Publishable summary SUPRABIO project (August 2012)

Summary description of project context and objectives

Declining petroleum resources, increased demand for petroleum by emerging economies, and political and environmental concerns about fossil fuels are driving our society to search for new sources of liquid fuels and commodity chemicals. The only current sustainable source of organic carbon is plant biomass. Large amounts of biomass are present throughout the world and the European Biomass Industry Association has estimated that Europe could produce 8.900 PJ of biomass per year. Biofuels, produced in biorefineries, give out significantly less greenhouse gas (GHG) emissions than fossil fuels and can even be greenhouse gas neutral if efficient methods for production are developed.

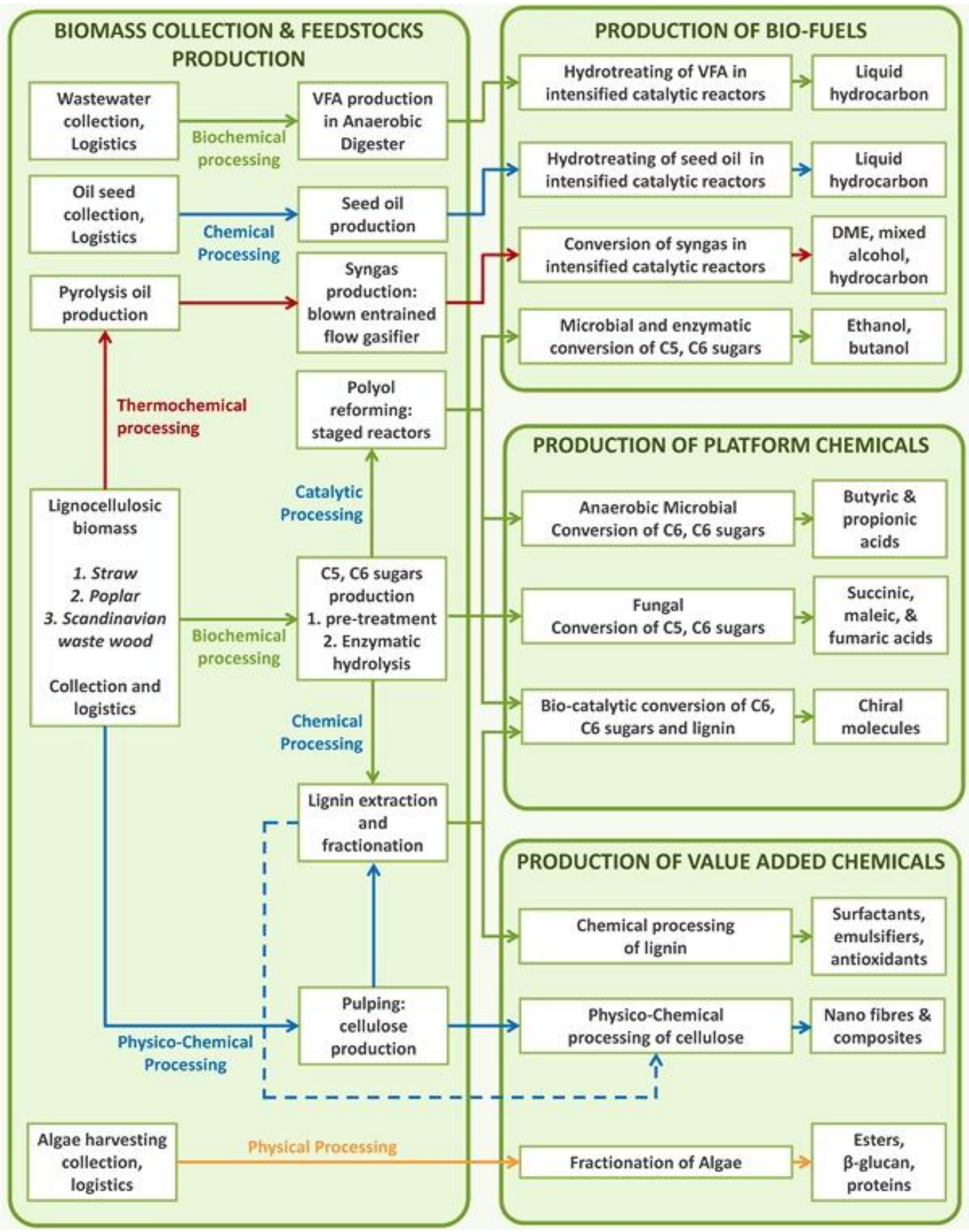

Figure 1: Organisation and scope of Suprabio

The biorefinery itself must address two strategic goals. A well-recognised driver is the substitution of imported petroleum with domestic raw materials, but realization of the energy goal requires a financial incentive to build or retrofit facilities capable of utilising renewable biomass as feedstocks, to justify industrial use of new raw materials and to incorporate technology for their conversion. Since fuel is a high volume, low value product, new, standalone fuel facilities are often burdened by a low return on investment, making their construction less desirable. A biorefinery based on chemical products alone can realize a much higher return on investment, but lacks the potential for a large energy displacement impact as chemical production accounts for only about 7 to 8% of our oil imports. Analysis reveals that producing both chemicals and fuels in an integrated biorefinery meets the energy and economic goals simultaneously. In integrated operations, such as those developed in SUPRABIO, high value products become an economic driver. This provides higher margins to support lower value fuels, leading to a profitable biorefinery operation that also exhibits an energy impact.

The SUPRABIO project researches, develops and demonstrates a toolkit of novel generic processes together with advanced intensification and integration methodologies that can be applied to a range of biorefinery scenarios based on sustainable biomass feedstocks. Supporting economic and lifecyle assessment of the resulting gains in energy efficiency and conversion of renewable carbon, together with an implementation strategy based on a product mix with optimal value, will inform step changes that contribute to achieving a more secure and sustainable economy in Europe. The organisation and scope of SUPRABIO is illustrated in figure 1.

Work performed and the main results achieved so far

Within the biochemical route, the pretreatment of both wheat straw and poplar with sulphuric acid has been optimized with high releases of sugars and low production of fermentation inhibitors as well. The stream from pretreatment of wheat straw has been supplied to other partner working on the biochemical route of Suprabio. Within ethanol production, the organism for SHcF is found and ready to be scaled up. Yields have already exceeded the targets. The organism for SScF has been isolated but needs metabolic engineering. Butanol production is moving forward as the genes for BDO production have been found in a class 1 organism.

For production of platform chemicals, the selection of bacteria has been completed and adaptation of the bacteria to the pretreated biomass is now up to 60 %. Also within the fungal conversion of the pretreated wheat straw, the strains are found and the insertion of the target genes had taken place. Biocatalytic conversion to form platform chemicals is in trials with reactions scaled from 20 mg to 5 g, and trial reactions in sc-CO_2 are in progress.

The work on lignin has been moved to a point where the optimal conditions for maximal filterability to obtain pure lignin have been found. Also a sample of pretreated wheat straw has been analyzed and fractionated to find the best combinations of pH and solvent type for optimal lignin recovery. For pulping of biomass, the pretreated wheat straw has been tested along with woody biomass. Pulp with low lignin content has been obtained and can now be used for production of nanofibers.

Biofuels production is carried out by both biological and catalytic routes. Bacterial strains capable of converting sugars to ethanol at high temperatures, and strains capable of converting sugars to 2,3 butanediol (BDO) are being investigated. Bacterial conversion of C5 and C6 sugars to ethanol and butanediol is being improved. A continuous fermentation system has been successfully developed and built, aimed at achieving simultaneous saccharification and fermentation (SSF) to ethanol.

For BDO, although major progress has been achieved during the project, an industrial fermentation process is not yet ready. Genes were detected in a risk class I organism, and they were cloned and verified as functional in the intermediate host. However, as an optimal host converting both C5

& C6 sugars in biomass was never recovered, and fermentation results are not yet sufficiently good to continue fermentation in larger scale. A series of recommendations have been made regarding further developments.

In a significant development, model BDO fermentation broths supplied by Biogasol have been successfully processed to 2-butanol via methyl ethyl ketone (MEK). This work, carried out at Brunel, involved extracting almost pure BDO from the broth at very promising yields. The BDO was then dehydrated to MEK, followed by hydrogenation to pure 2-butanol.

The catalytic syngas processing work has continued on delivering high efficiency intensified catalytic plate reactors. The intention is to determine how we can intensify the catalytic conversions to enable economic downsizing of future plants for biorefinery operations. Significant progress has been made in developing laboratory plate reactors coated with nanocrystalline catalysts for conversion of syngas to dimethyl ether (DME) in one stage, and we have obtained good selectivity with high yields. The catalysts are based on Cu/Zn methanol synthesis catalysts but developed to carry out simultaneous dehydration of methanol to produce DME directly. Similarly, good progress has been made in using multichannel coated reactors for Fischer-Tropsch synthesis (FTS) of paraffinic hydrocarbons. The reaction conditions have been optimised for diesel production. Later in the project, a decision will be made as to which process (DME or FTS) will be demonstrated in the final year using the gasifier sidestream.

Wastewater, algal biomass, and seed oil offer significant potential for biofuels and high value products in an integrated biorefinery scheme via other routes. Initial research suggests that wastewater such as biorefinery stillage, sewage sludge and farm slurries are suitable for VFA generation which may be recovered using a distributed system and converted to biodiesel or mixed alcohols in a central biorefinery. Experimental investigation of VFA production has focussed primarily on sludge as a substrate. Sludge biomass tends to be recalcitrant and although it has been found that caustic pre-treatment could release up to 80% of the available Chemical Oxygen Demand, the sustainability of chemical use remains a concern. Also critical to the development is the mean for effective and efficient recovery of the VFA from the fermentation and the subsequent purification steps leading to their conversion to a useable fuel. Amongst the evaluated techniques for downstream processing of VFA, ultrafiltration, reverse osmosis, ion exchange are proving to be very promising candidates for the developmental process train. Algal process development so far has succeeded in the identification of new microalgae strains suitable for large-scale production and more efficient lighting in an improved photo-bioreactor design. Work is still continuing with methods for extraction of ß-glucans and fractionating of the omega3-fatty acids, EPA and DHA. A number of potentially useful lipids have been identified as possible candidates for value-added modification with enzymes. Underpinning the advance of biofuel in other routes is the development of new catalysts and novel reactor systems where good progress has been made in this period. Catalytic conversion by hydrogenation/isomerisation of both rapeseed oil and Jatropha oil has been successfully carried out on a pilot plant that will provide a benchmark for the new intensified reactor designs

Process description and data collection have from the beginning of the project been highly emphasised. Such information is needed for the process evaluation and for identification of integration possibilities. However, the immaturity of many of the process has made this a challenge. At the Annual meeting in Mainz (23-25 January 2012) a one day workshop was therefore arranged to review all concepts and bringing up issues for discussion in the whole group. Actions were formulated to ensure that the processes are fully described within month 30 (July 2012).

Sustainability assessment is the subject of an entire work package within Suprabio. At the beginning of year 2, IFEU and IUS finalised an internal report (D7-1) which describes the biorefinery concepts to be assessed and provides all definitions and settings in order to ensure a coherent analysis throughout the entire work package. Secondly, BioGasol and Statoil have collected process-related information from the partners, based on which an initial technological assessment (D7-3) was performed. It showed that many of the processes are at a very early stage of development and helped revealing missing links. Moreover, by the end of year 2, it was possible to finalise the methodologies for the individual assessment of each the three pillars of sustainability: environment, society and economy. An interim report (D7-2) is now available. These methodologies have been harmonised across the three FP7-funded biorefinery projects (Suprabio, Eurobioref and Biocore). Suprabio partners have actively participated in this harmonisation process. Progress has also been made regarding market analysis and SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis. Now that the methodologies are in place, the main focus of work in period 3 will be on the actual assessments, e.g. performing LCA calculations.

Work is now going on market assessment and exploitation activities. A methodology for the market evaluation has been developed and reported (D7-2). This makes the basis for the market evaluation performed by the partners working on the different processes and the first contributions are already compiled in a report distributed to the whole group. In particular market sizes and expected prices for the end-products are important input parameters for the economic analysis.

Suprabio is also seeking to engage with other stakeholders in the biorefinery area (WP 8). The project website offers information and documents on the project and associated technology. Stakeholder workshops have been organised along with information exchange with other sister project.

Expected final results and their potential impact and use

In the coming period the work on the biochemical route will continue with regard to production, optimization and scaling up. The final results from this work will give a data and a broad picture of how to optimize a final biorefinery with the possibility to several end products. With the improvement of the microorganisms to produce platform chemicals, BDO and ethanol, the feasibility of the sugar conversion will be visualized. The sugar conversion with enzymes can also give a picture of the possibility to convert sugars without the need of microorganisms involved directly in the conversion.

The characterization of the lignin fraction and the work on fractionating the lignin derived from pretreatment of wheat straw will show the potential of utilizing the lignin fraction for production of high value products from low value substrates. The work on extracting and fractionating the lignin will show if the process is feasible.

The work on cellulose fibers will give insight in a new utilization of the cellulosic biomass other than for fermentation of sugars. With this insight, the biochemical route may give whole new opportunities for utilization of lignocellulosic biomass.

The development of the thermochemical pathway in SUPRABIO, converting biomass to clean syngas for downstream catalytic processing, provides significant opportunities in the integrated biorefinery concept. The conversion of a range of biomass materials to a more energy-intense bioenergy carrier (pyrolysis oil) will improve biomass logistics and reduce transportation and storage costs. The deployment of advanced catalytic plate reactors having very high throughputs and heat transfer rates within a small reactor volume, coupled with breakthough advances in catalysts able to carry out different reaction steps in one stage, will enable currently very large processes to be scaled down while at the same time reducing plant costs and increasing efficiency. This will overcome the “economies of scale” rule that usually makes downscaling of processes very expensive.

This approach to intensification of catalytic processes is being applied to DME, Fischer-Tropsch hydrocarbons and mixed alcohols. Intensive development work is continuing to optimise the DME single stage process, and it is expected that this may be the chosen route for the demonstration with the gasifier sidestream in the final year of the project.

The successful separation of BDO from fermentation broth (hitherto a challenging process), and subsequent catalytic conversion to MEK and then 2 butanol has shown that a viable process can be realised if the fermentation step can be made more efficient.

The development of the processes in other routes provides a cornerstone in the integrated biorefinery concept. The availability of a competitive process for VFA production would represent a breakthrough for the management of watery wastes, which is highly challenging because currently there are few sustainable options. Successful delivery of the new process by Suprabio would give sewerage undertakers, farmers and other wastewater producers in Europe a more beneficial option to deal with their wastes. VFA is an excellent energy carrier for regional operations and their conversion to biofuels would give rise to considerable synergy in a central biorefinery. On the other hand the availability of low cost, reliable intensified catalytic reactors would create opportunity for local biofuel production, cottage industry style. Reactors for hydrogenation of seed oil would also provide improved alternative for green diesel production. Although more speculative, successful delivery of processes for algal production, product extraction and fractionation would allow better biomass growth optimisation and solar energy capture using waste nutrients, CO_2 and heat from the operation thereby enhancing the financial and greenhouse gas reduction performance of the biorefinery.