I.1. Long version

EuroBioRef

EUROpean multilevel integrated BIOREFinery design for sustainable biomass processing

Project context and objectives

The EuroBioRef project (European Multilevel Integrated Biorefinery Design for Sustainable Biomass Processing; www.eurobioref.org) a 4 years program coordinated by CNRS, France, was launched on March 1st, 2010. It is supported by a 23 M€ grant from the European Union 7th Framework Program (FP7). EuroBioRef deals with the entire process of transformation of biomass, from non-edible crops production to final commercial products. It involves 30 partners (industry, SMEs, academics) from 14 different countries in a highly collaborative network, including crop production, biomass pre-treatment, fermentation and enzymatic processes, catalytic processes, thermochemical processes, assessed by a life cycle analysis and an economic evaluation of the value chain.

Executive summary (main results)

- **5 lignocellulosic plants** (willow, giant reed, miscanthus, switchgrass, cardoon) and **7 oil crops** (castor, crambe, safflower, lunaria, jatropha, as well as sunflower and rapeseed for comparison) were grown in test fields;
- **Large test fields** are being set for **willow and crambe** in Poland, **giant reed and safflower** in Greece and **castor** in Madagascar**, with ultimately the production of 10 t for this latter;**
- **Skeleton for the logistics model has been developed**, and **is populated with data for 4 crops, namely willow, castor, safflower and giant reed.**
- The construction of a **brand new pilot plant in Norway able to operate 50 kg of dry lignocellulosic materials per hour** from mid 2012 has been started after excellent results at the lab scale using a **new and versatile pretreatment process** validated at the lab scale on miscanthus, giant reed and switchgrass;
- **8 new patents** were filed, mostly related to vegetable oils conversions;
- A novel **Web-based LCA tool** has been designed, which also integrates the socio-environmental and economic impact assessments;
- **A 20 min video on the project** has been realised and is available on the EuroBioRef Website;
- The **first EuroBioRef Summer School** "*The concept of biorefinery comes into operation"*, took place on the 18-24th September 2011, in Castro-Apulia, Italy, with more than 80 participants from both the academy and the industry;
- **6 value chains corresponding to 6 different scenarios of biorefineries** integrating results and concepts developed in EuroBioRef have been designed, and are being now multidimensionaly assessed.

Outline of the main future actions

In the next period, efforts will be concentrated in the integrated assessment (LCA, socio-economics, logistics, mass balance, energy balance…) and the technological refinement (process design, further lab-scale development) of the aforementioned value chains along which the project has been reconfigurated, towards demonstration of the most promising ones.

Summary of the work performed and main results achieved during the 2nd year of the project

As a very strategic point, it has been decided after extensive analysis that **EuroBioRef biorefineries should definitely be chemicals/materials-driven**, meaning that the best part of the crops are being used to make high value chemicals and products, and that the residues are being used to produce energy, either consumed on-site or being exported under various forms. This is a rethinking of commonly admitted biorefineries concepts that are strongly biofuels-driven.

In the various test fields in Poland, Greece (example in Fig. 1) and Madagascar, **5 lignocellulosic plants** (willow, giant reed, miscanthus, switchgrass, cardoon) and **7 oil crops** (castor, crambe, safflower, lunaria, jatropha, as well as sunflower and rapeseed for comparison) were grown according to smart rotation strategies, and

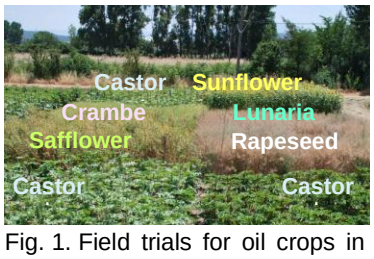

Fig. 1. Field trials for oil crops in Greece, July 2011.

all of them have already been harvested for feasibility evaluations and, when relevant, for further downstream applications in the biorefinery. Among all the considered plants, further **large test fields for demonstrations are being set with willow and crambe in Poland, giant reed and safflower in Greece and castor in Madagascar, with ultimately the production of 10 t for this latter**, while still working on other plants of interest for developing further potential applications An **international workshop on harvest, pretreatment and storage of biomass for biorefineries was also organised in Herning, Denmark on 11-12 January 2012, with more than 60 participants**, in order to evaluate the state-of-the-art of harvesting equipment for both lignocellulosic and oil crops and underlined requirements for further technological advances in order to ensure raw material of good quality and at low prices. In addition, **the skeleton for the logistics model has been developed**, and a first version has been tested with data from Salix. Now, **the model is populated with data for 4 crops, namely willow, castor, safflower and giant reed.**

Three different kinds of lignocellulosic materials (miscanthus, giant reed and switchgrass) were successfully tested in a new pretreatment process, showing its remarkable versatility. This motivated the construction of a brand **new pilot plant in Norway (Fig. 2) that will be able to operate 50 kg of dry lignocellulosic materials per hour from mid 2012**. Concerning oil plants, **economical issues were identified with jatropha, of which the cultivation by farmers seems not sufficiently attractive**. Its interest, however, relies in a possible use as fence for crop protection against stray cattle, wind and for limiting erosion, and then biofuel for local consumption. Cardoon exhibited the interesting property of being grown in the Mediterranean area without the necessity of being irrigated. However, its ashes are limiting its possible applications. In addition to the extraction and characterization of various oils, fatty acids were produced by saponification of Lunaria oil and a study on enzymatic splitting of triglycerides was initiated, in order to obtain fatty compounds suitable for downstream processing. **In the reporting period, 8 new patents were filed mostly related to vegetable oils conversions**. Further, we highlighted that bi-functional molecules can be efficiently obtained, which opens interesting perspective for our products to reach the high value monomers market. Thus, the lab work for the next reporting period moved to metathesis pilot test & polymer applications.

Upgrading of the solid co-products issued from primary transformation of biomass was also evaluated, for example, by gasification, in specifically designed/constructed units (Fig. 3). We found that, while cardoon is not adaptated for such a thermochemical process because it would need a specific technology that can handle high ashes contents, some other plants addressed by the project can be efficiently processed. As another way of upgrading the solid co-products of the biorefinery, carbonization to charcoal has been attempted on a wide range of different materials issued from the project. Some samples exhibit excellent properties, with a high specific surface area. The possible applications of such upgraded solids are investigated in the biorefinery concept. Indeed, they can be used as, *e.g.*, absorbents or catalysts supports.

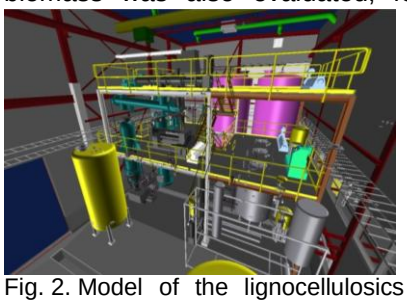

Fig. 2. Model of the lignocellulosics fractionation pilot plant planned in Norway.

Fig. 3. Gasification unit in Greece.

Further, a short list of the most relevant jet fuel properties has been prepared and the testing schedule has been fixed. Viscosity and density properties of firstly received samples were evaluated. Various options for modification of test stand fuel supply system were analysed and the most suitable version was chosen. The test combustion chamber was prepared for investigation of bio-aviation blending/combustion performances, and is now ready.

All the results obtained so far by the partners dealing with (bio)chemical transformations are continuously and methodically gathered, sorted and analyzed through conceptual process design, which enables selecting *a priori* the most viable options. This enables time-saving in technology development by discarding non-optimal options and retaining the most promising ones at their very early stage of development.

For evaluating the sustainability of the envisioned solutions, we started the development of some specific tools for life cycle assessment taking into account harmonisation efforts with major sister projects in the EU. As another strong point, this assessment is not restricted to the carbon footprint, but also integrates the socio-environmental and economic impact assessments. Internally, an interactive LCA database, which combines a user-friendly interface (for non-specialists) with a rigorous LCA approach, has been partially developed and tested. In parallel, and as a complementary

assessment tool, a basic framework for biorefinery costs modelling has been developed, which will enable economical viability classification of the various possible biorefineries configurations. The socio-economic assessment has included a detailed selected case study, designed to provide insights about best practice that can be transferred to the assessment of socio-economic impacts more broadly.

EuroBioRef is also developing a strong power of dissemination and education. The first EuroBioRef Summer School "*The concept of biorefinery comes into operation"*, aiming at the effective training of young researchers from academia and staff from industry on the most up-to-date scientific and technological aspects of biorefineries, took place on the 18-24th September 2011, in Castro-Apulia in Italy, with the edition of a textbook planned in August 2012. At last, a 20 min video on the project has been realised and will be soon available on the EuroBioRef Website.

These multilevel, multidisciplinary achievements are keystones for the further developments of the concept that will be translated to a full set of demonstrations in the next months. For doing this, 6 value chains corresponding to 6 different scenarios of biorefineries integrating results and concepts developed in EuroBioRef have been designed, and are being now multidimensionaly assessed.

Expected final results, intentions for use and impact

Business results are expected on:

- Demonstration of the economic and technical over performance of biobased products including bio-aviation fuels and chemicals markets;
- Demonstration of the increase in economical performance due to use of second-generation feedstock by using the whole plant in a zero waste concept;
- Demonstration of the sustainable value chain of non-food crops cultivated in synergy with food-crops, through rotation strategies that will benefit to both food and non-food crops yields;
- Definition of final products specifications and tests of new products to be able to propose them directly to customers.

Scientific innovations are focused on:

- Methods for conceptual process design widely applied in the chemical sector towards bio-/chemical applications;
- Heterogeneous, homogeneous and enzymatic catalytic systems including fermentation and optimization of the formulations taking into account the purity of the feedstock;
- New low energy separation techniques and adaptation to biomass-derived products, which will enable lowering of the overall cost;
- New reactor technologies for minimizing production of by-products while enabling substantial energy savings;
- Co-products reutilization technologies in order to further increase attractivity of the process;
- Integrated reaction/separation technologies for optimized process design;
- Development of new purification technologies of fermentation broth using green solvents, which will further improve the overall sustainability extent.

Technical advancements are expected on:

- Crop rotations optimization for Northern/Southern Europe and Africa, selection of appropriate sustainable biomass feedstock for diverse EU environments;
- Rationalization of the chain elaborated to yield each product and global integration/optimization of the whole process;
- Quality control of a variety of feedstock for a variety of end-products to set high level standards;
- Elaboration of multidisciplinary processes combining chemical catalysis with enzymatic catalysis, with demonstration of the benefits of such interweaving;
- Demonstration at the lab/bench scale of sub-units and demonstration at the pilot scale of integrated chains for significant products. Some demo will be also done at the industrial level;
- Integration of several reaction and separation steps for high selectivity and conversion, energy **and Capital investment costs savings**.

Sustainability assessment and performances

- Specific logistic methodology for cultures in Northern and Southern Europe;
- LCA methodology for evaluation of environmental performances;
- Economic modelling for assessment of economic viability;
- Sustainable assessment of the whole chain for economics.

Socio-economic impact and societal implications of the project

- Creation of specialized jobs in rural areas;
- Developing business/side businesses in local economies;
- It is estimated that 200,000 jobs could be created by the 4 EU initiatives.

Preparation of the Exploitation Plan of the project (Fig. 4)

EuroBioRef is preparing its exploitation plan taking into account sales from each partners in 2017 and at mature market, and self-assessing a probability of success. The workplan is adjusted accordingly in order to increase the chances to reach the market and to cross the “Valley of Death”.

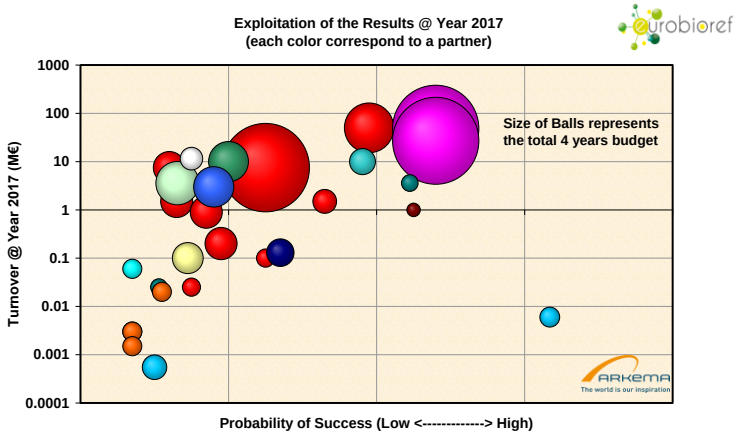

Fig. 4. Currently expected turnover in 2017 as a function of the probability of success assessed Y2.

EuroBioRef Consortium

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Partners

1. CNRS, Centre National de la Recherche Scientifique (UMR8181, UMR5256, UMR6509) France
2. ARKEMA FRANCE SA /CECA, France
3. BORREGAARD Industries. Ltd., Norway
4. NOVOZYMES A/S, Denmark
5. *Partner 5 quitted the project without contributing and was replaced by partners 29 and 30 below*
6. CRES, Center for Renewable Energy Sources, Greece
7. HALDOR TOPSØE A/S, Denmark
8. CERTH, Centre for Research & Technology Hellas, Greece
9. PDC, Process Design Center GmbH, Germany
10. QUANTIS, Switzerland
11. EUBIA, European Biomass Industry Association, Belgium
12. DTI, Danish Technological Institute, Centre for Renewable Energy and Transport, Denmark
13. Technische Universität Dortmund, Germany
14. MERCK KGaA, Germany
15. FEUP Faculdade de Engenharia da Universidade do Porto, Portugal
16. RWTH Aachen, Germany – *retired from 31/08/2011*
17. CIRCC, University of Bari, Italy
18. WSK "PZL-Rzeszow" S.A, Poland
19. OBRPR, Ośrodek Badawczo-Rozwojowy Przemysłu Rafineryjnego Spółka Akcyjna, Poland
20. SINTEF Materials and Chemistry, Norway
21. SOABE, Société Agricole de Befandriana-Sud & Partners Sarl, Madagascar
22. UMICORE, AG & Co KG, Germany
23. Nykomb Synergetics AB, Sweden
24. Alma Consulting Group SAS, France
25. Orgachim JSC, Bulgaria
26. Imperial College of Science, United Kingdom
27. Novance, France
28. University of Warmia and Mazury in Olsztyn, Poland
29. Technische Universität Hamburg – Harburg, Germany – *entered the project from M24*
30. BKW Biokraftwerke Fürstenwalde GmbH, Germany – *entered the project from M24*

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