PUBLISHABLE SUMMARY - LONG VERSION - M36 - APRIL 2013

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 15 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.

A project closely followed by the EC, with high expectations

"EuroBioRef – How a radical re-design is strengthening economic viability in the bioeconomy". *"For most people, the bioeconomy is the way of the future. A shift towards an economy based on renewable resources not on fossil fuels is no longer just an option, it's a necessity."*

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Executive summary (main results obtained so far)

- **5 lignocellulosic plants** (willow, giant reed, miscanthus, switchgrass, cardoon) and **10 oil crops** (castor, crambe, cuphea, lesquerella, lunaria, jatropha, safflower, as well as sunflower, camelina and rapeseed for comparison) were grown in test fields;
- **Large test fields** are set for **willow and crambe** in Poland, **giant reed and safflower** in Greece and **castor** in Madagascar**, with ultimately the production of at least 10 t for the latter;**
- **Win-win culture rotation strategies between food and non-food crops** have been developed and proven;
- **Efficient biotech technologies** have been developed to yield platform molecules from glycerol and biomass hydrolyzates, which even outperform the current state of the art;
- **A biomass supply logistics model has been developed**, which operates in an optional mode in terms of biomass quality (new and unexplored biomass types), system efficiency and reduced operational costs. It is populated with data for willow, castor, safflower and giant reed. Scenarios have been considered based on two plant capacities, namely 50 and 500 kt of dry matter/final product;
- A **brand new pilot plant in Norway able to operate more than 50 kg of dry lignocellulosic materials per hour** has been constructed, using a **new and feedstock agnostic pretreatment process** validated at the lab scale on miscanthus, giant reed and switchgrass;
- **15 patents** were filed, mostly related to vegetable oils conversions, which means that, to date, EuroBioRef reached 0.9 Patent applications per Million Euro of public money spent;
- **13 scientific papers** were published, and more are under preparation. Then, to date, EuroBioRef reached 0.80 publications per Million Euro of public money spent;
- **A 20 min video on the project** is available on the EuroBioRef Website (www.eurobioref.org);
- **A book 'Biorefinery: From Biomass to Chemicals and Fuels'**, Ed. by Aresta, Michele / Dibenedetto, Angela / Dumeignil, Franck, ISBN: 978-3-11-026028-1' is available (http://www.degruyter.com/view/product/177487);
- **6 value chains corresponding to 6 different scenarios of biorefineries** integrating results and concepts developed in EuroBioRef have been designed, and are being multidimensionaly assessed, to realize demonstrations of the developed technologies, but also to test scenarios of industrial exploitation.

Outline of the main future actions

In the next period, efforts will be concentrated in the demonstration of the aforementioned value chains along which the project has been reconfigurated, and to the delivery of the exploitation plans.

Summary of the work performed and main results achieved during the M25-M36 period

Figure1: Large-scale crambe field in Poland

A globalized strategy. It has been previously assessed 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**. This approach has recently been comforted due to a **remarkable change in the environment outside of the EuroBioRef project**, namely the announcement of plans for massive exploitation of cheap shale gas in the US, which might considerably change the deal. As a consequence, **only biobased products with superior technical properties will be able to compete with fossile ressources-derived products**.

Biomass production and logistics. Among the attempts performed so far on oil crops, it appears that castor, safflower, and crambe have shown a very good establishment in Greece and are anticipated to produce high yields, while crambe (Figure 1) and camelina have shown a very good establishment in Poland and are anticipated to produce reasonable yields in Poland and castor shows a remarkable potential in Madagascar. For this latter, a 10 ha test field has been set, and a specific dehulling pilot has been developed (Figure 2). Further, crop rotation trial tests have shown that the use of one type of edible crop as a rotation crop lowers the amount of fertilizer on the castor bean by 40% and maize by 30% and results in a good soil structure. Concerning the lignocellulosic biomass, in Greece, the field trials of the perennial herbaceous crops, cardoon, giant reed and switchgrass (Figure 3) are on-going and willow is proving its pertinence in Poland. A logistic model has been developed, and is now able to handle any given combination of any number of supply chains from up to four different crops. Optimization of storage operations in biomass handling chains cannot be looked at in isolated terms. Instead, whole chain considerations, especially the interconnection between harvest and storages, must form the basis for conclusions and recommendations regarding the optimum storage options. In many cases, it will not even be possible to point out one single supply chain as the most feasible. Instead, for all year supply to a biorefinery, two or more supply chains involving different harvesting and storage methods may very well be the best solution.

Figure 2: Dehulling pilot for castor

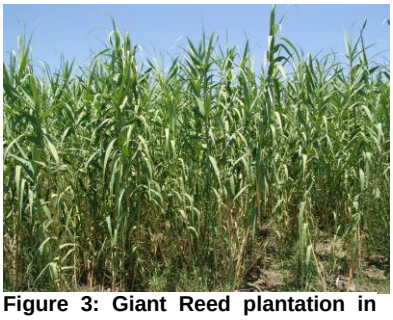

Figure 3: Giant Reed plantation in Greece.

Biomass fractionation and biotechs for platform molecules. A **brand new pilot plant in Norway able to operate more than 50 kg of dry lignocellulosic materials per hour** has been constructed (Figure 4) based on excellent results obtained at the lab scale using a **new and versatile pretreatment process** validated at the lab scale on miscanthus, giant reed and switchgrass. The initial evaluation of the lignin side stream has been conducted. Concerning oil crops, Studies on enzymatic splitting of triglycerides were pursued. In order to be able to scale up the process, the reaction kinetics were determined and modeled. The hydrolysates obtained from lignocellulosics, and the glycerol and seed meals obtained from extraction and processing of the oil seeds are further used as starting materials for synthesizing *1,3*-propanediol, *n*-butanol, *3*-hydroxy-propionic acid and generating biogas. The substrates issued from the project revealed as adequate ant the developed biotechnologies already gave promising results compared to the state-of-the-art.

Figure 4: Picture from the Borregaard pilot plant.

Figure 5: Arkema pilot plant equipped with a 100 L reactor.

Chemical and thermochemical processes. The project deals with a large variety of reactions and technologies and significant progress has been made for many reactions at the lab-scale, but demonstrations have also been already performed or are on the way in the short term. Metathesis reaction of fatty compounds from the project was successfully realised at a 100 L scale (Figure 5) and high value monomers precursors were successfully obtained. Similarly, we demonstrated also at the 100 L scale a new oxidative cleavage technology developed in the project. Further, high specific surface areas activated carbons could be obtained and are being assessed, *e.g.*, as absorbents.

Fuel applications. The products issued from the project are now assessed not only as aviation fuels but also as road fuels, as some of them exhibit relevant properties.

Book release. The book '**From Biomass to Chemicals and Fuels'** (Figure 6) has been released by the project and is now commercially available (sold out, new edition planned). It provides an introduction to the basic science and technologies for the conversion of biomass (terrestrial and aquatic) into chemicals and fuels, as well as an overview of innovations in the field. The entire value chain for converting raw materials into platform molecules and their transformation into final products are presented in details.

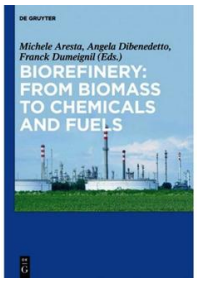

Figure 6: EuroBioRef book.

Realignment of the project along value chains. Six Value Chains corresponding to biorefineries scenarios smartly integrating the scientific/technical progresses of the project have been created. They are the base for conceptual process design of all the sub-processes developed in EuroBioRef. With the definition of these 6 value chains, the communication with all the partners was accordingly enhanced. A specific methodology was developed for the process integration. Socio-economic evaluation of the value chains is ongoing. Implementation of the value chains in the Quantis LCA Suite software was performed, and the LCA webtool was demonstrated to partners.

Expected final results, intentions for use and impact

Business results are expected on:

- Demonstration of the economic and technical performance of biobased products including bio-aviation fuels and chemicals;
- 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;
- Demonstration at the lab/bench scale of sub-units and demonstration at the pilot scale of integrated chains for significant products.
- Integration of several reaction and separation steps for high selectivity and conversion, energy and Capital (CAPEX) reduction.

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 (Figure 7)

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".

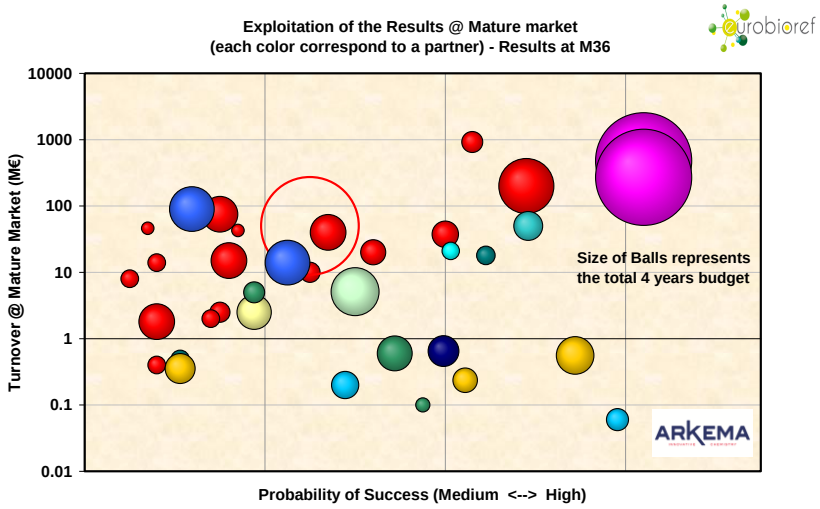

Figure 7: Currently expected turnover at mature market as a function of the probability of success assessed M36

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 left 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 the project on 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 – Hamburg, Germany – *entered the project from M24*
30. BKW Biokraftwerke Fürstenwalde GmbH, Germany – *entered the project from M24*

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