1 Executive summary

FUEL4ME: Future European league for microalgal energy

The EU funded FUEL4ME (FUture European League 4 Microalgal Energy) project was established to evaluate microalgae as potential sustainable source for second-generation biofuels that can compete with fossil fuels. To realise this an increase in the scale of microalgae production needed to be matched with a simultaneous decrease in production costs. The FUEL4ME project has achieved significant decreases in production costs of algal lipids, but the production costs for algal biodiesel are still (more than) an order of magnitude too high to make this process commercially attractive in the short term. However, microalgae as source for high-value components such as omega-3 fatty acids for application in food and feed products, has proven to be realistic and cost-effective using microalgae as production organism.

FUEL4ME aimed at exploiting algae's unique ability to produce high value biomass and lipids efficiently by photosynthesis. Such biomass and lipids could form an excellent starting material for the sustainable production of biofuels and other products such as animal feed. Moreover, microalgae, including the target algae of this project (*Nannochloropsis oceanica* and *Phaeodactylum tricornutum*), do not compete with food crops for land and freshwater as they are grown in sea, saline or other marginal water on unproductive dryland.

FUEL4ME investigated in detail the molecular and metabolic mechanisms governing lipid accumulation in two microalgae species and demonstrated enhanced lipid accumulation by metabolic engineering. Furthermore, we compared the current two-step batch nitrogen starvation production process for microalgal lipids with a newly developed continuous one-step nitrogen limitation process and optimised lipid production under different growth conditions. Researchers developed the various steps of the downstream processing chain, which involved harvesting, cell disruption, lipid extraction and fractionation and hydro-treatment of the lipids to create biofuel. In addition, biorefinery steps to valorise high value molecules such as omega-3 fatty acids, or high quality algae protein, were developed and demonstrated. They were shown to be successfully applicable to microalgae and are now ready to be used in commercial processes, especially for high-value applications in Food & Feed.

The consortium designed and set up three pilot plants for outdoor microalgae production based in Italy, the Netherlands and Israel, respectively, and one demonstration facility in Spain. At outdoor pilot scale it was shown that although with lower lipid content, the one-step N-limitation process had comparable lipid productivity to the traditional N-starvation batch process, but requires further testing for prolonged periods on a large scale.

To determine the actual state of the technology as well as study how key parameters influence the sustainability of the FUEL4ME integrated process a life-cycle assessment (LCA) study was performed. The main influences upon sustainability were cultivation and harvesting, electricity demand especially for PBR cooling, sources of freshwater and carbon dioxide, and suitable land. FUEL4ME has addressed some of these parameters by improving productivity of cultivation, high efficiency thermoregulation of the photobioreactors, and improved harvesting efficiency, including integrated water and resource re-use in cheap desert land. However, further major improvements, will be needed to make biofuel production with microalgae fully economic and environmentally sustainable. Currently the process is best suited for the production of high value products such as polyunsaturated fatty acids (PUFAs), and a promising biorefinery approach showed to have a strongly improved economic balance. We believe that FUEL4ME's long-term innovation strategy, with

initial focus on high value products, will result in economically feasible and environmentally sustainable microalgae-based products. This will ensure a further decrease in production costs and an increase in the scale of production. However, microalgae as source for biofuels seems only viable when the majority of the microalgal biomass is commercialized as high-value chemicals/commodities and the biofuels are a co-product instead of the main product. Both for microalgae cultivation and downstream processing FUEL4ME has provided an excellent opportunity for industrial partners to conduct pilot tests of their technologies, improving them and demonstrating their use within the microalgae field. This has helped to achieve more reliable and scalable industrial solutions.. Additionally, FUEL4ME has generated highly skilled professionals with expertise in algal microbiology and microalgae cultivation and processing systems. By developing knowledge and skills as well as sustainable valorised products from microalgae, the project has made a valuable contribution to Europe's research capacity and bioeconomy. Furthermore, this eco-friendly process has the capacity to reduce dependence on fossil fuels.