Biotechnology for sustainable use of bio-resources:

biorefining in the EU, the US and China

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INTRODUCTION

Global challenges such as limited of resources and climate change mobilize us to search for solutions. Biotechnology is among the key enabling technologies we look to as a possible provider of such solutions. The application of biotechnology in the agro-food sector or so called “green biotechnology” is expected to help increase yields, develop new resistant crop varieties or plants that can grow on marginal lands, provide ways for reducing the use of pesticides and other chemicals in agriculture, and to improve our diets. Besides these direct impacts, the new agricultural methods such as no till or lower application of chemicals would also have positive environmental and climate effects.

The application of biotechnology in the industrial production and in the environmental sector, known as white biotechnology, has the ultimate goals of shifting production to renewable biological raw materials, improving the efficiency of industrial processes, reducing the negative environmental impacts, and remediating polluted environments. Industrial or white biotechnology uses enzymes and micro-organisms to make biobased products in a wide variety of sectors: chemicals, food and feed, healthcare, detergents, paper and pulp, textiles and energy. Biotechnologies can be used and combined with other technologies in the existing industries or in specific biomass based refineries, i.e. biorefineries. Agricultural products, biomass, and organic waste, including food processing waste and effluents are transformed into other substances in the same way as crude oil is used as a feedstock in the production of chemicals. (OECD 2011, page 8).

A strong boost for improved utilization of biological raw materials came from biofuel’s mandatory targets established in the US and in the EU and the steady investments made in Brazil in this sector. According to the International Energy Agency the global production of biofuels has been growing steadily over the last decade from 16 billion liters in 2000 to more than 100 billion liters in 2011. Today biofuels provide around 3% of global road transport fuel, while Brazil, met nearly 23% of its road transport fuel demand in 2009 with biofuels. The rapid development of the biofuel sector creates a basis for increasing the biomass use in related processing industries such as chemicals and various materials industries.

This paper is inspired by the proposal of some 30-40 European companies and industry associations to the European Commission for establishing a public-private partnership for sustainable biomass conversion**.** This initiative, Biobased and Renewable Industries for Development and Growth in Europe (BRIDGE), is currently under scrutiny and discussion.

The aim of this working paper is to compare the competitive position of the European Union and the United States on the background of rapidly growing China in one of the key enabling technologies of future growth – biotechnology, notably industrial biotechnology. The paper is based on a desk-top review of the recent literature and presents updated figures and examples on the trends, notably as to the emergence of biorefineries in Europe, China and in the US. Emphasis will be given to the public policies and overall competitive situation, not to the technical details of individual technologies.

DEVELOPMENT OF BIOTECHNOLOGY

From a small set of technologies available in laboratories some 40 years ago, biotechnology has developed into a broad field of applications in pharmaceutical, medical, agriculture, food, chemical, environmental, and wood processing industries. Biotechnology covers a very heterogeneous range of sectors that makes the comparison of a country's competitive position difficult. The situation is further aggravated by the fact that the statistical offices do not collect data on biotechnology and therefore one has to often use indirect methods or specific surveys for assessment. Below I have used the latest data from the OECD in order to establish some general trends.

Unfortunately, the OECD data on biotechnology does not cover all the EU Member States; therefore the figures in Tables 1 and 2 are underestimates. Furthermore, the definition of a biotechnology firm itself seems somewhat open-ended, which explains why the OECD and Ernst and Young (Table 3) arrive at significantly differing figures as to the number of such firms. One reason for these differences might be the fact that Ernst and Young mostly focus on research-intensive pharmaceutical and medical sector firms.

Even though there are no statistics available on the number of companies involved in industrial biotechnology (which is the main fields of interest of this paper) it would be beneficial to establish some facts about the market size and trends. Industrial biotechnology has been utilized for decades in the production of biofuels, biochemicals for pharmaceuticals markets, food and feed, fine chemicals, detergents, and hygiene products. Bioethanol production has been increasing rapidly with world-wide annual growth rates above 10%. Since 2008, the US is the leading bioethanol producer, leaving Brazil in second place. Europe is lagging behind in these developments because of the very strong public objection to converting food crops to fuel, among other reasons. This is one of the reasons why Europe is now mobilizing efforts on the "second generation" (non-food) biofuels and biomaterials.

Biopolymers are emerging products with a broad range of applications. The value of biochemicals (other than pharmaceuticals) could increase from 1.8% of all chemical production in 2005 to between 12 – 20% by 2015. For decades, plastics from fossil fuels have grown faster than any other type of bulk chemicals. By 2100 an estimated 1 billion tons annual plastics would consume some 25% of current oil production. Biobased plastics are attractive in terms of using alternative raw materials, but also due to emissions and energy savings. A significant growth in the biobased polymers sector is expected from the development of new polymers with new properties, from continuous regulatory pressure to reduce carbon footprints and, from increased economic incentives to use renewable biological raw materials. (OECD, 2011). The bioplastics company representatives suggest that the bioplastics sector is growing at least 20% per year. (Goodall, 2011).

Sales of bio-based products in Europe in 2007 amounted to €48b or 3.5% of total chemical sales. By 2017, the sales are estimated to be €340b, totaling 15.4% of all chemical sales. (EuropaBio, 2012).

Table nr 1: Number of biotech firms. Data from 2011 or latest available

	Biotechnology firms	Dedicated biotech firms	Share of dedicated or dedicated R&D firms
United States	6213	2370	Dedicated R&D 38%
EU 18	6323	3410	Dedicated and R&D 54%

Table 1 is based on OECD 2012 Key Biotech Indicators. EU figure contains data from 18 Member States, but does not include Hungary, Bulgaria, Romania, Latvia, Lithuania, Luxemburg, Malta, Greece and Cyprus. For the Netherlands and Sweden only firms with 10 or more employees are included. The data for Slovenia is provisional. Therefore the actual EU27 figure would be higher.

Biotechnology firm is a firm that uses biotechnology to produce goods or services and/or to perform biotechnology R&D. These firms are captured by biotechnology firms' surveys.

Dedicated biotechnology firm is a firm whose predominant activity involved the application of biotechnology techniques to produce goods or services and/or to perform biotechnology R&D. These firms are captured by biotechnology firms surveys.

Dedicated biotechnology R&D firms devote 75% or more of their total R&D to biotechnology R&D. These firms are captured by R&D surveys.

Being fully aware of the shortcomings of the data, we can still generate some assessments:

- The number of the companies applying biotechnology in production or being fully dedicated to biotechnology research and innovation is higher in the EU than in the US.
- The share of dedicated R&D companies among the general firms using biotechnology varies a lot in Europe from 34% in Poland to 81% in Germany. It is, however, still likely that the average share of dedicated biotechnology R&D firms is higher in Europe than in the US.
- The business sector funding of biotechnology R&D is significantly higher in the US than in Europe. In 2011, private sector firms in the US spent $17-22 billion on R&D. Since the majority of this research takes place in dedicated biotechnology firms, we can deduce that a US biotechnology company had $9.2 million at their disposal for R&D compared to $2.4 million available for a European firm. (The OECD and the Ernst & Young data agree on this average for R&D funding per company)

Table nr 2: Funding for biotechnology research. Data from 2011 or latest available

In millions USD PPP	R&D expenditures in the business sector	R&D expenditures in the government sector
US	22030	
EU17	8219	
EU12		8502

Notes to Table 2. Table 2 is based on OECD 2012 Key Biotech Indicators. EU17 figure does not include the UK, Hungary, Bulgaria, Romania, Latvia, Lithuania, Luxemburg, Malta, Greece and Cyprus. EU12 figure includes Germany, Spain, Poland, Denmark, Italy, Czech Republic, Finland, the Netherlands, Ireland, Portugal, Slovak Republic and Slovenia. In both cases, for the Netherlands and Sweden only firms with 10 or more employees are included. The data for Slovenia is provisional. The actual EU27 figures would be higher.

The shortage of research and innovation funding in Europe is somewhat offset by public sector efforts. Again, the available data is unfortunately rather patchy. OECD data (Table 2) seems to suggest that the public sector support for biotechnology R&D in Europe actually exceeds the expenditures by private firms. This is consistent with the general R&D funding trends in Europe where the public sector provided 2.03% and the private sector 1.27% of GDP in 2011.

Table nr 3: Overview of the US biotechnology sector by Ernst & Young

US biotechnology at a glance, 2010-11 (US$b)

	2011	2010	% change	% change (normalized for large acquisitions)
Public company data				
Revenues	58.8	61.1	-4%	12%
R&D expense	17.2	17.2	0%	9%
Net income	3.3	5.2	-36%	-21%
Market capitalization	278.0	292.1	-5%	4%
Number of employees	98,560	113,010	-13%	5%
Financings				
Capital raised by public companies	25.4	17.1	49%	49%
Number of IPOs	10	15	-33%	-33%
Capital raised by private companies	4.4	4.4	-1%	-1%
Number of companies				
Public companies	318	320	-1%	0%
Private companies	1,552	1,594	-3%	-3%
Public and private companies	1,870	1,914	-2%	-2%

Source: Ernst & Young and company financial statement data.
Numbers may appear inconsistent because of rounding.

The 2011 Biotechnology Innovation Watch report by Technopolis Group (Table nr 4) generates some interesting new information:

- The report deals with dedicated biotechnology firms where the average R&D expenditure makes up 64% of the annual turnover;
- 9 out of 10 such companies have received public funding from the local, national, or EU level whereas in most cases such funding is combined. 100% of large companies had received public funding compared to 89 % of small companies.
- The biotech firms in Central and Eastern Europe receive significantly less support than their counterparts in Western, Northern, and Southern Europe. Public funding from local

sources is almost non-existent, funding from central government is lower, and the general EU support reaches only 24% of Central and Eastern European firms compared to 50% in Southern Europe.

- The penetration rate (63%) of the EU research and technological development funding is high. Large companies and companies located in Western and Northern Europe have been the most successful in obtaining funding from 5th and 6th framework programs.

Table nr 4: Engagement in R&D and R&D funding of firms

R&D activities and funding all in % of total	Country group			Firm size			All firms
	Central & East	West & North	South	Small	Medium	Large	
Total R&D expenditure/ Total turnover in 2004	38	64	79	62	64	82	64
Any public funding	73	100	89	89	90	100	90
Public funding from local or regional authorities	5	44	65	44	39	53	43
Public funding from central government	50	67	68	61	66	77	64
Public funding from the EU	24	42	50	33	48	82	41
Funding from EU's 5th or 6th framework program	41	79	61	53	72	94	63

Adapted from Enzing, C. (Technopolis Group). December 2011. Sectoral Innovation Watch

It might, however, be premature for the DG RTD biotech team to congratulate themselves for this success. First of all, the report talks only about the number of companies that have gained funding, but does not tell us anything about the sufficiency or efficacy of funding. Secondly, if the number of dedicated biotechnology companies in Europe remains stagnant, this may cause problems with the absorption capacity of the EU funding. Thirdly, we also need to be vigilant about establishing research priorities based not on the views of yesterday, but the opportunities of tomorrow. As presented in Figure 1, this is a real risk.

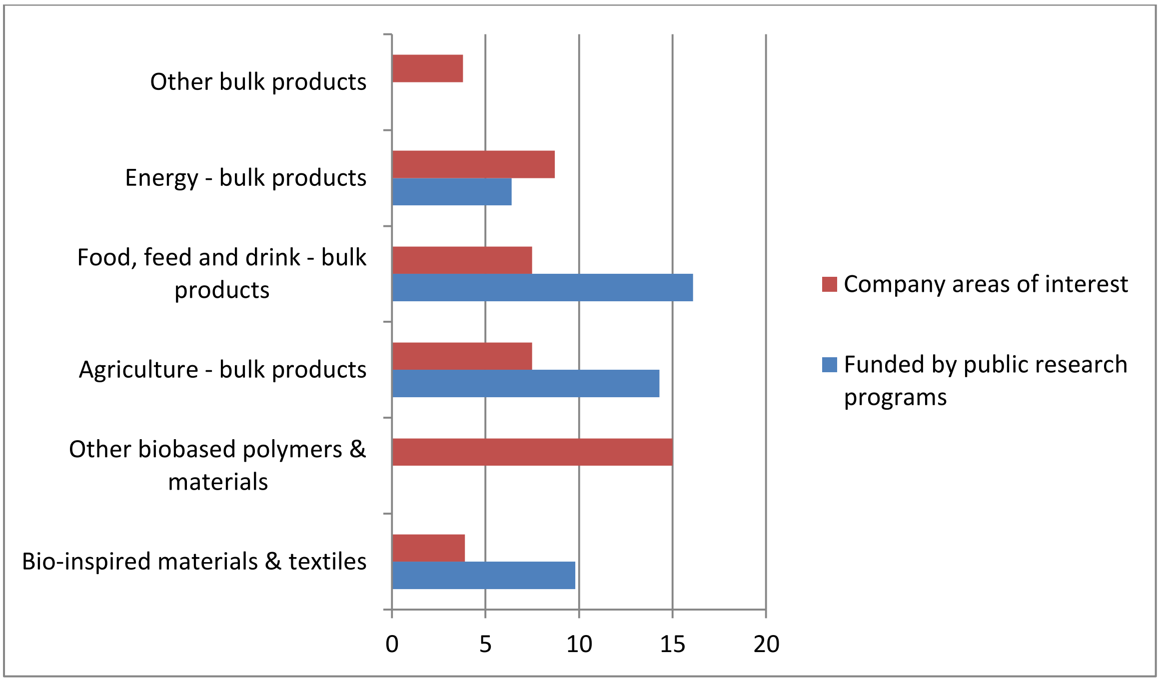
Figure 1 is based on a survey organized by the Industrial Biotechnology European Research Area Network (ERA-IB Net) where the member companies compared the available research funding with their actual needs. The message from this survey is clear:

- Public research funding for bulk agricultural products and for food and feed industries exceeds the needs of these sectors.
- Bio-based polymers and materials seem to remain off the radar of public funding. Bio-inspired materials and textiles receive much less compared to their needs.

The OECD 2011 overview of the Industrial Biotechnology development arrives at a similar conclusion, stating that there is a serious mismatch between the level of investment in industrial biotechnology R&D and the potential market opportunities for the sector. Only 2% of private biotechnology R&D went to industrial biotech in 2003, while the OECD expects industrial biotechnology will contribute up to 39% of the gross value added in 2030. The latter figure excludes the share of biofuels, which will clearly contribute substantially to the gross value added. The OECD therefore acknowledges the pressing need to boost research in industrial biotechnologies and invites both the public and private sectors to increase their investments, to establish public-private partnerships, and to reduce regulatory burdens for bringing new products into markets.

The European Industry association EuropaBio specifies in their 2012 report: “The right policies and incentives for R&D development are essential to growth in this industry… One of the key challenges faced by industrial biotechnology companies, who are often still in the early and start-up phase, is access to finance…funding for pilot and demonstration plants is crucial to bridge the gap from research to commercialization.”

Figure nr 1: Comparison of research areas of interest between firms and national public sector funding



Source: www.era-ib.net and OECD. 2011. Industrial Biotechnology and Climate Change. Opportunities and Challenges.

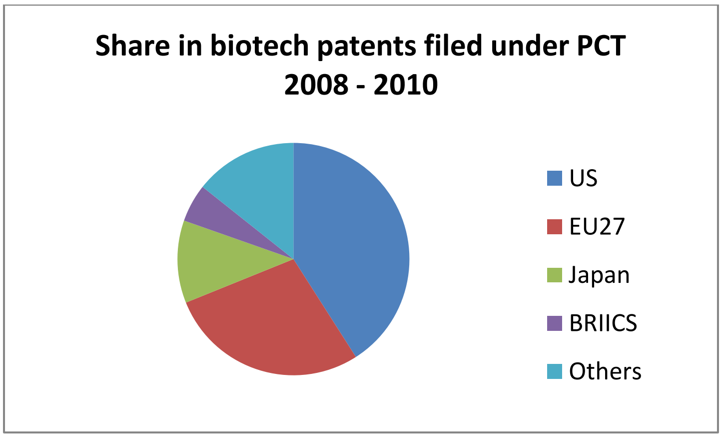
When we further analyze the outcomes of research and innovation, it is good to note that 66% of dedicated biotechnology firms report having actually innovated during the observed timeframe. Contrary to what we often hear, according to the Biotechnology Innovation Watch the large firms have introduced more innovations than the small firms (Table nr 5). The companies in Western and Northern Europe have been more successful in innovation. The latter may also reflect the availability of funding as discussed above. The biotechnology companies are active not only in product innovation, but pursue innovation in services or production methods with almost the same vigor as the share of companies reporting having innovated in the respective fields (46% versus 44% versus 41%).

Table nr 5: Innovation activities in European biotechnology firms

Innovative activity all in % of total number of firms	Country group			Firm size			All firms
	Central & East	West & North	South	Small	Medium	Large	
Overall innovation activity	52	77	61	61	77	91	66
Introduced onto the market new or significantly improved good	34	62	32	41	54	72	46
Introduced onto the market new or significantly improved service	26	57	36	40	48	70	44
Introduced onto the market new or significantly improved production method	38	46	35	36	47	75	41

Adapted from Enzing, C. (Technopolis Group). December 2011. Sectoral Innovation Watch. The underlying CIS4 data has been obtained directly at the premises of the Eurostat Safe Centre in Luxembourg. Due to reasons of anonymity, data availability and data protection policies at Eurostat, the data sets are limited. Overall such data is mostly suitable for comparative analysis between firms from different country groups and different size classes.

Figure nr 2: Share in biotechnology patents filed under PCT 2008 - 2010



Source: OECD. December 2012. Key Biotech Indicators. Last updated in December 2012

Another standard way of measuring the outcome of research and innovation is to look at the number of patent applications. Here the US, with 41% of total patent applications between 2008-2010, is a clear leader. 28% of the patent applications came from the European Union, 11 % from Japan, and more than 5 % from the BRICS countries (Figure 2).
Patenting in Europe has been significantly more expensive than in the US. With the recent agreement between 25 Member States to create a European Community Patent, a great step forward has been taken in speeding up the process and in reducing its costs. The first Community patents are expected to be issued in 2014.

SUSTAINABLE SUPPLY OF BIOMASS

When analyzing the potential of replacing fossil resources with biological renewable raw materials, the biomass availability in a sustainable and economically feasible way becomes crucial. Just as is the case for biotechnology, the data for biomass and bio-waste are also fragmented and the estimates vary significantly.

The International Energy Agency defines biomass as follows: "Biomass is any organic, *i.e.* decomposing, matter derived from plants or animals available on a renewable basis. Biomass includes wood and agricultural crops, herbaceous and woody energy crops, municipal organic wastes as well as manure."

One of the most recent estimates of sustainable biomass supply in the EU comes from the Biomass Futures project which primarily assesses the role of bioenergy in meeting Europe's renewable energy targets. The project has utilized the Member States' National Renewable Energy Actions Plans (NREAP) to extract the biomass and bio-waste estimates. Biomass Futures project has then done modeling work on the supply of different biomass sources under two different scenarios: 1) a Reference scenario based on current sustainability criteria for biomass and biofuels; 2) a Sustainability scenario anticipating stricter sustainability criteria applied to all bioenergy feedstock, including solid and gaseous bioenergy. The results are presented in Table 6.

The present EU biomass supply is estimated at 314 MTOE. The amounts indicated in Table 6 for additional harvestable roundwood and specific perennial crops under the current supply should be seen as potential since these categories are not currently utilized. As to roundwood and partially also other forestry biomass, one has to keep in mind that these resources are used for other competing purposes and would normally not be available for conversion into biofuels or biomaterials.

Both scenarios anticipate an increased supply of specific perennial crops and better use of waste as well as forestry residues. The Reference scenario arrives at a potential biomass supply worth of 429 MTOE in 2020, while the Sustainability scenario leads to a reduction of the domestic supply by about 13 % and gives 375 MTOE as the potential available biomass in Europe. In the Sustainability scenario the biomass available at a lower price becomes more limited. In the reference scenario there are 300 MTOE biomass available at a price of a maximum 250 euros per TOE, while in the Sustainability scenario the supply at this price drops to 270 MTOE.

Table nr 6: Biomass supply in Europe in MTOE (million tons oil equivalent)

Category	Current supply	Reference scenario 2020	Sustainability scenario 2020	Expected demand for energy sector 2020	Energy demand/ reference supply
Wastes	42	36	36	24	84%
Agricultural residues	89	106	106	17	16%
Rotational crops	9	17	0	9	71%
Perennial crops	0	58	52	23	40%
Landscape care wood	9	15	11	9	100%
Roundwood production	57	56	56	0	0%
Additional harvestable roundwood	41	38	35	0	0%
Primary forestry residues	20	41	19	32	77%
Secondary forestry residues	14	15	15	11	73%
Tertiary forestry residues	32	45	45	31	56%
Total	**314**	**429**	**375**	**155**	**37%**

Source: Adapted from the Biomass Futures project www.biomassfutures.eu

The expected demand for energy and biofuels use in 2020 is derived from the National Renewable Energy Action Plans and assumes the use for electricity and heat whereas biofuels share is projected at 9%. The model also compares the biomass raw material cost against fossil fuels and assumes that the economic agents would search for least expensive raw materials which may also be imported. These imports mostly consist of wood pellets, feedstocks for biofuel production, and biofuels.

The results of the Biomass Futures project indicate that the National Renewable Energy Plans underway in the Member States would not lead to optimal utilization of the available domestic biomass. In fact, even if we exclude fully the additional harvestable wood resources, the projected utilization of biomass supply would be only 37%. It is important to remember that these estimations look only at the energy and fuel use and do not include the raw material needs of processing industries. The national renewable energy plans also foresee imports of either cheap biomass or biofuels from other regions which will amount to approximately 46 MTOE.

It is interesting to note that under the Sustainability Scenario the Biomass Futures project foresees a sharp increase in production of 2nd generation biofuels and elimination of biofuels from European rotational food crops.

The estimations of the Biomass Futures project fall well in the range of earlier studies. In a 2006 study, European Environmental Agency (EEA) estimated the EU primary energy requirement to be 1.8 billion tons oil equivalent (TOE) in 2020 and projected biomass to be able to contribute with 13 % or 236 million TOE, compared to 69 million TOE actually provided in 2003. An almost identical projection is reproduced in the European Commission's Impact Assessment of the Renewable Energy Roadmap where the former scenario results in a biomass potential of 230 million TOE, the latter being 195 million TOE.

The European Commission Directorate General for Agriculture and Rural Development recognizes the crucial role agriculture is going to play in the future of sustainable provision of biomass both from fields as well as from forests. Through their policies, the EU supports biomass supply for bioenergy and biofuels, but so far unfortunately the other uses of biomass such as biomaterials are out of the scope of agricultural or rural measures. In the short to medium run, available but partly unused biomass potential from waste, forestry, and residues can readily be tapped into. In the longer run, the genuine growth in biomass potential will have to come from agriculture.

Wood to biodiesel in Finland

UPM will invest 150 MEUR to the first biorefinery in the world producing wood based advanced biofuels. UPM's biorefinery will have a production capacity of 100 000 tons per year and it will be located in Lappenranta, Finland. This is equal to 120 million liters of biofuels. The main product is advanced biodiesel. The investment decision was made in February 1, 2012, construction started in summer 2012, and production will begin in 2014.

Besides the better utilization of residues, the biomass market development should increasingly favor growing perennial grasses, short rotation forestry, and short rotation coppice. The European Biomass Association (AEBIOM) estimated the EU area at below 0.1 million ha in 2007 and expects about 2 million ha in 2020. Also, much more forest biomass could be harvested. Recent projections for 2030 quantify the sustainably realizable potential of wood for energy from EU forests as high as 675 million cubic meters (146 million TOE) per year, provided intensive wood mobilization efforts are applied. Only 60–70 % of the annual increment of EU forests is harvested. At present, about 42 % of the harvest is eventually used for energy; residues from higher value processing have a significant share. (DG AGRI, 2013).

Domestically available biomass could satisfy a much larger share of Europe's energy needs as well as to provide raw material to processing industry. More than half of the oil that Europe currently consumes could be replaced by biomass derived products (Table 7). However, not all of the domestic supply would be available at competitive price ranges (165 – 350 euros/TOE) without further investments in more efficient logistics and integration of the residue use in the primary forestry and agriculture sector activities.

A Bloomberg 2011 study arrived at a similar conclusion that up to half of the EU €40bn annual crude energy bill could be used for sourcing domestic biofuel if the necessary refining facilities and supply chains were put in place. However, raw material price matters. The biofuels industry consensus suggests biorefinery gate prices for agricultural residues in the next decade to be between 50 and 100 euros per dry ton.

Table nr 7: Share of biomass in Europe's total energy balance in MTOE

	Current level	Projections 2020
Total energy consumption 2009	1155	
Including oil products	*500*	
Including biofuel and waste	*71*	
Domestic biomass availability	314	429
MSs estimated utilization		155
Imported biomass/ biofuel		46

Source: International Energy Agency and Biomass Futures project

Furthermore, this underutilization of biological renewable resources is also largely due to the pre-commercial stage of technology for efficient conversion of wastes and various lingo-cellulosic materials. Additional difficulties arise from the lack of logistical supply chains of biomass and the first level processing facilities. In the following we will look into these issues and discuss how bio-refining could gradually and partially replace or complement oil-refining.

DEVELOPMENT OF BIOREFINING

Using biomass to replace fossil fuels as well as using biotechnological processes in the processing industry can bring various environmental and climate benefits such as reduced GHG emissions and other pollutants to water, air, and soil. The literature also refers to reduction in waste and to economies in energy and water consumption. The full climate change mitigation potential of industrial biotechnology ranges between 1 billion and 2.5 billion tons of CO_2 per year by 2030. (WWF, 2009).

The conversion of biomass into various product streams and the integration of biotechnologies with other technologies cover a wide range of industrial realities. The widely accepted definition for biorefining and biorefineries comes again from the International Energy Agency (IEA): "Biorefining is the sustainable processing of biomass into a spectrum of marketable products and energy".

“The Joint European Biorefinery Vision for 2030” which was created in collaboration with 5 European Technology Platforms specifies this definition further:

- Biorefinery: covering basic concepts, the facilities themselves, processes, and cluster formation
- Sustainable: encompasses maximizing economic efficiency, minimizing environmental impact, fossil fuel replacement, and also takes account of socio-economic aspects
- Processing: upstream processing, transformation, fractionation, thermo-chemical and/or biochemical conversion, extraction, separation, and downstream processing are all included
- Biomass: comprises crops, organic waste, agricultural and forestry waste, wood, and aquatic biomass
- Marketable: describes a product for which a market with quality, volume and price (acceptable to consumers) already exists or is expected to be developed in the near future
- Products: includes both intermediates and final products, i.e. food, feed, materials, and chemicals (specialties, commodities and platform molecules)
- Energy: fuels (liquid, gas and solid), power, and heat.

Table nr 8: Support estimates for biofuels in 2006

Total support estimates				
	Ethanol		Biodiesel	
	Total support estimate in Billions of $	Variable share in %	Total support estimate in Billions of $	Variable share in %
US	5.8	93	0.53	89
EU25	1.6	98	3.1	90
Approximate average and variable rates of support per liter of biofuels				
	Average	US$/ liter	Average	US$/liter
US	0.28	Federal 0.15, States 0.00-0.26	0.55	Federal 0.26, States 0.00 -0.26
EU25	1.00	0.00 – 0.90	0.70	0.00 – 0.50

Source: adapted from FAO. 2008. Biofuels: prospects, risks and opportunities

The variable share depends on the level of production or consumption and includes market-price support, production payments or tax credits, fuel-excise tax credits and subsidies to variable inputs. The EU average biofuels support refers to support by the Member States.

A crucial step in developing this industry is establishing integrated biorefineries that could convert various feedstocks simultaneously into affordable biofuels, energy, and wide range of biochemicals and biomaterials. This broad product range would help optimize the use of biological raw material and improve overall process economics. However, to arrive at such commercially viable biorefineries, significant technology development and large financial investments are needed.

Emerging biofuel industries enjoy government support worldwide as specific subsidies, mandates, adjustments to fuel taxes and, incentives for the use of flex-fuel vehicles have been made available. Several countries are now developing extra incentives for second generation biofuels. In stark contrast to biofuels, other biobased products suffer from a lack of tax incentives, subsidies, or other supporting regulations. In Table 8 the level of support for biofuel policies is presented. While it helps to create market and supply chains for other biomaterials, it also makes the emergence of the other uses difficult due to competition on feedstocks, subsidies, and finance.

The International Energy Agency estimates that about half of the estimated biofuel demand by 2030 could come from agricultural and forest residues, but this requires intensive RD&D efforts over the next 10 – 15 years. Due to the high skill and capital requirements the OECD countries along with Brazil and China and possibly India would be making the move. China and India could produce about 19% of the future second generation biofuels. (IEA, 2010)

BIOREFINING IN CHINA

A pilot phase for biobased ethanol was introduced in China during 2000 – 2005. This included building 4 large bioethanol plants with a total capacity of over 1 million tons of ethanol per year. These plants use corn as feedstock. Fiscal subsidies, a VAT refund, and income tax exemption were offered to the bioethanol producers. Petrochina and Sinopec were tasked to blend bioethanol with gasoline. As a consequence, the domestic bioethanol production picked up rapidly in China and reached some 1.7 million tons by 2011, covering reportedly 20% of gasoline consumption in the 9 provinces where they are available.
In 2006, the main large bioethanol production plants in China were (from Tan, 2008):

1. Huaren Group in Heilongjiang Province, Corn-based, 400,000t/y,
2. Jilin Province in North-East China, Corn-based, 400,000t/y,
3. Tianguan Group in Henan Province, Corn-based, 400,000t/y,
4. Fengyuan Group in Anhui Province, Corn-based, 440,000t/y,
5. Zhongliang Group in Guangxi Province, COFCO Cassava-based plant 1000,000t/y.

China's biofuel and biomaterial industry is still in its initial stage. The current level of production of 1.7 million tons of biofuel is mostly derived from food crops which the government has now prohibited as feedstock. But the 18th Party Congress has made green development key to China's future. Among other initiatives the 12th Five-Year Plan has set biofuel targets: 4 million tons of ethanol and 10 million tons of biodiesel by 2020. Fully flexible and integrated biorefineries have been identified as a priority, which means that public and private investments are likely to follow soon (WEF, 2012).

Following the initial focus on biofuels only, the programs have been enlarged to biobased chemicals and there are now numerous incentives for producers and a preferential tax treatment for selected firms in emerging biochemical industries in place. Since 2005 a specific program promotes production and consumption of biodegradable plastics. In 2007 there were 9 companies producing L-lactic acid for biomaterials (PLA) with the annual total output of close to 85 thousand tons. Pilot and demonstration plants for other biochemicals are also in operation.

The question of feedstocks is particularly problematic in China which has only 0.092 ha of arable land per capita compared to roughly 2 ha in Brazil or close to 1 ha in the US. Using non-arable lands in regions such as Inner Mongolia for energy crops as well as bio-wastes from cities and industries, and agricultural and forestry residues are being explored.

Chempolis, Henan Yinge joint venture for new biorefinery in China

Chempolis Ltd from Finland and Henan Yinge Industrial Investment have in 2011 established a joint venture in Luohe, Henan province, to construct a biorefinery producing 160 000 tons of non-wood papermaking fibers and biochemicals.

The biorefinery will utilize the Chempolis formicofib technology using wheat straw as raw material. Total project investment will be $40 million, of which Chemopolis will invest 25 percent. Chempolis' formicofib converts non-wood raw materials into papermaking fiber for paper and board, packaging, and hygiene products; while formicobio processes non-food raw materials into cellulosic ethanol.

Chempolis has also signed a license and EPC agreement with Tianjin Jiuqian Paper Co Ltd. to supply three formico® biorefineries, each capable of producing 100,000 t/a of bleached wheat straw pulp. The new plants are scheduled to start up in 2012-2013.

Due to the new policy of shifting away from food crops as feedstock, there are several pilot and demonstration plants now in operation or being constructed for 2nd generation biofuels and materials. The above mentioned corn ethanol plants are also experimenting with cellulosic feedstock (Heilongjiang and Tianguan) such as wheat straw, corn cobs, and rice bran. According to the World Economic Forum Platform for Biorefineries *Biotechnology and Bioenergy* report from the December 2012 Beijing meeting, China has the most bioethanol pilot plants in the world testing various technologies for 2nd generation fuels and materials. Large state-owned enterprises such as China National Petroleum Corporation (CNPC) have taken a leading role in developing biorefineries. CNPC has already established a 200,000-ton bioethanol project and is committed to building the first 60,000-ton aviation biofuel facility by 2014. Foreign investments and technologies are also moving in from the US, the EU, and Brazil.

BIOREFINING IN EUROPE

In the European Union several Union level policies influence the development of biorefineries: the renewable energy policy establishes mandatory biofuels targets, the common agriculture and rural development policy supports provision of biomass, regional and cohesion funds can support construction of necessary infrastructure and facilities, and the research and innovation policy devotes funds to technology development.

The central piece of legislation is the Renewable Energy Directive 2009/28/EC. It sets ambitious binding targets for all Member States such that the EU will reach a 20% share of renewable energy by 2020. For the transport sector, it sets a specific minimum 10% target for each Member State. The Directive also establishes a comprehensive sustainability scheme for biofuels. The Directive requires Member States to plan their development of each type of renewable energy, including bioenergy, by designing National Renewable Energy Action Plans. In addition to the general EU bioenergy/ biofuel policy, Member States have introduced their own incentives and subsidy schemes.

The Common Agricultural Policy (CAP) encourages, through its rural development measures, the supply of bioenergy from agriculture and forestry and the use of bioenergy on farms and in rural areas. Direct payments to farmers have been fully decoupled from production and are granted to farmers — regardless of what they grow and for what purpose (food, feed, energy, material) — provided they comply with the cross-compliance scheme.

In order to enable farmers to respond even better to changing market requirements, the latest revision of the CAP, called "Health Check", has abolished the energy crop premium and the set-aside scheme. Thus, specific aids for growing (annual) energy crops no longer exist. The rural development policy provides a variety of measures with which the Member States can support bioenergy production and consumption.

As to the research and innovation funding, it is important to note that only about 5% of funding is allocated at the EU level. The majority of research funding is still done by the Member States. The EU 7th Framework Program for Research and Technological Development devoted about €1.8bn to research on agriculture, food and biotechnology over the period 2007 – 2013. Various collaborative projects on biorefining were funded among others. Some relevant examples include the following.

SUPRABIO is one of four research projects developing biorefinery technology that is funded under the European Commission’s Sustainable Biorefineries Call. Its sister projects are EuroBioRef, BIOCORE, and Star-Colibri. The biorefinery projects co-operated and liaised with the aim to harmonize procedures for multi-criteria sustainability analyses, harmonize biomass characterization protocols, and explore opportunities to organize common training and education activities. The budget is €19m of which more than €12m comes from EU budget.

The Star-COLIBRI project is a Coordination and Support Action aimed at overcoming fragmentation and promoting cross-fertilization in the area of biorefineries research. It received ca €2 m from the EU budget. Website: www.star-colibri.eu.

The EUROBIOREF project targets research, testing, optimization, and demonstration of bio-refinery processes with the dual aim to use all fractions of various biomasses and exploit their potential to produce the highest possible value in an eco-efficient and sustainable way. It received €23.1m as part of the total budget of €37.4m. Website: www.eurobioref.org.

The BIOCORE project (*Biocommodity refinery*) with total budget of €20.3m (€14m from the EU) will conceive and analyze the industrial feasibility of a biorefinery that will allow the conversion of a variety of non-food biomass, including cereal by-products (straws etc.), forestry residues and short rotation woody crops, into 2nd generation biofuels, chemicals, and polymers. Through pilot scaling testing of certain technologies, BIOCORE will be able to demonstrate the industrial feasibility of biorefining under market-like conditions. Website: www.biocore-europe.org.

One example of national level initiatives would be biorefinery research center in Leuna, Germany where processes are developed to enable the extraction of basic chemicals from biomass for eventual use in industry. This involves the combination of both chemical and biotechnological methods. A total of €53 million has been invested in this German flagship project, which is now available for use for researchers in both academia and industry.

The European biorefineries are currently in their initial stage. According to one report there are 93 biorefineries in Europe of various types using cereals, oilseed, wood, waste, or green and dry agricultural biomass. More than half are produce biofuels (Enzing, 2011). This figure is still rather modest, notably when compared to the market penetration of some more established and cheaper technologies such as biogas plants. Europe has more than 8,000 biogas plants, many of them in the ranging from 100–500 kW of electrical output. Such installments have often benefitted from the support of either EU rural development or structural funds. In the early years the focus was on electricity and heat generation, but now there is a clear shift towards upgrading biogas (typically 50-60% methane) to almost pure (typically 97%) methane that is completely interchangeable with natural gas. Studies show that a substantial growth in the use of biomethane for transport will occur in the coming years, from the current first steps in some European cities to about 1MTOE in 2020. (Baxter, 2012).

The European Biorefinery vision paper provides a well-informed overview of which types of biorefineries are likely to emerge in which locations within Europe. Biorefineries based on locally produced wood are likely to be developed in Northern Europe or in densely forested rural areas in Western, Central, and Eastern Europe ("Mid-Europe").

Typical agricultural crops such as cereals, sugar beet, oilseeds, and dedicated non-food crops should give rise to biorefineries in the rural areas of Mid-Europe. The commercial biorefineries would range from 50,000-150,000 tons of annual ethanol output, plus other products. To produce one ton of cellulosic ethanol, about 4.5 tons of agricultural residue would be needed, requiring a sufficient collection area in the relative vicinity of the plant. The Bloomberg 2011 study indicates that farmers in Poland could earn some 84 €/ha for wheat straw and in France up to 222 €/ha.

Waste and wood for chemicals in Norway

Borregaard has developed a new technology for the production of green chemicals and sugars based on biomass from wood and agricultural and forestry waste. On April 16, 2013 the biorefinery demonstration plant at Borregaard's production facility in Sarpsborg was inaugurated.

Construction of the demonstration plant has cost just under NOK 140 m, 58 m of which is investment funding from Innovation Norway's Environmental Technology Support Scheme, NOK 19 m from the Research Council of Norway and NOK 35 m from the EU's FP7.

Borregaard is one of the world's most advanced biorefineries. All the components of wood are used in the production of advanced biochemicals that can replace petroleum-based alternatives. Borregaard's specialty cellulose is used in e.g. filters, adhesives and plastics. Lignin, which binds wood fibers together, is the raw material for a range of products used in concrete admixtures, car batteries, and animal feed products. Bioethanol is produced from the sugar in wood and is used in biofuels. Borregaard is the world's only producer of the vanilla flavor vanillin from wood.

If the sustainability and climate policies allow for continued importation of biomass, then large biorefineries based on imported biomass will be established near large ports such as Rotterdam. The development of biorefineries in Southern Europe is more difficult to predict, but they are most likely to develop in rural areas if appropriate dedicated crops are grown.

The European Biorefinery Vision paper further elaborates on the optimal scale of biorefineries: "Scale will have a major impact on the types of industrial biorefinery and their geographical distribution:

- Large-scale integrated biorefineries, mainly based on thermochemical process, are likely to emerge in northern Europe and/or be associated with large ports.
- Small/medium scale integrated biorefineries, mainly based on biotech processes, are likely to emerge in rural areas across Europe.
- Decentralized biorefineries will also emerge in all regions, as a consequence of the development of a network of pre-treatment units.

The world's first commercial-scale cellulosic ethanol plant in Italy

The world's first commercial-scale cellulosic ethanol plant, Beta Renewables in Crescentino Italy, started testing operations at the end of 2012 and has managed to stabilize production in this first-of-its-kind plant in the spring of 2013. Approximately 180,000 tons of dry biomass per year from the surrounding areas will be transported to the plant annually to produce 40,000 tons of ethanol. The main feedstocks are wheat straw and giant reed (Arundo donax). The plant is later aiming at achieving a full capacity of 60,000 metric tons of ethanol per year.

Beta Renewables is a €250m joint venture between M&G and TPG Capital and TPG Biotech. The main owner is Mossi & Ghisolfi (M&G), a $3 billion per year chemical firm that ranks as one of the world's largest PET producers, a polymer used in plastics bottles and multiple other products. The Danish enzyme producer, Novozymes SA, joined the venture in October 2012, investing $115m in cash and acquiring a 10% share in Beta Renewables along with marketing and other intellectual property rights.

Scale also has a major impact on technology choice and industrial strategy. Basically, there are three possibilities:

- Small/medium-sized production facility.
- Medium/large production facility linked to a network of decentralized primary processing plants (biomass fractioning and/or concentrating units). Low cost, de-centralized pre-treatment plants (e.g. fast pyrolysis, torrefaction) combined with centralized biorefineries to improve the overall biomass supply chain. High energy density feedstocks overcome low density biomass problems, can be transported further at an acceptable cost, and can be processed in bigger biorefineries to take advantage of economies of scale.
- Very large production facility, located near a port and using mainly imported biomass."

BIOREFINING IN THE UNITED STATES

There is a wide range of support available in the United States for biomass conversion into biofuels and bioproducts. The following list does not aim at being comprehensive, but rather highlights the most important developments.

In 2009, the US Department of Energy, in cooperation with the US Department of Agriculture, announced the selection of 19 integrated biorefinery projects to receive up to $564 million (average $29.7 million per project) from the **American Recovery and Reinvestment Act** to accelerate the construction and operation of pilot, demonstration, and commercial scale facilities. The projects—in 15 states—were expected to validate refining technologies and help lay the foundation for full commercial-scale development of a biomass industry in the United States. The projects would produce advanced biofuels, biopower, and bioproducts using biomass feedstocks at the pilot, demonstration, and full commercial scale.

Biomass Research and Development Initiative (BRDI) is specifically established to help increase the availability of alternative renewable fuels and biobased products for diversifying the nation's energy resources. Funding is provided through USDA's National Institute of Food and Agriculture (NIFA) and DOE's Biomass Program. Section 9008(e)(3) of the Food Conservation and Energy Act of 2008 provides direction and guidance on the technical areas addressed by the BRDI. Grant recipients are required to contribute a minimum of 20% of matching funds for research and development projects and 50% of matching funds for demonstration projects. Recipients must pursue projects that integrate science and engineering research in three areas: feedstocks development, biofuels and biobased products development, and biofuels development analysis. In 2010, DOE reports having committed over $1 billion to 27 cost-shared biorefinery projects. Table 9 presents the recent allocations from BRDI. Appendices 1 and 2 present an overview of the funded biorefinery projects.

Table nr 9: BRDI funding for research and development in biorefining

	Amount of funding in M$	Number of projects	Average per project M$	Purpose
2010	33			biofuels, bioenergy and high-value biobased products
2011	47	8	5.9	same
2012	41	13	3.2	same

Biomass Crop Assistance Program (BCAP), created by the 2008 Farm Bill, is a primary component of the domestic agriculture, energy, and environmental strategy to reduce U.S. reliance on foreign oil, improve domestic energy security, reduce carbon pollution, and spur rural economic development and job creation. BCAP provides incentives to farmers, ranchers, and forest landowners to establish, cultivate, and harvest biomass for heat, power, bio-based products, and biofuels. Many bioenergy crops need several years to become established. Many bioenergy facilities need several years to reach commercial scale. BCAP serves as a catalyst to unite these dynamics by reducing the financial risk for landowners who decide to grow unconventional crops for these new markets.

With BCAP, crop producers and bioenergy facilities can team together to submit proposals to USDA for selection as a BCAP project area. If selected, crop producers will be eligible for reimbursements of up to 75% of the cost of establishing a bioenergy perennial crop. Producers can receive up to 5 years of annual payments for herbaceous (non-woody) crops (annual or perennial), and up to 15 years of annual payments for woody crops (annual or perennial). Assistance for the collection, harvest, storage, and transportation of crops to facilities will be available to each producer for 2 years in the form of a matching payment for up to $45 per ton of the delivery cost. The BCAP Impact Statement estimates that by 2023, up to $88.5 billion in economic activity and 700,000 jobs could be created.

Farm Bill tax credits and incentives from 2013 Federal budget:

1) **Cellulosic biofuels producer tax credit.** Under current law, facilities producing cellulosic biofuel can claim a $1.01 per gallon production tax credit on fuel produced before the end of 2012. This provision was created in the 2008 Farm Bill. The provision would extend this production tax credit for one additional year, for cellulosic biofuel produced through 2013. The proposal also expands the definition of qualified cellulosic biofuel production to include algae-based fuel. This provision is estimated to cost $59 million over ten years.
2) **Incentives for biodiesel and renewable diesel.** The bill extends for two years, through 2013, the $1.00 per gallon tax credit for biodiesel, as well as the small agri-biodiesel producer credit of 10 cents per gallon. The bill also extends the $1.00 per gallon tax credit for diesel fuel created from biomass through 2013. This provision is estimated to cost $2.181 billion over ten years.
   The biodiesel tax incentive expired on Dec. 31, 2011. A recent study found that the industry would have produced an additional 300 million gallons this year with the tax incentive in place. That would have supported some 19,213 additional jobs, for a total of 83,258 jobs supported by the industry nationwide, according to the study, conducted by Cardno ENTRIX, an international economics consulting firm.
3) **Cellulosic biofuels bonus depreciation.** Under current law, facilities producing cellulosic biofuel can expense 50 percent of their eligible capital costs in the first year for facilities placed-in-service by the end of 2012. This provision was created in the 2008 Farm Bill. The provision would extend this bonus depreciation for one additional year for facilities placed-in-service before the end of 2013. The proposal also expands the definition of qualified cellulosic biofuel production to include algae-based fuel. This provision is estimated to cost less than $500,000 over ten years.

In 2012, the Obama Administration proposed $998 million for the second year of a cross-agency **Science, Engineering, and Education for Sustainability** initiative that will take an integrated approach to furthering U.S. energy independence, enhancing environmental stewardship, reducing energy and carbon intensity, and generating sustained economic growth. In conjunction with this initiative, the Obama Administration proposed $576 million, an increase of $209 million over the 2010 enacted level, for research—such as nanotechnology and biotechnology—that will lead to breakthroughs in clean energy technologies of the future.

There is also a support program for generating demand for biobased products: the **Bio-preferred program for public procurement.** Federal agencies are required to give special preference to BioPreferred products, as long as they meet the standards and cost effectiveness measures of those agencies. Under the Federal procurement preference program, USDA designates categories of biobased products. Federal agencies and their contractors are then required to give preferential consideration to these designated product categories when making purchases.

CONCLUSIONS

The number of companies applying biotechnology in the production or being fully dedicated to biotechnology research and innovation is higher in the EU than in the US. The share of dedicated R&D companies among the general firms using biotechnology varies greatly in Europe, from 34% in Poland to 81% in Germany. It is, however, still likely that the average share of dedicated biotechnology R&D firms is higher in Europe than in the US. However, these firms tend to be smaller (not to mention underfunded) than their American counterparts.

The business sector funding of biotechnology R&D is significantly higher in the US compared to Europe. In 2011, private sector firms in the US spent 17-22 billion dollars on R&D. Since a lion's share of this research takes place in dedicated biotechnology firms, we can deduce that a US biotechnology company had almost 4 times more, i.e. $9.2 million at their disposal for R&D compared to $2.4 million available for a European firm.

The shortage of research and innovation funding in Europe is somewhat compensated by public sector efforts. There is little data available, but OECD figures seem to suggest that the public sector support to biotechnology R&D in Europe actually exceeds the expenditures by the firms themselves. This is in line with the general R&D funding trends in Europe where the public sector provided 2.03% and the private sector 1.27% compared to GDP in 2011.

Nine out of 10 biotechnology companies in Europe have received some sort of public funding either from the local, national, or EU level, whereas in most cases such funding is combined. The biotech firms in Western, Northern, and Southern Europe receive significantly more support than their counterparts in Central and Eastern Europe, where public funding from local sources is almost non-existent, funding from central governments is lower, and the general EU support reaches only 24% of such firms compared to 50% in Southern Europe. The penetration rate (63%) of EU research and technological development funding is high. Large biotech companies and companies located in Western and Northern Europe have been most successful in obtaining funding from 5th and 6th framework programs.

There is a discrepancy between the public research funding offer both at the national and EU level and the needs of the industry. Public research funding for bulk agricultural products and for food and feed industries exceeds the needs of these sectors. At the same time, bio-based polymers and materials seem to remain outside of public funders radar screen. Bio-inspired materials and textiles receive much less compared to their needs and growth potential. These claims from European industries are supported by the OECD 2011 overview of the Industrial Biotechnology development which states that there is a serious mismatch between the level of investment in industrial biotechnology R&D and the potential market opportunities for the sector.

Europe has large untapped reserves of biomass and biowaste. Domestically available biomass could satisfy a much larger share of Europe's energy needs as well as provide raw material to the processing industry than the Member States national plans currently capture. More than half of the oil that Europe currently consumes could be replaced by biomass derived fuels and products. This underutilization of biological renewable resources is largely due to the pre-commercial stage of technology for efficient conversion of feedstocks such as wastes and various lingo-cellulosic materials. Additional difficulties arise from the lack of logistical supply chains of biomass and first level processing facilities.

The US, European Union, and China all have successful – in terms of creating substantial production quantities in the 1st generation biofuels – policies in place promoting biofuel production and consumption. Now the policies and attention are shifting away from food crops based biofuels towards 2nd generation ones and the policies along with support schemes are being revisited.

The US Federal level support to R&D in industrial biotechnology through the BRDI program is comparable in its size and focus to the EU FP7 funding over the last years, but Europe has nothing comparable to the 19 integrated biorefinery projects that received $564 million (average $29.7 million per project) from the American Recovery and Reinvestment Act in 2009 with the aim of accelerating the construction and operation of pilot, demonstration, and commercial scale facilities. Besides this massive stimulus, the US DOE claims to have already invested about $1 billion in biorefinery development.

Another difference between the EU and the US support to biorefining lies in the extent of synergies between energy and farm policies and the attention given to biomaterials other than biofuels. The USDA and DOE collaborate on their support to biorefining and have therefore provided joint financing to projects in order to create economically viable integrated biorefineries. Recipients must pursue projects that integrate science and engineering research in three areas: feedstocks development, biofuels and biobased products development, and biofuels development analysis. Although the earlier US biofuels programs may have neglected biobased materials, in recent years the biobased products have always figured among the expected results of federal funding. In Europe, the policies and funding for energy, agriculture, and R&D still tend to remain separated and pursue their specific mandates, thus undermining the opportunities for greater synergies. The 2012 European Bioeconomy Strategy and the future R&D program Horizon may help overcome this fragmentation.

There is further significant difference between the US Farm policy and the EU CAP: the former has specific incentives in place for non-food biomass cultivation and collection as well as for forming first-level processing capacities, the latter does not.

Europe has developed the first commercially viable lignocellulosic technologies based on agricultural residues and wood, which now need substantial funding from public and private sources for further fine-tuning and spreading of the technologies to bring down costs and increase performance reliability. In parallel, other technological paths are being pursued for conversion technologies needed for other types of raw materials, particularly marine biomass and various types of wastes. Significant funding is needed for the construction of pilot plants and first commercial biorefineries. The possible future public-private partnership, BRIDGE, for developing sustainable biorefineries in Europe can play a crucial role in bringing Europe up to speed with its main competitors.

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ANNEX 1

The following projects have been selected for awards in 2011:

- **Cellana LLC**, Kailua Kona, Hawaii, $5,521,173. Cellana will work to develop a protein supplement from algae as a byproduct of algal biofuels production, by demonstrating its nutritional and economic value in livestock feeds. The project will characterize types of algae, assess the nutritional values of algal proteins, assess the potential for algal proteins to replace soybean meal, and develop algal protein supplements.
- **Domtar Paper Company, LLC**, Fort Mill, SC, $7,000,000. This three-year project will work to build a demonstration plant using two technologies to convert low-value byproducts and wastes from paper mills into higher-value sugar, oil, and lignin products.
- **Exelus, Inc.**, Livingston, N.J., $5,185,004. Exelus will work to develop energy crops with improved tolerance to drought and salt stress to enhance yields on marginal lands. The project will also redesign a process to make hydrocarbon fuels using new catalysts and chemistry that avoids the high temperatures and large energy inputs required by current processes.
- **Metabolix, Inc.**, Cambridge, Mass., $6,000,001. Metabolix will enhance the yield of bio-based products, **biopower**, **or** fuels made from switchgrass. The project will use high temperature conversion to produce denser biomass and other products that can be further processed to make fuels such as butanol, chemicals such as propylene and other materials to improve the economic competitiveness of future biorefineries.
- **University of Florida**, Gainesville, Fla., $5,430,439. The purpose of this project is to improve the production and sustainability of sweet sorghum as an energy crop. The University will identify genetic traits in sorghum associated with drought tolerance through genetic mapping and will select strains that produce high biomass yields and can be easily converted to fermentable sugars.
- **University of Kansas Center for Research**, Lawrence, Kan., $5,635,858. The purpose of this project is to demonstrate a novel, sustainable technology at a pilot scale that produces diverse products, including advanced fuels, industrial chemicals and chemical intermediates.
- **University of Kentucky**, Lexington, Ky., $6,932,786. The purpose of this project is to improve the economics for biorefineries by using on-farm processing to convert biomass to a mixture of butanol, ethanol, acetone and organic acids. The product can then be easily transported to a biorefinery for further processing. The project will integrate input from experts in a variety of disciplines, including plant and soil scientists, horticulturists, chemical engineers, and economists.
- **U.S. Forest Service, Rocky Mountain Research Station**, Missoula, Mont., $5,309,320. This project will develop an integrated approach to investigate biomass

feedstock production, logistics, conversion, distribution and end use centered on using advanced conversion technologies at existing forest industry facilities.

2012 awarded projects include:

- **Quad County Corn Cooperative** ($4.25 million – Galva, Iowa). This project will retrofit an existing corn starch ethanol plant to add value to its byproducts, which will be marketed to the non-ruminant feed markets and to the biodiesel industry. This project enables creation of diverse product streams from this facility, opening new markets for the cooperative and contributing to the U.S. Environmental Protection Agency's goals for cellulosic ethanol production and use.

- **Agricultural Research Service's National Center for Agricultural Utilization Research** ($7 million - Peoria, Illinois). This project will optimize rapeseed/canola, mustard and camelina oilseed crops for oil quality and yield using recombinant inbred lines. Remote sensing and crop modeling will enhance production strategies to incorporate these crops into existing agricultural systems across four ecoregions in the Western United States. The oils will be hydrotreated to produce diesel and jet fuel.

- **Cooper Tire & Rubber Co.** ($6.85 million - Findlay, Ohio). Guayule is a hardwood perennial natural rubber-producing shrub grown in the semi-arid southwestern United States. This project will optimize production and quality of guayule rubber using genomic sequencing and development of molecular markers. The extracted rubber will be used in tire formulations, and the remaining plant residue will be evaluated for use in biopower and for conversion to jet fuel precursors.

- **University of Wisconsin** ($7 million - Madison, Wisconsin).This project will utilize dairy manure as a source of fiber and fertilizer. Fiber will be converted to ethanol, manure used for fertilizer, and oil from the crops will be converted to biodiesel used in farm equipment. The project goal is to develop closed-loop systems with new product streams that benefit the environment.

- **University of Hawaii** ($6 million - Manoa, Hawaii). This project will optimize the production of grasses in Hawaii, including napier grass, energycane, sugarcane and sweet sorghum. Harvest and preprocessing will be optimized to be compatible with the biochemical conversion to jet fuel and diesel.

ANNEX 2

Grantee	DOE Grant Amount	Non-Fed Amount	Project Location (City)	Project Location (State)	Description
1) Pilot and Demonstration Scale FOA – Pilot Scale					
Algenol Biofuels Inc.	$25,000,000	$33,915,478	Freeport	TX	This project will make ethanol directly from carbon dioxide and seawater using algae. The facility will have the capacity to produce 100,000 gallons of fuel-grade ethanol per year.
American Process Inc.	$17,944,902	$10,148,508	Alpena	MI	This project will produce fuel and potassium acetate, a compound with many industrial applications, using processed wood generated by Decorative Panels International, an existing hardboard manufacturing facility in Alpena. The pilot plant will have the capacity to produce up to 890,000 gallons of ethanol and 690,000 gallons of potassium acetate per year starting in 2011.
Amyris Biotechnologies, Inc.	$25,000,000	$10,489,763	Emeryville	CA	This project will produce a diesel substitute through the fermentation of sweet sorghum. The pilot plant will also have the capacity to co-produce lubricants, polymers, and other petro-chemical substitutes.
Archer Daniels Midland	$24,834,592	$10,946,609	Decatur	IL	This project will use acid to break down biomass which can be converted to liquid fuels or energy. The ADM facility will produce ethanol and ethyl acrylate, a compound used to make a variety of materials, and will also recover minerals and salts from the biomass that can then be returned to the soil.

Grantee	DOE Grant Amount	Non-Fed Amount	Project Location (City)	Project Location (State)	Description
Clearfuels Technology Inc	$23,000,000	$13,433,926	Commerce City	CO	This project will produce renewable diesel and jet fuel from woody biomass by integrating ClearFuels' and Rentech's conversion technologies. The facility will also evaluate the conversion of bagasse and biomass mixtures to fuels.
Elevance Renewable Sciences	$2,500,000	$625,000	Newton	IA	This project was selected to complete preliminary engineering design for a future facility producing jet fuel, renewable diesel substitutes, and high-value chemicals from plant oils and poultry fat.
Gas Technology Institute	$2,500,000	$625,000	Des Plaines	IL	This project was selected to complete preliminary engineering design for a novel process to produce green gasoline and diesel from woody biomass, agricultural residues, and algae.
HALDOR TOPSOE, INC.	$25,000,000	$9,701,468	Des Plaines	IL	This project will convert wood to green gasoline by fully integrating and optimizing a multi-step gasification process. The pilot plant will have the capacity to process 21 metric tons of feedstock per day.
ICM, Inc.	$25,000,000	$6,268,136	St. Joseph	MO	This project will modify an existing corn-ethanol facility to produce cellulosic ethanol from switchgrass and energy sorghum using biochemical conversion processes.
Logos Technologies	$20,445,849	$5,113,962	Visalia	CA	This project will convert switchgrass and woody biomass into ethanol using a biochemical conversion processes.

Grantee	DOE Grant Amount	Non-Fed Amount	Project Location (City)	Project Location (State)	Description
Renewable Energy Institute International	$19,980,930	$5,116,072	Toledo	OH	This project will produce high-quality green diesel from agriculture and forest residues using advanced pyrolysis and steam reforming. The pilot plant will have the capacity to process 25 dry tons of feedstock per day.
Solazyme, Inc.	$21,765,738	$3,857,111	Riverside	PA	This project will validate the projected economics of a commercial scale biorefinery producing multiple advanced biofuels. This project will produce algae oil that can be converted to oil-based fuels.
UOP LLC	$25,000,000	$6,685,340	Kapolei	HI	This project will integrate existing technology from Ensyn and UOP to produce green gasoline, diesel, and jet fuel from agricultural residue, woody biomass, dedicated energy crops, and algae.
ZeaChem Inc.	$25,000,000	$48,400,000	Boardman	OR	This project will use purpose-grown hybrid poplar trees to produce fuel-grade ethanol using hybrid technology. Additional feedstocks such as agricultural residues and energy crops will also be evaluated in the pilot plant.
2) Pilot and Demonstration Scale FOA – Demonstration Scale					
BioEnergy International, LLC	$50,000,000	$89,589,188	Lake Providence	LA	This project will biologically produce succinic acid from sorghum. The process being developed displaces petroleum based feedstocks and uses less energy per ton of succinic acid produced than its petroleum counterpart.

Grantee	DOE Grant Amount	Non-Fed Amount	Project Location (City)	Project Location (State)	Description
Enerkem Corporation	$50,000,000	$90,470,217	Pontotoc	MS	This project will be sited at an existing landfill and use feedstocks such as woody biomass and biomass removed from municipal solid waste to produce ethanol and other green chemicals through gasification and catalytic processes.
INEOS New Planet BioEnergy,LLC	$50,000,000	$50,000,000	Vero Beach	FL	This project will produce ethanol and electricity from wood and vegetative residues and construction and demolition materials. The facility will combine biomass gasification and fermentation, and will have the capacity to produce 8 million gallons of ethanol and 2 megawatts of electricity per year by the end of 2011.
Sapphire Energy, Inc	$50,000,000	$85,064,206	Columbus	NM	This project will cultivate algae in ponds that will ultimately be converted into green fuels, such as jet fuel and diesel, using the Dynamic Fuels refining process.
3) Increased funding to existing biorefinery projects					
Bluefire LLC	$81,134,686	$223,227,314	Fulton	MS	This project will construct a facility that produces ethanol fuel from woody biomass, mill residue, and sorted municipal solid waste. The facility will have the capacity to produce 19 million gallons of ethanol per year.