TASK 42

Biorefineries: Co-production of Fuels, Chemicals, Power and Materials from Biomass

A C6 sugars, C5 sugars and lignin biorefinery for bioethanol and animal feed from Arundo Donax, miscanthus, switchgrass, and agricultural waste straws [Beta Renewables, Italy]

Final Task Report, Triennium 2010-2012

ExCo71
Cape Town, South Africa
May 2013

Prepared by
Drs.ing. René van Ree (Task Leader)
Dr. Ed de Jong (Assistant Task Leader)

In close co-operation with Ir. Kees Kwant, SenterNovem and the Ministry of Economic Affairs of the Netherlands (Operating Agent)
INTRODUCTION
Currently, biomass is mainly used for human food, animal feed and the production of bioenergy (fuels, power and/or heat). Within a future Bio-Economy, however, biomass will be used for the sustainable and synergetic production of food, feed, bioenergy (power, heat, CHP and biofuels for transport) and bio-based products (chemicals, materials). The relatively scarce raw material availability requires the development and implementation of high-efficient biomass conversion technologies to maximise valorisation and the overall environmental benefits of the full biomass supply chains.

It is expected that current biomass supply chain expertise and facilities available in the energy sector will be used as starting point for the development of more sustainable multi-product and multi-stakeholder based biomass implementation strategies. In the short-term this approach potentially could improve the overall economics of business cases in the energy sector by valorisation of currently available agro and process residues to added-value bio-based products (i.e. biofuels for transport potentially could be produced in a market competitive way in case residues are optimally valorised); whereas in the longer-term the energy sector will become an integral part of full biomass refining strategies, i.e. using a variety of primary, secondary and tertiary organic residues as raw materials for their processes.

Biorefining, i.e. the sustainable processing of biomass into a spectrum of marketable bio-based products (food, feed, chemicals, and/or materials) and bioenergy (biofuels, power and/or heat) [IEA Bioenergy Task 42] is the main driver for large-scale implementation of biomass within the different market sectors of the global economy.

To open up the biorefinery application potential, technology and full chain development of multi-stakeholder consortia still is a necessity. Joint international priorities and RD&D-programmes between industry, research institutes, universities, governmental bodies and NGOs are necessary; whereas identification of market introduction strategies together with industry will be inevitably for the creation of a proper RD&D-framework.

The major objective of IEA Bioenergy Task 42 for 2010 – 2012 is to assess the worldwide position and potential of the biorefinery field, and to gather new insides that will indicate the possibilities to come to new breakthrough, competitive, sustainable, safe and eco-efficient processing routes for the simultaneous manufacture of transportation fuels, (CH)power, food, feed, and added-value bio-based products (chemicals, materials).

The information provided can be used by national and international governmental organisations to develop bioenergy-related policies, industrial stakeholders for focusing their RTD and deployment strategies on the most promising (i.e. sustainable) biomass value chains, NGOs to be included into their renewable energy scenarios, and research institutes and universities to focus their applied and strategic research programmes.
BACKGROUND
In a future Bio-Economy sustainable production and valorisation of biomass to both Food and Non-food applications will be the framework of operation. Sustainably produced biomass (crops, algae, residues) has to be used as efficient as possible - using bio-cascading and biorefining approaches – to meet future demands of Food, Feed, Bio-based Products (chemicals, materials) and Bioenergy (fuels, power, heat). Biorefineries are already applied for ages in for example the food industry. Large-scale implementation of biorefineries for Non-food (incl. Bioenergy) applications, however, is still lacking. Major reasons for this are that: some of the key technologies (fractionation & product separation) being part of integrated biorefinery plants are still not mature enough for commercial market implementation; there is still no level-playing-field for sustainable biomass use for Food and Non-food applications; market sectors that should co-operate (food, feed, agro, chemistry, energy, fuels, logistics, ...) for the development and commercialisation of full sustainable biomass value chains, including high-efficient biorefinery processes, are often still not working together, and there is still lack of knowledge/expertise on the advantages of biorefinery processes for optimal sustainable biomass use at both industrial, SME, (regional) governmental level.
Work programme
1. Further developing the Biorefinery Classification System (BCS), and related Biorefinery Complexity Index (BCI).
2. Identifying the most promising bio-based products – i.e. food, feed, added-value materials and chemicals – to be co-produced with bioenergy.
3. Assessing the current status and development potential of both Energy-driven Biorefineries (incl. biofuels) and Product-driven Biorefineries based on a Full Value Chain approach.
4. Providing a review of approaches and developing a guidance document for sustainability assessment, including economic, environmental and social acceptance aspects of biorefineries.
5. Preparing a Biorefinery Summarizing Paper to be used by national/international governmental organisations for their policy developments.
6. Organising bi-annual Task Meetings, workshops inviting national stakeholders, and visits to running pilot/demo and commercial facilities. External knowledge dissemination in general will be done by: i) set-up and management of the Task website, including linkage to many other national/international websites, and ii) preparation and distribution of a Task newsletter. Internal knowledge dissemination will be done by means of an intranet-site coupled to the Task website.
7. Updating of the Country Reports on Biorefinery Mapping and Biorefinery-related RD&D Programmes to help national governments to define their national biorefinery policy goals and related programmes.
8. Developing and delivering a broad Biorefinery Training Course to enable students, policy makers and industrial stakeholders to become familiar with the integral concept-thinking of biorefineries.

REPORT ON THE TASK’S OBJECTIVES

Biorefinery Classification System and Complexity Index
Task42 developed a Biorefinery Classification System (scheme, see figure 1.), based on raw materials used, platforms (intermediate biomass-derived products), and final products and secondary energy carriers produced, with the main goal to make the often complex biorefinery processes more understandable for interested stakeholders (industry, SMEs, policy makers, NGOs, ...).

Classified naming biorefineries
A [names platforms] platform biorefinery for the production of [names products and energy carriers] from [names raw materials]

A start was made with the development of a Biorefinery Complexity Index (BCI), with the main goal to give an indication on the complexity of the biorefinery facility, i.e. on the time-to-market, the amount of stakeholders to be involved, the initial investment and final operational costs, ... A high BCI has the disadvantage that the initial investment costs will be high and that a variety of stakeholders will be involved, potentially increasing the time-to-market. However, advantages are that when an implementation decision is taken, that it will be clearly possible to co-produce significant amounts of Bio-based Products and Bioenergy in a profitable way. The BCI will be further developed in 2013 and beyond at a low-profile level with a few countries (AT, NL, ...) involved. For the time being there is no consensus in the Task on the added-value or potential disadvantages of this BCI-methodology on biorefinery market deployment.
Figure 1. Biorefinery Classification Scheme [IEA Bioenergy Task42]
Bio-based products to be co-produced with bioenergy

A report has been published in February 2012 on “Value Added Products from Biorefineries – Bio-based Chemicals” (see success stories). This report was published as a glossy Task Report in Q1 2012, and is available for downloading at the Task42 website (www.iea-bioenergy.task42-biorefineries.com). This report will be expanded and updated in the 2013-2015 period.

A start was made with the set-up of a second report, viz.: “Value Added Products from Biorefineries – Proteins for Food and Non-food Applications”. During the triennium was decided by the Task partners to prepare this report instead of a report on Product-driven Biorefineries with the main reason that the results will be more directly applicable for the energy/fuel sector, the main sector dealt with within IEA Bioenergy. This report is currently being finalised, and will published, and available on the Task42 website, by the end of Q2 2013.

Current status and development potential energy-driven biorefineries

A report has been published in February 2013 on “Biofuel-driven Biorefineries – A selection of the most promising biorefinery concepts to produce large volumes of road transportation biofuels by 2025”. This report gives an overview of both commercial-scale, demonstration-scale and more conceptual biofuel-driven biorefineries in the participating countries, with a link to the Task42 classification system, to make the description of the biorefineries more understandable for the public.

The report also contains the results of the environmental assessment of a C6, C5, lignin platform biorefinery for the production of bioethanol, phenols, power, heat and CO₂ from wood (see figure 2a). The environmental assessment showed that the wood-based biorefinery system had the lowest annual greenhouse gas emissions [t CO₂-eq/year] (figure 2b); however, the highest cumulated primary energy demand [PJ/year] (figure 2c), compared to other system alternatives to produce the same amount of end-products. The economics were not assessed in this report.
**Figure 2a.** C6, C5, lignin platform biorefinery for the production of bioethanol, phenols, power, heat and CO₂ from wood

**Figures 2b** Greenhouse gas emissions and 2c Cumulated energy demand wood biorefinery vs. alternative production systems

The full report is available for downloading at the Task42 website ([www.iea-bioenergy.task42-biorefineries.com](http://www.iea-bioenergy.task42-biorefineries.com)).

**Sustainability assessment on biorefineries**
A draft set-up of a guidance document for biorefinery-related sustainability assessments was made in 2012. This document was finalised in Q1 2013, and is available on the Task42 website. The biorefinery-related sustainability activities will be continued in the 2013-2015 period with both specific Task42 activities (i.e. PROSUITE sustainability toolbox testing for some selected biofuel-driven biorefineries) and some joint Tasks activities (i.e. mobilising sustainable biomass supply chains, future demand for sustainable biomass from the broad Bio-Economy perspective).
National and international policy development support

Two types of activities have been performed within this framework, viz.: 1) the preparation of a new glossy Task42 Brochure, covering all Task results so far, and 2) the preparation of separate National Country Reports on biorefinery mapping and RD&D programmes, and an Integrated Report for all Task42 partnering countries, summarising the major efforts in all countries.

Concerning the new glossy Task42 brochure, a draft 60 pages version is available covering the following issues: biorefining – global status, future challenges, and country specific challenges; vision and contribution IEA Bioenergy Task42; biorefineries – definition and classification; sustainability issues biofuel-driven biorefineries; value-added products from biorefineries: food & feed ingredients – pharmaceuticals, chemicals & materials – fuels, power & heat; training activities, website, biorefinery status in participating countries (A4-page examples commercial facilities, demos and pilots, some examples see figure 3.); activity plan 2013-2015. This draft brochure will be finalised in Q2 2013, including data and examples of new partner countries, and will be disseminated both as hardcopies and electronically via the Task website before 30 June 2013.

Figure 3. Some example biorefineries that are in operation in the participating counties
[IEA Bioenergy Task42 Brochure, June 2013]
A whey biorefinery for ethanol and protein-based food products from milk
[Edgcumbe Milk Processing Plant, Fonterra Cooperative Group, New Zealand]

A sugar residue biorefinery sugar, bioethanol and animal feed from sugar beets
[Konya Seker San, Turkey]

A sugars, lignin and syngas biorefinery for bioethanol, power and heat from renewable biomass
and MSW [INEOS New Planet Bioenergy (USA)]

Figure 3 (continued). Some example biorefineries that are in operation in the participating counties [IEA Bioenergy Task42 Brochure, June 2013]
A turpentine, gum rosin, crude sulfate turpentine and tall oil biorefinery for terpenes, resins and neutraceutics from co-products paper industry and pine trees [Dérivés Résiniques et Terpéniques, (DRT) France]

An oil production and refinery pilot-plant for Omega-3, fuels, chemicals from microalgae [Wageningen UR, the Netherlands]

A biogas, bio-methane, green pressate, fibres, electricity & heat biorefinery for bio-methane, lactic acid, biomaterials and fertilizer from grass and manure [Utzenaich, Austria]

The Mackay Renewable Biocommodities Pilot Plant for bioethanol, lignin, various chemicals from sugarcane bagasse, corn stover, ...[Queensland University of Technology, Australia]

Figure 3 (continued). Some example biorefineries that are in operation in the participating counties [IEA Bioenergy Task42 Brochure, June 2013]
The Country Reports on biorefinery mapping and RD&D programmes in partnering countries include the following info per partnering country: current biomass use for both energy (power, heat, CHP, fuels) and non-energy (food, feed, materials, chemicals) applications, biorefinery-related policy goals and funding programmes, overview running commercial biorefineries, demonstration & pilot plants, major R&D-projects, and stakeholders involved (industry, SMEs, institutes, universities, GOs, NGOs). Both Canada and Ireland were not able to provide a Country Report because the data asked for could not be provided without significant efforts required (Canada) and because no biorefineries were in operation (Ireland). Also an Integrated Countries Report has been prepared by the Danish Team. Both the separate Country Reports and the Integrated Countries Report are available at the Task-website.

Knowledge dissemination
External dissemination of Task42 results was done by the set-up and management of a Task42 website: www.iea-bioenergy.task42-biorefineries.com, the preparation of several conference papers and reports, giving lectures at several national/international conferences, seminars and workshops, organising bi-annual industrial stakeholder events; further specification see attachment “participation in major events & deliverables”. Internal knowledge dissemination was done by means of a password protected intranet-site (document sharing) and by organising bi-annual Task42 meetings. During this triennium Task42 meetings have been organised in:

- 7th Task42 meeting, main organiser ADEME, Lille, France 4 March 2010, including a Thermochemical Biorefinery Session organised by the Austrian Team. This Task meeting was coupled to both a French industrial stakeholder meeting, an excursion to Roquette on 3 March 2010.
- 8th Task42 meeting, main organiser DOE, Chicago, Illinois, 4-6 October 2010. This event included a U.S. stakeholder event on 4 October, a Task42 progress meeting on 5 October, and excursions to both UOP and GTI/Haldor Topsoe on 6 October 2010.
- 9th Task42 meeting, main organisers ENEA/CHEMTEX (part of M&G), Tortona, Italy, 4-6 April 2011. This meeting consisted of an Italian stakeholder meeting on 4 April, an excursion to the Polibre and other demo-plants on 5 April, and a Task42 progress meeting on 5/6 April 2011.
- 10th Task42 meeting, main organiser Bioenergy Australia, Twin Waters Resort, Queensland, Australia, 22-25 November 2011. This event included: a Task42 progress meeting on 22 November, a technical tour on 23 November, and a Task42-contribution to the Bioenergy Australia Conference on 24/25 November 2011.
- 11th Task42 meeting, main organiser University of Copenhagen, Copenhagen, Denmark, 27 February 2012. This meeting included: a Task progress meeting on 27 February, a Task42-contribution to the Conference Advanced Biofuels in a Biorefinery Approach on 28/29 February 2012, and an excursion on 1 March 2012.
- 12th Task42 meeting, main organiser Joanneum Research, Vienna, Austria, 16 November 2012. This meeting was coupled to the End of Triennium IEA Bioenergy Conference in Vienna, Austria, 12-15 November 2012.
- 13th Task42 progress meeting will be organised by Wageningen UR in Wageningen, the Netherlands on 11 April 2013 coupled to the International Biomass for Food, Fuels & Materials Symposium (BFF-2013).
Training
Task42 has developed and implemented a M.Sc. level Biorefinery Training (Summer) Course to familiarise students with the concept of biorefineries and the underpinning logic.

- A first ½-day course was organised as part of the 5th International Conference on Renewable Resources & Biorefineries RRB5, Ghent, Belgium, 12 June 2009.
- A second full-day course was organised as part of an International Biomass Valorisation Congress in Amsterdam, the Netherlands on 13 September 2010. With about 70 Participants this event was very successful.
- A 4-days Training Course “1st European Training Course on Biorefining Principles and Technologies” was developed together with INRA (F), and successfully (about 120 participants) given in Paris, France, 28 August – 1 September 2011.
- The 2nd European Training Course on Biorefining Principles and Technologies” was developed together with INRA (F), and successfully (about 75 participants) given in Wageningen, the Netherlands, 3-6 June 2012.
- The 3rd European Training Course on Biorefining Principles and Technologies” is planned to be given in Galway, Ireland, August 2013.
SUCCESS STORIES

Biorefinery Classification System
The Biorefinery Classification System that was developed by Task42, clarifying what is happening in often complicated biorefinery processes, has been adopted by several countries and the EC in the preparation of their policy related documents, vision documents and Strategic Research Agendas. Some recent examples can be found in the European Biorefinery Joint Strategic Research Roadmap for 2020 (Star-COLIBRI, 2011) and the German Biorefineries Roadmap – part of the German Federal Government action plans for the material and energetic utilisation of renewable raw materials (2012).

Reports on Bio-based Chemicals & Biofuel-driven Biorefineries
The report Bio-based Chemicals: Value Added Products from Biorefineries was a first-of-a-kind report giving an overview of: the current production of bio-based chemicals (including global stakeholders involved), the potential production from bio-based intermediates, market growth predictions, economic benefits from co-production, commercial and near-market bio-based chemicals (C1-C6, Cn). More than 1000 hardcopies of this report have been disseminated all over the world, and a lot more were downloaded from the Task-website. A lot of positive response has been received from the market. This report will be updated and further expanded in the next (2013-2015) triennium.

The Biofuel-driven Biorefineries report that was finalised by the end of 2012 and printed in Q1 2013 gives an overview of both commercial-scale, demonstration-scale and more conceptual biofuel-driven biorefineries in the participating countries, with a link to the Task42 classification system, to make the description of the biorefineries more understandable for the public. The report also contains the results of the environmental assessment of a C6, C5, lignin platform biorefinery for the production of bioethanol, phenols, power, heat and CO2 from wood. Also this report will be distributed as hardcopy in significant amounts all over the world, and is downloadable from the Task-website from Q1 2013.

European Training School on Biorefining
The Biorefining Training School that was started with a ½ day event in Amsterdam in 2009 has been expanded to the major 4-day Biorefining Training Event in Europe. The extended course was successfully organised in both Paris, France (2011) and Wageningen, the Netherlands (2012), and will be the major annual biorefining training event in Europe in the next triennium (2013: Galway, Ireland, August 2013).
CONCLUSION AND RECOMMENDATIONS

Conclusion
The information (reports, Task and stakeholder meetings) that came available in this triennium in the participating countries showed that biorefining is becoming more and more the standard for the sustainable use of biomass for the production of bioenergy and bio-based Products. Market implementation is progressing, specifically in the bio transportation fuel sector, where chain and process residues are upgraded more and more to added-value bio-based products (both chemicals and feed ingredients), improving the overall production process economics. However, still some technical and non-technical critical success factors have to be solved before large-scale and optimal biomass use as base for the Bio-based Economy can be guaranteed.

Recommendations
- The circular Bio-Economy (zero-waste: re-use of water, minerals, ...) – synergetically co-producing human food, animal feed, bio-based products (chemicals, materials) and bioenergy (fuels, power, heat) – should be the framework for the sustainable worldwide production and use of biomass. Bioenergy will be a relatively low-value but essential link in the full biomass valorisation strategy, being the implementation driver in the short-term and the linking pin in the longer-term. Optimal sustainable biomass valorisation approaches for Food and Non-food (incl. energy/fuels) applications within a market-pull approach should be assessed.
- Contractibility and supply of sustainable biomass resources, including: the use of agro residues, process residues, post-consumer residues, and new crops (incl. aquatic biomass) still needs additional attention to be sure that enough biomass of the right quality will become available at the right locations to feed both current and future various biorefinery facilities.
- New – potential disruptive and game changing technologies – will be developed over time. Identification of these new technologies and dissemination of knowledge about them potentially will shorten the time-to-market of high-efficient sustainable biomass valorisation chains including these technologies.
- The advantages and disadvantages of decentral (regional) (pre) processing (relatively low initial investment, regional stakeholder support and development, social acceptability) vs. central processing making use of economy-of-scale should be further assessed.
- Support of industrial/SME stakeholders finding their position in a future BioEconomy.
ATTACHMENTS

Participation in major events
- Co-organisation together with EC FP7 projects StarColibri, Biocore, Suprabio and Eurobioref a Biorefinery Network Event in the Renewable Energy House, Brussels, Belgium, 7 February 2011.
- Chairing the Biorefinery Platform Day, incl. 2 presentations of IEA Bioenergy Task42 at World Biofuels Markets 2012, Rotterdam, the Netherlands, 22-24 March 2012.
- Presentation IEA Bioenergy Task42 at the European Expert Forum on Biorefineries, Budapest, Hungary, 12/13 April 2011.
- Towards a Common Approach for Comparing Biorefinery Systems to Conventional Systems – Findings of IEA Bioenergy Task 42 “Biorefineries”, G. Jungmeier, Joanneum Research, Graz, Austria, N. S. Bentz, H. Jörgensen, I. Skiadas (Denmark); M. Mandl, F. Cherubini (Austria); R. Van Ree, E. de Jong (The Netherlands); M. Dohy (France); P. Walsh (Ireland); M. Wellisch (Canada); T. Wilke, (Germany), 18th European Biomass Conference, Lyon/France, May 3 – 7, 2010.
- Biorefinery Driven Biorefinery Systems – Classification, Biorefinery Index and Sustainability Assessment, G. Jungmeier, Bioenergy Australia 2011, November 23 - 25, Queensland, Australia.
- Classification of Biorefinery - Examples for Bioenergy Driven Biorefineries, M. Hingsamer, G. Jungmeier, Finish Biorefinery Training School, 26, November 2012, Joennsuu, Finland.

Deliverables (conference papers, seminar proceedings, technical notes, newsletters, Industry Days, scientific publications, books, etc.), including website address or reference of the publication
- A printed version of a glossary IEA Bioenergy Task42 Biorefinery Brochure, including: biorefinery definition, biorefinery classification system, biorefinery mapping data, and examples of both running biorefineries and biorefineries has been made available both as hardcopy and electronically via the Task-website at the start of 2010.
- National Country Reports have been prepared by Australia, Austria, Denmark, France, Germany, Italy, the Netherlands, Turkey, the UK, and the U.S.
- A Summarising Countries Report has been prepared by the University of Copenhagen
- Biofuel-driven Biorefineries: A selection of the most promising biorefinery concepts to produce large volumes of road transportation biofuels by 2025, Task42-report, February 2013.

All deliverables can be found for downloading at the Task42 website: www.iea-bioenergy.task42-biorefineries.com
A deliverable that is still in progress is the preparation of the glossy information brochure “Adding value to the Sustainable Utilisation of Biomass at a Global Scale – BIOEFINING”. This paper will include all relevant Task42 results of the last 6 years (2007-2012) showing the economic, ecological and social advantages of co-production of Bioenergy and Bio-based Products for sustainable biomass use in a future BioEconomy.

Co-ordination with other Tasks within IEA Bioenergy
- Conference Advanced Biofuels – Sustainable Production using the Biorefinery Approach, Copenhagen, Denmark, 27-29 February 2012; co-operation University of Copenhagen, Task 39 and Task42.
- Contribution to set-up strategic fund joint Tasks project “Sustainable bioenergy supply chains”. Coordination: Task43; participation Tasks: 42, 40, 39, 38, and 29. This project will be executed in 2013 and 2014.
- Contribution to the set-up of a joint Task activity with Task40 on “Future market demand for biomass from the broader BioEconomy Perspective”. Coordination: Task40, Task42 will bring in specific expertise on (types of) biorefineries.

Co-ordination with other bodies outside of IEA Bioenergy, e.g. other Implementing Agreements; and other organisations – FAO
- Mr. Shoji Yamaguchi (Mitsubishi Chemical Corporation), as co-leader of the International Council of Chemical Association (ICCA), participated in the Task42 meeting in Tortona, Italy, 4-6 April 2011.

Industry participation: How was the industry involved in the Task activities? How did it influence the work carried out by the Task? Which industries participated and what activities did they participate in?
The industry was involved in Task42 by participation in the bi-annual industrial stakeholder meetings and by providing data on both running commercial, demo and pilot biorefinery plants for the assessment work and reports delivered.