low concentration in the growing medium.

Constraints in microalgae production capacity are being addressed in 3 different ways: (i) Microalgae strain selection and optimization with the aim to increase productivity; (ii) Optimization of production equipment, including the identification of the limiting factors that control the growth of microalgae and control over the production process, leading to cultivation in closed systems and last but not least (iii) Reduction of harvesting costs. ALGAEMAX addresses the sometimes overlooked need to reduce downstream costs as a necessary step towards overall process cost reduction. A combination of optimization at all 3 levels is key to increasing SME competitiveness.

The ALGAEMAX project started in October 2012 and during 2 years it has achieved some key milestones in the scale-up of an innovative technology based on the use of acoustic standing waves for harvesting of high quality microalgae biomass.

The approach of ALGAEMAX is based on the use of this innovative technology for pre-concentration, significantly reducing capital investment in the centrifuge step, which represents a great barrier for SMEs. ALGAEMAX provides gentle, chemical-free treatment that ensures the quality of the concentrate, a key issue in high added value applications of microalgae.

Summary description of project context and objectives

The ALGAEMAX project has put together a group of SMEs with a common interest in developing an efficient technology to reduce microalgae harvesting costs and a group of RTDs with wide experience in the fields of acoustics, microalgae production and process optimization.

ALGAEMAX addresses these issues via the development and demonstration of an **ultrasound based flow-cell** to **pre-concentrate the microalgae**. The technology will be integrated into harvesting systems, reducing investment and operational costs and helping SMEs grow their business to address larger markets.

The ultimate goal of the project is to reduce the high **energy cost** of the dewatering step while ensuring the high quality and long shelf life of the microalgae products.

The main target in terms of technical specifications for the ALGAEMAX prototype can be summarized as follows:

- ✓ Maximum flow rate: 500 L/h
- ✓ Yield: >90%
- ✓ Concentration factor: >10x
- ✓ Power needs: ~600W
- ✓ Preservation of algae cell quality

During the first year of the project, efforts were focused on the demonstration of the feasibility at laboratory scale as proof of concept. The promising result obtained in the laboratory encouraged the ALGAEMAX team to go ahead with scale up, optimization and integration into a mobile unit suitable for demo purposes of the ALGAEMAX technology.

Description of the main scientific and technological results and foregrounds

ATEKNEA (Spain), NPL (UK) and Fraunhofer (Germany) started to collaborate in October 2012 with a core group of European small and medium enterprises (SMEs) towards the achievement of the goals of the ALGAEMAX project. The work performed by the ALGAEMAX R&D organizations observes the specifications provided by microalgae production experts CDU (Turkey) and SALATA (Germany) and has the technical support from technology manufacturers SONIC (UK) and HAUS (Turkey).

Thanks to the ALGAEMAX project, a prosperous collaborative partnership has been forged in which companies and research centers with highly distant areas of expertise have worked together to develop a suitable solution for an emerging sector.

SPECIFICATIONS AND CONSTRAINTS: During the first year of the project, efforts were focused on **revising the specifications** as well as identifying the **technical constraints** (WP1). The microalgae species and culture methods (eg. Raceway pond & PBR) and the typical concentration levels that best represent the current markets for ALGAEMAX were defined. Nannochloropsis species and Chlorella species were selected due to their differences which represent a high range of conditions, although tests on additional microalgae species were not discarded. The main performance indicators to evaluate operation of the flow cell were also identified.

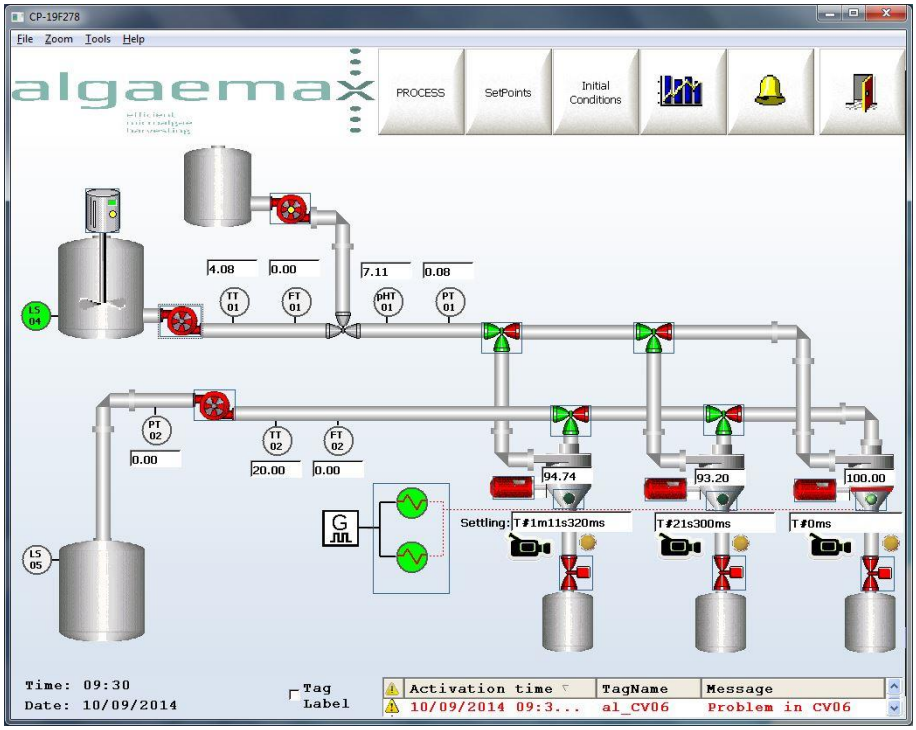
ULTRASOUND SYSTEM DEVELOPMENT: Based on these specifications research activities were undertaken, starting at laboratory stage, combining acoustic field simulations with the construction of simple experimental set-ups aimed at assessment of the results yielded by the model (WP2). The development of the ALGAEMAX acoustic chamber, along with the modules allowing continuous flow operation, constitutes the core of the ALGAEMAX project. Therefore, the design, construction and optimization tasks extended almost until the end of the project, when the scaled-up pre-competitive prototype was successfully assembled with the auxiliary systems and successfully started up. The process also involved identification, specification and assembly of the right components (power amplifiers, piezo-electric transducers, etc.) to be integrated in the ALGAEMAX flow cell.

BATCH TESTING: During the second year of the project, exhaustive experimental testing was undertaken (WP3), yielding the critical design parameters and leading to the final prototype, designed for a processing capacity of 123 L/h of microalgae suspension. The scale-up involved design, construction and testing of different intermediate prototypes to experimentally evaluate the most efficient design for the ultrasound treatment chamber. The performance was assessed in batch conditions. The tests, performed by Fraunhofer, allowed the characterization of the microalgae behavior under the effect of acoustic standing waves.

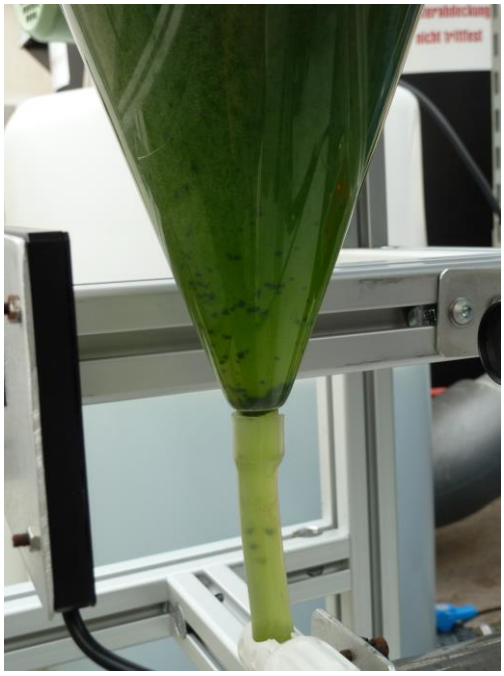
PILOT PLANT INTEGRATION FOR CONTINUOUS FLOW OPERATION: NPL, in close collaboration with SONIC (manufacturers of ultrasound systems), led the design and assembly process of the ultrasound chamber prototypes, from laboratory to pilot scale. ATEKNEA coordinated integration and developed all the required adaptations for continuous process operation, adjusting to the specifications and constraints defined by NPL in the ultrasound chamber design.

Adaptations for continuous flow processing involved mechanical design of flow cell accessories, specification and installation of auxiliary systems, integration into a compact prototype and automation of the complete

process, including the development of a user friendly interface to facilitate validation in an industrial environment (WP4).



DEMONSTRATION: During October 2014, following optimization of the integrated system performance in a laboratory environment, the final ALGAEMAX prototype was delivered to end user SALATA's all-year round microalgae production facilities in the region of Thuringia (Germany). Tests with three microalgae *Chlorella* (Chlorophyceae), *Haematococcus* (Chlorophyceae) and *Nannochloropsis* (Eustigmatophyceae) were undertaken.



Demonstration activities proved the robustness of the ALGAEMAX prototype and the feasibility of harvesting microalgae in a **continuous mode at industrial scale.**

Concentration factor was in line or above requirements for *Chlorella* and *Haematococcus* (>10x for *Chlorella* and approximately 60x for *Haematococcus*) although yield was below expected in the case of *Chlorella*. Yields of 90% were achieved for *Haematococcus*, while *Chlorella* reached an average yield of around 25%. Power applied to the flow cells was in the range of 960 to 1320 W.

A number of **advantages of ALGAEMAX** as a pre-concentration technology were assessed:

- Reduction of investment costs thanks to reduction of the size of the required centrifuge
- No need for maintenance, reagents or wear and tear parts, leading to minimization of operational costs.
- Possibility to reuse supernatant
- Proved quality of concentrate (live, viable cells) thanks to mild treatment. The cell structure remains unaltered no valuable compounds were released from the cells during treatment.
- No mechanical moving parts, no need for safety engineering measures
- Highest flow through for any ultrasonic system reported

On the other hand, certain **limitations** were identified at this point that need to be overcome in order to ensure a marketable product. Using the feedback provided by end users (SALATA and ÇAGLAR), the RTDs (ATEKNEA, NPL, FRAUNHOFER) and technical SMEs (SONIC, HAUS) have issued a number of improvements to be implemented. This will allow the exploitation board to outline a roadmap to eventually achieve the successful commercialization of the ALGAEMAX technology.

Potential impacts, main dissemination activities and foreseen strategy for the exploitation of results

Production capacity, quality of the final product and the associated production costs are critical for algae biomass producing SMEs to continue growing within the high-value products market (livestock, nutraceuticals, pharmaceuticals, specialty chemicals, with an estimated size of €1 billion) and also to expand into low-value products like algae biomass for CO2 capture (estimated €50 billion market) or the much anticipated third generation biofuels market, with a potential size of €1 Trillion.

The efforts of the scientific community have been diversified in 3 directions: (i) selection and optimization of microalgae strains, (ii) optimization of cultivation technologies, e.g. improving the design of photobioreactors and (iii) optimization of the downstream process, reducing harvesting time and costs (both investment costs and operational costs).

End users of the technology, primarily European SMEs producing microalgae for different applications will primarily benefit from a reduction in the capital investment in the harvesting equipment thanks to pre-concentration. **Direct savings of 6-10% in capital investment have been provisionally estimated.**

ALGAEMAX has several advantages over other widespread technologies increasingly used for pre-concentration purposes: (i) no associated maintenance, reagents or wear and tear parts; (ii) possibility to

reuse supernatant; (iii) proven quality of concentrate thanks to gentle flocculation; (iv) no mechanical moving parts, and thus no need for safety engineering measures.

The preservation of the microalgae biomass quality is one of the main assets of the ALGAEMAX technology. The ALGAEMAX SMEs expect to fulfill the moderate production rates of the high added value market in the short to mid term with a commercial product, while additional improvements will be necessary to reach the target capacity and operational costs of bigger markets.

The overall impact of the project for the players of the European microalgae producing industry will be to gain highly competitive positions in European and international markets, creating jobs, increasing revenues and contributing to a sustainable environment. To this effect, during the second period, SMEs have increased their dissemination activities to promote the ALGAEMAX technology among end users in relevant trade fairs and other business oriented events. SALATA, ÇAGLAR, SONIC and HAUS have established an exploitation agreement defining the most relevant decisions regarding IP protection strategy as well as a strategy for eventual commercialization.

ALGAEMAX will also generate additional social and economic benefits deriving from the development of a widely accessible, cost-effective solution for small-scale algae growing.

Project public website and relevant contact details

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