Developing the next generation Macro-Algae based biofuels for transportation via advanced bio-refinery processes

Reporting

Project information

MacroFuels

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Project website

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Periodic Reporting for period 2 - MacroFuels (Developing the next generation Macro-Algae based biofuels for transportation via advanced bio-refinery processes)

Reporting period: 2017-07-01 to 2018-12-31

Summary of the context and overall objectives of the project

MacroFuels’ overall goal is to produce advanced biofuels i.e. ethanol, butanol, furanics and biogas from seaweed. Key to the MacroFuels concept is the valorisation of a currently underused biomass with great potential for complementing and eventually replacing fossil resources that is not competing with arable land or food, while showing environmental benefits if sustainably produced, which could substantially contribute to EU goals for renewable energy and sustainable transport. Ambitious targets were set as:
• Increase the biomass supply to the target yield at 25kg ww/m² per year.
• Improve the pre-treatment and storage of seaweed to yield fermentable and convertible sugars at economically relevant concentrations.
• Increase the bio-ethanol and butanol production to economically viable concentrations.
• Increase the biogas yield to convert 90% of the available carbon in residues.
• Develop thermochemical conversion processes of seaweed sugars to furan-based fuels.
• Perform an integral techno-economic, sustainability and risk assessment of the entire seaweed to biofuel chain.
Target sectors for the liquid biofuels are the heavy transport and aviation sectors. Fuels will be tested in a real car engine, which will allow to assess and demonstrate their performance already at lower technology readiness levels.

Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

• Seaweed cultivation, seeding and harvesting processes: A novel year-round cultivation approach for seaweeds was developed at test sites in Scotland and Denmark under different cultivation conditions (e.g. exposed vs. sheltered, high vs. low nutrients). Year-round cultivation with rotating crops was proven although yields did not meet the target of 25 kg ww/m² due to local weather conditions causing loss of biomass. The exposed off-shore Danish site was better for seaweed cultivation compared to sheltered sites, which is promising for upscaling European offshore seaweed cultivation. The concept of direct seeding on advanced cultivation substrates with novel binders was proven at sea with improved efficiency and reduced cost of operation. A prototype of an automated harvester was tested and proved the technical feasibility of automated harvesting. Novel seaweed storage bags allowed storing the biomass at sea and ensiling at the same time.

• Conditioning of seaweed: Chemical and biological ensiling processes were developed and optimized, of which especially biological ensiling showed a promising potential as a cost-effective option for industry-scale long term preservation method due to the low requirement of energy input.

• Hydrolysis of seaweed sugars to fermentable substrates: Fermentable sugars were obtained by using optimized loadings of commercial enzymes or novel recombinant enzymes directly on seaweed biomass or on the extracted laminarins, or by using mild chemical hydrolysis methods on seaweed biomass. The MacroFuels target of a total of fermentable sugars of 60 g/L in the hydrolysate was achieved. Sugar concentration was increased through membrane filtration, and salts were removed by ion-exclusion chromatography.

• Biofuel fermentation: Final ethanol titer at 4.9% (v/v) was achieved by yeast fermentation using a new strategy combining extraction of seaweed laminarins and hydrolysis and fermentation. 8 g/L butanol was produced from de-salted S. latissima hydrolysate with addition of sugars. Glucose and mannitol were metabolized at 95% efficiency. A novel strain of C. beijerinckii for direct conversion of algal biomass to ABE was constructed. Pilot production of ethanol production was demonstrated and the distilled ethanol will be tested in a real engine. Pilot production of ABE will soon be finished, followed by a similar engine test.

• Thermochemical fuel production: Routes to produce furanics by dehydration of carbohydrates from seaweed were developed. Production of a diesel additive was proven most promising from red seaweeds via its conversion to a fuel precursor which can react with butanol to an intended fuel mixture. Furfural was selectively produced via pyrolysis from alginate in low yields (<2% wt). The conversion of other seaweed-derived sugars i.e. xylose, glucose and rhamnose resulted in very high yields of furfural (>80% mol), 5-methylfurfural (>60% mol) and other furfural derivates (>70% mol) in aqueous and biphasic reaction systems. Furfural was also successfully converted to tetrahydrofuran-based fuel additives by reductive etherification with (algae-based) ethanol and butanol. Furanic fuel additive (at kg scale) produced from red seaweed will be ready for realistic engine testing in April 2019.

• Engine tests: The engine tests have been set up. Once the new gasoline engine that is suitable for
testing the MacroFuels’ fuel samples is delivered, the test will be performed (in April 2019).

• Techno-economic and sustainability assessment: The whole value chain has been assessed. The results showed that the biomass production and automated harvesting costs are currently too high for fuel applications unless integrated in a cascading biorefinery. Assessments also showed that enzyme hydrolysis is favorable to acid hydrolysis. Other elements of the sustainability assessment incl. environmental, social and business aspects are underway and will be published in public reports between July and Novem

Progress beyond the state of the art and expected potential impact (including the socio-economic impact and the wider societal implications of the project so far)

Realistically, seaweed-derived biofuels could be available in the market by 2030. Thus, MacroFuels will make a substantial contribution towards EU’s energy and climate goals for 2030. MacroFuels progressed well beyond the state of the art by:

• Seaweed cultivation: Demonstrating the concept of year-round cultivation of seaweed with rotating crops and automated harvesting will boost seaweed industries and create a large number of high-quality work places. Especially in coastal areas this could lead to a revival and infrastructural development.

• Demonstrating high fermentative yields of fuels from seaweed: The MacroFuels concept of first mild extracting algal sugar polymers (e.g. laminarin) for a second step conversion to ethanol or butanol by fermentation will generate an option for biorefinery of the residues to high value components such as protein, fucoidan, alginate, antioxidants and minerals. This is needed for a sustainable and economically viable production of biofuels from seaweed.

• Demonstrating efficient one-step thermochemical conversions of seaweed to furanics: The conversion of all seaweed-derived sugars resulted in outstanding high yields of furfural (>80% mol), 5-methylfurfural (>60% mol) and other furfural derivates (>70% mol). Furfural could be further converted to tetrahydrofuran-based fuel additives by reductive etherification with (algae-based) ethanol and butanol.

• Demonstrating the biorefinery concept that accompanied the biofuel production: This will be discussed with relevant projects on seaweed biorefineries (e.g. MacroCascade, Searefinery, MAB4) during the final project phase and considered for exploitation and follow-up actions.
Spring time in Scotland, showing textile substrates covered with seeded S. latissima (photos SAMS)

The car with PEMS package for testing the MacroFuels fuel samples under real driving circumstance

Pilot production of bioethanol from dried S. latissima by DTI (in AU Biorefinery Pilot)

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