BACAS

Royal Belgian Academy Council of Applied Science

Industrial Biomass: Source of Chemicals, Materials, and Energy!

Implications and limitations of the use of biomass as a source for food, chemicals, materials and energy

February 2011

Koninklijke Vlaamse Academie van België voor Wetenschappen en Kunsten
Paleis der Academiën
Hertogsstraat 1, 1000 Brussel

Académie royale des Sciences, des Lettres et des Beaux-Arts de Belgique
Palais des Académies
Rue Ducale 1, 1000 Bruxelles

The Belgian Academy Council of Applied Science (BACAS) consists of KTW (class of technical sciences of the Koninklijke Vlaamse Academie van België voor Wetenschappen en Kunsten) and CAPAS (a committee of the class of sciences of the Académie royale des Sciences, des Lettres & des Beaux-Arts de Belgique). End 2009 CAPAS was dissolved and its activities were taken over by the new “class of technology and society” (CTS) of the Académie royale de Belgique, made up of professionals from the academic, industrial, economic and cultural world, many of them former members of CAPAS.

Based upon a dialogue between stakeholders from the scientific community, the business world and society in general, BACAS intends to make a future-oriented evaluation of the interactions between science (technology in particular), society and culture.

KONINKLIJKE VLAAMSE ACADEMIE VAN BELGIE
VOOR WETENSCHAPPEN EN KUNSTEN

ACADEMIE ROYALE DES SCIENCES, DES LETTRES ET DES BEAUX ARTS DE BELGIQUE

Paleis der Academiën
Hertogsstraat 1
1000 Brussel

Palais des Académies
Rue Ducale 1
1000 Bruxelles

D/2011/0455/02
ISBN 9789065690777

Printed by UNIVERSA, Wetteren

Authors of the report

Vandamme Erick, Anthonis Tom, Dobbelaere Sofie

Bourdeau Philippe, Carrez Dirk, Gosselin Derrick, Huyghe François, Kretzschmar Jan, Meers Erik, Michiels Leo, Pelckmans Luc, Van Roost Joost, Van Vaerenbergh Ivo, Verstraete Willy,

Contributors of data:

Beauprez Joeri, Boerenbond, Centexbel, Cepi, Cobelpa, Copa, Eurostat, European Commission, FAO, OESO, VCM

Members of Working Group 59

Vandamme Erick, Chairman
Anthonis Tom
Bourdeau Philippe
Carrez Dirk
Dobbelaere Sofie
Gosselin Derrick
Huyghe François
Kretzschmar Jan
Meers Erik
Michiels Leo
Pelkmans Luc
Soetaert Wim
Van Roost Joost
Van Vaerenbergh Ivo
Verstraete Willy

Table of contents

Executive summary

Biomass seemed a very promising resource for substituting fossil hydrocarbons as a renewable source of energy and as a sustainable raw material for various industrial sectors. However, during the first decade of the 21st century, competition between the use of biomass for food and feed on the one hand, and for energy and industrial applications on the other hand, became a big issue. Dramatic food price rises in the first half of 2008 were blamed to the use of arable land for the production of first generation biofuels at the expense of food and feed.

On purpose, the present report of the BACAS working group does not focus on the food and feed issue, but examines thoroughly the implications and limitations of the use of non- food (industrial) biomass as a source of chemicals, materials and energy. For its analysis, the BACAS report started from the widely accepted “5 F-cascade”, a list of priorities regarding the use of biomass:

1. Food and feed
2. Fine and bulk chemicals and pharma
3. Fibre and biomaterials
4. Fuels and energy
5. Fertilisers and soil conditioners.

The authors have covered the impact of an increasing use of industrial (or technical) biomass as a renewable resource for various industrial sectors and for power generation. The use of biomass as a renewable primary energy source will be of key importance for achieving the 20/20/20 targets of the European Union, i.e. use of at least 20% of renewables for energy production, 20% less greenhouse gas emissions and 20% more efficient energy use by the year 2020: biomass is expected to provide 2/3 of the renewable energy target by 2020.

The report starts with an overview of state-of-the-art processes and technologies for converting industrial biomass. Next, it focuses on the 5 F-cascade of applications of biomass and on the legislation affecting the bio-based economy. Finally a number of recommendations are formulated meant for government, industry, research and development agencies.

The EU’s common agricultural policy (CAP) should develop an integrated policy for the bio-based economy, including the removal of still existing trade barriers, a scientifically substantiated policy with regard to genetically modified crops and sustainability criteria.

The public and private scientific communities are urged to set up public-private partnerships in order to support coordinated research programs, in particular with regard to feedstock yields and biomass optimization in view of maximizing the efficiency of processes converting biomass into energy or industrial products.

1. TOWARDS A BIOBASED ECONOMY

1.1. General introduction

In the last century the chemical industry was largely based on – ánd tightly interwoven with – the fossil oil sector. Energy production is still largely dominated by oil, coal and natural gas utilization. Only during the last decennia the rising oil prices and the environmental impact of many petrochemically based processes have led to a critical rethinking of the currently widely applied fossil based chemical and energy technologies. Worldwide more sustainable technologies are now gradually introduced to produce "renewable" energy and "bio-based" chemicals. This mind-switch will channel the use of all available resources towards more economically as well as environmentally sound production systems. The whole fabric that interconnects petrochemistry with the conventional *chemical* syntheses processes is now loosened up; it increasingly allows for the introduction of *biochemical* syntheses alternatives, resulting in more sustainable routes for the production of chemicals, materials and energy, based on industrial biomass as a renewable resource.

The idea of sustainable development is not new; it has been an issue especially since the Brundtland report was published in 1987: "Our common future" (Brundtland, 1987). In the mean time, tangible results have already emerged from the Brundtland report, for instance the international agreements such as the Montreal and Kyoto protocols, and Agenda 21, which further enshrined the concept of environmentally sustainable development. Although the energy supply problem and climate change issues have recently been most prominent in these actions, the concept of sustainability has much more far reaching implications. Also the North-South contrast has been highlighted even more, ever since the thesis 'development versus sustainability' was introduced. While for industrialised countries, it is relatively easy to advocate solidarity towards the future generation, developing countries still struggle to meet the needs for the current generation. Lack of technology transfer between North and South and protectionist measures by the North barely give the South the breathing space – it needs to develop its own solutions for the environmental issues the world is facing these days. Indeed, these issues are grounded in many political, social and economical debates, leading up to different visions on sustainability and its implementation.

In this context the European Commission (EC) and EU-Member States have recently promoted the use of non-food (technical or industrial) biomass, to tackle three bottlenecks within the EU:

1. Finding an alternative to dwindling fossil energy resources;
2. Reducing our CO_2 emissions to reduce the greenhouse effect and to respect the Kyoto agreement;
3. Upgrading agricultural surpluses and residues (now called technical or industrial biomass) for non-food applications i.e. chemicals, materials and bioenergy.

In this respect context the integration of the chemical sector with the agricultural sector will grow significantly in the coming decades. At a global level, society is changing already towards a 'biobased economy'. In a biobased economy, biomass replaces (portion of) the fossil resources, such as oil, coal and natural gas, for the production of biochemicals, biomaterials and bioenergy.

Industrial biomass is a valuable renewable and underestimated source of carbon for the chemical industry. It can be used directly and indirectly for the production of simple building blocks, which are essential platform molecules for the chemical industry. In addition, unique biomass components can be extracted by chemical, physical, microbial or enzymatic treatments and then used for applications in sectors such as food, health and medicine, chemistry, materials and energy. Biomass derived residues and wastes can also be valorised as energy source, fertilizer or soil conditioner (OECD, 2010).

1.2. The "5 F cascade"

Especially the last decade has been dominated by a rapid development and controversy of the first generation of biofuels. Indeed the feedstock here is the same raw material – sugars, plant oils,... – as for food production. Soon the first criticism arose and at the top of the steep food price increase mid 2008, biofuels where the first, or almost the only one to blame.

In hindsight the public debate about the issue 'food versus fuel' was not nor logical nor consistent (see insert page 22, Food versus fuel). Whereas many consumers were concerned by the so-called "food crisis", others perceived it as a chance for world-wide progress. Also in terms of the "biomass: food versus fuel" slogan, the consumer is not very consistent. Agriculture has supplied biomass and crops, which provide products for non-food applications since a very long time, i.e. cotton or linen for clothing, wood for building, paper and energy, rubber, botanicals as pharma, etc... Even though these bio-products are produced in huge quantities and compete far more with food production than biofuels, the general public is even today unaware of this.

In this respect, a now generally accepted priority list as to the different applications of biomass has recently been defined, also called **the 5 F-cascade**:

1. Food & feed;
2. Fine & bulk chemicals & pharma
3. Fibre & biomaterials
4. Fuels & energy
5. Fertiliser & soil conditioners

Biofuels are thus only one - but highly 'mediatised' - aspect of the developments towards a bio-based economy, which is gradually picking up speed now. The issues at stake are indeed very complex and interwoven with science and technology, economics, and society behaviour (Mc Donough & Braungart, 2002; Morris, 2006; Vos, 2007; De Wulf et al., 2010; Soetaert and Vandamme, 2010.

An effort has been made here to produce a report, covering the impact of gradually introducing industrial (or technical) biomass as a renewable resource into the broad chemical and energy sector. The authors have aimed at an independent scientifically, technologically and ethically sound approach.

2. CONVERSION TECHNOLOGIES AND PROCESSES FOR INDUSTRIAL BIOMASS

2.1. General comments

Developing biomass into a sustainable, domestic source of affordable biochemicals and biofuels will require the flexibility to use a wide variety of (non-food) biomass resources. International research is focusing on new cost-efficient biomass conversion processes. These feedstocks include a.o. agricultural residues, energy crops, forest thinnings, and alternative plant-oil sources, such as Jatropha, or micro-algae (Morris, 2006; Soetaert and Vandamme, 2006; Spolaodre et al., 2006; Weiland et al., 2009).

Cellulosic biomass – the fibrous, non-edible part of plants – is an abundant resource that can potentially provide a renewable feedstock for many, next-generation, bio-derived products. The plant cell walls are comprised of long chains of sugars (polymeric carbohydrates such as cellulose, hemicellulose and lignin), which can be converted to monomeric common sugars such as glucose, xylose,... the ideal substrates for chemical, physical and fermentation processes, leading to valuable biochemicals, biomaterials and biofuels.

Considerable research efforts have recently been made to improve the "hydrolysis" of lignocellulosic materials. Pretreatments of those materials to remove lignin and hemicellulose can significantly enhance the hydrolysis of the cellulose component. Also the development of transgenic plants (e.g. poplar, willow, maize,...) with lowered lignin content is a major step forward. On the other hand lignin on its own could become an important source for certain (poly)aromatic chemicals.

Over the years, numerous research and development efforts have been undertaken to develop and apply different technologies for the conversion of industrial biomass. So far there is no clear trend showing which technology will be the most promising future option. The three main conversion routes are:

– **Chemical route**: The most conventional (and traditional) way of conversion of biomass is by the universally applied process of combustion (burning); chemical catalysis is another well-known principle, with different processes in use or under development;
– **Thermo-chemical route:** The first step in the process here is the gasification of the biomass feedstock under high temperature into synthesis gas. This gas can then be transformed into different types of liquid or gaseous fuel, so-called "synthetic fuels", such as Biomass to Liquid (or BtL-diesel), bio-SNG (Synthetic Natural Gas) or into biochemicals;
– **Bio-chemical route:** This process is based on enzymatic and microbial hydrolysis ("bio-cracking") of the biomass (lignocellulosic) material through a variety of microbial actions or their enzymes that hydrolyse the cellulosic matrix into sugars. In a subsequent step of the process, these sugars can be chemically transformed or fermented into bio-alcohols (i.e. bio-ethanol, butanol, methanol,...) or into a wide range of useful biochemicals (e.g. bio-plastics, biodetergents, biovitamines,...).

The cost of ethanol production from lignocellulosic materials is relatively high based on current technologies, and the main challenges are the low yield and high cost of the current hydrolysis processes.

The main ways of processing biomass are shown in figure 1 and 2.

2.2. Chemical conversion of industrial biomass

2.2.1. *Combustion*

Combustion or burning is the most common way of converting solid biomass into energy. Wood and charcoal are by far the most commonly used biomass-based 'bio-energy' carriers.

The FAO estimates that still in 2010 approximately 60% of the world's total wood removals from forests and trees outside forests are used for energy purposes. In other words, **energy is the main application of woody biomass from forests and trees outside forests.** In developing countries, the everyday life dependency on such biomass is high; it provides about one-third of the total energy in these countries,

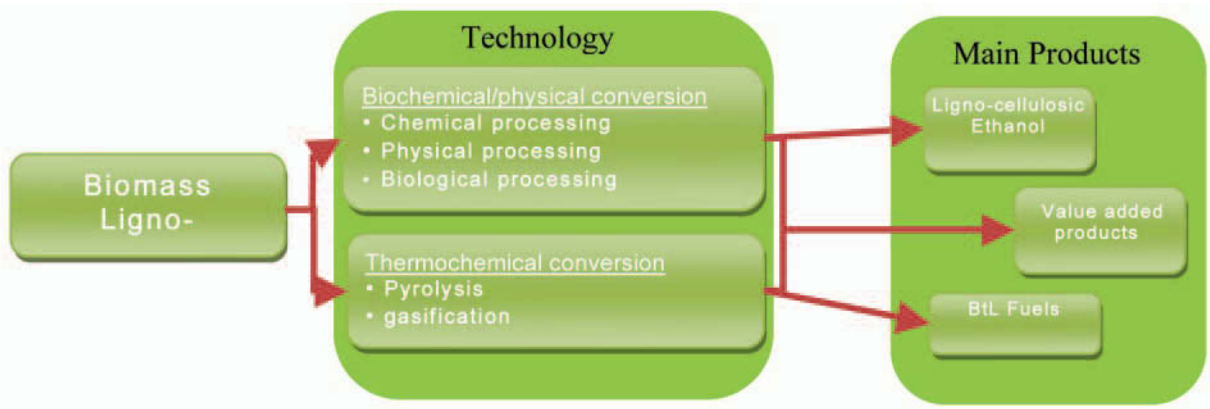


Figure 1. — Schematic representation of the classic chemical conversion of biomass and the newer routes of thermo- or biochemical conversion (adapted from U.S. DOE)

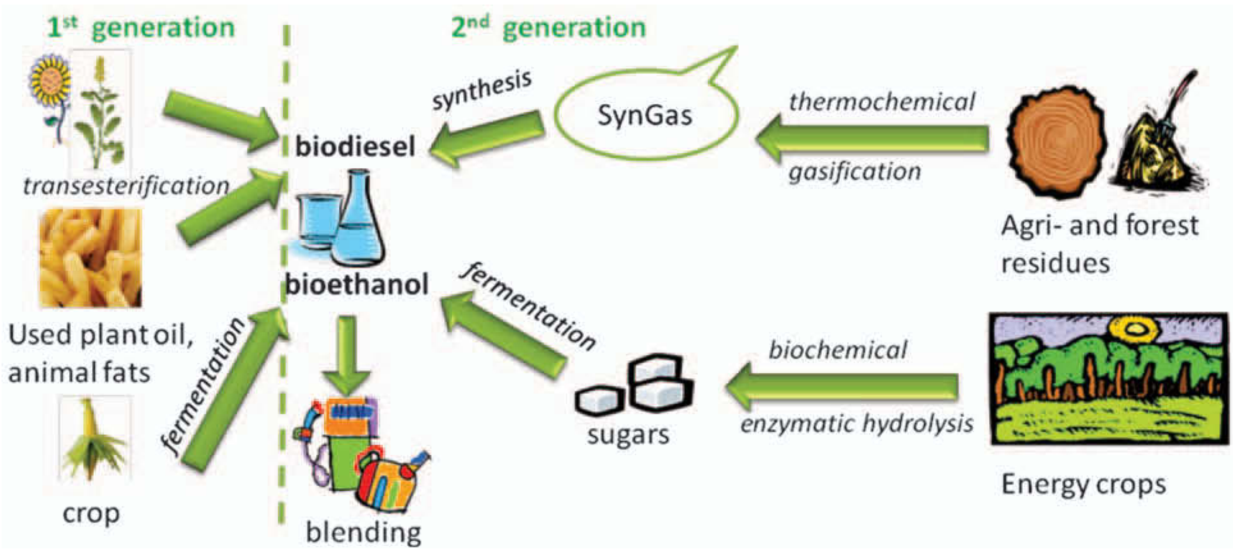


Figure 2. — Schematic representation of the classic chemical conversion of biomass to liquid biofuels of the 1st generation and of future pathways by thermo- or biochemical routes towards the 2nd generation biofuels

and as much as 80% of energy need is derived from woodfuels in some sub-regions of Africa (FAO, 2009).

In the developed countries the generated heat from the combustion of biomass can be used depending on the need for heating, electricity production, and steam production for industry. It is well understood, relatively straightforward, and commercially available, and can be regarded as a proven technology.

Cogeneration, also known as **c**ombined **h**eat and **p**ower (CHP) generation, is the combined production of electrical (or mechanical) and useful thermal energy from the same primary energy source, here biomass. It encompasses a range of technologies, but always includes an electricity generator and a heat recovery system. The principle behind cogeneration is simple. On average, conventional power generation, is only 35% efficient, since up to 65% of the energy potential is released as waste heat. More recent combined cycle generation can improve this to 50%, excluding losses for the transmission and distribution of electricity. Through the utilisation of the heat, the efficiency of cogeneration plant can reach 90% or more(Bellman et al., 2007).

2.2.2. *Chemical catalysis*

The production of most industrially important chemicals involves catalysis, using inorganic catalysts (e.g. acid hydrolysis, transesterification,...) (Serrano-Ruiz, 2010). A few examples are given below. Similarly, many biochemically significant processes are catalysed, but here enzymes or microbial cells are the catalysts (see 2.3).

Acid hydrolysis

The ability to recover and use the major components of lignocellulosic biomass (cellulose, hemicellulose and lignin) is critical in developing economically viable bioproducts and biorefineries. In order to be able to valorise these fractions, *acid hydrolysis* is an important pretreatment step to recover the (hemi)cellulosic sugars and prepare the biomass for subsequent enzymatic or acid conversion. The ultimate goal is here to identify promising technologies to reduce the sugar production cost, in turn facilitating and reducing the costs of the subsequent fermentation or chemical transformations.

Many different acid hydrolysis or chemical transformation techniques have been studied; recently also the use of ionic liquids has been documented with a nearly 90% yield of glucose from cellulose and 70-80% yield of sugars from untreated corn stover. This simple chemical process, which requires neither an edible plant nor cellulase enzymes, could enable crude biomass to be the sole source of carbon for a scalable biorefinery.

Transesterification

Alkaline or basic catalysis is by far the most commonly used reaction type for the production of fatty acids esters, e.g., **f**atty **a**cid **m**ethyl **e**sters (FAME), nowadays the most commonly produced biodiesel from plant oils or animal fats.

In the transesterification of vegetable oils, a triglyceride reacts with an alcohol (methanol, ethanol,…) in the presence of a strong acid or base, producing a mixture of fatty acids alkyl esters and glycerol. The overall process is a sequence of three consecutive and reversible reactions, in which di- and monoglycerides are formed as intermediates.

Acid catalysis offers the advantage of also esterifying free fatty acids contained in the fats and oils and is therefore especially suited for the transesterification of highly acidic fatty materials.

Ammonia steam fibre explosion

Ammonia **f**ibre **ex**plosion (AFEX) treatment of lignocellulosic fibre materials as a pretreatment for the ethanol production is very interesting. AFEX is a combination of a chemical and physical digestion of the biomass in order to increase the fermentation yields.

2.3. Thermochemical conversion

Thermochemical conversion processes use heat ànd chemical treatments to convert biomass into liquid or gaseous *intermediates*. The intermediates, such as syngas and bio-oil, subsequently go through customized processing to produce biopower or biofuels, such as gasoline, diesel, and jet fuel (Figure 3).

Thermochemical processes enable production of any type of advanced biofuels, including:

- Ethanol derived from cellulose, hemicellulose or lignin;
- Longer-carbon-chain alcohols (such as butanol);
- Advanced hydrocarbon fuels that can be used as direct substitutes for gasoline, diesel, and jet fuel.

Thermochemical processes allow productive use of a wide spectrum of biomass resources. The elevated temperatures of thermochemical processes (300 to 1000°C) overcome the natural resistance of biomass to chemical or enzymatic conversion, thus expanding the range of feedstocks that can potentially be used in bio-refineries.

Collaborative teams from industry and academia conduct innovative R&D to improve the efficiency and cost-effectiveness of thermochemical conversion technologies: it focuses on producing intermediates via gasification, pyrolysis, and other chemical means

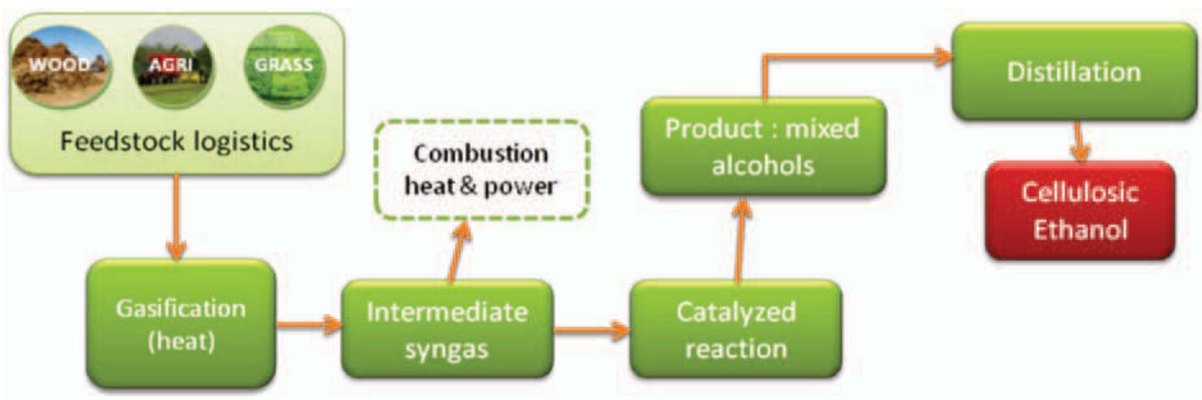


Figure 3. — Schematic representation of the thermochemical conversion processes of biomass (adapted from U.S. DOE)

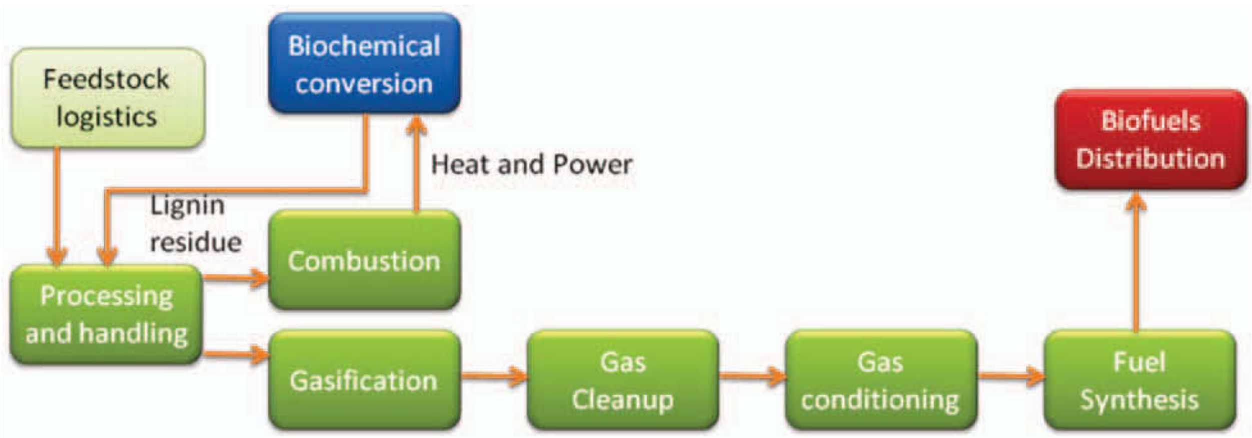


Figure 4. — Thermochemical conversion route - gasification (adapted from U.S. DOE)

from biomass and organic residues, and then converting these intermediates into fuels, chemicals, or power.

Common thermochemical approaches are **gasification** and **pyrolysis** of biomass.

Gasification

The gasification process uses heat and a limited amount of oxygen to convert biomass into a synthesis gas (syngas), which consists primarily of carbon monoxide and hydrogen. Product-specific catalysts are then used to turn the syngas into liquid fuels (Figure 4).

The main challenges are here are:

- Demonstrating reliable reactor operation
- Developing improved catalysts for liquid fuel production
- Refining efficient gas cleaning technologies

Pyrolysis/Liquefaction

This process decomposes biomass by heating it in the absence of oxygen to produce a bio-oil. Cleanup, conditioning, and stabilisation of the bio-oil are necessary to convert it into a product suitable for delivery to a petroleum refinery, where it can be further upgraded to renewable diesel, gasoline, or jet fuel (Figure 5). The main challenges here are:

– Increasing product yield
– Cleaning and stabilising the bio-oils
– Improving catalysts for upgrading bio-oils into finished fuels

2.4. Biochemical conversion

Biochemical conversion entails breaking down or “cracking” biomass by using enzymatic and/or microbial action, to make the polymeric carbohydrates available as (fermentable) sugars, which can then be converted into biofuels and bioproducts using microorganisms (bacteria, yeasts, fungi,...) and their enzymes (Figure 6).

Among the key challenges for biochemical conversion are the considerable difficulty and expense involved in breaking down, or “bio-cracking”, the tough, complex structures of the plant cell walls in cellulosic biomass.

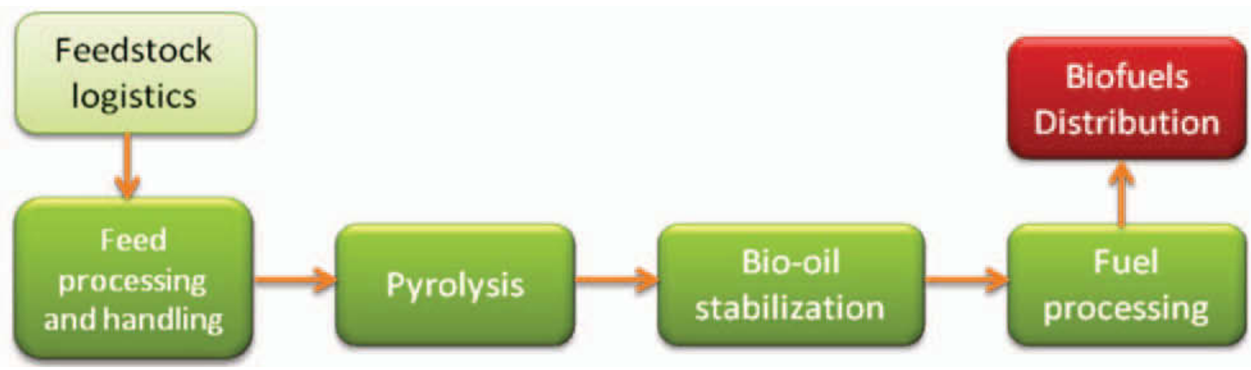


Figure 5. — Thermochemical conversion route – pyrolysis (adapted from U.S. DOE)

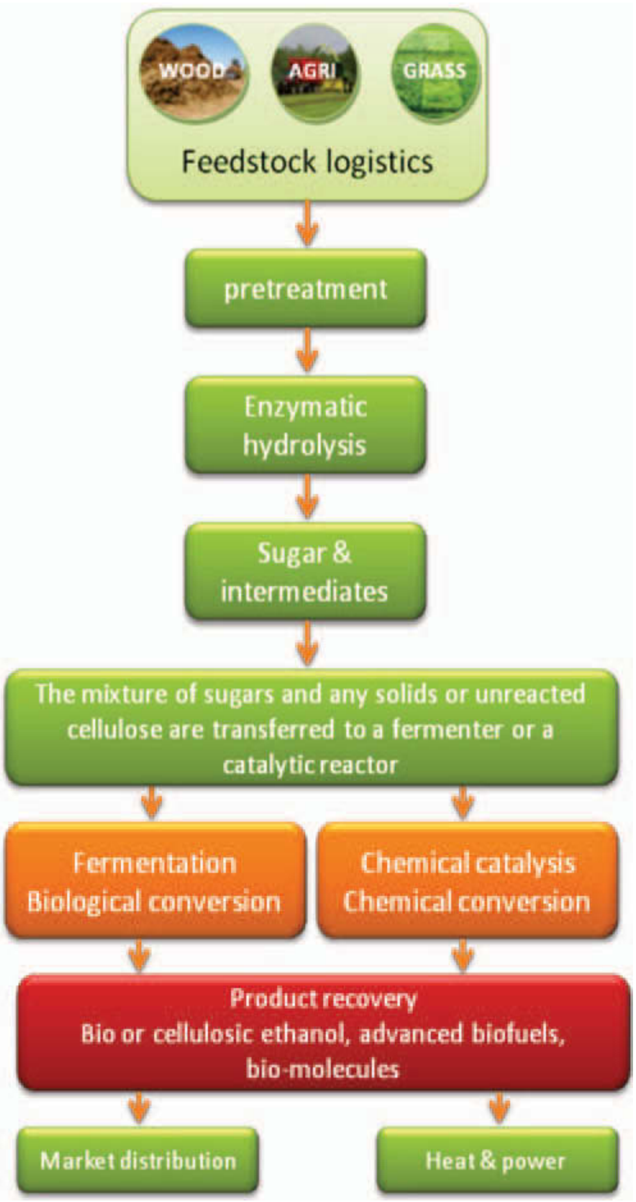


Figure 6. — A general scenario for biomass conversion via biochemical processes (adapted from U.S. DOE)

Research is exploring now more efficient and cost-effective ways to gain access to these useful sugars for further processing. Current R&D focuses on high-yield (non-food) biomass feedstocks. Another potential research pathway involves improving upon the fairly recent development of new metabolic pathways and more efficient enzymes, in tailor made microorganisms that enable the efficient fermentation of sugars into advanced biochemicals, including biofuels (Vandamme, 2007; Soetaert and Vandamme, 2009; 2010).

To optimize the role of biochemical conversion within this flexible production scenario, researchers are developing technologies needed throughout the process. A few examples:

- **New enzymes for hydrolysis.** A new generation of enzymes and enzyme production technologies are needed to cost-effectively hydrolyze the cellulose and hemicellulose in biomass to free the sugars for conversion. Programs are under way to identify the most productive, naturally occurring or man-made enzymes and to increase their efficiency. Research objectives also include lowering the cost of the enzyme unit operation in the sugar extraction process (saccharification) (Vandamme et al., 2005; 2006).
- **New microorganisms for fermentation.** Researchers use sophisticated metabolic engineering techniques to develop microorganisms that can more effectively ferment, or convert the variety of sugars derived from biomass. For example certain microorganisms can coferment both the five-carbon sugars (such as xylose from the hemicellulose) and the more common six-carbon sugars (such as glucose) in cellulosic biomass.

2.5. Towards the Biorefinery concept

The World's population needs feedstocks that are widely available, at relatively low cost in terms of economics and carbon, that are renewable and that can be grown and processed in a sustainable manner. It is now indisputable that biomass can fulfil these requirements. The conversion of biomass into energy carriers and into a wide range of useful chemicals and materials – apart from the primary use for food and feed – can be carried out in so-called multi-product biorefineries. A crucial step in developing this industry is to establish ***integrated biorefineries*** capable of efficiently converting a broad range of industrial biomass feedstocks simultaneously into affordable biofuels, biopower, and a wide range of biochemicals and biomaterials (Figure 7) (Griffiths, 2001; Dale, 2003; Gavrilescu and Chisti, 2005; Zhang, 2008).

Although the biofuel and associated co-products markets are not yet fully developed, first generation biorefinery operations that focus on single products (such as ethanol and biodiesel) are regarded as a starting point in the development of sustainable biorefineries. The most profitable of these are based on sugar cane. Some of these 'first generation' plants are also subject to changes in market conditions such as strongly fluctuating commodity prices, as has recently been seen with the price evolutions of wheat and corn. With an increasing demand for alternative sources of energy carriers, platform chemicals and bio-based materials, 'first generation' production systems may have a limited lifespan. It may be argued that advanced biorefineries will have a distinct advantage over conventional refineries (based on mineral oil) and over first generation 'single product focus' biorefineries, (for example, based on recovered vegetable oil, animal fat or rapeseed oil to produce biodiesel), in that a variety

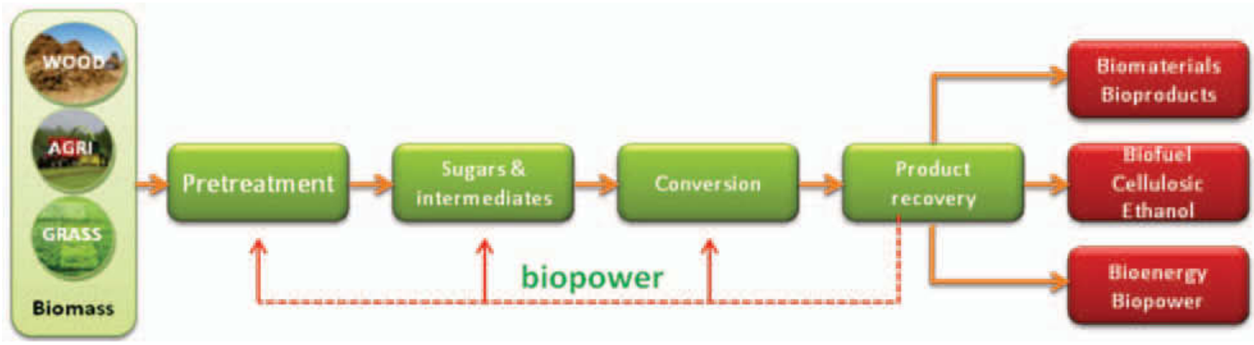


Figure 7. — Integrated biorefinery concept (adapted from U.S. DOE)

of raw materials may be utilised to produce a wide range of added-value products.

Advanced or second generation biorefineries are now being developed on the basis of sustainably-derived biomass feedstocks, and cleaner thermochemical and biological conversion technologies to efficiently produce a range of different energy carriers and marketable chemicals and co-products. To avoid the criticism attributed to first generation biorefineries, these new designs should aim to reduce the impacts and maximise the benefits of social, economic, and environmental factors on a lifecycle basis (De Wulf, et al., 2010). These emerging advanced biorefineries keep promise to provide a range of bioproducts to supply our chemical and manufacturing industries in the near future, as well as contributing partially to energy needs in a more sustainable way.

Integrated biorefineries are similar to conventional petrorefineries in that they produce a range of products in order to optimise use of the feedstock and improve process economics. However, integrated biorefineries employ new technologies and adapted feedstocks, requiring significant technology development, integration, and financial risk.

3. INDUSTRIAL BIOMASS RESOURCES FOR INDUSTRIAL APPLICATIONS

3.1. General aspects

Biomass is the general term used to describe all non-fossils biologically produced matter on Earth. The raw material of biomass can be derived from plants, animals and microorganisms. Biomass can be defined as “all organic material of microbial, vegetal or animal origin, which is produced in natural or managed ecosystems (agriculture, aquaculture, forestry), all or not industrially transformed”.

Industrial biomass sources are often divided into two main categories: specific crops and wastes or residues. Biomass wastes or residues refer to the remaining biomass after harvesting and/or processing a.o. for food/feed or for other use. The two categories differ significantly in the economics of utilisation as well as in biophysical terms.

Specific crops refer to plantations of trees, grasses, oilseed crops and other crops that are optimised for the production of bioenergy or biobased products. The harvested biomass is used directly or serves as feedstock (e.g. sugar, starch, oils, willow and poplar) for further processing. The principal challenges centre on lowering biomass production costs and reducing the risks for biomass growers (e.g. stable prices) and biobased products producers (e.g. guaranteed biomass supply). However, in order to develop a robust biobased economy in Europe, it is and will continue to be important to have access to renewable biomass feedstock in sufficient quantity of good and guaranteed quality. The impact of improved agricultural practice and of plant molecular biotechnology will be crucial in this respect.

Biomass residues include forest (e.g. wood, chips,...) and agricultural residues (e.g. straw, grasses, stoves,...), organic wastes, including animal wastes. They normally offer the most widely available and least-cost biomass resource options. The principal challenge here is to develop or adapt reliable and cost-effective logistics, handling methods and conversion technologies.

However, there are concerns about resource availability in Europe: both on the potential of biomass feedstock to deliver sufficient raw material for all future applications (chemicals, biomaterials, bioenergy,…), as well as on its long time price level. Agricultural and industrial developments are long term processes. Accordingly, policies aiming at supporting these developments need to be stable and consistent in the long term in order to provide security for innovation an encouragement for investments. This is particularly important in this emerging field in order to build our economy on more biobased and sustainable foundations.

To ensure fact-based policies and sound business development, it is crucial to have a reliable European and global evaluation of the biomass and agricultural development potential.

There is an (urgent) need both for up to date statistics and a feasibility study on feedstock availability and logistics in the EU, both from dedicated crop production and from agricultural and industrial waste, including market surveys on bio-based products. Political initiatives such as reform of the Common Agricultural Policy (CAP) after 2013 should be carried out with the needs of the biobased-economy in mind, to increase and ensure the supply of biomass. Several studies on biomass availability and land use were already performed recently due to the announcement of the Commission of the Renewable Energy Directive. However it is much more difficult to find studies on the biomass needed for commodity production of chemical intermediates or other biobased products.

The Nova institute in Germany estimates that 500 million ha of land are available world-wide (and this without cutting down forest or using artificial irrigation) to produce biomass in a sustainable way in response to the growing food, chemicals, materials and energy need. Meeting this challenge without hindering the production of food for a fast growing world population and without negatively impacting the environment and biodiversity also requires optimising production per hectare of land through increased crop productivity (use of improved and transgenic plant varieties, soil conditioners, fertilisers,...), land and water management. This requires improved technologies and research related to better agricultural system management but also involves better access to and use of existing technologies.

Biomass including waste is by far the largest renewable energy source consumed in the EU-27 and is consumed in all three sectors of power and heat generation, and transportion. In 2007, consumption of biomass and waste grew by almost 10% taking it to a total of 98,3 million toe (tonnes oil equivalent) and by another 5% in 2008 to 102,3 million toe. It so represented 70% of the gross inland consumption of *renewable* energy sources in the EU. In the total energy consumption in the EU, biomass and waste represented already 8% (Figure 8).

How much energy will be derived from biomass in the future? This will depend on many factors: market forces, economic incentives and speed of technological change in the different renewable energy subsectors will inter alia determine the energy mix necessary to achieve the 20% target in 2020. The projected contribution of biomass thus hinges heavily on assumptions.

The European Environmental Agency (EEA) estimated EU primary energy requirement at 1.8 billion toe in 2020 and projected biomass to be able to contribute with 13% or 236 million toe.

An almost identical projection is reproduced in the Commission's "Impact Assessment of the Renewable Energy Roadmap" where the higher scenario results in a biomass potential of 230 million toe, the lower being 195 million toe (Figure 9) (EC, 2006).

The FORRES 2020 study also has analysed two scenarios: The business as usual scenario anticipates 215 million toe, whereas the policy scenario (assumed to maximise renewable energy) suggests a much higher potential in 2020: 455 million toe (Ragwitz et al., 2005).

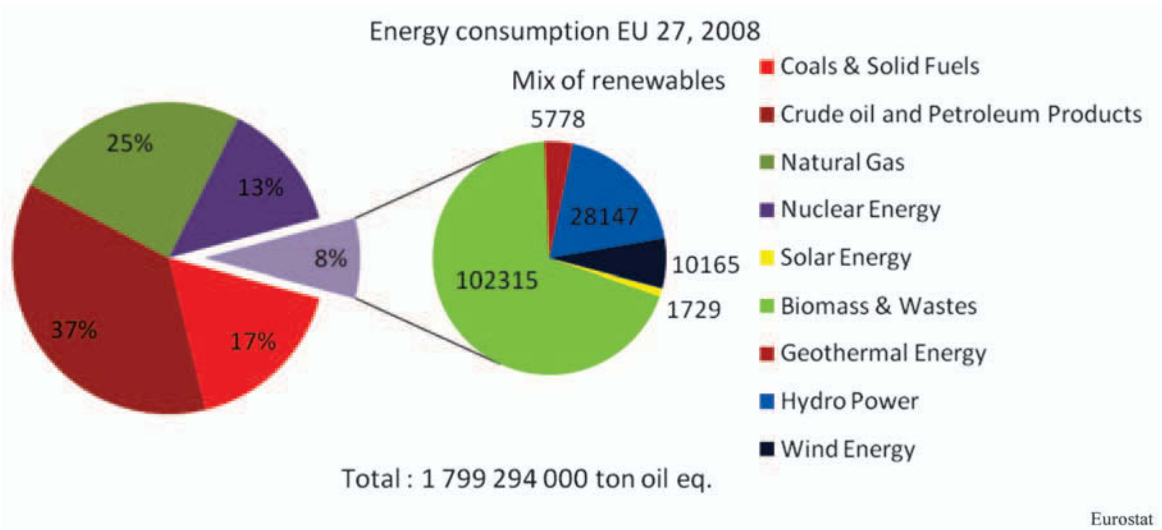


Figure 8. — EU 27 energy consumption in 2008, according to fuel source (× 1000 toe)

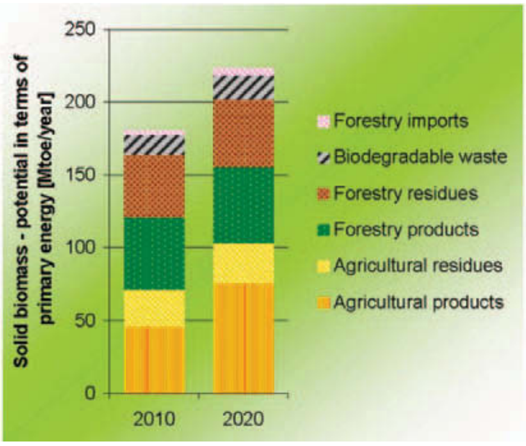


Figure 9. — Solid biomass potential in primary energy terms (million toe/year) (EC, 2006)

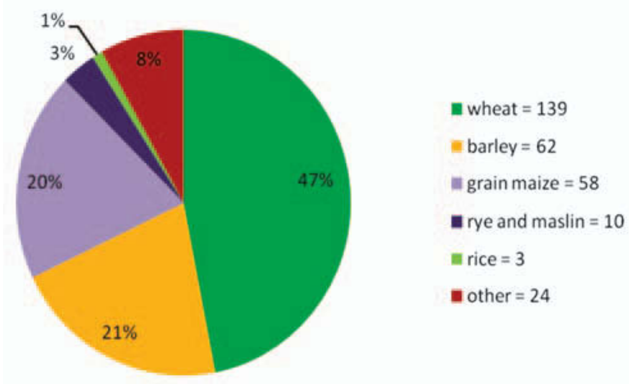


Figure 10. — Harvested production of cereals by type of cereal, in million tonnes, EU-27, 2009

COLOR PRINT ?

Based on current knowledge, it is thus reasonable to assume that biomass could account for two thirds of the renewable energy target in 2020. For this to become reality, biomass use has roughly to triple. Those two studies, which give a sectoral breakdown, allow to discern a similar two stage pattern:

- 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, they agree that most of the genuine growth in biomass potential will have to come from "agriculture" (EEA study) or "agricultural products" (Impact Assessment of the Renewable Energy Roadmap).

3.2. 1st F: Food & feed

It goes without saying that biomass is to be used as a first priority for food and feed supply. Indeed crop production plays a key role in human and animal food security. As a major user of the soil, agriculture shapes the rural landscape. Half of the surface area of the European Union (EU) is used for agricultural purposes, hence the importance of agriculture to the EU's natural environment. European agriculture is increasingly prioritising the kind of high-quality, environmentally-friendly products demanded by the consumer market.

In terms of the area that they occupy and their importance in human and animal food supply, cereals (including rice) constitute the largest crop group in the world. Also in the EU cereals are the most widely produced crop.

The Eurostat Pocket booklet "*Agricultural statistics, Main results 2008-2009*" gives a good overview of the most important figures on agriculture in the EU (EC, 2010).

Wheat, barley and grain maize are the cereals most grown in the European Union in 2009. These crops accounted for some 30% of the EU's utilised agricultural area in 2009 (Figure 10).

Nevertheless, cereal production has fluctuated considerably over time. After a very high increase in 2004 (29% higher than 2003), cereal production fell sharply between 2004 and 2007 (- 20%). In response to the very high cereal prices in 2007, production in 2008 increased by 19% but dropped by 6% in 2009, still good for about 296 million tonnes.

Wheat at 139 million tonnes, represents almost half of all cereal production in 2009 (47%). It is also one of the most widely distributed crops in the EU, on a total area of 24,5 million hectares (Figure 11). Wheat is primarily used in human and animal food products, but also for making processed products, such as starch and bioethanol.

Barley production totalled 62 million tonnes, accounting for 21% of all cereal production. Barley is the main crop for brewing beer.

In 2009, 57.8 million tonnes of grain **maize** were produced in the EU (Figure 11). Grain maize is mainly intended for animal feed but it is also used for industrial products, such as starch, glue and biofuels.

Rye and **Maslin** production totalled approximately 10 million tonnes, or 3% of cereal production. **Rice** accounted for 1% of production at around 3 million tonnes.

In 2009, 20.1 million tonnes of **rapeseed** were produced in the EU, or almost the double of the 11.2 million tonnes in 2000. Rapeseed is used in the manufacture of oil (mainly non-edible oil, such as biodiesel, but also edible oil) and animal feed

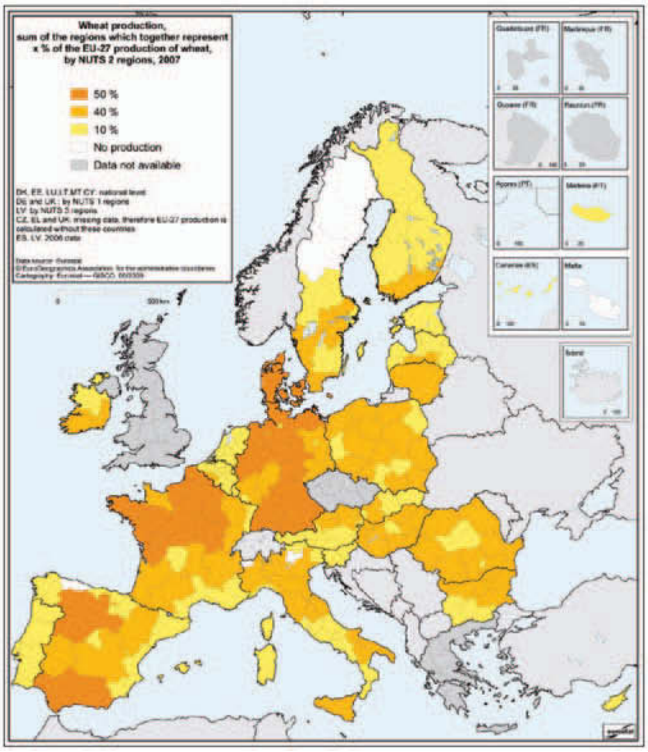


Figure 11. — Distribution of wheat production in % of Member States in EU 27 in 2007

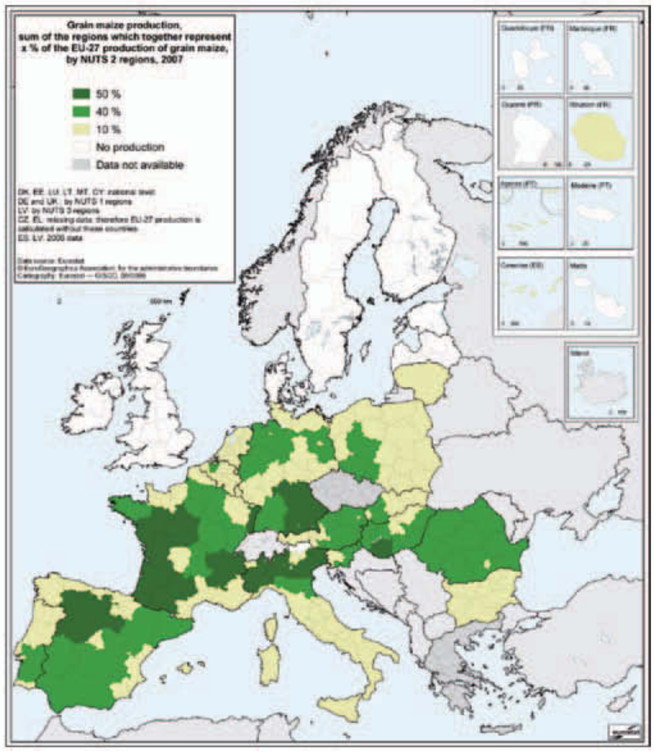


Figure 12. — Distribution of maize production in % of Member States in EU 27 in 2007

(rapeseed cake from the crushing of rapeseed grain). The increase in rapeseed production is clearly due to the high demand in recent years for renewable energy, such as biodiesel. Rapeseed is best suited for a temperate climate. Germany and France are the regions with the highest production.

Sugar beet production grew steadily between 2003 (110 million tonnes) and 2005 (147 million tonnes), subsequently decreasing by 23% in 2006. Since 2006, production has been more stable, fluctuating around the 100 million tonnes (110 million tonnes in 2009). France and Germany are the greatest producers, together accounting for 55% of the total EU27 production. Surprisingly production dropped by more than 98% in Latvia between 2003 and 2008 and in 2009 the production completely stopped. Also in Ireland the production dropped by more than 95%.

Utilised Agricultural Area (UAA) represents 37% of the whole EU-27 territorial area of 432,5 million ha. As part of UAA, arable land represents almost one quarter, 25%, of the whole EU-27 territory. Denmark has the highest share of arable land (57%). Land under permanent crops represents less than 3% in the EU-27.

Permanent grassland represents 14% of EU-27 territory. In Ireland and the United Kingdom 45% of the land used is permanent grassland, mainly used for animal grazing. It is therefore not surprising that in these countries, various projects are initiated to determine whether grass can be used as a useful biomass feedstock for bio-energy and in biorefinery projects. In Flanders we have the project 'Graskracht.be', where twelve partners: with the funding of EFRO they will look into the possibility to use grass for the production of biogas as energy source.

3.3. 2nd F: Fine & bulk chemicals and pharma

3.3.1. *Industrial biomass conversion into chemicals via industrial biotechnology*

As worldwide demand for petroleum, so far our main fossil-resource to produce not only energy, but also chemicals and materials is steadily increasing, particularly to satisfy the fast growing economies of countries such as China and India, petroleum prices are expected to rise further. Whereas this fossil resource will certainly not become exhausted from one day to another, it is clear that its price will follow a long-term upward trend. Its scarcity and high price will not only afflict the chemical industries and energy sectors drastically all around the world, but it will impact on society as a whole.

Consequently, concerns have arisen not only about our future energy supply, but also about our increasing needs for fine and bulk chemicals. In the first place, this has caused an ongoing search for renewable energy sources that will in principle never run out, such as hydraulic energy, solar energy, wind energy, tidal energy, geothermal energy and also energy from renewable raw materials such as biomass. Bioenergy, the renewable energy released from biomass, is indeed expected to contribute significantly in the mid to long term. The same holds more than true for the synthesis of fine and bulk chemicals, materials and polymers, now also mainly based on fossil resources, petroleum, gas and coal. Hence the chemical industry will be confronted with the switch to biomass sooner than anticipated and to introduce the concept of reuse and resource technology (Mc Donough and Braungart, 2002; Dale, 2003; De Wulf et al., 2010).

In contrast to these fossil resources, bulk agricultural raw materials such as wheat, rice or corn have till a few years ago been continuously low (and even declining) in price because of increasing agricultural yields, a tendency that has recently drastically changed, especially with the "suspected" and "advocated" competition between biomass for food use versus biomass for chemicals or biofuels use, becoming a societal issue. However in reality, climate changes, droughts, high oil prices and the switch to non-vegetarian diets in fast developing economies such as China are actually the main underlying causes of the increasing food prices. New developments such as plant genetic engineering (Van Beilen, 2008) - specifically of industrial or energy crops - and the production of bioenergy and chemicals from agricultural waste and agro-industrial residues can relieve these trends. Agricultural crops such as corn, wheat, rice and other cereals, sugar cane and beet, potato, tapioca, etc. are already for decades processed in the starch and sugar refineries into relatively pure carbohydrate feedstocks (starch, sugars,…), primary substrates for the food industries, but also for most industrial fermentation processes and for some chemical processes (Dahod, 1999; Kamm and Kamm, 2004). Especially fermentation processes can convert those agro-feedstocks into a wide variety of valuable chemical products, including bulk and fine chemicals, pharmaceuticals, and enzymes as well as biofuels such as bioethanol, and organic solvents such as butanol (An, 2005; Demain 2007; Kunz, 2008; Wall et al., 2008; Soetaert and Vandamme, 2006; 2009; 2010).

Oilseeds such as soybean, rapeseed (canola) and oilpalm (but also waste vegetal oils and animal fats) are equally processed into oils that are subsequently converted into food ingredients but now increasingly into oleo-chemicals and biodiesel (Canakci and Sanli, 2008; Vasudevan and Briggs, 2008).
While these technologies are rather mature, agro-industrial residues or waste streams such as straw, bran, beet pulp, corn cobs, corn stover, oil cakes, waste wood, … all rich in lignocellulosic materials, are now either poorly valorised or left to decay on the land (Zhang, 2008). These residues are now already efficiently converted into biogas and used for heat, steam or electricity generation (Weiland et al., 2009; Soetaert and Vandamme, 2009). These waste materials attract now increasingly attention as an abundantly available and cheap renewable feedstock for chemicals, materials and biofuels production. Improved physical, chemical and biotechnological treatments must now quickly be developed to upgrade and valorise these agro-industrial side streams (Singh-Nigam and Pandey, 2009).

As stated above, novel technology is needed. The question is: Which technologies need to be developed and which biochemicals will be of use in this context? The US Department of Energy (DoE) and the European Commission have confronted this issue by ordering a study on sustainable production of chemicals from renewable resources. These reports indicated several chemicals that can be biochemically produced and that can be economically viable, stipulating the necessity for further research in industrial (or white) biotechnology.

Table 1 gives an overview of some of these chemical building blocks, divided in acids and alcohols and amino acids (An, 2005; Demain, 2007; Soetaert and Vandamme, 2010).

3.3.2. *Fermentation and biocatalysis as enabling technologies*

It is only now being fully realized by the chemical industry that also microorganisms (bacteria, yeasts, fungi and micro-algae) are an inexhaustible source of a wide range of useful enzymes and chemical compounds: indeed, an ever increasing number of fine and bulk chemicals, solvents, food additives, enzymes, agrochemicals and biopharmaceuticals is now being produced based on microbial biotechnology via industrial fermentation or biocatalysis processes (Gavrilescu and Chisti, 2005; Demain, 2007; Vandamme, 2007). Often, there is no alternative route for their synthesis but fermentation. Also bioconversion reactions, based on the use of (immobilised) microbial biocatalysts (cells or enzymes), yield useful interesting regio- and enantioselective molecules under mild reaction conditions, often starting from racemic precursors (Vandamme et al., 2005; 2006; Wohlgemuth, 2010). Furthermore, all these microbial processes have a positive environmental impact.

These microbial products generally display desired chirality, are biodegradable and practically all are produced, starting from renewable (agro)-substrates, till now mainly starch and sugars. Indeed, these nutrient substrates, which are the "workhorse" ingredients in

Table 1. — Overview of some important chemical building blocks that can be produced via biotechnological processes. (F, E and C indicating the main current production process: fermentation enzymatic or chemical process).

Type of chemical							
Acids and alcohols						Amino acids	
Sugar	Building block	Method of production	Sugar	Building block	Method of production	Building block	Method of production
C2	Ethanol	F	C5	Itaconic acid	F	L-Alanine	F
	Acetic acid	C/F		Glutamic acid	F	L-Arginine	F
	Glyoxylic acid	C				L-Aspartate	F
	Oxalic acid	C				L-Glutamine	E
						L-Glutamate	F
						L-Histidine	F
						L-Hydroxyproline	E
						L-Isoleucine	F
						L-Leucine	F
						L-Lysine	F
C3	Lactic acid	F	C6	Citric acid	F	L-Phenylalanine	F
	3-hydroxypropionic acid	C/F		Aconic acid	F	L-Proline	F
	Glycerol	C/E		Cis-cis muconic acid	F	L-Serine	F
	1,2-propanediol	C/F		Gluconic acid	C/F	L-Tryptophan	F
	1,3-propanediol	C/F		Kojic acid	F	L-Threonine	F
	Propionic acid	C		Adipic acid	C	L-Valine	F
	Acetone	C/F					
C4	Fumaric acid	F					
	Succinic acid	C/F					
	Malic acid	C/E					
	Butyric acid	C/F					
	1-butanol	C/F					
	2,3-butanediol	C					
	1,4-butanediol	C					
	Acetoin	C/F					
	Aspartic acid	F					
	1,2,4-butanetriol	C					

industrial fermentation processes worldwide, are mainly derived from agricultural crops, being processed in the established sugar and starch refineries. Agricultural practice as well as this industrial processing leads to agro-industrial residues, which should be considered now also as nutrient or resource substrates, rather than as a waste!

The ultimate choice of feedstock source type for a given fermentation process is a complex decision, based on imperatives given by the microbial strain involved, or on the nature of the end product and on technical and economic considerations (Table 2).

Some important factors in comparing the benefits and/or disadvantages of using crude or refined carbohydrates or oils as carbon source in industrial fermentations have been compiled by Stowell (Stowell et al., 1987). The key point here is that microorganisms can convert these abundantly available and renewable nutrient sources into a vast range of very complex biochemicals with often unsuspected application potential (Demain, 2007; Vandamme, 2007). Submerged fermentation has been the mainstay industrial biotechnology production process in use, but as increasingly crude (solid) agro-industrial residues will become available, solid state fermentation processes will experience a remarkable revival in the near future (Robinson et al., 2001; Singh-Nigam and Pandey, 2009).

When switching to agro-industrial residues or even agro-waste streams, the bottleneck remains to release the fermentable sugars, left in the lignocellulosic

Table 2. — Economic and technical considerations in the selection of fermentation nutrient sources.

Availability	Consistency of nutritional quality
Cost per unit of nutrient	Flexibility in application
Transportation cost	Rheological properties
Price stability	Surface tension factors
Pre-treatment costs	Product recovery impact
Stabilisation costs	Process yield
Storage costs	Product concentration and type
Safety factors	Overall productivity

matrix, the main component of these residues (Zhang, 2008; Sarath et al., 2008; Vasudevan and Briggs, 2008; Canakci and Sanli, 2008).

Special pre-treatments of these agro-industrial side streams are a prerequisite: mechanical (thermo) physical, chemical and enzymatic pretreatments will be primordial in most cases, before microbial fermentation technology or enzymatic upgrading (biocatalysis) can start. An exception here is the use of solid state fermentation technology, where crude lignocellulosics are directly provided as a substrate for microbial productions (Singh-Nigam and Pandey, 2009). The switch to agro-industrial residues will also put even more emphasis on pretreatment (upstream-processing) and on downstream-processing costs in the overall economics of such "second generation" fermentation processes!

The production potential of a wide range of fine and bulk chemicals, fuels, materials and fibres based on these agro-industrial and biomass residues is enormous. If these processes materialise in the near future, it will relief drastically current societal tension whether to use biomass and crops for food or for platform chemicals and biofuels (Morris, 2006). This potential is outlined in Figure 13.

Several groups of microbial products are known as fine chemicals and biopharmaceuticals to be relevant to the *medical* community. Examples are antibiotics and antitumor agents, anti-virals, immune stimulating and suppressive agents, cholesterol lowering drugs and other enzyme inhibitors, as well as toxins and siderophores, and many more.

Also, there are many "chemical" products of microbial origin already produced on an industrial scale that play an important role in the *agricultural and food* industry. Examples are dyes and vitamins, polyunsaturated fatty acids (PUFAs) such as omega-3 and omega 6-fatty acids, food flavours, L-amino acids and organic acids such as acetic, citric and lactic acid, and a range of biopesticides.

Rather unexpectedly, *the polymer industry* has recently created the biggest boost towards biochemical production. The fermentation products, lactate, 1,3-propanediol, 1,4-butanediol, polyols, … are all primarily used in the production of biopolymers.

Lactic acid production may be called a success story in fermentation technology. Classical chemical synthesis was based on lactonitrile derived from acetaldehyde and hydrogen cyanide, but it results in a racemic DL-lactic acid mixture, which is very difficult to purify. Fermentative routes have overcome this chemical problem.

The application fields are very versatile, ranging from food industry, over textile and pharmaceuticals to the chemical and polymer industry. Particularly in the polymer industry poly-lactic acid (PLA) has shown to be promising, e.g. as a green plastic.

Succinate as base chemical has first been pointed out by Jain and coworkers in 1989, after which the US Department of Energy marked it as one of the top added value chemicals from renewable resources (Jain et al., 1989).

Nowadays the succinic acid market is still quite modest, about 15000 tonnes per year worldwide. The market potential is estimated at 270000 tonnes per year, due to the many applications in a wide variety of economic sectors.

The existing succinic acid markets are the detergent/surfactant market, the ion chelator market, food market (e.g. acidulants, flavours or antimicrobials) and the pharmaceutical market.

3.4. 3rd F: Fibres & biomaterials

3.4.1. *Textiles and biobased fibres*

The textile and clothing sector remains one of the key manufacturing branches in a significant number of countries of the European Union. The sector has an annual turnover of more than 200 billion Euros and employs some 2,5 million people in over 150 000 companies across the EU-27. The EU is the world´s second biggest exporter of textiles and

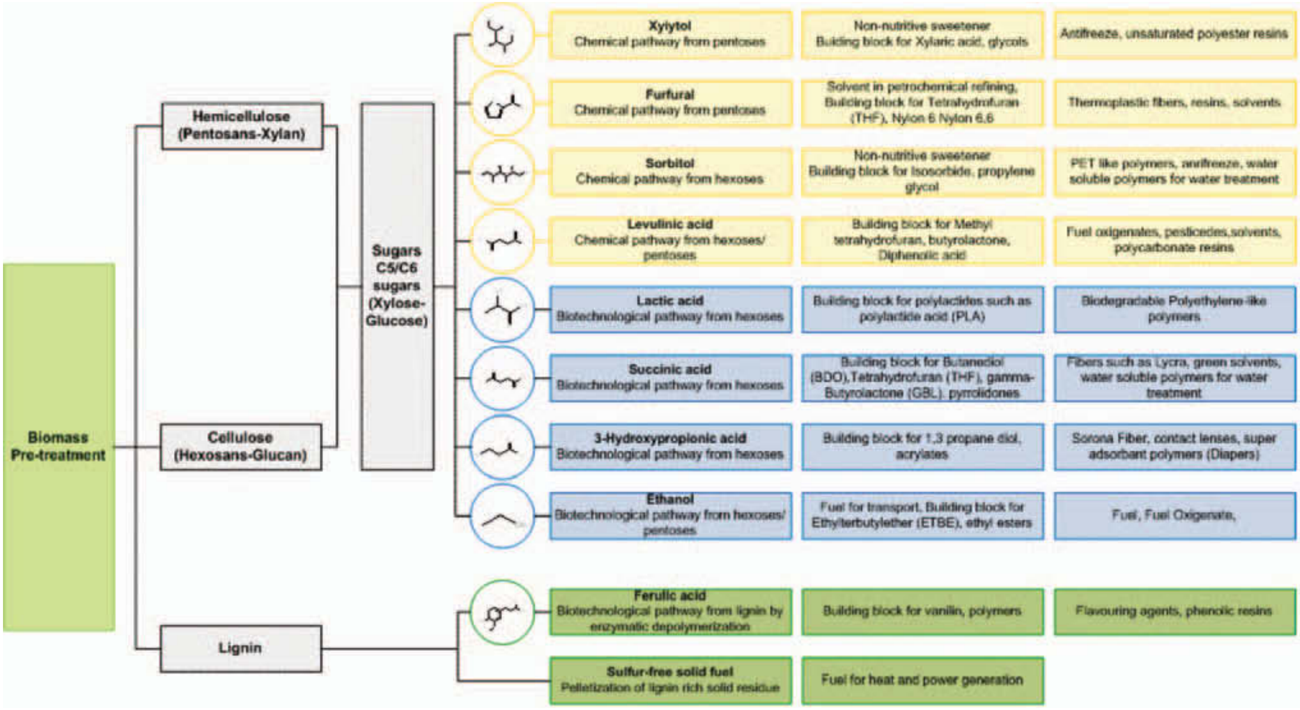


Figure 13. — Sugar-lignin platform potential for value-added chemical production (http://bpe.epfl.ch)

world´s third biggest exporter of clothing. Faced with fierce global competition from low-wage countries, its sustainability strongly depends on a new multi-disciplinary approach based on innovative high quality products and flexible, environmentally-friendly production systems. In addition, new initiatives to develop new attractive end-use markets for textiles need to be stimulated.

Industrial biotechnology has a major potential to drive the textile sector into employing new possibilities of selective enzymatic catalysis (as an alternative to harsh chemical processing); new bio-based materials can be expected to lead to the launch of textiles with new functional properties (being an alternative source of textile auxiliary agents, creating new functional properties for technical, medical, wellness and other smart textiles). Increased utilisation of natural renewable fibre sources and of artificial (bio-fermented) fibrous polymers via biotechnological processing will result in cleaner production processes. It is also an instrument to arrive at new surface architecture of hybridized fibrous matrices.

Since the oil price influences many textile industry related factors (energy cost, textile fibre costs, the dyes and chemicals used !) it is expected that the use of sustainable technologies (industrial biotechnology and other environmental friendly technologies) and of bio-based materials will be beneficial for the sector.

A broad range of biorefinable fibres already exists e.g. waste material from bast fibres (flax, hemp) as well as emerging technical biomass, such as Spanish broom (*Spartium junceum*), straw, wood and woodchips. These co-products have potentially a high value as new materials for composite reinforcement as new qualities of construction and manufacturing materials, as fibrous additives in building materials, etc.

Not only bio-fibres but also bio-resins, essential oils, surface-active bio-substances, etc... can be extracted from the biomass. These can be introduced as a new source of functional finishing auxiliary agents (e.g. UV absorbers, antimicrobials, health and body care). Biotechnological processes such as controlled "bio retting" can be part of tailor-made processing technology to enhance utilisation of biomass in (rural) bio-refineries.

This evolution can be compared to the utilisation of locally available renewable sources in textile manufacturing which was one key element of European textile industry genesis. This development could provide new opportunities for fashion garments and technical textile applications. Direct use of extracted fibres as such followed by special surface (bio)modification (elementarisation, resin adhesion improvement, fibre fineness, cottonisation etc.) as well as the extrusion (co-extrusion) of natural fibres and extracted polymers offer also great potential.

On the other hand, textile wastes could be studied as one of the larger sources of feedstock for biorefineries within a biofuel program; the synthetic part of textile blend products can be recycled separately (with the natural, cellulosic part being utilised as fermentation feedstock).

3.4.2. *Wood, pulp and paper*

Wood counts for approximately 80% of the biomass used for renewable energy. A clear potential to intensify forest utilisation for energy exists in the EU as only 60-70% of the annual increment of EU forests is harvested. At present about half of the harvests are eventually used for energy; by-products from higher value processing have a significant share. Significant expansion potentials locate in smaller private forest holdings and are related to forest residues and complementary fellings, namely first thinnings.

The "Forest Statistics Eurostat Pocketbook, 2009" gives a brief overview of the forest sector (EC, 2010).

There are two categories of *roundwood*: industrial roundwood and fuelwood. The commodities included in *industrial roundwood* are logs, pulpwood and other industrial wood (the final use determines the commodity). Logs are used for the production of sawnwood (including sleepers) and veneer sheets. Pulpwood is wood in the rough used for the manufacture of pulp, particle board and fibreboard. Other industrial roundwood includes roundwood that will be used e.g. for poles, piling, posts, fencing, pit props, tanning, distillation or match blocks. *Fuelwood* is wood in the rough (from trunks and branches of trees), to be used as fuel for cooking, heating and power production.

Since 1998, there has been a relatively steady rise in the level of roundwood production in the EU-27, both for coniferous (softwood) and non-coniferous (broadleaved or hardwood) species. The 420,5 million m^3 of roundwood produced, of which 104.9 million m^3 of sawnwood, within the EU in 2009 was about one tenth less than the relative peak that was recorded in 2007. This peak was due to exceptional windthrow caused by storms in many parts of Europe – notably in Sweden and Germany – after which much more wood had to be removed from forests than planned. Among the Member States, Sweden was the largest producer of roundwood, followed by France, Germany and Finland.

The production of paper and paperboard in the EU-27 was about 100 million tonnes in 2008, which was 2.4% down on the level of the previous year, bucking the relatively steady upward trend in output during the previous nine years. A little less than half of the EU's paper and paperboard production in 2008 came from three Member States; Germany (22.9%), Finland (13.6%) and Sweden (12.4%).

Residues and waste streams from wood, pulp and paper processing can be turned into energy or converted into (bio)chemicals.

3.5. 4th F: Fuels & energy

3.5.1. *From fossil energy to bio-energy*

Energy sources and technology evolve over time - and each influences the other. By overlooking the history of energy and technology use, the future course of the energy challenge can easier be understood. It shows how energy sources and technologies have changed over the last 150 years and how it enhanced the development in the Northern Hemisphere (Figure 15). Back in 1850, the fuel most widely used in the world was still wood. 50 years later, as mining evolved, coal became the primary source of energy in the North. Access to energy enabled growth into an industrial economy. Another 50 years later, as the streets began

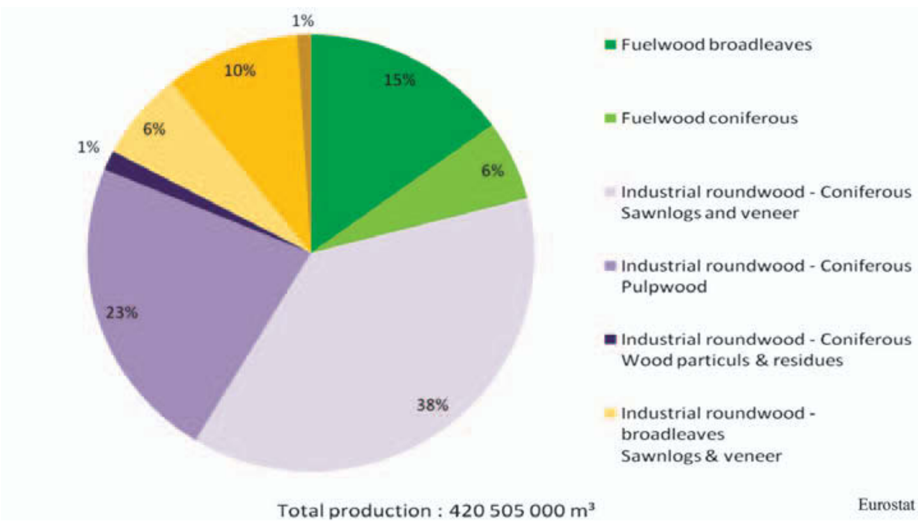


Figure 14. — Total wood production (%) in 2009 in EU-27

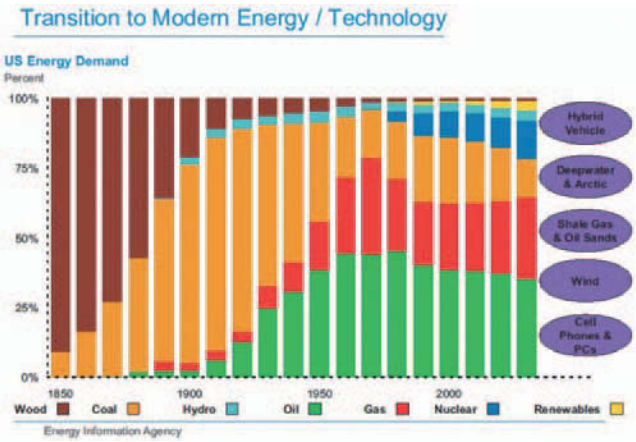


Figure 15. — The historic evolution of energy use over the last 150 years (source ExxonMobile)

to fill with buses, cars and trucks and airlines started offering regular services, oil use had risen by 1950 to place it ahead of all other fuels. By then, natural gas – considered nearly worthless a generation earlier – and hydroelectric power emerged as significant energy sources. The period between 1950 and 2000 saw the introduction and growth of nuclear power, and the first meaningful appearance of modern renewable energies. Also it was realised that fossil oil production was soon to reach its peak (see page 28, Peak Oil theory). In the years ahead we will see more new technologies opening up new energy sources, and new end-use technologies will reshape demand patterns. Yet such developments take decades to evolve to the point of revolutionising the way we obtain and use energy.

Energy is also what makes Europe and the world economy tick. It is essential, then, for the European Union to address the major energy challenges facing us today, i.e. climate change, our increasing dependence on imports, the strain on energy resources and access for all users to affordable, secure energy. The EU is putting in place an ambitious energy policy – covering the full range of energy sources from fossil fuels (oil, gas and coal) to nuclear energy and **r**enewable **e**nergy **s**ources (RES, i.e. solar, wind, biomass, geothermal, hydro-electric and tidal) – in a bid to spark a new industrial revolution that will deliver a low-energy economy, whilst making the energy we do consume more secure, competitive and sustainable.

Peak oil theory

The Hubbert Peak, also known as Peak Oil, is the time to reach a peak in oil production - based on a mathematical model that was developed in 1956 by M. K. Hubbert, an American geophysicist employed by Shell in Texas. The model shows how oil production in the U.S. could proceed. The Peak theory can also be applied to global oil and other fossil fuels or even other resources like natural gas and coal (Hubbert, 1956). During the extraction of oil or other minerals yield will have a specific lifecycle. The aggregate production rate from an oil field over time usually grows exponentially until the rate peaks and then declines – sometimes rapidly – until the field is depleted (Figure 16).

In 1956, Hubbert predicted that U.S. oil production in the late sixties and early seventies would peak before declining. His logistic model described with reasonable accuracy the peak and decline of production from oil wells.

Only after his predictions in the early 70s showed that he had been right, his theory was taken seriously.

In essence, the Peak Oil theory states that oil production will peak irrespective of the technological improvements taking place. The question is when. According to some, the peak was reached already in 2005, to others (OPEC) the peak will occur in the period 2020 to 2030; and still others assume that the Hubbert Peak will take place in the first decades of the twenty-first century (Campbell 1998).

The Hubbert Peak can be considered to be the end of the first part of the oil era : cheap, abundant energy availability and an ever-increasing economic growth. After the Hubbert Peak begins the second part of the oil era: increasingly scarce and expensive energy. Modern society still depends on oil as a supplier, not only for energy but also as raw material for numerous chemicals and products.

Opinions are divided about the future after the Peak Oil (Figure 17). According to some, the world economy (and civilization) will collapse. Some think that it will cause especially for the Western civilizations major changes, while the poorer countries – who still have relative low energy consumption – will suffer less pain.

Others expect a soft landing, with a steady increase in more sustainable renewable energy, and a more energy-efficient way of life. Furthermore new technical developments will probably find new solutions.

Depending on the timing and the speed at which oil production begins to drop, more responsible use of energy and reduction in consumption can have a great impact at reasonable cost.

Technical developments as answer to the energy equation of the future could be: biofuels, increased use of nuclear energy, fusion, and increased use of renewable energy resources such as biomass, wind, tidal, solar, geothermical, hydrogen...

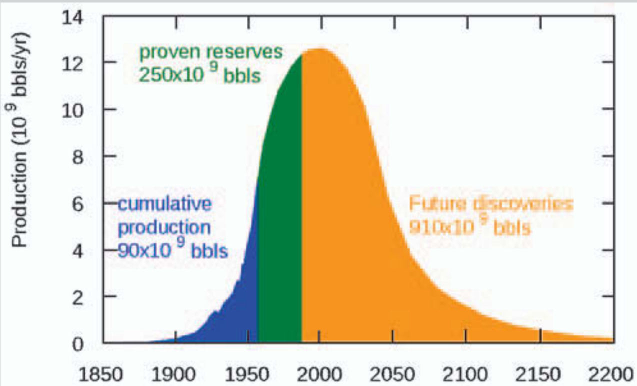


Figure 16. — A production curve of an oil well, as originally suggested by M. Hubbert in 1956, now known as the peak oil theory

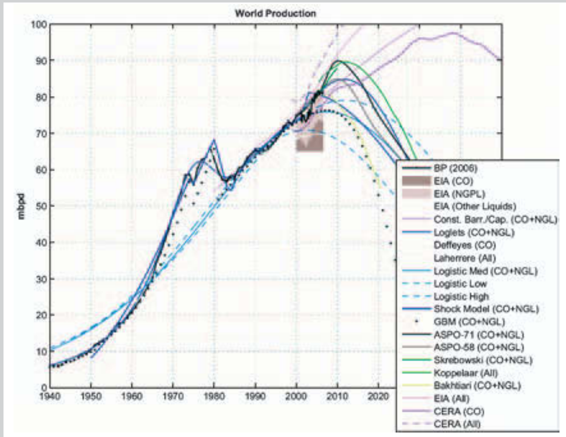


Figure 17. — Peak oil depletion scenarios graph, which depicts cumulative published depletion studies by the ASPO* and other depletion analysts.

*The Association for the study of Peak Oil & Gas, www.peakoil.net

3.5.2. *Biofuels as a test case*

Biofuels are (transportion) fuels made from biomass. The most important biofuels today are bioethanol (made from sugar and cereal crops, used to replace petrol) and biodiesel (made mainly from vegetable oils and animal fats, used to replace diesel). Biofuels accounted for about 3.4% of transport fuel consumption in 2008 – up from 0.5% five years earlier. The mix of biofuels in the total fuel consumption in the EU 27 is steadily increasing (Table 3).

Food versus Fuel

As the first generation of biofuels (mainly bio-ethanol and biodiesel) is based on the same raw materials (sugars and plant oils, resp.) as for food production, the strong increase and fluctuations in food prices worldwide in 2008 have been widely blamed (by the media) on the development of biofuels. It is an easy message that anyone understands and that has caused consumers concern.

A comprehensive study on land use to meet future needs for biobased chemical intermediates (bio-energy not included) shows for instance clearly some targets for policy and investment. Three scenarios were evaluated, in which low, medium and high (respectively 16%, 40% and 83%) percentages of conventional (petro) chemicals would be replaced by biomass derived chemicals. In Europe this would mean that about 1 million (low) to 38.2 (high) million ha of arable land would be needed in 2050 if starch would be used as a substrate. In the case of lignocellulosics, these land areas would drop to 0.4 to 15.6 million ha. In the assumption that there would be a full substitution towards biochemicals, the starch scenario would need 126 million ha and the lignocellulosics scenario would need 52 million ha. As a reference, the total agricultural area of the EU-27 in 2005 is 192 million ha. Because about 15% of this total area is now set aside and agricultural yields in Central and Eastern Europe are still low, about 77 million ha would be available by 2050, making only the lignocellulosics scenario feasible in the long run.

Based on the above comments, it is now becoming clear that the development of biofuels was not really the main culprit for the observed increase in agricultural food prices, but rather a combination of several events:

1. The increasing world population, coupled with a remarkable increase in the overall standards of living, has resulted in a strong increase in demand for food. Also the change in dietary habits has added substantially more pressure on the world's grain markets, as animal protein (meat) production demands five times more grain crops than a vegetal diet. This "crops for feed" has impacted food prices far more than "food for fuel".
2. Many of the so-called "grainbasket countries", such as Australia, Ukraine, Russia,... have experienced a few years ago (2007-2008) a series of poor grain harvests. These have consumed the world's grain reserves to low levels, paving the way for strong speculation, resulting in high prices of agricultural commodities. However, recent harvests reach record yields, such that this trend will turn.
3. The current agricultural practice is still strongly dependent of fossil energy inputs, so that the overall rise in energy prices reflects also in increased costs of production for agricultural products.

The development of biofuels can have a range of positive and negative consequences. Whereas an increased demand for biomass (for both food and fuels) can give rise to undesired effects, such as tropical deforestation for palm oil plantations in Indonesia, Malaysia,…, this increase in demand and resulting prices for agricultural commodities also supports rural development and permits farmers to reap a decent income. New crops such as Jatropha plants that can grow on marginal land are now developed all over the world for producing inedible oil that can be converted into biodiesel. More importantly, second generation biofuels are under development, that start from agricultural by-products such as straw, corn cobs, etc, and waste products from the forest, agro -and food production chain. Also, use of certain microalgae, fixing CO2, as a source of fuel-oil also looks promising, In this context, second generation biofuels no longer compete, but are complementary with food production (Soetaert and Vandamme, 2009; Carcoca, 2010).

Table 3. — Fuel consumption in EU-27

Fuel Consumption in EU-27 in Million litres/year				
Year Fuel	2006	2007	2008	2009
Biodiesel	5507	6435	8733	10187
Diesel	218028	227252	230607	224727
Bio-ethanol	1608	1803	2855	3703
Gasoline	125735	122401	117400	108994

Sources: Biofuels Platform and European 2009 Annual Report.

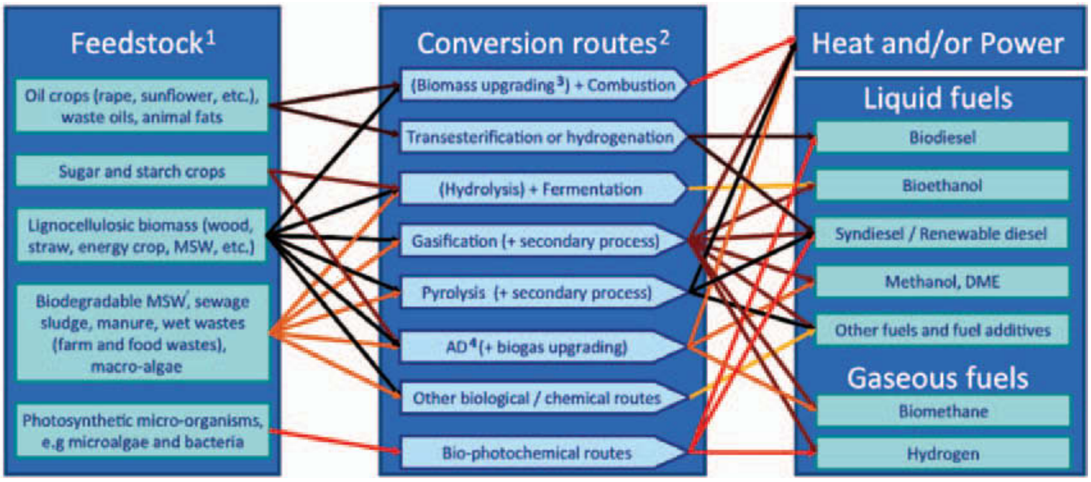
Biofuels are commonly categorized into different 'generations' according to their level of development and the feedstocks they use, though there is no universally agreed definition (Figure 18) (Kunz, 2008; (Pelkman et al., 2008; 2009).

1st generation biofuels are produced from (parts of) agricultural crops with high energy density like oil seeds or fruits. Mature and well developed technologies are used for the production of:

– bioethanol from sugar and starch crops;
  ○ common feedstock: sugar cane, corn …
– biodiesel and renewable diesel from oil crops and animal fats;
  ○ common feedstock: rapeseed, palm oil, soy oil, animal waste oil,….
– biomethane from the anaerobic digestion of wet biomass (see 3.5.3)

2nd generation biofuels are based on new feedstocks, the overall ligno-cellulosic biomass (containing lignin, cellulose and hemi-cellulose) to produce a broad range of novel biofuels. These include:

– Bioethanol and biodiesel produced with conventional technologies but based on novel sources of starch, oil and sugar crops, mostly non food crops, such as Jatropha or Miscanthus;



1. Parts of each feedstock, e.g. crop residues, could also be used in other routes; 2. Each route also gives co-products; 3. Biomass upgrading includes any one of the densification processes (pelletisation, pyrolysis, torrefaction, etc.); 4. AD = Anaerobic Digestion; 5. MSW = Municipal Solid Waste.

Figure 18. — Schematic view of the wide variety of bioenergy routes (Source: Bauen et al., 2009)

– A range of conventional and novel biofuels (e.g. ethanol, butanol, syndiesel) produced from ligno-cellulosic materials (i.e. fibrous biomass such as straw, wood, and grasses). These routes are based on biochemical (ligno-cellulosic ethanol) and thermochemical technologies such as Biomass to Liquid (BtL) and bio-synthetic natural gas (bio-SNG);
– In alternative categorisations, upgraded biogas, hydro-treated vegetable oil or similar, are also denoted as 2nd generation biofuels.

3rd generation biofuels (also called advanced biofuels) generally include biofuel production routes which are at the earlier stages of research and development or are significantly further away from commercialization (e.g. biofuels from algae, hydrogen from biomass).

The goal for 2nd and 3rd generation technologies is to produce sustainable, low cost biofuels from a broad range of resources that do not compete with food production and that have significantly lower greenhouse gas emissions than 1st generation biofuels (Fargione et al., 2008; Soetaert & Vandamme, 2009; Carioca, 2010; Li et al., 2010; Agrowal and Singh, 2010).

3.5.3. *Biomass conversion to biogas*

Anaerobic digestion of the organic matter of biomass to biogas (generally about 65% CH_4 and 35% CO_2) is already a widely established technology. The conversion has the major advantage that all biodegradable molecules without exception, by means of a network of biological conversions, are funnelled to become two gases that distil as such from the wet matrix in which they are formed. The major disadvantage of anaerobic digestion is that it is a relatively slow process relying on a very complex microbial community which is hard to understand and as a consequence often hard to monitor and control.

In Flanders, there are at present some 36 agro-industrial digesters in operation. Their total capacity in 2010 is of the order of 1,64 million tonnes wet biomass digested per year. Most agro-installations convert the biogas to electricity and have a capacity of the order of 0.5-1 MW(e). Yet, the number of larger installations of 2 MW(e) and higher is increasing. In Flanders by digesting agro-organics power is provided of the order of some 61,7 MW(e) (Megawatt equivalent) to the grid. In Wallonia there are 19 digester in operation for a total capacity of 24,5 MW(e) (Meeus et al., 2010). Besides the numerous agricultural reactors worldwide (some 4000 in Germany alone), there are also some 4000 industrial anaerobic digesters worldwide, dealing with agro-industrial wastes.

Due to the fact that methanogenic biocatalysis makes use not only of prime carbohydrates, but of all reducing equivalents present in the incoming substrate, the net recovery of energy by the biogas technology per hectare outranks by far the other technologies (Figure 19). Also in case one does not consider electricity as the end product, but fuel for transportion, biogas outranks the other technologies. Moreover, during the digestion only the energy captured and stored in the form of reduced carbon is removed. Hence, all nutrients (such as N, P, K,...) remain in the digestate and closed loop agriculture can thus be installed whereby the ecosystem services of the productive agricultural soil can be maintained.

Within the biorefinery concept, full priority is given to the recovery of high value chemicals and commodities

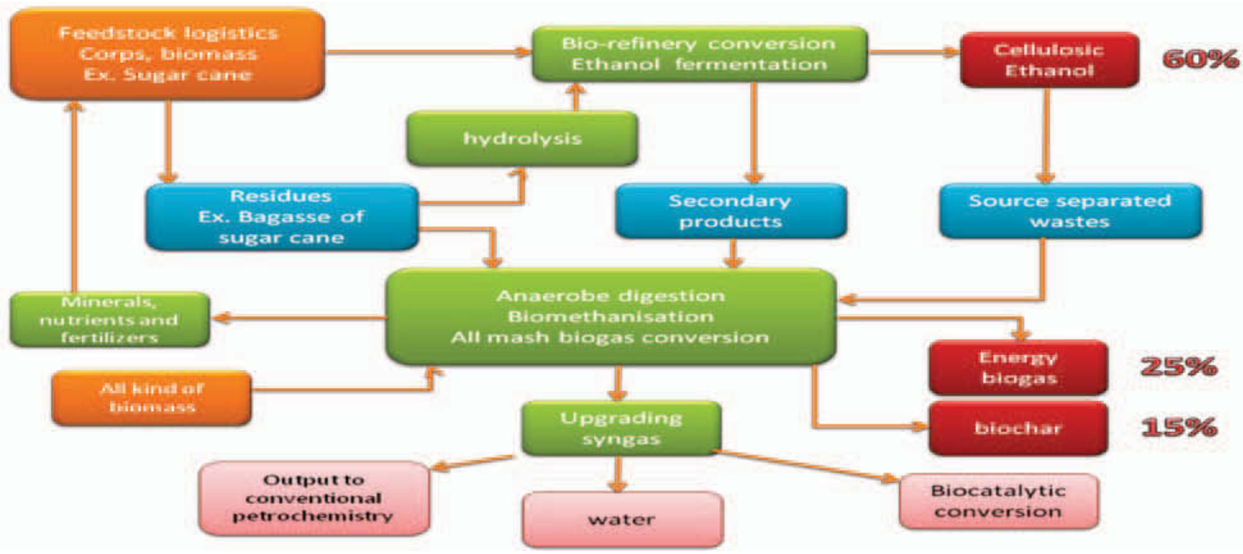


Figure 19. — Biomethanisation scheme of biomass with the incorporation of the biorefinery concept of sugar cane and the potential 'energy' yields in %

from renewable biomass (Figure 19). Each step in the process, some side products of low value and also some waste products can be formed. The latter, together with the eventual final residues of the consumer goods can be recovered in a green and clean way by means of anaerobic digestion. It is assumed that even in much optimized biorefineries a minimum of some 20% of the overall flow will go to biomethanisation in order to guarantee a closed cycle process.

An industrial example where biogas can really make a difference is given by the sugar cane refinery. Indeed, at present in the sugarcane cropping and upgrading industry, a major part of the plant biomass (the leaves) are burnt on the field and another important part (the bagasse) is hardly used or burnt in an extensive way. At present, research is strongly focussing on expanding the net energy recovery, which at this moment is hardly 40% to a fully "Cradle to Cradle" system (McDonough & Braungart, 2002; Carioca, 2010) by incorporating the potentials of biomethanisation in the overall process.

Alternatively, one can also use the anaerobic digestion as a first step in the biorefinery concept.
Indeed, by digesting the biomass to methane, the latter can subsequently be used by conventional chemical processes to produce a variety of commodities (Figure 19). Moreover and most interesting, there have been recent advances in the purification of biogas by means of selective membranes and in the catalytic conversion at low temperatures of methane to methanol which strongly corroborate this route of biorefinery development.

Overall, the biomethanisation of biomass is steadily growing in importance because it operates at numerous levels i.e. the treatment of waste streams, the production of a valuable form of energy, being the cornerstone of a sustainable energy oriented agriculture and finally permitting to contribute to decrease the carbon footprint. In case a very elegant process to convert methane to methanol can come around, it is quite evident that biomethanisation also and as no other process will enter in the domain of harvesting chemicals from biomass.

3.6. 5th F: Fertilisers & soil conditioners

Composting

Compost is composed of organic materials derived from plant biomass and animal matter that has been decomposed largely through aerobic decomposition. The process of **composting** is simple and practiced by individuals in their homes, farmers on their land, and industrially by cities and factories.

Compost can be rich in nutrients. It is used in gardens, landscaping, horticulture, and agriculture. The compost itself is beneficial for the land in many ways, including as a soil conditioner, a fertiliser, addition of vital humus or humic acids, and as a natural pesticide for soil. In ecosystems, compost is useful for erosion control, land and stream reclamation, wetland construction, and as landfill cover.

Will compost decline in favour of anaerobic digestion ?

The last decade anaerobic digestion has known a rapid growth. The technique is mature and is more and more cost effective, due to the production of biogas and electricity. In this context competition with compost was increasing.

Compost needs as input a good mix of organic waste, were the wood fraction is needed for the aeration of the aerobic composting. Anaerobic digestion works more with the 'wet fraction'. The digestate can be use for aerobic composting.

In Flanders the non-profit organization Vlaco vzw promotes the use of compost, but is also responsible for the control on the quality of the compost produced in Flanders. The organization is unique in its kind in Europe!

In 2009 in Flanders almost 766 000 tonnes of organic biological waste was used directly for composting. Another 881 000 tonnes was used as input mix in anaerobic digestion. This is a decrease of 58% in comparison with 2008. Biothermal drying had an input of 341 000 tonnes (Information supplied by VCM (Vlaams Coördinatiecentrum Mestverwerking)).

Manure treatment

Manure contains a lot of valuable nutrients, although not in a stable form. Excessive use of manure in the past has led to nitrate and phosphate pollution of surface- and groundwater. Manure treatment has shown to be a very effective policy measure to cope with local manure surpluses. Various techniques have been and are still being developed for treatment of different types of manure, in order to stabilise, concentrate or remove the nutrients, i.e. mechanical separation, drying, composting, biological N removal, incineration and liming. Techniques like drying, composting and liming generate end-products where the nutrients are stabilised, and which can be marketed as organic fertilisers or soil conditioners. Pelletized, dried animal manure can be used as organic fertiliser (with a known N, P, K-ratio) while the ashes, which result from manure incineration, can be used as a substitute for primary phosphate rock in the fertiliser industry. Recently, a lot of attention is given to the pyrolysis of the dry residue, to produce biochar.

A generic trend is to recover energy from the manure through anaerobic digestion. The treatment of the digestate (which still contains all off the nutrients of the input material) is still a bottleneck. The solid fraction can be dried or directly applied as fertiliser. Finding a feasible treatment with recycling of the nutrients present in the liquid fraction as a replacement form for conventional mineral is still a challenge.

Mineral recuperation

Prices for mineral fertilisers (N, P and K) have gone up considerably. To produce 1 kg of fertiliser nitrogen requires roughly the equivalent of 2 L. fossil fuel energy. Recovery of these nutrients from raw animal manure or after the digestion process for re-use as green chemical fertilisers or as input streams for chemical processes is thus an important challenge, both from an economic and an ecological point of view.

Different techniques have been and are being developed (i.e. ultra- and reverse osmosis filtration, evaporation/condensation,...) in order to recuperate the nutrients present in animal manure and digestates. However, beside several technical bottlenecks, there are major environmental and regulatory obstacles needed to be tackled.

In Flanders, end-products of animal manure treatment processes are still considered as animal manure, in terms of the maximum amounts which may be applied on arable land. However, some processes generate concentrated end-products, which might be comparable to mineral fertilisers based on their high and relatively constant nutrient concentration. Manure and digestate processing end products thus might decrease the need for importing expensive, mineral fertilisers, but this would require them to be recognized as a valuable substitute first.

Biochar – improvement of soil structure

Biochar is found in soils around the world as a result of vegetation fires and historic soil management practices. Intensive study of biochar-rich dark earths in the Amazon (terra preta), has led to a wider appreciation of biochar's unique properties as a soil enhancer. Biochar can be an important tool to increase food security and cropland diversity in areas with severely depleted soils, scarce organic resources, and inadequate water and chemical fertiliser supplies.

But biochar can also be produced as the result of thermal conversion of biomass (carbonisation) by pyrolysis, torrefaction or hydrothermal conversion — processes that heat biomass in the absence (or under reduction) of air (Figure 20).

In addition to creating a soil enhancer, sustainable biochar practices can produce oil and gas by-products that can be used as fuel, providing clean, renewable energy. When the biochar is buried in the ground as a soil enhancer, the system can become "carbon negative" (Lehmann et al., 2006).

Biochar and bioenergy co-production can help combat global climate change by displacing fossil fuel use and by sequestering carbon in stable soil carbon pools. It may also reduce emissions of nitrous oxide.

The carbon in biochar resists degradation and can hold carbon in soils for hundreds to thousands of years.

This simple, yet powerful, technology can be used to store 2.2 gigatons of carbon annually by 2050. It is one of the few technologies that are relatively inexpensive, widely applicable, and quickly scalable.

It is expected that this practice will overcome the problems related to intensified use of crop residues and even improve soil fertility to a level that surpasses that obtained through conventional agricultural practice. This concept offers a solution to this problem by permitting the recovery of crop residues in conjunction with returning biochar back to the soil.

Biochar application to the soil is expected to be an enormous help in maintaining the soil fertility and agricultural productivity at a high level.

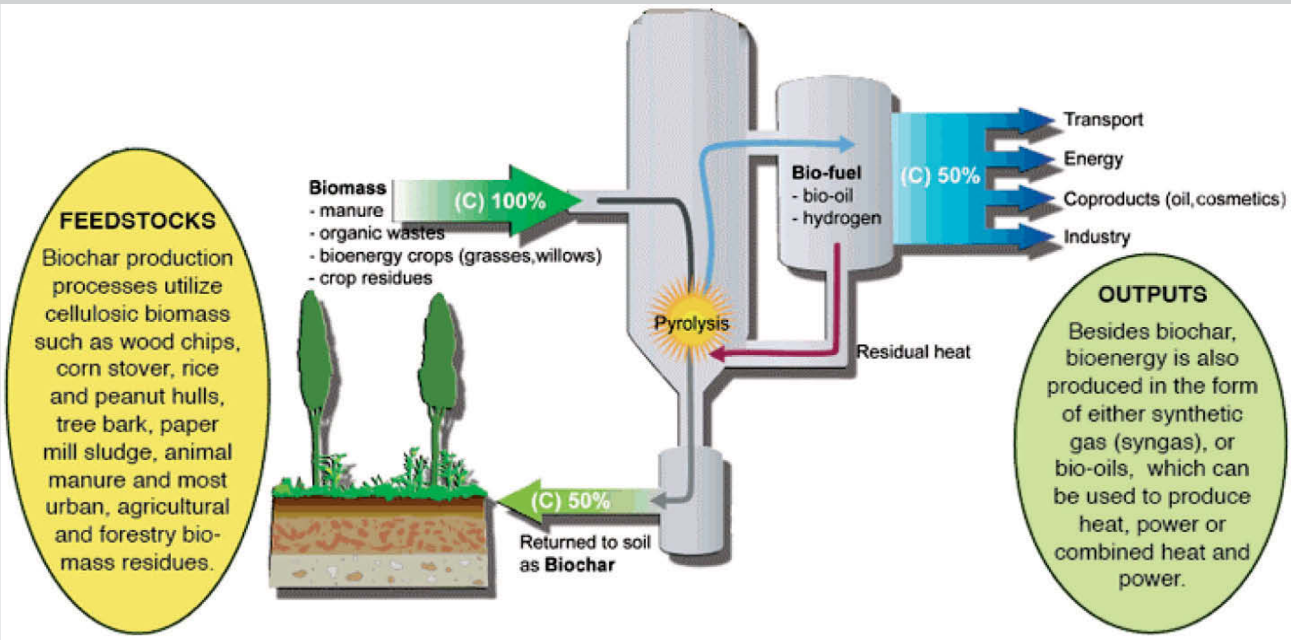


Figure 20. — Biochar production diagram, courtesy of Lehmann (2006) (www.biochar-international.org)

4. LEGISLATION AFFECTING THE BIO-BASED ECONOMY

4.1. The Common Agricultural Policy (CAP)

4.1.1. *Introduction*

The Common Agricultural Policy is a system of European Union agricultural subsidies and programmes, and represents almost half of the EU's budget. The aim of the CAP is to provide farmers with a reasonable standard of living, consumers with quality food at fair prices and to preserve rural heritage. The original CAP combined a direct subsidy payment for crops and land which may be cultivated with price support mechanisms, including guaranteed minimum prices, import tariffs and quotas on certain goods from outside the EU. Recent reforms reduced import controls and transferred significantly subsidy to land stewardship rather than specific crop production. The CAP is the most important policy in Europe having an impact on availability and price of feedstock also for industrial (non-food) use.

4.1.2. *The CAP and the cultivation of energy crops*

The reform of **1992** made it possible to grow non-food crops on set-aside land, without losing the set-aside premium (around 300€/ha, depending on average yields). However, the amount of oilseed grown for biofuels on set-aside was limited by the Blair House Agreement which restricted the maximum EU oilseed area for food use to somewhat less than 5 million ha, and the annual output of oil meal from oilseeds planted on set-aside land for industrial use to 1 million tonnes of soybean meal equivalent. In the mid- 1990s, most energy crops in Europe (mainly rapeseed) were produced on set-aside land.

In the **1997-1999** period, this changed because of the lower set-aside obligations in the EU (Figure 21). Total non-food rapeseed production declined and part of it had to be grown on basic non-supported land. From 1999 on, the set-aside obligation stabilised at a higher level (10%) up to 2007, and more set-aside land was used for non-food rapeseed.

After the year **2000**, the demand for biodiesel rose very rapidly, especially in Germany, and it became profitable to grow rapeseed on basic arable land (no support) for biodiesel production. As of 2004, an energy crop support of 45€/ha was available in the EU15 for the production of energy crops on basic land (with a maximum of 1.5 million ha). The system was extended to the new member-states in **2007**, with an increase of the maximum area to 2 million ha. Initially the response for this premium from agriculture was lower than expected, probably due to the fairly low premium, and the red-tape needed to receive it. After a few years the energy crop premium started to meet with greater success. By 2007 the maximum area was reached, and practically no energy crops were grown without this support (Table 4).

In its recent "Health Check" of the CAP, the European Commission abolished the energy crop premium and the compulsory set-aside [EC DG AGRI, 2008]. In this case no specific support for bioenergy production is left in the first pillar of the CAP. It is assumed that biomass production for energy will be stimulated by strong demand due to the policy targets for biofuels.

Apart from the measures in the first pillar of the CAP, which aim at increasing the supply of energy crops, there is a variety of instruments in the second pillar, the rural development policy, which addresses both

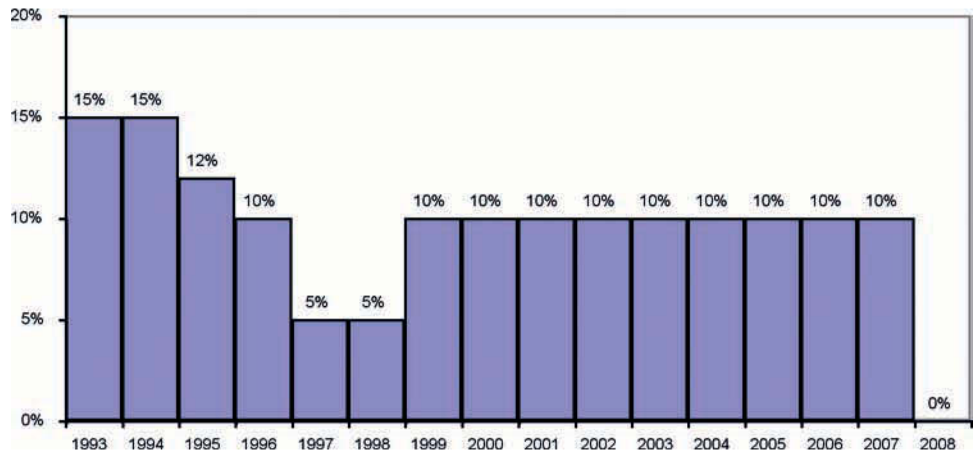


Figure 21. — EU set-aside obligations (% of arable land)

Table 4. — EU arable land with energy crops, according to type of support (EC, DG AGRI, 2008)[1]

Million ha	2003	2004	2005	2006	2007
Total non-food land use on set-aside area	0.9	0.5	0.9	1.0	1.0
– oilseeds		0.5	0.7	0.8	0.8
– of which rapeseed		0.4	0.7	0.8	0.8
– cereals		0.0	0.1	0.1	0.1
Total land use on land with crop premium		0.3	0.6	1.3	2.8
– oilseeds		0.2	0.4	0.9	2.0
– of which rapeseed		0.2	0.4	0.8	2.0
– cereals		0.0	0.1	0.2	0.3
Total land use on land without support	0.3	0.8	1.6	1.4	0.2
– oilseeds (rapeseed)		0.8	1.3	0.9	0.1
– cereals			0.3	0.4	0.0
Total	1.2	1.6	3.1	3.7	4.0

[1]This area compares to a total use of arable land of 109 million ha in the EU-27 [Eurostat].

the supply and use of bioenergy. Examples are support for biogas production facilities, perennial energy crops, processing of biomass towards energy, installations and infrastructure for renewable energy from biomass.

4.1.3. *The sugar regime*

The EU sugar regime was introduced in 1968 as part of the Common Agricultural Policy (CAP), covering the production and marketing of beet and sugar cane within EU member countries. The EU is by far the largest sugar beet producer in the world, with annual production at 17 million metric tonnes. Sugar (=sucrose) is also a major feedstock for the production of (bio)chemicals and enzymes via fermentation processes.

The regime is based on three key elements. Firstly, it guarantees minimum prices to producers. Second, high tariff barriers effectively kept foreign competitors out of the EU marketplace. Thirdly, around 2/3 million tonnes of surplus European sugar each year is disposed of on world markets at heavily subsidised prices. The guaranteed minimum price made EU sugar three or four times more expensive than world market prices.

The sugar regime may be the only area of the CAP that remained unchanged since its inception, but in 2006 the EU decided to reduce the guaranteed price of sugar by 36% over four years, starting in 2006. According to the EU, this was the first serious reform of sugar under the CAP for 40 years. Although the aim was to drastically lower the minimum guaranteed price for sugar in the period 2006-2010, in anticipation of the envisaged free global market for sugar (2014), this price cut is currently being applied only to sugar used in the food industry, which accounts for the bulk of EU sugar, but not for industrial sugar, which represents about 3% of the total.

The European sugar market is divided into quota sugar and out-of-quota sugar, which includes industrial sugar. For quota sugar there is a minimum guaranteed price, but not for out-of-quota sugar: this can be sold to the industry at freely negotiable prices, hence lower than quota sugar. Obviously, for sugar producers the margins on quota sugar are more attractive. The European sugar market is fully isolated from the rest of the world because imports are subject to very high duties. Due to the fact that there is insufficient competition between suppliers and the industry is effectively prevented from importing (raw) sugar from outside Europe, there is a major and structural difference between the European and the world market sugar prices.

4.2. Legislation related to biofuels

4.2.1. *The European situation*

Specific policies for the development of bio-based products are more extensive for bioenergy (including liquid biofuel use and solid biomass applications) than for biochemicals or biomaterials. Worldwide, many governments support their emerging biofuel industries far more than other bio-based economy sectors via subsidies, mandates, adjustments to fuel taxes and incentives for the use of flexi-fuel vehicles.

The legislation and policy on bioenergy and biofuels is determined both on an EU and Member State level, with the instruments being closely interlinked. While agricultural production is regulated on an EU-level (as the Common Agricultural Policy is a common policy under sole EU responsibility), in most other areas, the EU provides the **framework**, leaving the decision on concrete policy measures to the Member States. In the past decade most focus was on biofuels policy support. The two main relevant acts of European legislation to support market implementation of biofuels are the Biofuels Directive **2003/30/EC** and, more recently, the Renewable Energy Directive (RED) **2009/28/EC** which was adopted in April 2009, as part of the Energy and Climate Change Package (CCP). There are other relevant pieces of legislation such as the Energy Taxation Directive (2003/96/EC) and the 1998 Fuel Quality Directive amendments of 2003 (2003/17/EC) and 2009 (2009/30/EC).

In Europe, the first so-called biofuel (2003/30/EC) directive aimed for a 2% share of renewables by the end of 2005 and a 5.75% share by the end of 2010, and a second directive (2003/96/EC) declared that biofuels are exempt from tax on mineral oil products. The Renewable Energy Directive of 2009 is calling for a mandatory target of a 20% share of renewable energies in the EU's energy mix by 2020, and by the same date each Member State must ensure that 10% of total terrestrial transport such as road transport and train fuel comes from 'renewable energy', defined to include biofuels and biogas, as well as hydrogen and electricity. In addition, to stimulate the use of the so-called second generation biofuels, biofuels from waste, residues, non food cellulosic material, and lignocellulosic material will count twice towards achieving the renewable energy transport target. Biofuels produced on degraded lands, believed to reduce pressure on natural ecosystems, are also incentivised. The overall 20% renewable energy target to be achieved by 2020 will require a rapid deployment of solid biomass applications for heat and electricity. Every European Member State must implement the Renewable Energy Directive in national legislation by December 2010.

4.2.2. *The situation in Belgium*

The targets adopted in Belgium were: 2% in 2005, 2.75% in 2006, 3.5% in 2007, 4.25% in 2008, 5% in 2009 and 5.75% in 2010 (note that in 2003 the market share was 0%). A Belgian legal frame has been implemented from 2006 in order to favour yearly quotas of 380.000 m^3 of biodiesel and 250.000 m^3 of bioethanol with tax reductions in blended form with fossil fuel (biodiesel in 5% blend with diesel; ethanol in 7% blend with gasoline). The quotas were distributed through a call for tenders between 3 Belgian bioethanol plants (BioWanze, Syral and Alco Bio Fuel) and 4 Belgian biodiesel plants (Neochim, Proviron, Bioro and Oleon). Belgian quotas will represent theoretically at maximum 4.3% (in energy) of foreseen transportion fuel consumption in Belgium for 2010.

In practise, the uptake of biofuels on the Belgian market did not go as well as intended (26% of target was achieved in 2008). In July 2009, the Belgian government introduced a biofuel obligation requiring fuel suppliers to achieve a minimum of 4% (in volume) biofuel share in their total sales of diesel and gasoline.

Case study: Overview of European policy milestones related to biofuels

1992	Common Agricultural Policy (CAP): bioenergy crops on set-aside
1997	White paper on renewable energies
2000	Green paper on energy supply security
2001	Communication on alternative fuels for road transport
2003	Biofuels Directive 2003/30/EC (indicative targets 2% by 2005, 5.75% by 2010)
	Energy Taxation Directive 2003/96/EC (detaxation allowed, no overcompensation)
	Revision of the Fuel Quality Directive 2003/17/EC (gasoline norm EN228)
	Revision of diesel norm (EN590, max 5% biodiesel) & Biodiesel quality norm EN14214
	CAP Reform: energy crop premium (45€/ha)
2005	Biomass Action Plan
2006	EU Biofuels Strategy
2007	Renewables Roadmap & Revision of the Biofuels Directive
	Draft revision Fuel Quality Directive (up to 10% ethanol blending; transport fuel GHG reduction 1% per year between 2010 and 2020)
2008	Draft Renewable energy directive (binding target of 10% of renewable fuels in total gasoline/diesel sales by 2020, sustainability criteria for biofuels)
	CAP health check: set aside reduced to 0% and energy crop premium abolished
2009	Renewable Energy Directive 2009/28/EC on the promotion of the use of energy from renewable sources
	Revision of the Fuel Quality Directive 2009/30/EC amending the Fuel Quality Directive and introducing a mechanism to monitor and reduce greenhouse gas emissions
2010	Communication on the practical implementation of the EU biofuels and bioliquids sustainability scheme and on counting rules for biofuels [OJ C160]
	Publication by members states of Renewable energy National Action Plan (implementation of Directive 2009/30/EC)

4.3. Legislation related to other bio-based products

In contrast to biofuels, there is currently no European policy framework to support bio-based products and materials. As a result, these products suffer from a lack of tax incentives or other supporting regulations. Although the Ad-hoc Advisory Group for the Lead Market Initiative for Bio-based Products has developed a series of recommendations to stimulate market uptake and development, these measures still have to be implemented. Other demand-driven policies focus on the sustainability agenda (including green public procurement) and are often implemented as a mix of public procurement procedures, legislation and direct financial incentives.

4.4. Sustainability aspects

4.4.1. *Introduction*

Sustainability is not solely about greenhouse gas emissions reductions or climate change, as it also concerns waste reduction, minimising energy consumption and efficient use of resources and technologies (Vos, 2007; De Wulf et al., 2010). In Europe it is an important driver for many of our policies, and several of the demand-side policies include sustainability aspects such as 'green' public procurement. An example is the European Renewable Energy Directive, and in particular the support for second generation biofuels, and the introduction of specific sustainability criteria for the use of biomass.

Because of the interdependencies between processes involved in growing, harvesting, manufacturing, distributing and disposing of a product, sustainability requires a life cycle analysis encompassing the whole value chain. This includes the production of biomass (e.g. land use, consumption of water, energy, pesticides and fertilisers), the processing of biomass, and the production and use of the final products. Some national and international efforts to develop more comprehensive, systems-oriented sustainability frameworks for bio-based products are currently under development.

Addressing sustainability issues through all segments of the value chain of bio-based products (from biomass production to end-use) in a fair, evidence-based regulatory framework, represents an enormous policy challenge. Addressing these sustainability concerns is a major challenge for biofuels and other bio-based products, as the sector has to demonstrate that it possesses sustainability credentials in order to gain a strong “license to operate” from governments and consumers, especially if supporting policies have to be developed.

4.4.2. *Some considerations on sustainability with regard to energy production*

The sustainability of using biomass for chemicals and fuels entails the consideration of various aspects: sustainably should increase from the first to second and third generation systems, but most information now available relates to the first generation.

Biofuels and bio-energy play a substantial role in the switch from a fossil energy based society, towards renewable energy based. Important factors are the abatement of greenhouse gas emissions and the reduction of energy dependency. Part of the biomass needs to be imported from outside the EU. Although biomass has a ‘green’ image, an increasing concern arises that a surge in the production of biofuels based on current technologies - which mainly involve transforming food and feed crops into fuels - could have more negative implications for the environment than positive ones.

Case study: sustainability of biofuels – major discussion points and challenges

Although these discussion points mainly focus on biofuels, these considerations can also be taken into account in the discussion on biochemicals and biomaterials.

- *Energy balance*
  There is controversy over the energy balance of biofuels production. The energy balance is the amount of energy needed over the life-cycle to produce biofuels (input) versus the amount of energy produced (output). Some studies state that it takes more energy to make certain biofuels than is contained in the biofuel itself. The balance also varies largely according to the crops used and the transformation process.
- *Climate change reduction potential*
  In principle, biofuels are "carbon neutral": when they are used, no more carbon dioxide is released than has been absorbed during the growth of the plants used to make these biofuels. Therefore replacing fossil fuels with biofuels for transport could help in the fight against climate change.
  But other studies, including a May 2007 report by the United Nations Energy division, contest this conclusion, saying that the use of biofuels could actually increase greenhouse gas emissions as land would be converted from forests, wetland and reserves for conservation to grow more corn or soya beans. The report notes that with respect to reducing greenhouse-gas emissions, biofuels would be more appropriately used for combined heat and power production rather than for transport.
- *Land Use*
  Using agricultural land to grow bio-energy crops would compete with the use of land for food and animal feed production, driving up the prices of commodities like cereals. According to the European Environmental Agency (EEA), reaching the initial 5.75% target of the biofuels directive would already require biofuel crops to take over between 4% and 13% of the total agriculture area of the EU-25.

Nevertheless a July 2007 study by the Commission's DG Agriculture foresees that reaching the new 10% target for biofuels in transport by 2020 would not "overly stretch the EU's land availability", requiring a "relatively modest" 15% of arable land, which it claims could be largely covered by "set aside" land, previously reserved under the Common Agricultural Policy in order to limit excessive production by farmers.

- *Environment and sustainability*
  Energy crops generally require fertilisers and pesticides to grow. They also require water, which in some regions is already scarce. What's more, biodiversity loss – especially in developing countries seeking to enter this growing market – is an important risk as forests and grasslands may be cleared to plant vast quantities of crops needed to make significant contributions to fuel production.
  Calls for binding "sustainability criteria" to be introduced in laws promoting increased biofuel use therefore are emerging from all sides.

4.4.3. *Sustainability criteria on biofuels*

In 2006, the Dutch government asked a national group of experts (Cramer et al., 2007) to define principles and criteria for the production and the processing of biomass for energy, transport fuels and chemicals. The **Cramer principles** and criteria are divided in six themes:

1. greenhouse gas emissions balance,
2. competition with food, local energy supply, medicine and construction materials,
3. biodiversity (no adverse effects on protected areas or valuable ecosystems),
4. environment (management of waste, erosion, water and emissions),
5. prosperity,
6. social well-being (social, human and property rights).

In parallel or shortly thereafter the UK and German governments have initiated similar activities in an attempt to introduce more sustainable biomass on their internal market. From April 2008, UK suppliers of biofuels in the transport sector need to report the product's sustainability. This **Renewable Transport Fuel Order (RTFO)** includes the idea that future limits or stricter requirements could be issued. The Renewable Fuels Agency has been given the task to arrange for accreditation and data assessment. In Germany, a **Biofuels Sustainability Ordinance** has been approved in the beginning of 2008, wherein biofuels will only be credited to the EU-quota obligations and are only eligible for tax reductions if the fulfilment of the requirements of the Ordinance is proofed.

Meanwhile, on EU level, **the Renewable Energy Directive (RED)** on the promotion of the use of renewable energy sources was finally published in June 2009. In response to concerns within society on the EU transport biofuel targets, following sustainability criteria should be met; otherwise **biofuels** or **bioliquids** will not be counted towards the targets of 10% renewable energy in transport, as well as the overall target of 20% renewable energy:

- Biofuels should achieve a minimum greenhouse gas reduction of 35% compared to fossil fuels. From 2017 this is scaled up to at least 50% in 2017 and 60% in new installations thereafter. Emissions related to indirect land use change (ILUC) was not included in this method, but the Commission shall propose a report by end 2010 describing the impact of indirect land use change.
- Biofuels shall not be made from raw material obtained from land with high biodiversity value (primary forest and other wooded land, nature protection areas, vulnerable ecosystems, grasslands with high biodiversity), unless evidence is provided that the production of that raw material did not interfere with those nature protection purposes;
- Biofuels and bio-liquids shall not be made from raw material obtained from land with high carbon stock, namely land that had one of the following statuses in January 2008 and no longer has that status: wetlands, continuously forested areas, peat land.
- Agricultural raw materials cultivated in the European Community and used for the production

of biofuels and bioliquids shall be obtained in accordance with the requirements and environmental standards of good agricultural practice under the common agricultural policy. Because of WTO principles this criterion cannot be applied for raw materials from outside the European Union.

By the end of 2010 every European Member State needs to implement a control system in its legislation as to require economic operators to show that the sustainability criteria set out in the RED have been fulfilled.

The Directive also mentions that the EC would prepare a report on sustainability requirements for the use of **solid biomass and biogas in electricity, heating and cooling**. This report was presented in March 2010. The EC choose not to put binding sustainability criteria for these purposes, but makes recommendations on sustainability criteria to be used by those Member States that wish to introduce a scheme at national level, in order to avoid obstacles for the functioning of the internal market for biomass. The recommended criteria relate to:

1. A general prohibition on the use of biomass from land converted from forest, other high carbon stock areas and highly biodiverse areas;
2. A common greenhouse gas calculation methodology which could be used to ensure that minimum greenhouse gas savings from biomass are at least 35% (rising to 50% in 2017 and 60% in 2018 for new installations) compared to the EU's fossil energy mix;
3. The differentiation of national support schemes in favour of installations that achieve high energy conversion efficiencies; and
4. Monitoring of the origin of biomass.

It is also recommended not to apply sustainability criteria to **wastes**, as these must already fulfil environmental rules in accordance with waste legislation at national and at European level.

Case study – the effect of Indirect Land Use Change (ILUC)

An important discussion on the global GHG balance of biofuels is the inclusion of greenhouse gas emissions related land use change, both direct (dLUC) and indirect (iLUC). Land conversion can cause large changes in carbon content of the soil and the upper soil vegetation. Direct changes in land use are in principle covered within the methodology of the European Commission, and are also largely avoided when following the land use conditions of the RED. Emission related to indirect land use change is not covered in this methodology. The principle of iLUC is as follows: when biofuels are grown on existing arable land, current demand for food and animal feed may push these production activities into new areas such as forests or grasslands. Conversion of forest or grassland to agricultural land can lead to very significant releases of carbon to the atmosphere. When this indirect change is also allocated to biofuels, this can have an important effect on the overall GHG balance, when compared to fossil fuels. We should however keep in mind that the methodology for calculating iLUC emissions is still quite controversial. Mostly these calculations base their a reference on a status-quo of other (unsustainable) policy, like a poor agricultural policy in developing countries, lack of protection of valuable nature areas, inefficient use of food and feed products, … while in the mean time world population and economies are growing. If real improvements in agricultural policy, and subsequent yield increase in the developing world are taken into account, or a stricter protection of valuable natural areas and rainforest (for all applications of biomass), this could significantly reduce these iLUC effects (Pelkmans et al., 2010).

5. RECOMMENDATIONS

5.1. Develop an integrated policy for the biobased economy

In order to develop a competitive bio-based economy, broad approaches, such as creating and maintaining markets for environmentally sustainable products, funding basic and applied interdisciplinary research, and access to sustainable feedstock at a competitive price will be necessary. In addition, these will need to be combined with shorter term policies such as the application of new breeding techniques and biotechnology for improving plant varieties, improving access to technologies for use in a wider range of plants, fostering public dialogue, and other incentives designed to reward environmentally sustainable technologies.

Within this bio-based economy it will be critical to ensure that the feedstock is produced using good management practices and according broadly supported sustainability criteria. To realise this, there is an urgent need for a more integrated and strategic approach, with supportive policies in the areas of climate change, energy security, renewable feedstock supplies (agricultural policy), research and innovation, the environment and trade.

5.2. Recommendations related to feedstock availability

5.2.1. *Introduction*

In order to develop a robust bio-based economy in Europe, it is and will continue to be important to have access to renewable feedstock in sufficient quantity, of good and guaranteed quality at competitive price. The Academy wants to put forward a number of recommendations, directed towards the government, the political and the industrial world. It hopes that a number of recommendations can be translated into an effective agricultural policy. Ideally, this can occur in a concerted action by the government, the farmers associations, the involved industrial sectors and research institutions. The creation of a **"PLATFORM FOR INDUSTRIAL BIOMASS UTILISATION",** bringing together all important stakeholders can make sure that the government, the industry, the agriculture sector and the academic world cooperate towards a common goal, as is specifically addressed below.

To develop, integrate, and validate novel biomass based technologies for commercial use, worldwide governments are encouraged to work in partnership with research bodies and industrial partners to help launch biorefineries at various scales. Public (financial) support for large-scale, first-of-a-kind integrated biorefineries can significantly reduce the financial risk for these projects and thus speed the growth of the biomass based industry

5.2.2. *A new CAP (post 2013) for food and industrial crops*

Efficient agricultural policy is essential for guaranteeing equitable competition conditions within the EU. Maintaining a single market for agricultural products must remain the guiding principle for the future. It is important to ensure that national flexibilities and exemptions do not create distortion that would harm the single market and the supply of raw materials to the food and non-food industry.

Absolute coherence is needed across all policy areas driving supply, including food safety, innovation and new technologies, trade, development, the environment, animal welfare, consumer and public policies. Impact assessments should be a mandatory requirement when legislation which could significantly impact on food supply or feedstock availability for industrial production, is amended or imposed. Horizontal policy coherence should result in reduced raw material market disruptions and should also contribute to a competitive EU agriculture.

To become a lead market for biobased products, one necessary prerequisite is the assurance of a secure, varying, sustainable and affordable supply of biomass achieved without disruption to food supply. Until now, the hope that biomass will show less cyclicality than crude oil prices has not been realized. Furthermore, in debates around biofuels, land use remains a controversial issue. This will remain an issue notably with regard to food production, where there are rising food and feed demands driven by population growth and increasing prosperity. In addition, the acceptance problem of green biotechnology, especially in Europe, could have an indirect impact on availability and/or price of renewable feedstock in the long term.

For these reasons it will be essential that the new CAP promotes sustainable and competitive agricultural production, and that it ensures balanced access to raw materials for the food and feed sectors, as well as for industrial applications without disrupting food supply. Through the new CAP, we should maintain a competitive supply that meets EU standards, notably in the areas of safety and environment. The CAP should also address situations of extreme price volatility, and act as a safety net ensuring security of supply by preventing crisis situations and remedying temporary market imbalances.

In order to stimulate the development of local biorefineries and to support rural development, it is important to develop and support a reliable upstream supply chain able to mobilize a sufficient level of

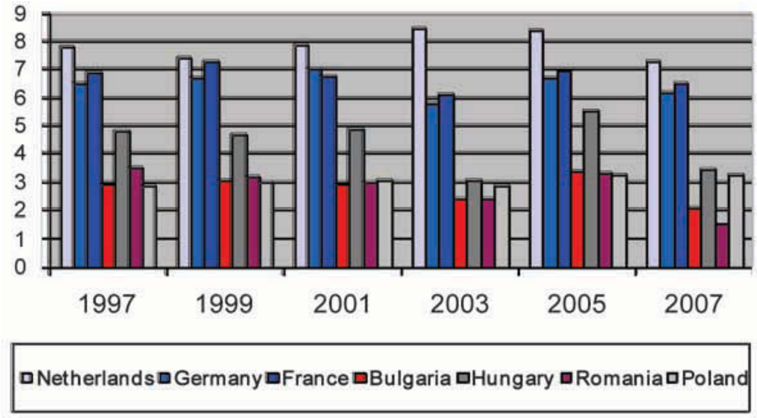


Figure 22. — Yield of cereals (t/ha) over the last 10 years

feedstock for conversion. This must of course be achieved without negative impacts on either food production or land use. For this reason, it is also important to invest in local and regional infrastructures and logistical capabilities to allow all biomass, including agricultural, forestry and waste-based raw material, to be utilised.

5.2.3. *Improve land productivity and land management in a sustainable way*

In order to develop and secure a supply for the biobased economy, it is important considering measures to increase European agricultural production. Meeting this challenge without hindering the production of food for a fast growing world population and without negatively impacting the environment and biodiversity also requires optimising production per hectare of land through increased crop productivity and land management. Sustainability (i.e. without major agricultural land extension) of biomass supply lies in increased productivity by developing:

– the crops themselves, for traditional crops but also ‘energy' or ligno-cellulosic crops (use of best cultivars, good agricultural management techniques, etc.). Biotechnology and modern genetic methods for plant breeding could be a good tool to achieve this.
– the cropping system (mobilise existing biomass) and efficient land use, and infrastructure development.
– biorefining technologies to ‘make more out of the biomass and development of biorefinery infrastructure.

The newer EU Member States still have much lower productivity than the EU-15. This is illustrated on the following graph showing the yield of cereals (t/ha) over the last 10 years (Figure 22). The EU in collaboration with these Member States and with the support of the structural funds must urgently develop policies to enable the newer states to boost production and catch up with their older EU neighbours. This will mean ensuring access to modern and adapted production technologies and investing in inputs and management skills.

The growth of perennial crops could be further encouraged and developed through the new CAP. This could be achieved by developing a series of measures to encourage farmers to increase the production of perennial crops as was the case in the US via the Biomass Crop Assistance Program (BCAP). Although the cultivation of perennial crops is a long term policy, from an industry perspective this could create the possibility to have access to feedstock the whole year round rather than only in specific seasons. Furthermore, from an environmental point of view, the cultivation of perennial crops could stimulate diversification of agriculture, lower the environmental impact of agriculture, and optimise land use efficiency (including using unutilised land more effectively).

5.2.4. *Establish and optimise infrastructures and logistical capabilities*

The use of agro-food by-products and wastes should be strongly encouraged. They are representing huge amounts of biomass (several millions of tonnes each year in the EU) already available and at low costs. Using such matrices as feedstock for biobased products would bring a two-fold benefit: the sustainable disposal of impacting wastes, and the generation of added value bioproducts with remarkable improvements of the sustainability of the agro-food industry.

Investments in developing and optimising infrastructures and logistics capacities are crucial to ensure that all the biomass that can be mobilised in a sustainable way (both from an environment and economic point of view) is actually used. Most of these actions will be supported and implemented at national and regional level. Strong European goals and guidelines need to be set in order to encourage the implementation at national and regional level (e.g. renewable energy directive and national biomass action plan). For new Member States, structural funds are an important possible tool to improve infrastructure (roads and storage).

5.2.5. *Remove trade barriers on agricultural products and develop transition measures for industrial applications for the European industry*

Biobased raw materials for industrial use should be readily available at competitive market prices, but the security of supply and a competitive price (compared to world market price levels) can only be achieved in a sustainable way by removing some trade barriers on agricultural products for industrial applications. By industrial applications – is meant that the agricultural product is transformed into another substance similar to the use of crude oil as a feedstock for the production of biobased products such as chemical substances, materials or enzymes. Even if the European supply of biobased raw materials is the preferred choice, having access on a permanent basis of these feedstock from other regions is a must to secure the supply.

Over the last 20 years, the “production refund” has been the main CAP instrument designed to bridge the gap between the high prices of EU raw materials and the lower prices of the world market for sugar, cereals and potatoes. During the 1990s, the production refund gave support to the manufacturers of paper, board, biochemicals, pharmaceuticals and other non-food products. This enabled them to use sugar, starch products and starch derivatives produced in the EU (more than 4 million tonnes every year) to manufacture their biobased products. But since the recent sugar reform, the sugar production refund system has been abolished.

In the short term, and as a transition period, some temporary measures could be developed. This would allow biobased product producers to have access to competitive raw materials (European-produced where possible). During this transition period, possible alternative measures to the production refund have to be found to ensure that the biobased industry has access to competitive, sustainable, EU-produced raw material. If such measures cannot be put in place in the given timeframe, as an alternative, the development of specific programs under the second pillar (rural development) and the setting of a flexible import duty system allowing imports of cereals when prices are above a certain threshold price or the opening of a TRQ (Tariff-Rate Quotas) could be envisaged. However, both measures would only apply for the specific use of starch for biobased production. This would avoid the current unacceptable distortion of competition between sugar and starch for non-food uses brought about by the setting of a duty-free import quota for sugar. The impact of such measures would first need to be carefully analysed before any action could be taken.

5.3. Recommendations related to research and innovation

5.3.1. *More and better coordinated funding for interdisciplinary research and innovation*

In order to make a fast shift towards developing more innovative and sustainable bio-based products, integrated and sustainable production and processing systems, the level of R&D funding in the bio-based economy should be increased through **multidisciplinary research programmes** at national and European level.

Furthermore, **improved coordination and collaboration** between member state, regional and European public programmes for research and innovation is the only way to avoid overlap and fragmentation and to keep track of the massive research programmes elsewhere in the world. This should be done in conjunction with improvements in the cooperation between the private and public sectors.

In order to better align academic knowledge to industry needs, industry will need to develop an earlier understanding of the application potential of new technologies provided by academia. Similarly, academic researchers will need a sharper focus on industry’s needs and specifications. Therefore, building competence networks between industry and academia could be key to overcoming the knowledge gap and competence hurdle that currently exists. In addition, better interdisciplinary and collaborative research would also lead to new business activities.

In order to facilitate innovation and encourage the uptake of its results by the industrial partners involved, such research programmes should cover the **entire value chain** including plant engineering, crop harvesting and local processing, logistics, pre-treatment in the biorefinery, industrial enzymes, fermentation organisms, secondary manufacturing, compounding, side-product valorisation and product recovery. It should also extend to the supply side, incorporating research to improve the yield and sustainability of new feedstock, such as crops and trees, for raw materials supply.

5.3.2. *Setting up Public-Private Partnerships and innovation clusters*

There is an urgent need to mobilise sufficient resources to support a coordinated research programme by means of a Public-Private Partnerships (PPP). This type of joint undertaking would achieve a pooling of resources which would help in setting more ambitious goals in terms of reducing the time-to-market and which would also help industry to adopt long-term investment plans in the field of the bio-based economy, taking into account the market perspective. Such PPPs should cover the entire value chain (from feedstock to end-product), and should also encourage the uptake of research results by industry. Such public-private partnerships can also optimise knowledge transfer and dissemination of knowledge towards SME's.

5.3.3. *More specific research on feedstock optimisation and industrial biotechnology*

In its "Bioeconomy 2030" report, the OECD estimates that approximately 75 percent of the future economic contribution of biotechnology and significant environmental benefits are likely to come from applications derived from agricultural and industrial biotechnology (OECD, 2010). However, these sectors currently receive less than 20% of all research investments made by the private and public sectors. Therefore there is a pressing need to boost research in agricultural and industrial biotechnologies by increasing public research investment and by encouraging private-public partnerships.

Secure a sustainable supply of feedstock for the bio-based economy in Europe requires further research into methods of improving feedstock yields and/or the composition of biomass for optimal conversion efficiency. This research will involve both plant genomics and new breeding programmes, and also research into efficient crop rotation, land management and land-use change issues.

Future increases in feedstock supply will have to take place despite the new challenges presented by climate change, reduced soil quality, and unpredictable growing conditions. Therefore, instead of adapting the environment to the needs of crops through the use of precious natural resources such as water and energy, we will need to start modifying crops to their environment. Increasing yield will require a number of different approaches involving biotechnology, genetically assisted breeding and crops developed by classical cross breeding.

But the EU and the member states needs to acknowledge through the development of their policy the role of science and technology in increasing yield per hectare of farmed land whilst reducing the negative impact of agriculture on the environment. This includes adopting a rational and science based approach to the use of genetically modified (GM) crops. As the EU continues to make politically motivated decisions and use procedural delaying tactics to stall the widespread introduction of these crops, yield gaps are further widening between the EU and the more advanced agricultural economies.

5.4. A need for science based sustainability criteria

Sustainability criteria should aim to measurably reduce the key impacts associated with feedstock production, consumption and use (Vos, 2007; De Wulf et al., 2010). While dependency on the feedstock variations will persist, it is likely that key aspects to consider for the future will be biodiversity, soil protection, water conservation, carbon dioxide emissions reductions, air quality and social sustainability. Implementation of these measures will necessitate the active participation of all stakeholders in the supply chain. For example:

– Industry, agriculture and related enterprises will have to ensure that production and processing of resources and materials is performed using best management practices.
– Governments will need to focus on wider sustainability issues, such as managing demand, food security, competition between various end-uses and incentives.
– International organisations should provide support to producer countries to enable them in establishing harmonised, robust frameworks for feedstock production.

5.5. Overview of the main recommendations

RECOMMENDATIONS TOWARDS THE AUTHORITIES
European authorities – Develop an integrated policy for the bio-based economy at EU level – Include feedstock for industrial use in the new CAP – Integrate support for "logistics for biomass collection" in the second pillar (rural development) of the new CAP – Develop programmes to increase land productivity (research programmes, regional development, land management programmes, etc.) – Remove trade barriers on agricultural material for industrial use – Adopt a rational and science based approach to the use of genetically modified (GM) crops – Develop a framework for science based sustainability criteria

Federal and Regional authorities in Belgium

- Develop an integrated policy for the bio-based economy at federal and regional level
- Set up a national/regional "Platform for Industrial Biomass Utilisation"
- Support the integration of renewable feedstock for industrial use in the new CAP
- Develop a national/regional programme to increase land productivity in a sustainable way
- Set up programme to valorise agro-food by-products and organic waste
- Develop multidisciplinary research programmes – covering the entire value chain – in the area of the bio-based economy, by preference linked to similar programmes in other member states or regions in order to improve coordination and collaboration
- Support research into methods of improving feedstock yields and/or the composition of biomass for optimal conversion efficiency. This research should involve both plant genomics and new breeding programmes, and also research into efficient crop rotation, land management and land-use change issues.
- Adopt a rational and science based approach to the use of GM crops
- Develop a framework for science based sustainability criteria

RECOMMENDATIONS TOWARDS THE SCIENTIFIC COMMUNITY (public & private)

- Build competence networks between academia and industry to overcome knowledge gap and competence hurdle
- Set up public-private partnerships to support coordinated research programmes
- Boost research in green chemistry and agricultural and industrial biotechnology
- Develop research programmes into methods of improving feedstock yields and/or the composition of biomass for optimal conversion efficiency. This research should involve both plant genomics and new breeding programmes, and also research into efficient crop rotation, land management and land-use change issues.

RECOMMENDATIONS TOWARDS THE INDUSTRY

- Set up public-private partnerships to support coordinated research programmes
- Boost research in green chemistry, agricultural and industrial biotechnology

6. REFERENCES

- Agrowal R. and Singh N. (2010). Solar Energy to Biofuels. *Annu. Rev. Chem. Biomol. Eng.*, 1, 343-364.
- An Z. (2005). *Handbook of Industrial Microbiology.* New York: Marcel Dekker Inc.
- Bauen A., Berndes G., Junginger M., Londo M. and Vuille F. (2009). *Bio-energy – A Sustainable and reliable energy source. A review of status and prospects.* EIA Bioenergy.
- Bellman D. (2007). *Power Plant Efficiency Outlook.* Washington DC: Working Document of the NPC Global Oil & Gas Study.
- Brundtland G.H. (1987). *Our Common Future.* New York, USA: UN, World Commission on Environment and Development.
- Campbell C. (1998). The future of oil. *Energy exploration and exploitation*, 16, 125-152.
- Canakci M. and Sanli H. (2008). Biodiesel production from various feed stocks and their effects on the fuel properties. *J Ind Microbiol Biotechnol.*, 35, 431-441.
- Carioca J. (2010). Biofuels: problems, challenges and perspectives. *Biotechnol. J.*, 5, 260-273.
- Cramer J. (2007). *Toetsingskader voor duurzame biomassa.* Verslag Tweede Kamer, Den Haag, Nederland.
- Dahod S. (1999). Raw materials selection and medium development for industrial fermentation processes,. In *Manual of Industrial Microbiology and Biotechnology*, 2nd ed., 213-220.
- Dale B. (2003). Greening the chemical industry: research and development priorities for biobased industrial products. *Journal of Chemical Technology & Biotechnology*, 78, 1093-1103.
- De Wulf J.; Van Langenhove, H.; and Vandamme, E.J. (2010). Resource Technology – a challenge for scientist and engineers. *J. Chem. Technol. Biotechnol.*, 85, 1299-1300.
- Demain A.L. (2007). The business of biotechnology. *Ind Biotechnol.*, 3, 269-283.
- EC. (2010). *Eurostat Pocketbooks Agricultural statistics Main results 2008-2009.* Luxemburg: Publications Office of the European Union.
- EC. (2010). *Forest Statistics Eurostat Pocketbook*, 2009. Brussel, Luxembourg: EC-Eurostat.
- EC. (2006). *Renewable Energy Road Map Renewable energies in the 21st century: building a more sustainable future.* European commission, Commission Staff working document, Brussel
- FAO. (2009). *FAO, Forestry, Wood Energy*. Retrieved 15/10/2010, from http://www.fao.org/forestry/energy/en/
- FAO. (2008). *The state of food and agriculture. Biofuels: prospects, risks and opportunities.* Rome: FAO.
- Fargione J. (2008). Land clearing and the biofuel carbon debt. *Science*, 319 (5867), 1235-1238.

– Gavrilescu M. and Chisti Y. (2005). Biotechnology: a sustainable alternative for chemical industry. *Biotechnol. Adv.*, 23*,* 471-499.
– Griffiths M. (2001). *The Application of Biotechnology to Industrial Sustainability, OECD Report.* Retrieved 15/10/2010 from OECD: http://www1.oecd/org/publications/e-book/9301061e.pdf
– Hubbert M. (1956). *Nuclear Energy and the Fossil Fuels,.* Plaza Hotel, San Antonio, Texas, March 7-8-9, 1956: Presented before the Spring Meeting of the Southern District, American Petroleum Institute.
– Jain M. and Zeikus J. (1989). One Carbon Metabolism in Anaerobic Bacteria: Regulation of Carbon and Electron Flow During Organic Acid Production. *Michigan Biotechnology Institute, 11*.
– Kamm B. and Kamm M. (2004). Principles of biorefineries. *Appl Microbiol Biotechnol.*, 64, 137-145.
– Kunz M. (2008). Bio-ethanol: Experiences from running plants, optimization and prospects. *Biocat Biotransf.*, 26, 128-132.
– Lehmann J., Gaunt J. and Rondon M. (2006). Bio-char sequestration in terrestrial ecosystems? A Review. *Mitigation and Adaptation Strategies for Global Change*, 11, 395-419.
– Li H., Cann A. and Liao J. (2010). Biofuels: biomolecular engineering fundamentals and advances. *Annu. Rev. Chem. Biomol. Eng.*, 1*,* 19-36.
– McDonough W. and Braungart M. (2002). *Cradle to Cradle: Remaking the waY we make things.* North Point Press.
– Meeus B., Vanacker K., Pante J., Demolder L. and Maes G. (2010). *Voortgangsrapport 2010 anaërobe vergisting in Vlaanderen.* Kortrijk: Biogas-E v.z.w.
– Morris D. (2006). The next economy from dead to living carbon. *J Sci Food Agric*, 86, 1743-1746.
– OECD (2010). *The Bioeconomy to 2030 Designing a Policy Agenda.* Paris: OECD International Futures Project.
– OECD-FAO. (2009). *The Agricultural Outlook 2009-2018.* Paris: OECD and FAO.
– Pelkmans L., Dobbelaere S. and Borgo E. (2009). *Biobrandstoffen van de eerste, de tweede en de derde generatie, wetenschappelijk eindrapport.* IST – Instituut Samenleving en Technologie.
– Pelkmans L., Govaerts L. and Kessels K. (2008). *(2008), Inventory of biofuel policy measures and their impact on the market. Report D2.1 of ELOBIO subtasks 2.1-2.2.* Brussels: ELOBIO.
– Ragwitz M., Haas R., Huber C., Resch G. and Faber T. (2005). *FORRES 2020: Analysis of the renewable energy sources' evolution up to 2020.* Karlsruhe (Germany): EG, DG Energy.
– Robinson T., Singh D. and Nigam P. (2001). Solid state fermentation: A promising microbial technology for secondary metabolite production. *Appl Microbiol Biotechnol.*, 55, 284-289.
– Sarath G., Mitchel R., Satler S., Funnell D., Pedersen J., Graybosch R., et al. (2008). Opportunities and roadblocks in utilising orages and small grains for liquid fuels. *J Ind Microbiol Biotechnol.*, 35, 343-354.
– Serrano-Ruiz J., West R. and Dumesig J. (2010). Catalytic conversion of renewable biomass resources to fuels and chemicals. *Ann. Rev. Chem. Biomol. Eng., 1*, 79-100.
– Singh-Nigam P. and Pandey A. (Eds.) (2009). *Biotechnology for Agro-Industrial Residues Utilization.* Springer.
– Soetaert W. and Vandamme E.J. (Eds.) (2009). Biofuels. Willey Series in *“Renewable Resources”*, ed. C. Stevens (p. 242). J. Wiley.
– Soetaert W. and Vandamme E.J. (Eds.) (2010). *Industrial Biotechnology: sustainable growth and economic success* (p. 499)*.* Wiley-VCH.
– Soetaert W. and Vandamme E.J. (2006). The impact of industrial biotechnology. *Biotechnol J.*, 1(7-8), 756-769.
– Spolaodre P., Joannis-Cassan C., Duran E. and Isambert A. (2006). Commercial ap-plicationsof micro-algae. *J Biosci Bioeng.*, 101, 87-96.
– Stowell J., Beardsmore A., Deevil C. and Woodward J. (1987). *Carbon substrates in biotechnology.* Oxford-Washington DC: IRL-Press.
– Van Beilen J. (2008). Transgenic plant factories for the production of biopolymers and platform chemicals. *Biofuels Bioprod Bioref.*, 2, 215-228.
– Vandamme E.J. (2007). Microbial gems: Microorganisms without frontiers. *SIM-News (Society for Industrial Microbiology)*, 57(3), 81-91.
– Vandamme E.J., Cerdobbel A. and Soetaert W. (2005). Biocatalysis on the rise: Part 1 Principles. *Chem Today*, 23(6), 47-51.
– Vandamme E.J., Cerdobbel A. and Soetaert W. (2006). Biocatalysis on the rise: Part 2 Applications. *Chem Today*, 24(1), 57-61.
– Vasudevan P. and Briggs M. (2008). Biodiesel production: Current state of art and challenges. *J Ind Microbiol. Biotechnol.*, 35, 421-430.
– Vos R. (2007). Refining sustainability: a conceptual orientation. *J. Chem. Technol. Biotechnol., 82*, 334-339.
– Wall J., Harwood C., Demain A.L. (Eds). (2008). *Bioenergy; ASM-Press, Washington DC.* ASM-Press, Washington DC.
– Weiland P., Verstraete W. and Van Haandel A. (2009). Biomass digestion to methane in agriculture: a successful pathway for the energy production and waste treatment worldwide. (pp. 172-195). In Soetaert W. and Vandamme E.J. (Eds.), *Biofuels* (pp. 172-195). John Wiley & Sons Ltd.
– Wohlgemuth R. (2010). Asymmetric biocatalysis with microbial enzymes and cells. Current Opinion in Microbiology, 13, 283-292.
– Zhang Y. (2008). Reviving the carbohydrate economy via multi-product lignocellulose biorefineries. *J Ind Microbiol Biotechnol.*, 35, 367-375.

BACAS MEMBERSHIP

KTW MEMBERS (previously CAWET)

Board

Jan Kretzschmar, President
Ludo Gelders and Achiel Van Cauwenberghe, Past President
Jacques Willems, Vice-President
Paul Verstraeten, Representative in KVAB Directory Committee

Ordinary members

Guido Beazar
Ronnie Belmans
Jean Berlamont
Alain Bernard
Luc Bossyns
Hugo De Man
Bart De Moor
William D'Haeseleer
Dirk Fransaer
Dirk Frimout
Ludo Gelders
Derrick Gosselin
Hilde Heynen
Monica Höfte
Jan Kretzschmar
Paul Lagasse
Jan Leuridan
Egbert Lox
Christiane Malcorps
Leo Michiels
Paula Moldenaers
André Oosterlinck
Johan Schoukens
Luc Taerwe
Erik Tambuyzer
Hendrik Van Brussel
Achiel Van Cauwenberghe
Erick Vandamme
Jozef Vanderleyden
Joos Vandewalle
Hendrik Van Landeghem
Willy Van Overschée
Joost Van Roost
Ivo Van Vaerenbergh
Eric Van Walle
Pierre Verbaeten
Pascal Verdonck
Ronny Verhoeven
Ignaas Verpoest
Willy Verstraete
Paul Verstraeten
Dirk Wauters
Martine Wevers
Jacques Willems

Honorary members

Etienne Aernoudt
Jean Beeckman
Stanislas Beernaert
Jozef Deman
Jean-Pierre Depaemelaere
Herman Deroo
Gilbert Froment
Robert Gobin
Guy Haemers
Jan Jongbloet
Rob Lenaers
Roland Maes
Urbain Meers
Michel Naze
Marcel Soens
Stanislas Ulens
Norbert Van Belle
Jean Van Bladel
Valentin Van den Balck
Georges Van der Perre
Jan Van Keymeulen
Jacques Van Remortel
Daniël Vandepitte
Roland Wissaert

Foreign members

Robert Byron Bird
Adrianus T. de Hoop
Alessandro Ferrero
Iven Mareels
Sophie Vandebroek
Luc Van Wassenhove
Roland Waterman
Willy Zwaenepoel

CTS MEMBERS

Board

Philippe Bourdeau, President
Nicolas M. Dehousse, Past President
André Delmer
Benoît Macq
Jean-Louis Migeot
Jean-Jacques Van de Berg, Vice-President

Members

Charles Bienfait
William Bracke
Armand Broucke
Arsène Burny
Jean-Pierre Contzen
Marcel Crochet
Bernard Delmon
Daniel Dobbeni
Daniel Gauthier
Jean-Pierre Hansen
Hervé Hasquin
Léo Houziaux
Jacques Leclerc
Willy Legros
Joseph Martial
Jacques Pélerin
Jean-Pol Poncelet
André Preumont
Philippe Robert-Jones
Marc Stubbe
Jean-Pierre Swings
Thierry Van Cutsem
Paul Vandenplas
André Vander Vorst
Claude Veraart
René Winand

Associated Members

Luc Chefneux
Marco Citta
Jean-Pierre Conerote
Michel Geradin
Léon Ghosez
Michel-Daniel Judkiewicz
William Kirkpatrick
Paul Levaux
Jacques Rondal
Alexandre Samii
Marie-José Simoen
Jan Van Keymeulen
Marco Van Overmeire

Honorary Member

Paul-Etienne Maes

BACAS Board

Ludo Gelders, President
Philippe Bourdeau, Past President
Michel Crappe
Nicolas M. Dehousse, Past President
Pierre Klees, Past President
Jan Kretzschmar
Achiel Van Cauwenberghe, Past President
Jean-Jacques Van de Berg
Paul Verstraeten, Secretary
Jacques Willems

Price: € 15,00