Research and Development on Renewable Energies

A Preliminary Global Report on Biomass

ISPRE

International Science Panel
on Renewable Energies

ISPRE

The International Science Panel on Renewable Energies was established in 2007 by the International Council for Science (ICSU) and the International Council of Academies of Engineering and Technological Sciences (CAETS). The central mission of ISPRE has been to provide analysis and strategic guidance for renewable energy research and development (R&D) efforts worldwide. It aims to help improve the intensity, effectiveness and coherence of R&D programmes being implemented at national, regional, and international levels. Generous financial support has been provided by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, under the contract 0329971A.

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Foreword

This preliminary ISPRE report on biomass was compiled at the same time as a more complete analysis on photovoltaic and wind energy (ISPRE, 2009). These are the three technologies that are currently considered to have the greatest sustainable potential and widest applicability. Initially, the intention was to produce a full analysis of global R&D issues relating to all three technologies. However, biomass energy is a very complex area that is evolving rapidly, and it was not possible for ISPRE to cover all aspects with the time and resources available. For example, during the course of this work the potential effects of land-use change due to planting of crops for fuel has become a 'hot' scientific issue, which is only briefly mentioned in the current report.

This report is presented as a preliminary analysis, fully recognising that it is incomplete in several aspects, but with the hope that it nevertheless represents a useful compilation and assessment that can provide a basis for further work.

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Biomass in a variety of forms—solid stock, herbaceous matter, seeds, algae, biowaste, and crop residues—occupies a unique place among renewable energy systems, being the source of food, fodder, fibre, forest products and chemical feedstocks as well as fuel. Liquid transport fuels from biomass represent one of the most important options for the sustainable supply of transport fuels. In addition, the resulting solid residues and wastes from the processing of liquid fuels can be used as an energy source.

Improving the productivity of both agricultural and plantation crops through improved crop varieties, agronomic practices and the use of advanced genetic research and molecular biology is vital for enhancing the contribution of biomass as a source of energy.

Issues relating to increasing land productivity are critical given: (i) the conflict between growing fuel versus food in some countries; (ii) reliance on fossil fuel imports in others; and (iii) the technical challenge of improving the genetic quality of the feedstock and in particular, its interaction with water and nutrients.

First generation biofuels include biomass for direct burning, biogas, bio-oil, bio-ethanol and biodiesel. *Second generation* biofuels are now being developed. Both cellulosic ethanol and synthetic biofuels derived from syngas hold considerable promise. Low temperature conversion processes include the anaerobic digestion of non-lignocellulosic wastes and the fermentation of sugars and starch to obtain ethanol. High temperature processes include combustion, pyrolysis and gasification.

R&D is addressing all the areas identified above. Activity is currently concentrated in Europe, the US and Brazil but is growing in China, India, South Africa and some Latin American countries. While most R&D effort is aimed at large throughput processes, R&D focusing on technologies suitable for small throughputs is relevant in countries where landholdings are smaller and per capita income is low.

Distributed rather than centralised generation is better suited to areas where the population is dispersed. The developing world requires 'small' systems compared to the developed world. For example, a 1 MWe power generation system might be considered 'large' in a developing country, while 5 MWe would be 'small' in a developed country. Additionally, R&D to enhance efficiency and reduce indoor air pollution would help the 2.5 billion households in developing countries that use biomass for domestic cooking.

R&D support is essential if biomass is to increases its share of the energy mix. Research covering a range of disciplines is required to address challenges along the entire production chain. Two broad priority areas are (a) the utilisation of bio-waste and biomass which cannot be otherwise used as food or feed, and (b) the development of lignocellulosic crops which are more productive in energy terms. The following research directions, necessarily specified at a high level because of the breadth of the agenda, are critical:

- Plant biology and crop improvement targeted at developing desirable traits for bio-energy purposes.
- Agronomic practices.
- Biomass utilisation, including the development of fuels for domestic stoves and biogas digestion.
- Biomass conversion for heat and electricity.
- Biomass conversion to liquid fuels.
- Development of bio-refinery concepts.
- Cost reduction and performance improvement across the biomass chain.

1. Introduction

Biomass potential on a global scale

Biomass in a variety of forms (solid stock, herbaceous matter, seeds, algae, biowaste and crop residues) has been supplying us with food, fodder, fibre, liquid and solid fuel and chemical feedstocks for several thousand years. Until the 21st century, firewood for cooking was almost the only widespread use of biomass for energy. This is still prevalent in developing countries.

In the context of global climate change, air pollution and declining supplies of conventional fossil fuels, the use of biomass could be expanded quickly to substitute for fossil fuels like natural gas, petroleum and, to some extent, coal.

Biomass for energy can come from non-food materials (crop and agro-industry residues and biowastes) or by cultivating energy crops, like amylaceous and oil crops or cellulose intensive plants in pastures or forests. Recent statistics show that 1.4 billion ha of land is being cultivated round the world including pastures, crops, fruits, vegetables and forests (FAO, 2004). Another 1.2 billion ha could be cultivated if the relevant technology were available. This would require progress in areas such as irrigation and drought tolerance, plant nutrition and plant genetics.

Several countries or regions are mapping potential annual biomass supply from different non-food sources. The US Department of Agriculture (USDA) concluded that the annual potential for biofuels in the US is close to 1.3 billion tonnes (DOE/USDA, 2005). Preliminary results from research conducted by the European Environmental Agency indicate that the potential of environmentally compatible primary biomass for producing energy could increase from around 180 Mtoe* in 2010 to about 300 Mtoe in 2030 (EEA Briefing, 2005).

As there are potential conflicts surrounding the use of biomass, it is important to view it as a bridge to a more sustainable world. Eventually other renewable sources will supersede it. R&D aimed at increasing the energy content of biomass as we progress from first to second generation biofuels and beyond is needed. Meanwhile, other renewable energy sources could help to satisfy increasing energy demands, thereby reducing the pressure to expand biomass production.

Sustainability is a key criterion when extracting energy from biomass. Importantly, there should be:

- no conflict between energy and traditional biomass uses;
- a large positive energy balance. Energy output should be several (say 4–10) times greater than the energy put into the system;
- a neutral or positive greenhouse gas (GHG) emissions balance compared to fossil fuels;
- no threat to biodiversity; and
- no adverse effects on soil, water and air quality, along the whole production chain.

* Mtoe = millions of tonnes oil equivalent

Energy from biomass

Today, the most widely used forms of bioenergy are firewood, bio-ethanol, biodiesel and biogas. As the crops used as feedstock were not specifically bred for providing energy, the yields of biomass used for energy production, in terms of carbohydrate and oil, are not optimal. The energy content of biomass and the efficiency of processes will have to be dramatically improved. This is where R&D will prove vital.

Biomass can generate energy without undergoing previous chemical or biological transformation, for example, when using firewood for power, heating or cooking (Figure 1.1). Biomass can also be processed to produce energy which can be transported long distances or used as liquid fuel for engines.

Amongst the many conversion processes, the most important are: (i) low temperature processes, including the anaerobic digestion of wastes, fermentation of carbohydrates to obtain alcohols and chemical reaction to produce biodiesel; and (ii) high temperature processes, including combustion, pyrolysis and gasification.

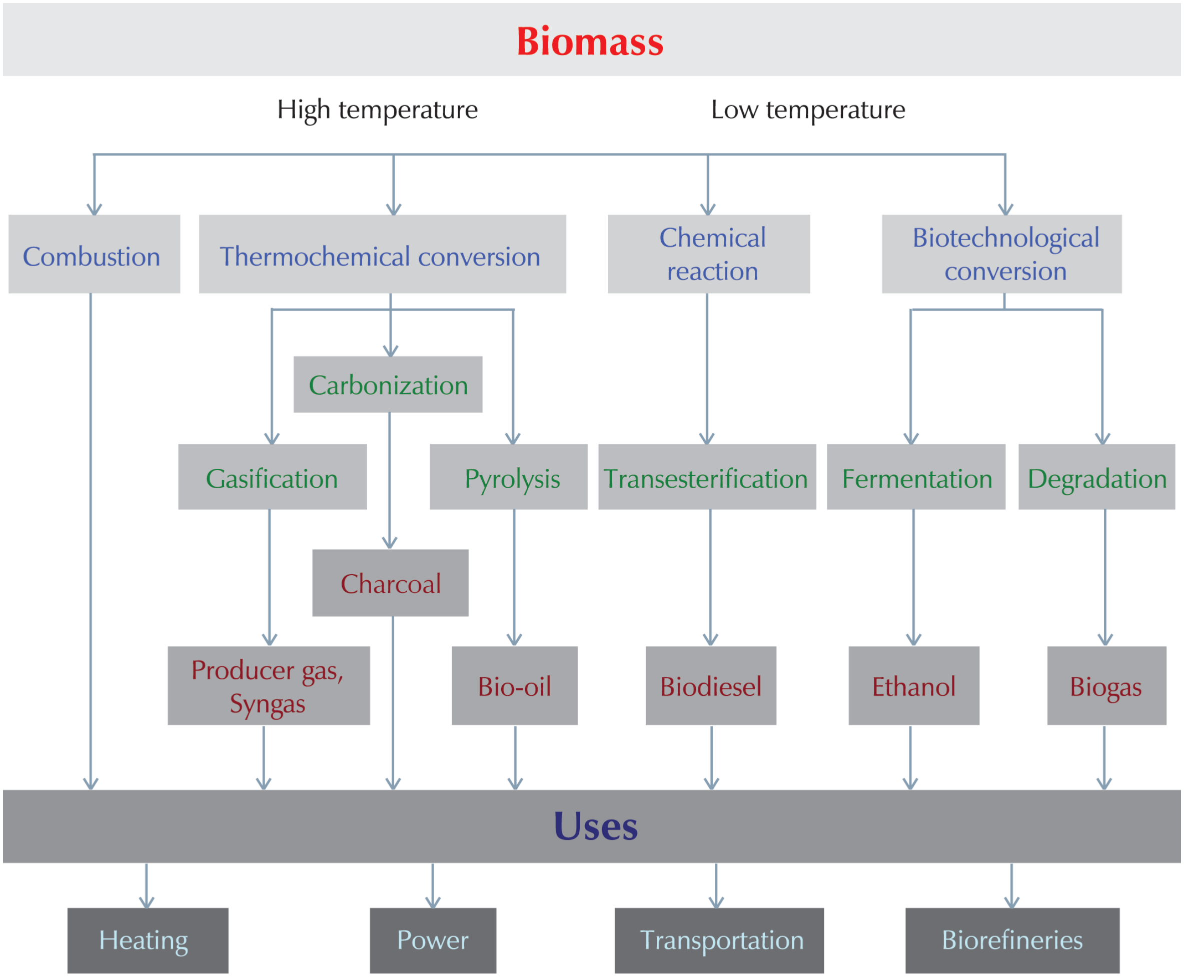

Figure 1.1: Technologies for converting biomass to energy. (A biorefinery is a complex involving the co-production of a spectrum of bio-based products including food, feedstocks, materials and bio based chemicals, and energy in the form of fuel, power or heat.)

The anaerobic digestion of biowaste needs micro-organisms able to break complex organic molecules (chiefly, but not only, carbohydrates) into smaller ones, including volatile products like methane. The volatile portion will be a mixture of several substances. It must be washed and purified before being burned directly (for cooking or heating) or used in internal combustion engines.

Fermentation is also a biotechnological process mediated by micro-organisms that convert carbohydrates (cellulose, sugar or starch) into alcohols such as ethanol.

Chemical processes include the extraction of methanol from biomass (for example wood) and the transformation of vegetable oil or animal fat into biodiesel by chemical reactions mediated by catalysts or enzymes. Biomass can also be transformed via pyrolysis into bio-oil or syngas, or gasified to obtain a volatile fuel. These processes require high temperatures (400–1000°C).

Bio-oil, and gas derived from gasification processes, can be burned in engines directly. Syngas can be used as the primary input to synthesise artificial fuels with similar properties to fossil fuels.

Technology should be adapted to the feedstock and to the scale of energy demand. Domestic applications can be adequately supplied with low density firewood, small gasifiers or biodigesters. The demand for large amounts of liquid fuel requires complex plants for the fermentation, chemical reaction or pyrolysis of large amounts of biomass. According to the United Nations, the ratio of the rural to urban population was 71:29 in 1950; 50:50 in 2008; and will be 30:70 in 2050 (UN, 2007). Urbanisation implies that fewer people will be in the fields producing biomass and more will demand grid electricity or transportation fuels in cities. It will require constant innovation to increase the efficiency with which biomass is converted to avoid expanding the area used for biomass production.

There are two major concerns associated with the use of biomass energy, and both can be addressed by increasing R&D efforts into:

i. The conflict between traditional uses and energy production, which could result in lower food production and higher prices. Further assessment of the arable area still available, the possibility of reducing losses along the food chain and the potential for increased productivity can offset this risk.

ii. The cost of energy derived from biomass could be reduced by the co-production of energy and food in biorefineries. The high market value of chemical substances (catalysts, hormones, enzymes, etc.) could help to guarantee the profitability of the entire chain.

Installed capacity

Studies demonstrate that biomass and waste meet about 11% of world primary energy demand (GEF–STAP, 2006). Table 1.1 shows that the developing world is heavily dependent on biomass where it is used chiefly as firewood. The use of modern liquid biofuels reached 1.28 EJ* in 2007, with 1.12 EJ from ethanol and 477 PJ# from biodiesel.

In 2007, 50 billion litres of ethanol and 11 billion litres of biodiesel were produced worldwide. The use of modern biomass is set to increase in the future as a result of national or regional legislation mandating an increased share for renewables energy. It is predicted that installed capacity in the next decades will increase from the current estimate of 550 ethanol and 250 biodiesel plants (2007) to over one thousand. In addition, new plants will be larger than those currently in use.

Table 1.1: The Energy usage over different regions of the world (EJ/year), (GEF-STAP, 2006)

Region	Primary Energy Usage (EJ/year)	Energy from Biomass (EJ/year)	Biomass share (%)
Africa	21.5	10.5	49
Latin America	18.8	3.3	18
Asia (excl. China)	48.2	15.0	31
China	48.4	9.0	19
Middle East	16.3	0.0	0
CIS, Central Europe	43.7	0.6	1
OECD	223.3	6.8	3
World	420.3	45.2	11

* 1 EJ = 1 exajoule = 1×10^{18}
# 1 PJ = 1 petajoule = 1×10^{15}

Large scale energy production

Biomass accounts for 3–4% of total primary energy consumption within the European Union. Some member states have bioenergy shares of more than 10%—for example, in Finland it accounts for 16%, Sweden 14%, Portugal 13% and Austria 11% (IEA, 2007). Much of this energy consists of heat production from wood, both for households and industrial processes; the contribution of biomass to electricity production is much smaller. Total electricity production from biomass-fired power stations in the OECD Europe in 2007 was about 75.3 TWh[†], or 2.1% of total electricity production (IEA, 2008b). Table 1.2 shows installed capacity, energy output, present costs and projected costs for energy from biomass in Europe.

The total realistic potential for biomass (excluding digestion) in EU countries is expected to be approximately 4.2 EJ per year by 2010 growing to 5 EJ per year by 2030. The countries with the largest potential are France, Spain, Italy and Germany. Commercial production of energy crops is expected to make a substantial contribution in Spain and Italy (Jorgensen and Van Djik, 2003).

Table 1.2: Energy capacity, output and costs for biomass in Europe (IEA, 2007).

Source	Installed capacity (GW thermal)	Energy output (PJ/yr)	Costs in 2005		Projected average cost reduction 2030/2005 (%)
			Range (€/GJ)	Average (€/GJ)	
Total biomass	1000–1200	3000–4000			
Pellet heating			8–99	52	42
CHP			7–67	26	5
Anaerobic digestion			6–32	15	3
MSW[‡] to energy			2–12	5	9

Europe is the global leader in biodiesel production (6.4 billion litres), representing about 60% of worldwide production in 2007 (Biofuels Platform, 2009a). Within the EU, Germany, France and Italy are the top three producers, with Germany alone accounting for 3.3 billion litres. Other major players are the United States (1.7 billion litres), Indonesia (0.76 billion litres) and Brazil (0.73 billion litres).

Bio-ethanol production is concentrated in the US (24.5 billion litres) and Brazil (21.3 billion litres), which account for 90% of worldwide production—estimated to be almost 51.3 billion litres in 2007 (Biofuels Platform, 2009b). Sugar cane or cereals like corn or wheat are used as feedstock for ethanol production. In the case of sugar cane, the conflict with other biomass uses is minimal. However, the use of cereals as energy crops directly conflicts with food and fodder demands, potentially adversely impacting supply, stocks and prices. Moreover, the energy balance for ethanol production from sugar cane ranks is 8–10:1 (output: input), well above 1.3:1 for cereals.

† TWh = terawatt hours
‡ MSW = Municipal Solid Waste

2. Research and Development Activities

Domestic energy needs

Biomass accounted for 1186 Mtoe of global primary energy demand in 2006 (IEA, 2008a) of which 771 Mtoe was used to meet residential energy demand in developing countries. This amounts to around two billion tonnes of biomass. Given that an estimated 2.5 billion people are dependent on biomass for cooking, this equates to just under one tonne of biomass per person per year.

Distributed electricity generation for improving rural quality of life

Distributed electricity generation increases the quality of life in villages and hamlets that are far from or not connected to the electrical grid. The technologies that can deliver power at 10 to 1000 kWe are based on gasification and reciprocating engines. The key challenge for these small systems is to design a gasifier that produces a clean gas without a heavy load (tar and particulates) on the cleaning system. This issue was addressed in the late 1980s at the Indian Institute of Science (IISc) by using a geometrically simple reactor design which is available today (IISc, 2003).

Recently, scientists in Denmark have embarked on a two-stage gasification system with good performance (Gøbel et al., 2004). The configuration is promising but will require careful operational controls. Independent controls are needed, unlike the earlier designs (WW II and IISc class designs) where a single control can be used to obtain the desired throughput. Another group has started an even more complex three-stage gasification process (Kwant and Knoef, 2004). The efficacy of these systems, taking account of the need to develop the skills to operate and manage them effectively, remains to be proven.

New techniques which use and adapt old ideas include the Stirling engine (at 10 to 50 kWe power) and superheated steam-turbines, where the turbine is derived from the classic turbo-super charger of reciprocating engines and connected to an alternator to generate electricity. Such technologies could offer cheaper, user-friendly solutions, particularly for power generation in distant locations and would benefit from further development.

Biorefineries

Conceptually, a biorefinery is complex, involving the co-production of a spectrum of bio-based products (food, feed, materials and bio-based chemicals) and energy (fuels, power, heat) from biomass (IEA Bioenergy Task 42, 2009). The biorefinery concept integrates the biomass conversion processes to produce fuels, power, and value-added chemicals, resembling the present petroleum refinery (see Figure 2.1).

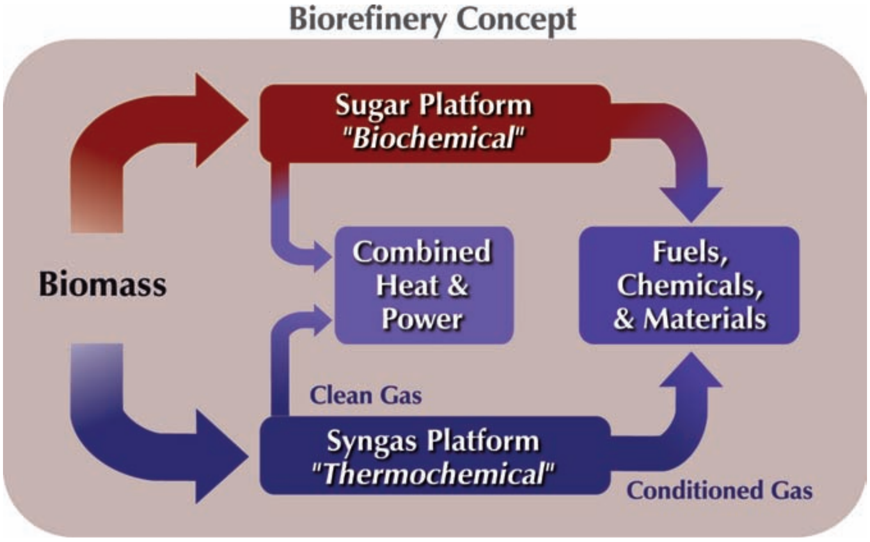

Figure 2.1: From biomass to biofuels and bioproducts using the biorefinery concept. (NREL, 2008)

It is possible that the value of 'speciality' products like catalysts, enzymes or hormones will rise relative to the value of commodities, including energy. A biorefinery producing multiple products could take advantage of the various components in the biomass feedstock and intermediate products, maximising the value derived. Several low-volume, but high-value chemical or nutraceutical products could be more profitable than low-value, high volume ones. High-value products improve profitability, while high-volumes of fuel would help meet energy needs. Power production helps to lower energy costs. Taken together, all of these contribute to reducing GHG emissions.

The biorefinery concept shows considerable promise. In all major uses of wood (charcoal, firewood, pulp and paper), a substantial amount of wood is lost as low quality fuel or in the form of pollution. The aim now is to extract lignin, hemicelluloses and derivatives, carbohydrates, extractives, resins, turpentine, etc. from wood and wood residues (Figure 2.2). The opportunity lies in the pulping process, using the cellulose fibres to manufacture paper, and part of the remaining chemicals to generate other valuable products. In the integrated production of ethanol and pulp, the initial phase of the kraft digestion would be a light hydrolysis to extract the loose fraction of hemicelluloses. Around 10 to 15% of the wood may be removed by a mild water hydrolysis, allowing mannans and xylans to be fermented and converted to alcohol.

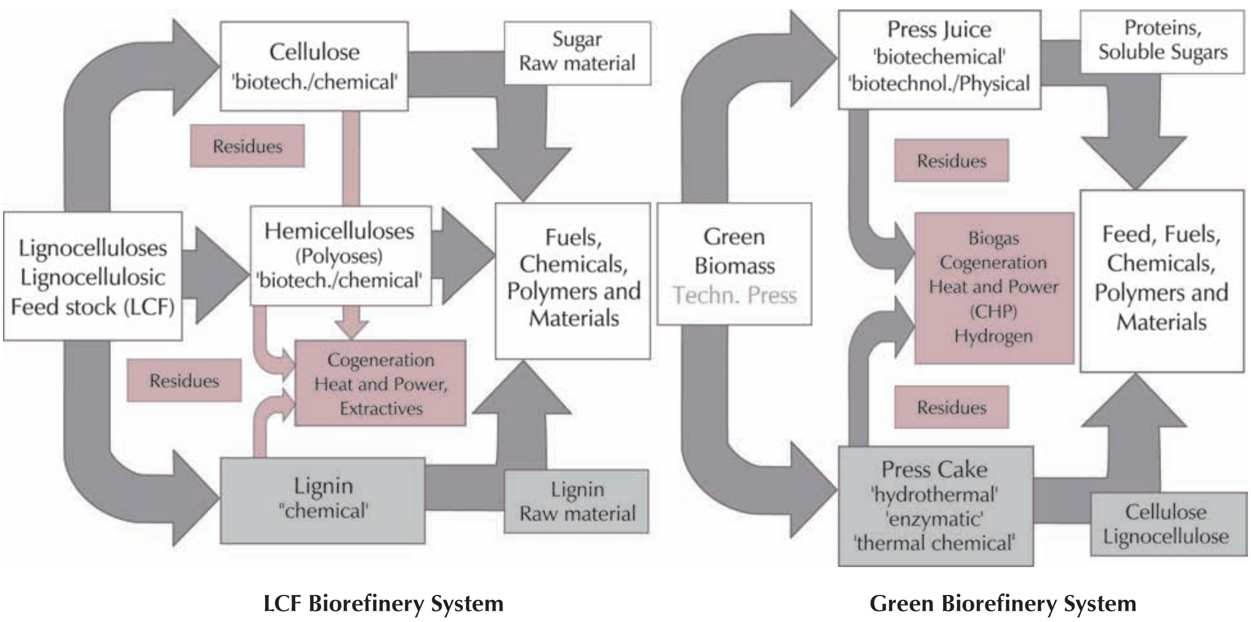

Figure 2.2: Example of fluxes on biorefineries. LCF = lignocelluloses feedstock.

While the petrochemical industry relying on fossil fuels is likely to phase out during the 21st century, the demand for biodegradable polymers is steadily growing at an annual rate of between 20 and 30%. This will continue to grow as the present market share is modest, accounting for less than 0.1% of the total plastics market.

Today, the bioplastics available in the market are mainly carbohydrate-based materials. Starch can either be physically modified, used alone or used in combination with other polymers. It can also be used as a substrate for fermentation in the production of poly-hydroxy-alkanoates or lactic acid, transformed into poly lactic acid (PLA) through standard polymerisation processes.

The increasing use of bioplastics could lead to entirely new generations of materials with new levels of performance compared to traditional plastics. The fact that bioplastics are recyclable, biodegradable and minimise pollution, could lead to significant environmental and social benefits in a wide range of disposal options such as sewage sludge water treatment plants, composting and incineration.

Biomass productivity

Just as the technologies for processing must be more efficient, it is important that biomass is grown efficiently and sustainably. Land, nutrients, water, plant genetics and ambient climatic conditions control plant growth rates. The productivity of several energy-related biomass crops is presented in Table 2.1 (solid biomass) and Table 2.2 (oil bearing trees). The oil bearing trees generate feedstock at a rate of about 1 to 3 dry t/ha yr.

The oil seeds themselves contain 25 to 60% oil by volume and full extraction requires a solvent process. The residue after oil extraction is also available for energy use but is often ignored. Its uses can be many—as part of food, fodder or alternatively as an ingredient in making fuel pellets for heat and/or electricity. The last column in Table 2.1 shows the magnitude of this waste material. The second (and subsequent) generation biofuels will address this issue, as all the solids can be converted to liquids via a gasification process or degraded to carbohydrates for alcohol production.

The energy intensity per unit of area is as important as physical productivity. In the near future, biomass yield will be measured in terms of the potential quantity of convertible joules a crop can deliver over a given area rather than tonnes of dry matter.

To supply the feedstock to ethanol and biodiesel plants, for example, R&D efforts must be directed at developing new crop varieties and technologies to enable around 400 GJ of potential energy to be extracted per hectare. This compares with today's maximum of 180 GJ/ha from African palm or 140 GJ/ha from sugar cane. In addition, industrial processes will have to be optimised and improved to keep pace with levels of sustainability required in bioenergy production. Technological innovation can lead to second and subsequent generation biofuels which are more energy efficient, thereby mitigating competition with other biomass uses such as food.

A significant amount of research is needed to understand the pathways by which light is converted to biomass. The most efficient plants can convert only 1% of the energy from solar radiation to energy embodied in biomass. Biotechnology and nanotechnology have the potential to bring about major technological breakthroughs for improving biomass productivity, enhancing the overall process of conversion to biofuels.

Table 2.1: Land productivity for bio-residues in dry t/ha yr (5 year average) (European Commission, 2005).

Crop	Crop Yield (dry t/ha yr)	Wastes
Unattended forest	3–10	30% lops & tops
Tropical plantation, with nutrients and water	20–25	30% lops &tops
Short rotation coppice (Willow, Poplar)	10–15	30% lops & tops (unless whole tree is used)
Miscanthus, Switchgrass	10–15	–
Sugar cane	30–50	Dry bagasse (15%), trash 5%
Coconut solid waste	8–10	Fronds, coir pith & shell

Table 2.2: Land productivity in terms of liquid fuel and energy output, (GEF-STAP, 2006; Annadana, 2005).

Biofuels	kilolitre/ha	GJ/ha	Solid waste output, dry t/ha (GJ/ha)
First generation fuels—Biodiesel from:			
Palm oil (edible oil)	5.0	178.5	20.0 (340)
Coconut oil (edible oil)	2.2	78.2	Edible products
Jatropha curcas	1.6	56.5	4–6 (60–90)
Jojoba	1.5	53.0	3–5 (45–75)
Sunflower (edible oil)	1.0	35.7	Food/Fodder, 2 (30)
Rapeseed	1.0	35.5	2.0 (32)
Groundnut (edible oil)	0.9	32.1	Food/Fodder, 1.5 (21)
Pongemia	0.8	28.5	2–3 (30–45)
Soybean (edible oil)	0.5–0.7	17.8–25.0	Food/Fodder, 1 (15)
First generation fuels—Ethanol from:			
Sugar cane	5.3–8.5	112.0–138.0	Bagasse
Sugar beet	5.5	116.6	Fodder
Maize	3.1	65.7	Fodder
Wheat	2.5	53.0	Fodder
Second generation fuels			
DME from solid biomass	45–60	846–1128	–
Biomethanol from solid biomass	49–66	772–1029	–
FT* biodiesel from solid biomass	13–18	463–617	–

* FT = 2nd generation Fischer-Tropsch

3. Research and Development Institutions

There are two main groups of countries conducting biomass energy R&D. The first represents the largest share and includes the European Union, the US and Brazil. The second represents several developing countries, including China, India and South Africa.

The USDA has encouraged development of US bio-based resources in a number of ways, primarily through support for R&D but with some support for demonstration projects and commercialisation. The Agricultural Research Service is the in-house research arm of the USDA, with several federal laboratories. Through its research programmes, new and advanced technologies are developed, modified, and utilised to convert animal and plant components (protein, oil/fat, starch, fibre, and processing by-products) to new products and to develop new crops to meet niche market opportunities. The primary focus is to develop industrial and bioenergy products that can meet environmental needs, replace imports and petroleum-based products, and expand market opportunities.

The US Department of Energy's (DOE) R&D programme helps to develop enzymes that can efficiently and cost-effectively break down cellulose into simple sugars for use in fermentation to produce liquid fuels. Several other R&D institutions in the USA—mainly Universities and Technology Institutes—have programmes dedicated to discovering and improving agronomic and industrial technologies to transform biomass into biofuels or bio-based products.

In the European Union there are various institutions dedicated to biomass R&D. These focus on agronomics, conversion pathways and the development of biorefinery processes. Research is advancing chiefly at the national level. A recent, comprehensive survey by ERA Bioenergy indicates that 90% of bioenergy R&D in Europe is funded by national sources (Bioenergy NoE, 2009). However, there are important pan-European R&D networks, for example BEGIN (Biomass Energy Genetics Improvement Network), led by Rothamsted Research, dedicated to the improvement of biomass as a feedstock for the energy industry.

The European Commission is becoming an increasingly important source of R&D finance, supporting the Bioenergy Network of Excellence (NoE), a group of eight leading European bioenergy institutes. Its main purpose is to integrate individual R&D activities to create a Virtual Bioenergy R&D Centre. In its 7th Framework Programme, the European Commission is continuing to support biofuels. It is believed that this research and technological development will lead to high social and economic benefits. A particular focus is placed on the biorefinery concept and on second-generation biofuels.

Brazil has particular expertise in tropical agricultural technology and biomass production for energy, with a focus on cultivated forest species, oil crops and sugar cane. It has also developed state-of-the-art technology for ethanol and biodiesel production and has several active networks dealing with the improvement of biomass traits, conversion process and biorefinery concepts.

Many countries looking to expand their use of renewables are investing in R&D focusing on second generation biofuels. Cellulosic conversion to ethanol is most likely to become a mature technology, but continued investment will be required to optimise the conversion of lignocellulosic material to biofuels and the conversion of residues to bio-based products.

Industrial activities

The biomass industry has the largest installed capacity of any renewable energy source (Martinot, 2005); it operates in both the formal and informal sectors of the economy. In most developing countries, biomass (firewood) trading occurs in villages and village markets, as well as larger urban markets. There is some conflict with forest authorities, as part of the firewood, based on ‘lops and tops’, is derived from forest lands. There are also substantial privately owned plantations from which ‘lops and tops’ are transported. Charcoal produced in regions with deep forest is being transported to urban market centres avoiding regulatory measures being imposed on environmentally harmful charcoal production.

In India, biomass-based power generation has attracted many industries; several hundred MWe* of electricity generation, based on biomass, have been installed. In China and Europe, however, co-firing of biomass with coal is more widely practiced (Mao, 2003). Countries like India and China have a number of industries that provide a range of services for biomass-based combustion systems, boilers and steam turbines as well as gasification based power plants.

In Europe and the US there are large biomass processing industries. Pelletizing has been addressed seriously in industrial establishments and there is a large market for district and home heating applications. Full scale power generation equipment is also designed, built and marketed in these countries. Latin American countries like, Brazil, Argentina, Mexico, Chile, Uruguay and Costa Rica have the necessary infrastructure to design, build and market biomass combustion equipment. On the African continent, South Africa has developed a high degree of experience in the use of biomass based conversion devices.

Brazil, Europe (particularly Germany) and the US have made substantial progress in encouraging private industrial activity in the production and marketing of ethanol and biodiesel. This is in addition to governmental and semi-governmental agencies taking direct interest in production and marketing.

More information on industrial activities can be found on the websites of the European Association of Renewable Energy Research Centers (EUREC; http://www.eurec.be), European Biomass Industry Association (EUBIA; http://www.eubia.org) and the Sugarcane Industry Association (UNICA; http://english.unica.com.br).

* MWe = megawatt electric (10^6 Watt)

4. Directions for Future Research and Development

As is the case with other sources of renewable energy, R&D into bioenergy will be the key to expanding its share of the energy mix. In the case of bioenergy, a considerable amount of agronomic and forestry technology can be imported from traditional agricultural production systems.

There are, however, several other areas of biomass R&D addressing both feedstock production and its further processing are required. The list below summarises the most important approaches to maximising energy production from biomass, using a holistic approach, including the concept of end use and biorefineries.

Biomass productivity: Plant biology

Next 5 years	Next 15 years
Set up, characterise and maintain plant DNA banks of new oleaginous species and expand existing DNA banks	Introduce desirable traits for productivity, soil adaptation and stress tolerance to plants for biomass production
Identify new plants with outstanding energy production per unit of area	Develop commercial varieties of new crops with high energy yield per unit of area
Identify the pathways of photosynthesis and modes of enhancing solar energy capture	Develop new crop varieties with enhanced yield
Basic research into lignin and cellulosic metabolic pathways	Determine the cell wall processes and modes of enhancing the carbohydrate pathways
Perform research to optimise the energy output/input for various target plants	Enhance the output in field conditions
Identify basic metabolic pathways for plant resistance to biotic (pests) and abiotic (drought, temperature, pH or salinity) stresses	Develop plant models describing different pathways for overcoming biotic or abiotic stresses
Identify plant genes linked to resistance or tolerance to major biotic or abiotic stresses	Introduce genes and develop plant varieties able to withstand certain degrees of biotic and abiotic stresses
Identify genetic material with improved soil nutrients uptake and use	Develop new crop varieties with enhanced soil nutrients uptake and use
Identify methods for altering carbon flows into higher energy compounds like lipids	Develop new crop varieties with higher lipid concentration
Identify and characterise algae with desired traits for producing energy	Develop production systems to use algae for biomass production
Identify genes and biochemical pathways to produce pharmaceuticals from biomass	Introduce genes to produce or to enhance the production of pharmaceuticals from biomass

Biomass productivity: Agronomic practices

Next 5 years	Next 15 years
Develop studies for further understanding symbiotic plant bacteria associations for atmospheric nitrogen fixation	Improve production systems to incorporate new standards for atmospheric nitrogen fixation
Investigate novel microorganisms able to associate to plants outside the Leguminosae family for symbiotic fixation of atmospheric nitrogen	Improve microorganisms for association with plants aiming to higher levels of symbiotic nitrogen fixation
Investigate plant – microorganisms associations with growth promotion capabilities	Develop processes and application technologies to introduce growth promoters and nitrogen fixating microorganisms on production systems
Identify phyto-hormones biochemical pathways and substances acting as hormonal bio-activators	Integrate the use of bio-activator substances into biomass production systems
Validate soil carbon impact on crop residue removal	Develop systems that sequester soil carbon and enable carbon reallocation for energy
Identify and analyse data on potential environmental impacts of intensive agriculture (i.e. soil erosion, run-off etc.)	Test and demonstrate technology designed to reduce nitrogen and phosphorous run-off
Create understanding and demonstrate the potential increase in productivity of new crops	Develop optimal practices for producing and handling the new crops
Develop studies on plant, soil, water interactions	Implement improved techniques for soil water storage and water use by the plants
Develop studies on plant, pest, predator relationships	Implement improved techniques for bio-controlling agricultural pests
Establish optimal agronomic practices for sustainable production, including existing residue removal	Develop and test agronomic practices to enhance crop production, improve consistency and reduce stress susceptibility
Develop studies on the life cycle and energy balance of biomass feedstock, looking at reducing the energy consumption of the systems	Develop improved production systems less intensive in energy demand
Identify the most suitable soils and regions to grow energetic intensive crops	Establish agro-ecological zoning for energetic crops in the new agricultural expansion areas
Develop harvesting and processing systems to improving the oil extraction activities and the use of co-products and residues	Introduce new harvesting and processing techniques on improved production systems
Develop basic studies on forestry parameters (spacing, fertilisation, rotation, rate of growing, net photosynthesis, etc.)	Establish forestry parameters that maximise sustainable forest biomass production
Develop technologies to enable the establishment and management of energy forests in areas unsuitable for agriculture or degraded areas	Validate forestry production systems on marginal lands
Identify requirements for establishing agro-forestry arrangements on the small scale	Develop agro-forestry arrangements appropriate for small farms

Biomass for domestic cooking

Next 5 years	Next 15 years
Prepared fuels for cooking	Advanced biomass stoves
Avoidance of charcoal for primary cooking	New stove technologies with less health and environmental impacts

Oil seeds to biodiesel for Diesel cycle engines

Next 5 years	Next 15 years
Improving existing processes or develop new processes for substituting vegetable oil or animal fat as feedstocks for biodiesel production	Improve pyrolysis, gasification and syngas production routes
Develop adaptations on diesel engines to run on bioethanol	Develop adaptations on diesel engines to run on further generation biofuels
Improving oil extraction methods, especially adapted to small and medium size plants	Develop devices for completely extract oils from feedstock, on small and medium size plants
Develop studies on the catalysts and reagents used in industrial processes	Improve biodiesel production techniques aiming to reduced energy demand, low cost and larger scales

Biomass to clean heat and electricity

Next 5 years	Next 15 years
Research and develop reliable, fuel-flex, energy efficient, cost optimised gasification systems	Adopt widespread utilisation of these technologies in developing and developed countries
Generate technologies for the recovery of condensable gaseous products during the wood carbonisation process	Implement widespread use of technologies for recovering gases on carbonisation plants
Improve the use of black liquor for energy	Implement widespread use of improved technologies for using black liquor as energetic feedstock
Set up protocols, certification and technical standards for the technologies associated with the supply and use of energy from forest biomass	Implement certification protocols on the biomass power chain
Develop studies on the quality of charcoal to be used in blast furnaces, with emphasis on carbon fines studies	Implement improved technologies for using charcoal and fines for energy purposes

Biogas digesters to heat and electricity

Next 5 years	Next 15 years
Develop domestic, multi-feedstock, modern high rate biomethanation systems	Adopt widespread utilisation of these in developing nations
Develop and evaluate the kinetics of anaerobic digestion in different biodigester models	Supply biodigester with biomass heating, stirring and thermal insulation to increase biogas production and improve the efficiency of organic matter removal
Develop and evaluate complementary systems for the final treatment of liquid biodigester wastes	Further evaluate the environmental impact of biodigester wastes

Next 5 years	Next 15 years
Evaluate the quantitative and qualitative characteristics of biogas as a function of climatic seasonality and type of animal production system	Evaluate and develop mathematical models for estimating biogas generation and evaluating the qualitative and quantitative characteristics of biogas as a function of the effect of climatic seasonality
Evaluate the use of bio-fertilisers, such as organic manure, to replace chemical fertilisers in grain and pasture planting systems	Evaluate the environmental risks that intensive use of organic bio-fertilisers in grain and pasture planting systems would pose to superficial and underground waters
Develop equipment for the use of biogas, instead of PLG and firewood, as heat source in swine and poultry production facilities	Develop equipment for the use of biogas, instead of PLG and firewood, as heat source in grain drying
Develop equipment to compress and transport biogas under low pressure	Develop ion exchange membrane for fuel cells using biogas
Develop low-pressure biogas storage systems for use in swine and poultry production farms	Generate novel biogas treatment and purification systems to reduce corrosion, diminish humidity and increase the methane ratio

Sugars, starch and cellulose to ethanol for Otto cycle engines

Next 5 years	Next 15 years
Improve fermentation processes, specially using microorganisms with high ethanolic efficiency	Develop conversion of cellulose and hemi-cellulose to ethanol
Identify improved biofuels with low molecular weight derived from biomass	Develop process for obtaining succedaneums of ethanol, with improved energy efficiency
Describe the life cycle of ethanol production plants to identify inefficiency gaps	Develop process for reducing the use of water, inputs and energy on ethanol production
Identify ways for improving co-generation efficiency	Develop processes for maximising the energy output on co-generation systems

Biorefineries and co-products processing

Next 5 years	Next 15 years
Identify chemical substances present in biomass with interest to the chemical industry	Develop process to extract, purify and refine bioproducts
Identify chemical substances presently extracted from fossil sources that can be obtained from biomass	Develops process to produce chemical substances replacing fossil sources by biomass
Identify chemical routes for expansion of oil and ethanol chemistry	Develop process for producing chemicals derived from oil and ethanol
Develop economic uses for the glycerol generated on biodiesel plants	Deployment of new uses of glycerol into the market
Develop novel nutritional uses from bioenergy residues	Continue developing novel nutritional uses from bioenergy residues

Novel approaches using existing technologies

Next 5 years	Next 15 years
Develop compact domestic biomethanation plants using high rate biomethanation	Adopt on global scale
Develop advanced clean combustion and Stirling engine technologies for electricity at affordable investment costs	Produce at small scale making the technology accessible for remote locations
Develop advanced clean combustion—super heated steam and turbo-supercharger based power generation	Produce at large scale enabling wide use

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