SUPRABIO Final Newsletter – February 2014

suprabio
innovative bio solutions

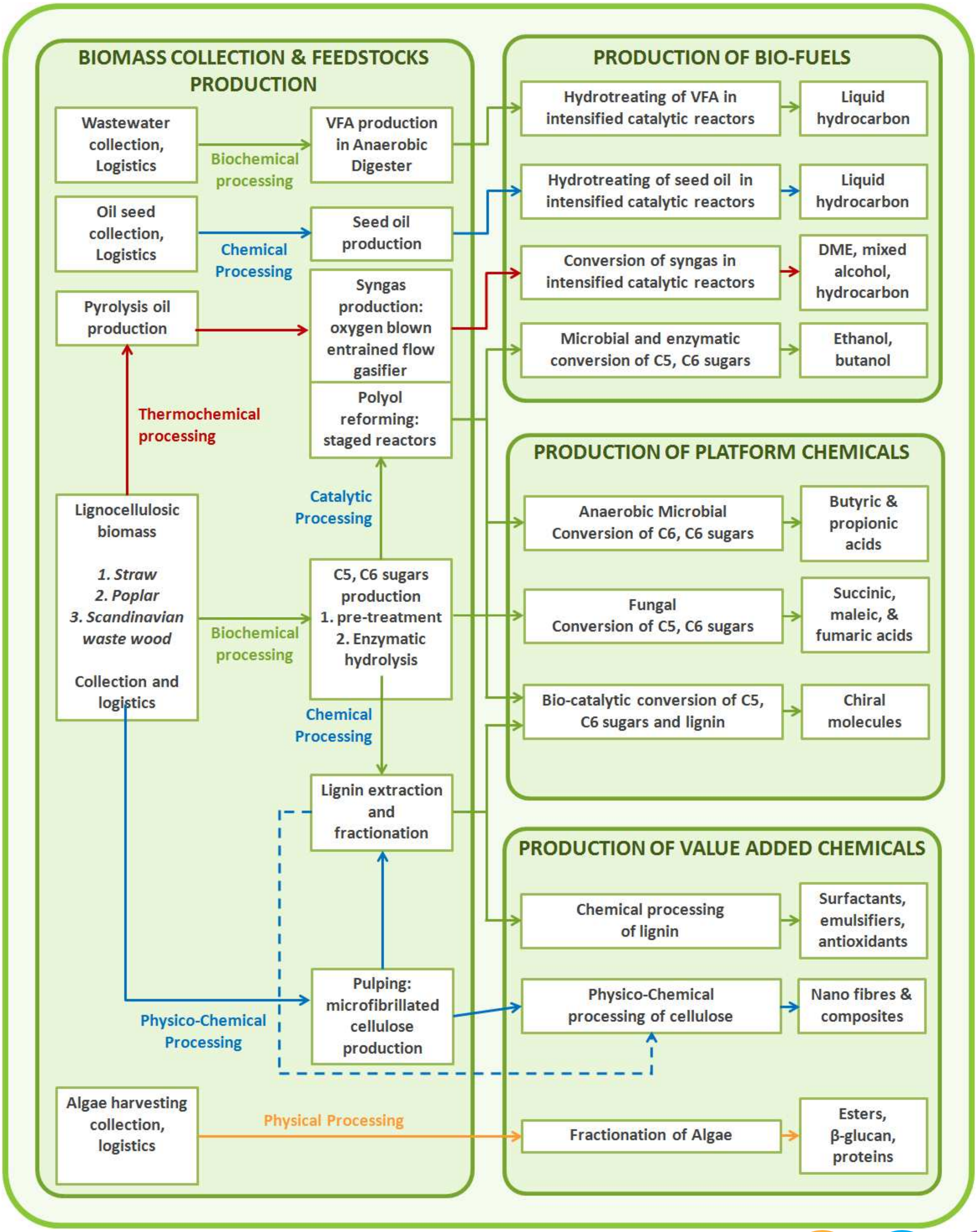
Sustainable products
from economic processing of biomass
in highly integrated biorefineries

The overall objective of the SUPRABIO project (www.suprabio.eu) is the research, development and demonstration of novel intensified unit operations that can be integrated into economic and sustainable biorefinery options for the production of second generation biofuels, intermediates and high value products, together with assessment of the outcomes to inform and enable sustainable implementation. SUPRABIO is working on a number of fronts with the aim of producing a toolkit of processes which can be used in a variety of applications.

This fourth and final SUPRABIO newsletter presents the main outcomes of the project.

SEVENTH FRAMEWORK PROGRAMME

Overview of the SUPRABIO project



The exploitation potential of SUPRABIO

Lesley Hanna, Brunel University

In addition to the knowledge, expertise and opportunities to work with new and relevant organisations that arise for all participants in a collaborative project of the nature of Suprabio, the partners have been able to highlight particular opportunities they have identified. Many of these opportunities have direct commercial potential, others develop the tools and capabilities that will need to be in place for biorefining to become a viable proposition.

Biomass pretreatment and biochemical conversion

Pretreated wheat straw is being produced at demonstration scale (up to 1 t/hr of raw wheat straw) by **BioGasol** in a continuous pretreatment system, and the pretreated biomass shows positive results in subsequent conversion.

The conversion of sugars from pretreated biomass to ethanol has been successfully demonstrated using a novel micro-organism developed by **BioGasol** aimed at achieving simultaneous saccharification and fermentation to ethanol converting both C5 and C6 sugars.

Improved C5 sugar fermentation has been achieved in **Brunel University** work aimed at butanol production along with work on a safe chassis strain for 2,3-butanediol (BDO) production. Recovery of BDO from fermentation broth is more challenging than recovery of ethanol, and work on that issue has yielded encouraging progress.

Aalborg University made significant progress in modification of *Clostridium* and *Aspergillus* species with a view to producing organisms capable of manufacturing useful chemical building blocks.

Thermo-chemical conversion

Production of pyrolysis oil (PO) from biomass addresses the issues associated with fractionation and transport of unprocessed biomass and offers a raw material which can be processed into fuels via synthesis gas (syngas). **BTG** has applied their method of producing PO and constructed a transportable PO-feed skid to allow the testing of a continuous, stable PO feed to an oxygen-blown entrained flow gasifier constructed by **ETC** in Sweden. In addition, **BTG** developed a staged gasification process able to convert biorefinery waste streams and simultaneously recover the mineral residue. The work by **ETC** on characterisation of liquid biomass atomisation has been accepted for publication and their work represents significant progress in the journey to process scale.

Fraunhofer ICT-IMM brought its microreactor technology to the project and has worked with Brunel University on syngas conversion utilising **Brunel University**'s expertise in catalysis. Highly efficient catalytic conversion of syngas to dimethyl ether and to Fischer-Tropsch hydrocarbon products has been demonstrated at laboratory scale with good promise for similar performance in a scaled-up system. The same partners developed a new microreactor configuration for efficient hydrogenation of seed oils to hydrocarbon fuel.

Fraunhofer ICT-IMM has made use of its work in Suprabio to develop new coating, structuring and sealing techniques for its microreactors and improve the microreactors's operational parameters; it has developed a gas conditioning reactor and a reactor for liquid hydrocarbon processing, and developed online analytical monitoring to optimise performance.

Other conversion pathways and uses of solid biomass

The work by **Borregaard** has concentrated on the production and use of microfibrillated cellulose (MFC) from various biomass sources and included the development of a pilot-scale unit for MFC production. The fibres have been tested successfully in selected product systems and shown to give added value in different applications

Following a linear approach through extraction, enrichment and stabilisation of EPA and DHA, as well as ß-glucan, **IGV** is looking forward to substantiate the novel technologies through securing the generated IP foregrounds in forms of industrial design, utility models, copyrights and full patents. **IGV** believes that the outcomes gained will substantially improve the overall effectiveness of microalgae biotechnology refining concepts throughout Europe.

Waste streams and wastewater treatment

During its work on production and recovery of volatile fatty acids (VFA; also known as short-chain fatty acids, or SCFA) **United Utilities** has used mixed culture fermentation to produce C3-C5 acids including a demonstration in a pilot-scale plant. It successfully evaluated ultrafiltration and reverse osmosis for increased yield and purification.

The work of **AlgoSource Technologies** has centred on recycling industrial waste (heat, carbon dioxide, minerals) to optimise the microalgae production. The technologies they have developed are being trialled at pilot scale with a view to commercialisation in the near future.

Knowledge-based outcomes

In the absence of an internationally standardised methodological framework for integrated sustainability assessments, a comprehensive and streamlined approach has been developed in SUPRABIO. Based on exactly the same system boundaries, potential impacts of SUPRABIO biorefineries on all major aspects of sustainability were investigated individually, using a set of existing state-of-the-art methodologies. The latter were harmonised with the sister biorefinery projects BIOCORE and EUROBIOREF. These individual analyses, performed by SUPRABIO partners **IFEU, IUS, WI, Statoil and Biogasol,** yielded very detailed and useful information for various stakeholders (e.g. process developers), among others by identifying optimisation potentials and providing guidance from a sustainability point of view.

The collection of process description data has been an important part of SUPRABIO, and by leading the process integration activity **Statoil** has amassed a great deal of knowledge which will be used in consideration of future directions for the company within the biorefining area. It also generated some of the information required to develop the integrated biorefinery concept and was the basis for the integrated sustainability assessment. Many SUPRABIO partners have contributed their data to achieve the goal of a better understanding of how the integrated biorefinery might be optimised, and this knowledge will be shared with the wider community at the joint biorefinery conference planned for 11 and 12 February 2014.

Biomass pretreatment at BioGasol

Mads Pedersen, BioGasol ApS

BioGasol has developed a unique system for continuous pretreatment of lignocellulosic biomass for second generation (2G) biofuels and biochemicals, and are to deliver a 4t/h small-scale commercial unit in 2014 (Figure 1).

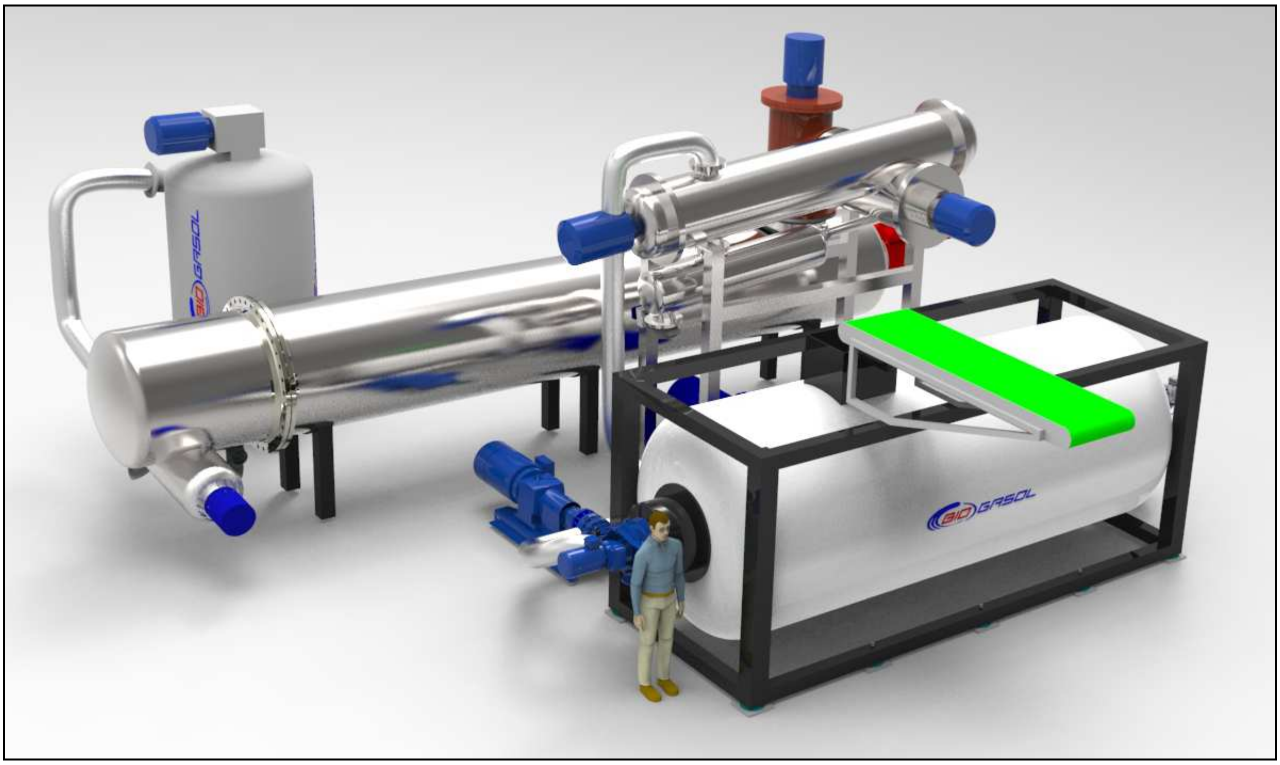


Figure 1: Upcoming Carbofrac® 400 pretreatment unit from BioGasol with capacity of treating 4 tonnes

At the beginning of SUPRABIO, the sample optimisation was carried out at batch scale (300 g dry biomass per hour). The work on process optimisation has now lead to pilot pretreatment (up to 50 kg dry biomass per hour) and pretreatment at demonstration scale (500 kg and 1,000 kg dry biomass per hour). The ability to scale up whilst reproducing the pretreatment process has been an important step for BioGasol as it has ensured that the pretreatment unit, Carbofrac®, is now ready for commercial scale high-yield pretreatment at future biorefineries.

In addition to the scaling up of the process, the pretreated biomass has been analysed and tested at Suprabio partners for utilisation in various downstream processes, resulting in various end-products (i.e. ethanol, butanediol, nanocellulose, healthcare products, acids, synthesis gas). Feedback from the Suprabio partners has brought new dimensions into the optimisation process, since multiple end-products need to be considered in order to achieve the best results i.e. the best material after pretreatment for the downstream processing which is typically dictated by the requirement for optimising one component, e.g. monosaccharides, in the biomass but at the same time limiting others e.g. inhibitor compounds such as furfural or Hydroxymethylfurfural (HMF).

At present most biofuel producers are linked to first generation (1G) fuel production (using potential food/feed). Adding a Carbofrac® pretreatment unit to such a plant enables a shift towards 2G biofuel production (e.g. using agricultural, non-food/feed residues). Furthermore, the Carbofrac® has shown to be feedstock flexible as the system can be configured to use both herbaceous biomasses like wheat straw and woody biomass such as poplar. Due to the flexibility of the system, the Carbofrac® can utilise the growth and harvest cycles of various biomasses and thus be operational throughout the year while limiting the need for storage of biomass. Besides biomass flexibility and high yields, the Carbofrac® pretreatment unit offers a low total cost of ownership due to the extensive use of standard components, modular design and high dry-matter pretreatment, the latter resulting in low water and steam consumption.

Entrained flow gasification of pyrolysis oil at BTG and ETC

Evert Leijenhorst, BTG

Biofuels and bio chemicals can be produced from a wide variety of biomass feedstocks via fast pyrolysis and entrained flow gasification. This process chain, referred to as the thermo-chemical route, is feedstock flexible and self-sufficient in terms of energy requirement. In the fast pyrolysis process biomass is converted to a liquid product, called pyrolysis oil, with a volumetric energy density 5-10 times that of the original biomass. Ideally the fast pyrolysis process is operated at relatively small scale and located near the biomass source. Pyrolysis oils from multiple plants are then transported to a central, large scale entrained flow gasifier for syngas production and subsequent product synthesis.

In SUPRABIO, BTG produced some 10 ton of pyrolysis oil from wood and straw at its home base in The Netherlands. A pump skid was designed, built and commissioned to feed the pyrolysis oil to the entrained flow gasifier of ETC in Sweden. A first test campaign was performed in 2012, to test all equipment and provide information on the optimal operational window. In 2013 a second campaign was performed to demonstrate continuous steady state operation and to test the impact of using a different feedstock. At a capacity of 84 kg/h pyrolysis oil (400 kW_{th}) syngas was produced at temperatures between 1250 and 1450°C and a pressure of 5 bar. The gasifier was operated in total over 60 hours on wood derived pyrolysis oil, and 5 hours on straw derived pyrolysis oil. Carbon to gas conversions of 91-97% were obtained, with cold gas efficiencies up to 67%. The observed differences in quality between the straw derived pyrolysis oil and the wood derived pyrolysis oil were only marginal.

The thermo-chemical process chain has a high potential for exploitation in future biorefineries due to the ability to convert different feedstocks into selectable biofuels. The potential benefits of having a decentralised pyrolysis process, to allow transport over lager distances to a central refinery, is a key feature. Besides improving economics, this approach enables the mobilisation of biomass residue streams which use was previously unfeasible do to logistic limitations.

A selection of photographs on the entrained flow gasification of pyrolysis oil campaigns is presented in Figure 2.

Figure 2: Several photographs of the entrained flow gasification of pyrolysis oil campaigns. Clockwise from left top: Biomass feedstock in big bags. Pyrolysis plant at BTG. Pump skid dedicated to feed the gasifier. Pyrolysis oil and pump skid ready to be shipped. Unloading pump skid at ETC. Entrained flow gasifier at ETC. Stable operation in the gasifier (timeline > 8 hour). Empty IBC's after 50 hour gasification campaign.

Integrated catalytic microreactors for fuel production

Martin O'Connell, Fraunhofer ICT-IMM

In SUPRABIO, two possible thermo-chemical routes applicable in biorefinery operations are considered. One of these involves the processing of pre-treated pyrolysis oil, char or lignin residues, into transport fuels via the synthesis gas, or syngas, route. Synthesis gas (H2/CO mixture) is a platform "molecule" for the (petro-)chemical industry. From syngas, a wide range of products can be obtained, three of which have been explored in SUPRABIO i.e. (a) Fischer-Tropsch synthesis to produce synthetic diesel, (b) conversion to mixed alcohols and (c) dimethyl ether (DME). An example of catalytically coated plates for DME synthesis can be seen in Figure 3.

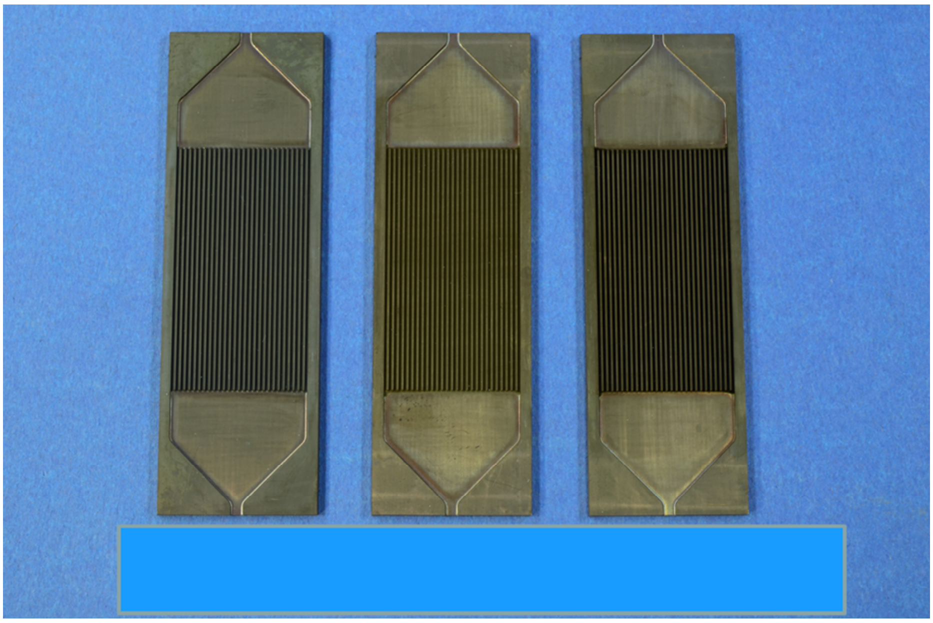


Figure 3: Fraunhofer ICT-IMM microstructured plates coated with Brunel catalyst

All of the performed work, while challenging, has shown good promise for further investigation. There are advanced plans to demonstrate the production of Fischer-Tropsch hydrocarbons from the sidestream. Following gas conditioning by a water gas shift reactor, the syngas, optimised for H2/CO ratio, will be sent to an integrated catalytic reactor, as shown in Figure 4.

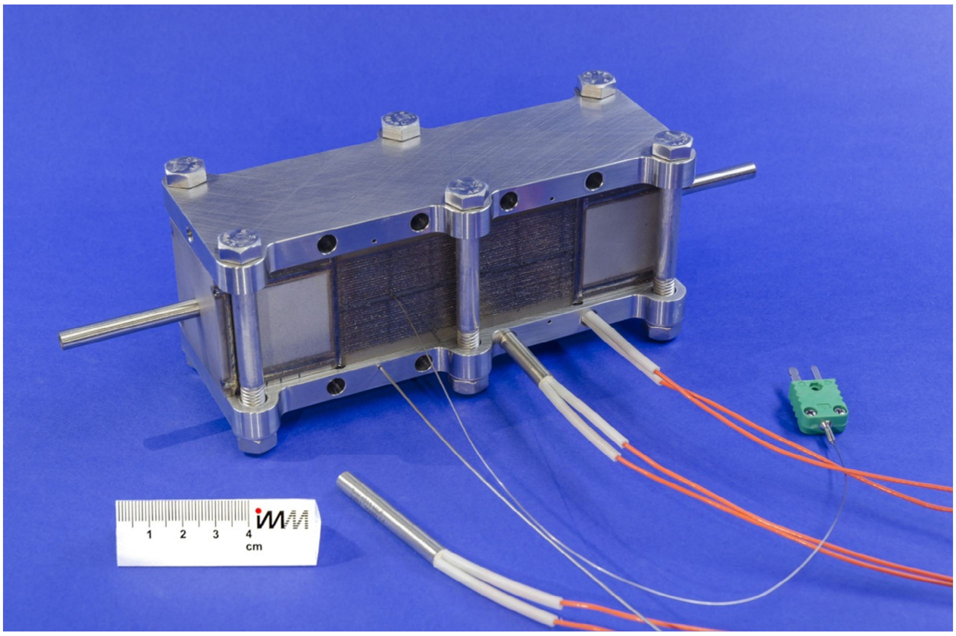


Figure 4: Finished, scaled-up Fischer-Tropsch reactor for side stream testing

The reactor consists of a cobalt-based catalyst, prepared by Brunel University, and coated onto a highly intensified microchannel plated miniplant reactor (coatings and reactor manufactured by Fraunhofer ICT-IMM). The reactor consists of 34 catalytic coated double sided plates, sealed by laser welding. In 2014, the complete chain will be tested for up to 100 hours during which the performance of the different stages will be carefully monitored.

For further exploitation, it is hoped that these reactors (further scaled) can be used as key components in BtL plants (Biomass to Liquid) as such systems can be built on a modular basis and thus located nearer the feedstock resource.

Catalyst work at Brunel University

Costa Komodromos, Brunel University

DME is a clean fuel, which can be produced by conversion of syngas derived from natural gas reforming or from conversion of biomass feedstocks. Industrially, DME is traditionally produced by a two-step process involving synthesis of methanol from syngas in the first step followed by dehydration of methanol in the second step.

In SUPRABIO, Brunel University has developed an efficient thermo-chemical route to DME starting from biomass. Pyrolysis oil is produced from different biomasses and the oil is gasified in a high-pressure entrained flow gasifier to provide a clean synthesis gas for subsequent conversion (see the article by Leijenhorst elsewhere in this newsletter). A notable achievement is carrying out the conversion of syngas to DME in a single stage using specially developed bi-functional catalysts. These catalysts are mixtures of active metal component containing oxides such as copper oxide, zinc oxide and alumina, among others for the synthesis of methanol, and an acid component (γ-alumina or zeolites) for the transformation of methanol into DME.

Many test catalysts have been prepared using nano-crystalline preparative routes which give extremely active catalytic sites, and these catalysts have been tested at different reaction conditions, both as powders in conventional laboratory micro-reactors and as thin catalyst coatings on metal plates. Carbon monoxide conversion and DME selectivity have been studied over a range of catalyst formulations in order to observe the links between catalyst design and DME production. The best formulations have been identified, as well as the optimum conditions. As ever, the challenge is to decrease carbon dioxide formation and to improve selectivity towards high DME yields. Our results are extremely promising, as the CO conversion and DME selectivity are significantly higher, while CO_2 selectivity is significantly lower, compared to the best published results

The best results are obtained at high pressure (>30bar), with a carbon monoxide/hydrogen ratio of 1:2, an inlet temperature of 275^{o}C. The catalyst that gave the highest values of CO conversion, DME selectivity, and lowest selectivity for methanol and other products, is a 20:80 copper/zinc formulation combined with a commercial grade of activated alumina. DME selectivity is improved by more than 40% (calculated on all the products, including CO2) and that of CO_2 is reduced by 30%, relative to the results obtained with other catalyst formulations. These results exceed the best published data.

Work is in progress to scale the process up and to demonstrate DME production on the side stream of a large industrial gasifier.

Producing microfibrillar cellulose at Borregaard

Ali Moosavifar, Borregaard

Borregaard has developed a method of producing microfibrillar cellulose (MFC) from wood pulp and constructed a demonstration plant with pre-commercial capacity. The MFC material is a sustainable fibre based on renewable raw materials and has three main properties that are of market interest: i) as an additive for controlling the flow properties of products; ii) as a reinforcement fibre for composite materials; iii) as a barrier compound. The fibres has been successfully tested in selected product systems and shown to give added value to different applications.

MFC as a Mean for Exploiting Energy Potential in Wastewater

Son Le, United Utilities

A Microbial Fuel Cell (MFC) is a device that converts chemical energy to electrical energy using microorganisms with up to 80% conversion efficiency. Within the MFC special types of bacteria break down organic material, such as found in wastewater, at the anode under anaerobic conditions and release electrons, protons and carbon dioxide into solution. The anode collects the electrons, which then travel to the cathode via an external circuit. The protons travel through the solution in the cell to the cathode. In an MFC, electricity is produced by extracting it from the electron-carrying external circuit. The electrons arriving at the cathode combine with the protons and oxygen, typically from the air, to form water. A typical MFC system consists of anode and cathode compartments separated by a cationic membrane.

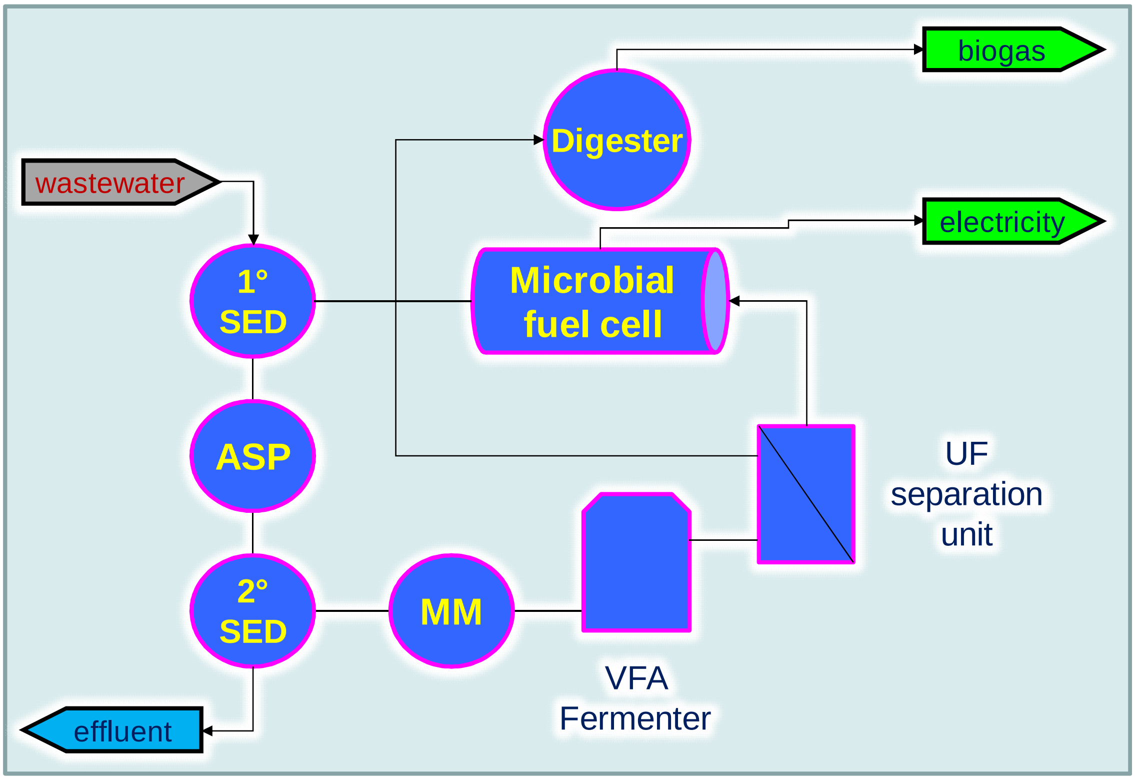


Figure 5: A system for the generation of electricity from wastewater using a Microbial Fuel Cell.

Figure 5 shows a realistic system, tested by United Utilities for the production of electricity using MFC technology exploiting the energy potential in wastewater through the Volatile Fatty Acids (VFA) route. Wastewater is fed to first sedimentation tank (1° SED) where any suspended solids are removed; conversion of the organic compounds from wastewater into biomass takes place in the activated sludge process tank (ASP); separation of the biomass from the wastewater takes place in the second sedimentation tank (2° SED); the cell lysate is generated by treating the biomass with in a micro-mill grinder (MM); The VFA substrate is generated by fermentation of the cell lysate in a VFA fermenter; an ultrafiltration (UF) separation unit is used to produce a clarified substrate solution which is fed to the Microbial Fuel Cell for electricity production; the sludge stream from the first sedimentation tank and the waste streams from both the UF separator and the MFC are combined to provide the feed to a digester where extra energy in the form of biogas is generated.

Fermentation processes and genetic modification

Peter Westermann, Aalborg University

Despite their pungent repelling smell, short-chain fatty acids such as propionic acid and butyric acid are used as flavouring agents in the food industry and as fragrance components in perfumes and cosmetics. Both acids are also used for the production of plastics and other polymers. The current world production is 180.000 tons/year, and is steadily increasing due to the value also as animal feed preservatives.

The acids are currently produced from mineral oil, and since several known bacterial species are able to produce the acids, it has been obvious to investigate the potential for a biological production based on renewable resources such as wheat straw in a biorefinery context.

Aalborg University developed organisms and processes to convert the sugars present in pretreated wheat straw into propionic and butyric acid. In this development there are four major challenges:

1. The pretreated wheat straw contains high concentrations of inhibitory compounds that affect the bacteria negatively.
2. The wild-type bacteria produce several unwanted by-products
3. The acids are produced at too low concentrations and rates to be economically interesting.
4. The pretreated wheat straw contains several sugar species, which all should be converted to acids.

Figure 6: Freshly pretreated wheat straw (left), and filtrated pretreated straw used for the fermentations (right).

In SUPRABIO Aalborg University managed to overcome all four challenges: During careful selection they have adapted acid-producing bacteria to increase their tolerance from 15% to 100% pretreated wheat straw. By genetic engineering they managed to reduce the amount of by-products produced by the bacteria. However, during the adaptation processes they succeeded in developing a natural mutant with the same capabilities as the engineered bacterium. This organism can be grown in production systems without any of the precautions and safety measures necessary to grow GMO`s. In the up-scaling of the acid production processes, an on-line separation process has been included and optimised, which has enabled us to decrease the fermentation time from 4 days in batch to 1 day in continuous fermentation due to the low product concentrations. Also, the low substrate concentrations achieved by continuous processes and online separation has resulted in that all sugar species are converted into acids.

During the project Aalborg University has demonstrated that a highly efficient biological production of important commodity chemicals such as short-chained fatty acids can be achieved by careful adaptation and selection of efficient micro-organisms in combination with state-of-the-art fermentation and separation processes.

Figure 7: The bench-scale fermentation and separation system consisting of the fermenter and control unit (left), the separation unit (middle), and the separation control unit (right).

Seed oil hydrogenation

Manickam Jayamurthy, Brunel University

Vegetable oils, including seed oil, and animal fats may be used for the production of diesel-like fuel, though the final fuel composition and properties are largely dependent of the starting material. The oil of Jatropha curcas is found to be an ideal candidate for this purpose due to the advantages of a high energy density, easy conversion, low price and above all, the non-edible nature (due to its toxicity) resulting in relatively low impact in competing with food use.

To produce a green diesel substitute as a direct replacement for mineral diesel, there is a need to convert the seed oil into a diesel-like fuel having no oxygenates and with an improved cetane number. Hydrogenating the seed oil (addition of hydrogen to the oil over an active catalyst) to produce hydrocarbons can do this but the process is difficult because of the exothermicity (heat release) during the reaction and the low selectivity to the required diesel fraction.

In SUPRABIO, Brunel University has designed and installed a new type of reactor for carrying out the hydrogenation in a staged manner (5 stages) to control the exothermicity of the reaction, and to get very uniform, well-controlled temperature distribution along the reactor. By controlling the reactor temperatures very carefully, it is possible to improve the conversion and the selectivity of the process. A schematic representation of the reactor arrangement is shown in Figure 8.

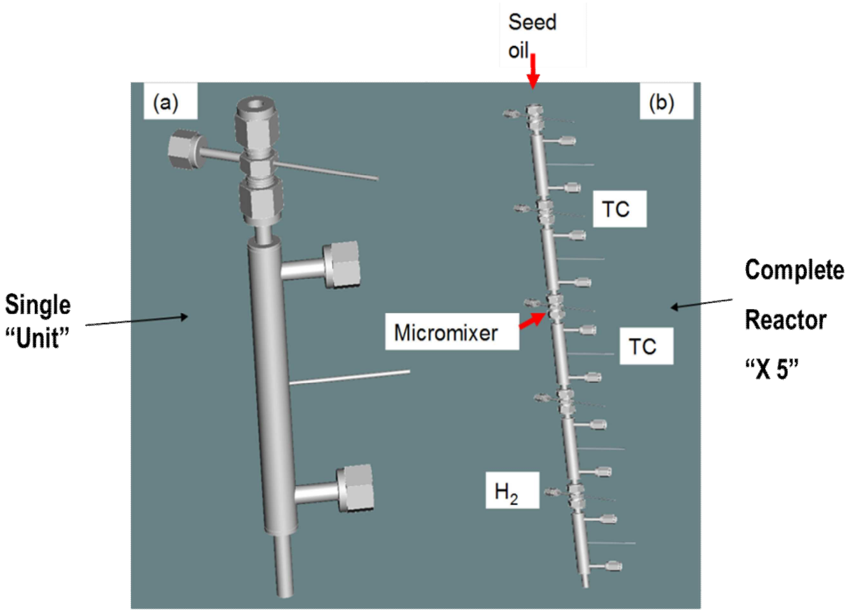


Figure 8: Schematic representation of the reactor arrangement

Nanoparticle-catalysts consisting of Cobalt, Nickel and alumina have been prepared and tested for hydrogenation. Preliminary results indicate that the new approach is very promising, with improvements in the conversion of the seed oil by over an order of magnitude when compared to conventional processing. The work is continuing to establish optimum process parameters and fuel quality.

Integrated sustainability assessment

Nils Rettenmaier, IFEU

Sustainability assessment is covered in a dedicated work package within SUPRABIO. The objective is to provide a multi-criteria sustainability evaluation of the entire value chain in order to identify the most promising biorefinery options as well as optimisation potentials.

Inspired by recent methodological developments (e.g. life cycle sustainability assessment, LCSA), a set of existing state-of-the-art methodologies covering all major aspects of sustainability was applied. All of them were based on exactly the same system boundaries. The list includes technological assessment, environmental life cycle assessment (eLCA), elements of environmental impact assessment (EIA) and social impact assessment (SIA) / social life cycle assessment (sLCA), cost and market analysis as well as an analysis of further sustainability aspects such as policy and regulatory issues. Initially, these major aspects of sustainability were addressed individually. In the past half year, work has progressed considerably and reports on these individual elements of the sustainability assessment (covering the classical pillars of sustainability: environment, society and economy) have been or are about to be completed. A report on further sustainability aspects and biomass competition is forthcoming.

During the remaining project time, the challenge is to combine the above mentioned individual analyses in order to form an integrated assessment of sustainability. In the absence of an internationally standardised methodological framework for this kind of assessments, a comprehensive and streamlined approach has been developed in SUPRABIO which – thanks to the common system boundaries - ensures that the results from the individual analyses (targeting different aspects of sustainability) can finally be combined and undergo a multi-criteria evaluation. It is anticipated that all investigated SUPRABIO product portfolios will show advantages and disadvantages both compared to their conventional equivalents and to other, established biomass and land use options. Nevertheless, it will be possible to depict those product portfolios which show most benefits regarding many sustainability indicators.

The resulting integrated sustainability assessment hopefully constitutes an invaluable tool for the ex-ante evaluation and optimisation of complex biorefinery systems. Next to project-specific conclusions, the final report (due in July 2014) will also contain recommendations and guidance for different stakeholders from science, industry and policy.

Final conclusions and recommendations

Mattias Ljunggren, Biogasol and Astrid Lervik Mejdell, Statoil

Many of the products from crude oil are very difficult to produce from alternative feedstocks in a cost competitive manner and will be difficult to replace. However, for some of the bulk products from crude oil (e.g. gasoline and diesel) already today renewable alternatives exist. For these products the question is not if it can be done but if sufficient amounts can be produced in a sustainable and cost-competitive way. Biochemicals can potentially bring value to businesses in three ways:

- Allow existing products to be produced at a lower cost
- Allow companies to produce products with unique properties not achievable in any other way
- Create opportunities for nature-based products, for example vanillin produced by Borregaard

In general the market for bio-based products is increasing in specific areas and the markets for biobased chemicals and fuels will most likely grow in the future. In 2011 the bio-based chemical market reached a value of 3.6 billion US$ (excluding biofuels) and is forecasted to grow to 12.2 billion US$ by 2021. The interest for bio-based chemicals also increases but the main hurdle for a large expansion is in general higher costs for bio-based products compared to the competing fossil-based products. Also a premium price for most bio-based products cannot be expected for the reason of just being “green”, they would also need to show superior properties. For a large expansion of bio-based chemicals many of the processes which today are in the development phase must have been commercialised. Also large scale production of cheap biofuel is needed which would allow other companies to valorise part of the fuel and wastes into chemicals. This could indeed happen but it is an optimistic scenario and would most likely also require that the crude oil prices increases further. If nothing changes an increased crude oil price is likely but if, for example, electric vehicles have a break though, this would reduce the demand for gasoline and diesel and in turn reduce the price of crude oil. Therefore the future market for bio-based fuels and chemicals is uncertain and to bloom on a larger scale several events need to take place.

Suprabio scope and partners

SUPRABIO is a €19M project, part (€12.6M) funded by the EC and aimed at finding improved methods of producing fuels, chemicals and materials from biomass. The consortium of 16 partners from 8 European countries is committed to making biorefineries a realistic proposition within Europe; reducing our dependence on fossil fuels for transport and energy by moving towards the use of biomass feedstocks to produce the products we need.

The 4-year project started in February 2010 and would finish in January 2014. It has been awarded a 6 month extension, until July 2014. However the bulk of the work had been completed as per the original timetable. The SUPRABIO project is co-ordinated by Brunel University. An overview of the other partners and their role is the project is presented on the next page.

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Brunel University
Project coordination, catalytic processing of polyols and syngas, nanotechnology and process integration.

IGV GmbH / IGV Biotech
Microalgae production in photobioreactors.

Borregaard Industries Ltd (Borregaard)
Demonstration of microfibrillated cellulose production.

Aalborg University (AAUK)
Genetic manipulation of anaerobic microbes and fungi, bioconversion C5, C6 sugars to platform chemicals.

United Utilities Water PLC (United Utilities)
Enzymatic hydrolysis, algae and carbohydrates digestion, waste management. Digestion of biorefinery residue.
Demonstration of mixed alcohol production.

University of Manchester (UNIMAN)
Selective enzymatic conversion of C5, C6 sugars, lignin fractions and lipids to platform pharmaceutical platform chemicals.

Statoil ASA (Statoil)
Catalytic processing, demonstration of liquid hydrocarbon production from oils, Process integration.

Institut für Umweltstudien - Weibel & Ness GmbH (IUS)
Environmental Impact Assessment Strategic Environmental Assessment and SWOT analysis.

BioGasol ApS (BioGasol)
Pre-treatment of biomass.
Metabolic engineering of production organisms.
Demonstration scale production.

Energy Technology Centre, Piteå (ETC)
Process optimisation for the gasification of charcoal, lignin, slurry in entrained flow gasifier.

BTG Biomass Technology Group BV (BTG)
Gasification of biorefinery residues for process heat, and electricity, syngas clean up and conditioning.

Wuppertal Institute for Climate, Environment and Energy (WI)
Sustainability, societal and legal aspects.

Fraunhofer ICT-IMM
Development of microchannel, integrated catalytic reactors and mini-plants.

AlgoSource Technologies (AST)
Process optimisation for algae production.

Institut für Energie- und Umweltforschung Heidelberg (IFEU)
Life Cycle Assessment.

GreenValue SA (Greenvalue)
Fractionation and extraction of lignins, healthcare products