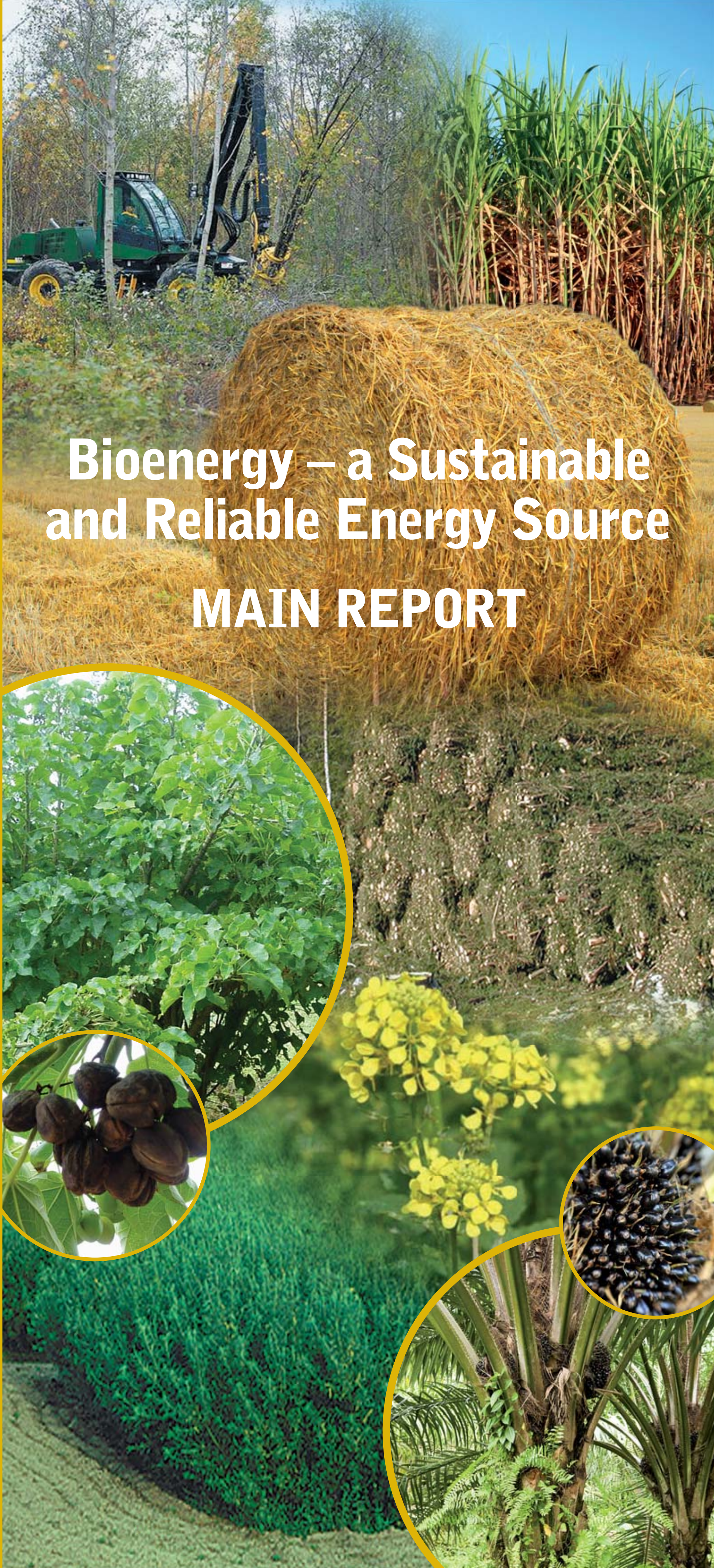

Bioenergy – a Sustainable and Reliable Energy Source

MAIN REPORT

This report was jointly prepared for IEA Bioenergy by the Energy Research Centre of the Netherlands (ECN), E4tech, Chalmers University of Technology, and the Copernicus Institute of the University of Utrecht. The purpose of the report was to produce an authoritative review of the entire bioenergy sector aimed at policy and investment decision makers. The brief to the contractors was to provide a global perspective of the potential for bioenergy, the main opportunities for deployment in the short and medium term and the principal issues and challenges facing the development of the sector.

IEA Bioenergy

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BIOENERGY – A SUSTAINABLE AND RELIABLE ENERGY SOURCE
A review of status and prospects

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KEY MESSAGES

Bioenergy is already making a substantial contribution to meeting global energy demand. This contribution can be expanded very significantly in the future, providing greenhouse gas savings and other environmental benefits, as well as contributing to energy security, improving trade balances, providing opportunities for social and economic development in rural communities, and improving the management of resources and wastes.

Bioenergy could sustainably contribute between a quarter and a third of global primary energy supply in 2050. It is the only renewable source that can replace fossil fuels in all energy markets – in the production of heat, electricity, and fuels for transport.

Many bioenergy routes can be used to convert a range of raw biomass feedstocks into a final energy product. Technologies for producing heat and power from biomass are already well-developed and fully commercialised, as are 1st generation routes to biofuels for transport. A wide range of additional conversion technologies are under development, offering prospects of improved efficiencies, lower costs and improved environmental performance.

However, expansion of bioenergy also poses some challenges. The potential competition for land and for raw material with other biomass uses must be carefully managed. The productivity of food and biomass feedstocks needs to be increased by improved agricultural practices. Bioenergy must become increasingly competitive with other energy sources. Logistics and infrastructure issues must be addressed, and there is need for further technological innovation leading to more efficient and cleaner conversion of a more diverse range of feedstocks. Further work on these issues is essential so that policies can focus on encouraging sustainable routes and provide confidence to policy makers and the public at large.

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EXECUTIVE SUMMARY

INTRODUCTION

The supply of sustainable energy is one of the main challenges that mankind will face over the coming decades, particularly because of the need to address climate change. Biomass can make a substantial contribution to supplying future energy demand in a sustainable way. It is presently the largest global contributor of renewable energy, and has significant potential to expand in the production of heat, electricity, and fuels for transport. Further deployment of bioenergy, if carefully managed, could provide:

- an even larger contribution to global primary energy supply;
- significant reductions in greenhouse gas emissions, and potentially other environmental benefits;
- improvements in energy security and trade balances, by substituting imported fossil fuels with domestic biomass;
- opportunities for economic and social development in rural communities; and
- scope for using wastes and residues, reducing waste disposal problems, and making better use of resources.

This review provides an overview of the potential for bioenergy and the challenges associated with its increased deployment. It discusses opportunities and risks in relation to resources, technologies, practices, markets and policy. The aim is to provide insights into the opportunities and required actions for the development of a sustainable bioenergy industry.

BIOMASS RESOURCES

At present, forestry, agricultural and municipal residues, and wastes are the main feedstocks for the generation of electricity and heat from biomass. In addition, a very small share of sugar, grain, and vegetable oil crops are used as feedstocks for the production of liquid biofuels. Today, biomass supplies some 50 EJ[1] globally, which represents 10% of global annual primary energy consumption. This is mostly traditional biomass used for cooking and heating. See Figure 1.

There is significant potential to expand biomass use by tapping the large volumes of unused residues and wastes. The use of conventional crops for energy use can also be expanded, with careful consideration of land availability and food demand. In the medium term, lignocellulosic crops (both herbaceous and woody) could be produced on marginal, degraded and surplus agricultural lands and provide the bulk of the biomass resource. In the longer term, aquatic biomass (algae) could also make a significant contribution.

Based on this diverse range of feedstocks, the technical potential for biomass is estimated in the literature to be possibly as high as 1500 EJ/yr by 2050, although most biomass supply scenarios that take into account sustainability constraints, indicate an annual potential of between 200 and 500 EJ/yr (excluding aquatic biomass). Forestry and agricultural residues and other organic wastes (including municipal solid waste) would provide between 50 and 150 EJ/year, while the remainder would come from energy crops, surplus forest growth, and increased agricultural productivity. See Figure 2.

Projected world primary energy demand by 2050 is expected to be in the range of 600 to 1000 EJ (compared to about 500 EJ in 2008). Scenarios looking at the penetration of different low carbon energy sources indicate that future demand for bioenergy could be up to 250 EJ/yr. This projected demand falls well within the sustainable supply potential estimate, so it is reasonable to assume that biomass could sustainably contribute between a quarter and a third of the future global energy mix. See Figure 2. Whatever is actually realised will depend on the cost competitiveness of bioenergy and on future policy frameworks, such as greenhouse gas emission reduction targets.

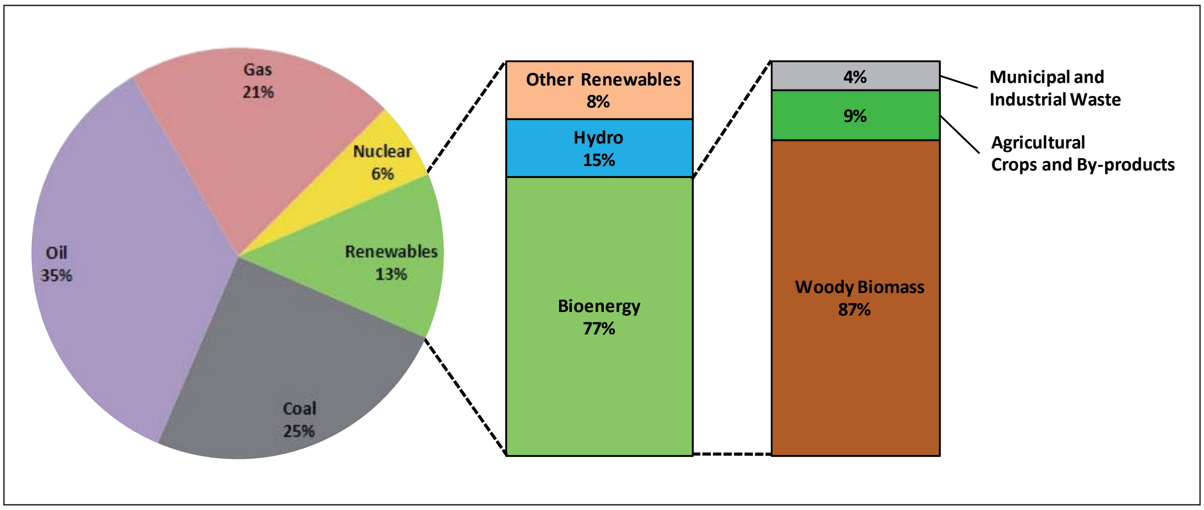
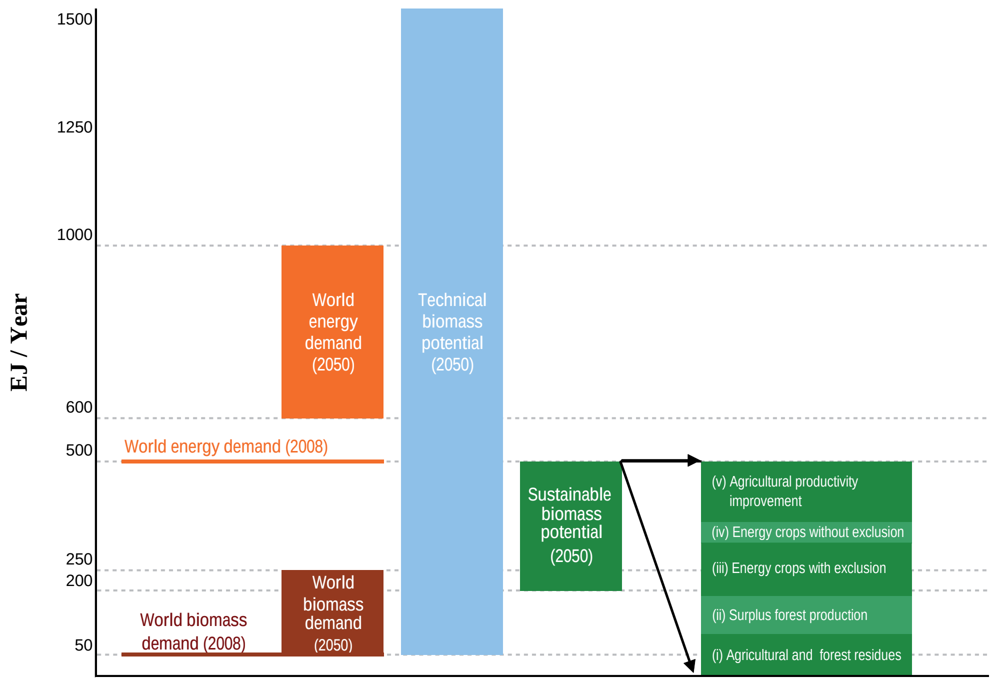


Figure 1. Share of bioenergy in the world primary energy mix. Source: based on IEA, 2006; and IPCC, 2007.

[1] 1 EJ = 10^{18} Joules (J) = 10^{15} kilojoules (kJ) = 24 million tonnes of oil equivalent (Mtoe).



- Current world energy demand (500 EJ/year).
- Current world biomass demand (50 EJ/year).
- Total world primary energy demand in 2050 in World Energy Assessment (600 - 1000 EJ/year).
- Modelled biomass demand in 2050 as found in literature studies (50 - 250 EJ/year).
- Technical potential for biomass production in 2050 as found in literature studies (50 - 1500 EJ/year).
- Sustainable biomass potential in 2050 (200-500 EJ/year). *Sustainable biomass potentials consist of: (i) residues from agriculture and forestry (~ 100 EJ); (ii) surplus forest production - net annual increment minus current harvest (~ 80 EJ); (iii) energy crops, excluding areas with moderately degraded soils and/or moderate water scarcity (~ 120 EJ); (iv) additional energy crops grown in areas with moderately degraded soils and/or moderate water scarcity (~ 70 EJ) and (v) additional potential when agricultural productivity increases faster than historic trends thereby producing more food from the same land area (~ 140 EJ).*

Figure 2. Technical and sustainable biomass supply potentials and expected demand for biomass (primary energy) based on global energy models and expected total world primary energy demand in 2050. Current world biomass use and primary energy demand are shown for comparative purposes. Adapted from Dornburg et al. (2008) based on several review studies.

Growth in the use of biomass resources in the mid-term period to 2030 will depend on many demand and supply side factors. Strong renewable energy targets being set at regional and national level (e.g. the European Renewable Energy Directive) are likely to lead to a significant increase in demand. This demand is likely to be met through increased use of residues and wastes, sugar, starch and oil crops, and increasingly, lignocellulosic crops. The contribution of energy crops depends on the choice of crop and planting rates, which are influenced by productivity increases in agriculture, environmental constraints, water availability and logistical constraints. Under favourable conditions substantial growth is possible over the next 20 years. However, estimates of the potential increase in production do vary widely. For example, the biomass potential from residues and energy crops in the EU to 2030 is estimated to range between 4.4 and 24 EJ.

The long-term potential for energy crops depends largely on:

- land availability, which depends on food sector development (growth in food demand, population diet, and increased crop productivity) and factors limiting access to land, such as water and nature protection;
- the choice of energy crops, which defines the biomass yield levels that can be obtained on the available land.

Other factors that may affect biomass potential include the impact of biotechnology, such as genetically modified organisms, water availability, and the effects of climate change on productivity.

The uptake of biomass depends on several factors:

- biomass production costs – US$4/GJ is often regarded as an upper limit if bioenergy is to be widely deployed today in all sectors;
- logistics – as with all agricultural commodities, energy crops and residues all require appropriate supply chain infrastructure;
- resource and environmental issues – biomass feedstock production can have both positive and negative effects on the environment (water availability and quality, soil quality and biodiversity). These will result in regulations restricting or incentivising particular practices (e.g. environmental regulations, sustainability standards, etc.).

Drivers for increased bioenergy use (e.g. policy targets for renewables) can lead to increased demand for biomass, leading to competition for land currently used for food production, and possibly (indirectly) causing sensitive areas to be taken into production. This will require intervention by policy makers, in the form of regulation of bioenergy chains and/or regulation of land use, to ensure sustainable demand and production. Development of appropriate policy requires an understanding of the complex issues involved and international cooperation on measures to promote global sustainable biomass production systems and practices.

To achieve the bioenergy potential targets in the longer term, government policies, and industrial efforts need to be directed at increasing biomass yield levels and modernising agriculture in regions such as Africa, the Far East and Latin America, directly increasing global food production and thus the resources available for biomass. This can be achieved by technology development, and by the diffusion of best sustainable agricultural practices. The sustainable use of residues and wastes for bioenergy, which present limited or zero environmental risks, needs to be encouraged and promoted globally.

BIOMASS CONVERSION TECHNOLOGIES

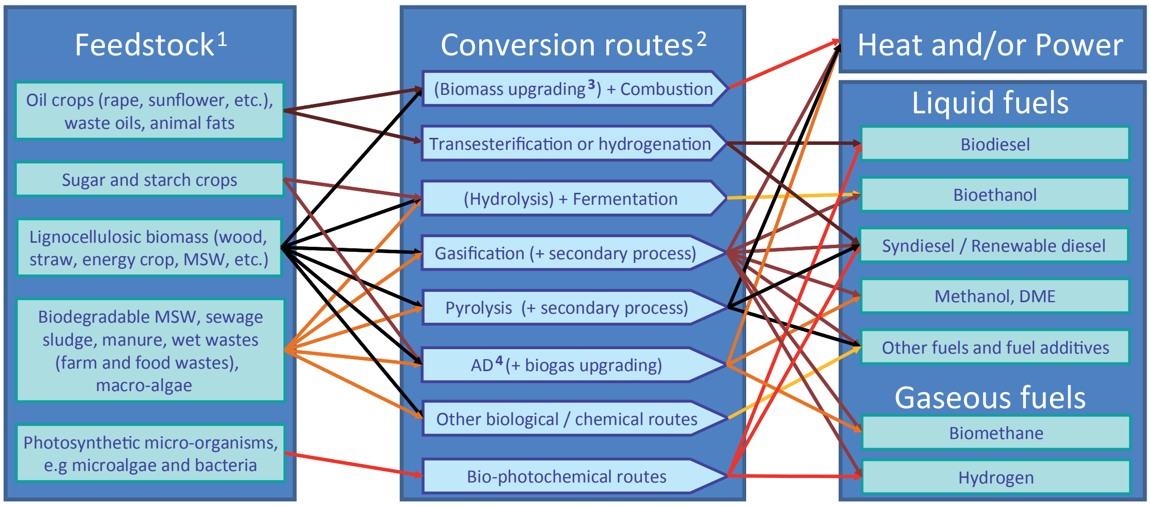
There are many bioenergy routes which can be used to convert raw biomass feedstock into a final energy product (see Figure 3). Several conversion technologies have been developed that are adapted to the different physical nature and chemical composition of the feedstock, and to the energy service required (heat, power, transport fuel). Upgrading technologies for biomass feedstocks (e.g. pelletisation, torrefaction, and pyrolysis) are being developed to convert bulky raw biomass into denser and more practical energy carriers for more efficient transport, storage and convenient use in subsequent conversion processes.

The production of heat by the direct combustion of biomass is the leading bioenergy application throughout the world,

Ethanol pilot plant based on corn fibre and other cellulosic material, New Energy Company of Indiana, USA. (Courtesy DOE/NREL and W. Gretz)

and is often cost-competitive with fossil fuel alternatives. Technologies range from rudimentary stoves to sophisticated modern appliances. For a more energy efficient use of the biomass resource, modern, large-scale heat applications are often combined with electricity production in combined heat and power (CHP) systems.

Different technologies exist or are being developed to produce electricity from biomass. Co-combustion (also called co-firing) in coal-based power plants is the most cost-effective use of biomass for power generation. Dedicated



[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

Figure 3: Schematic view of the wide variety of bioenergy routes. Source: E4tech, 2009.

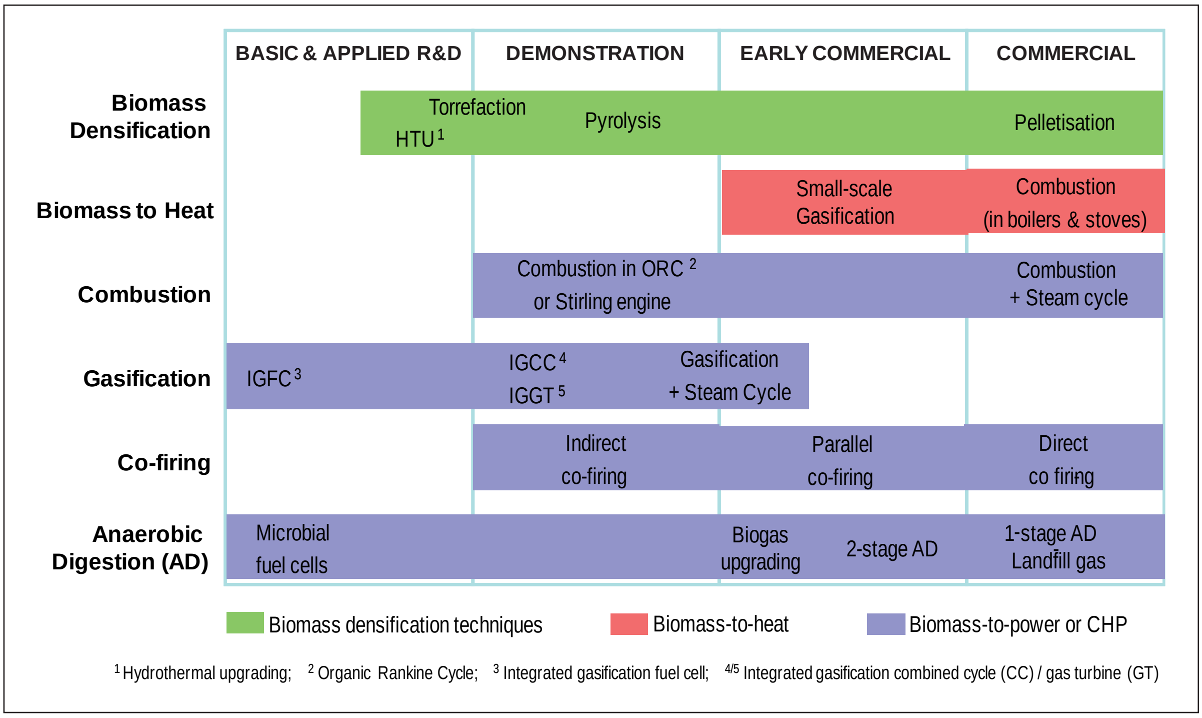


Figure 4. Development status of the main technologies to upgrade biomass and/or to convert it into heat and/or power. Source: E4tech, 2009.

biomass combustion plants, including MSW combustion plants, are also in successful commercial operation, and many are industrial or district heating CHP facilities. For sludges, liquids and wet organic materials, anaerobic digestion is currently the best-suited option for producing electricity and/or heat from biomass, although its economic case relies heavily on the availability of low cost feedstock. All these technologies are well established and commercially available.

There are few examples of commercial gasification plants, and the deployment of this technology is affected by its complexity and cost. In the longer term, if reliable and cost-effective operation can be more widely demonstrated, gasification promises greater efficiency, better economics at both small and large-scale and lower emissions compared with other biomass-based power generation options. Other technologies (such as Organic Rankine Cycle and Stirling engines) are currently in the demonstration stage and could prove economically viable in a range of small-scale applications, especially for CHP. See Figure 4.

In the transport sector, 1st generation biofuels are widely deployed in several countries – mainly bioethanol from starch and sugar crops and biodiesel from oil crops and residual oils and fats. Production costs of current biofuels vary significantly depending on the feedstock used (and their volatile prices), and on the scale of the plant. The potential for further deploying these 1st generation technologies is high, subject to sustainable land use criteria being met.

1st generation biofuels face both social and environmental challenges, largely because they use food crops which could lead to food price increases and possibly indirect land use change. While such risks can be mitigated by regulation and sustainability assurance and certification, technology development is also advancing for next generation processes that rely on non-food biomass (e.g. lignocellulosic feedstocks such as organic wastes, forestry residues, high yielding woody or grass energy crops and algae). The use of these feedstocks for 2nd generation biofuel production would significantly decrease the potential pressure on land use, improve greenhouse gas emission reductions when compared to some 1st generation biofuels, and result in lower environmental and social risk. 2nd generation technologies, mainly using lignocellulosic feedstocks for the production of ethanol, synthetic diesel and aviation fuels, are still immature and need further development and investment to demonstrate reliable operation at commercial scale and to achieve cost reductions through scale-up and replication. The current level of activity in the area indicates that these routes are likely to become commercial over the next decade. Future generations of biofuels, such as oils produced from algae, are at the applied R&D stage, and require considerable development before they can become competitive contributors to the energy markets. See Figure 5.

Further development of bioenergy technologies is needed mainly to improve the efficiency, reliability and sustainability of bioenergy chains. In the heat sector, improvement would lead to cleaner, more reliable systems linked to higher quality fuel supplies. In the electricity sector, the development of smaller and more cost-effective electricity or CHP systems could better match local resource availability. In the transport sector, improvements could lead to higher quality and more sustainable biofuels.

Ultimately, bioenergy production may increasingly occur in biorefineries where transport biofuels, power, heat, chemicals and other marketable products could all be co-produced from a mix of biomass feedstocks. The link between producing energy and other materials deserves further attention technically and commercially.

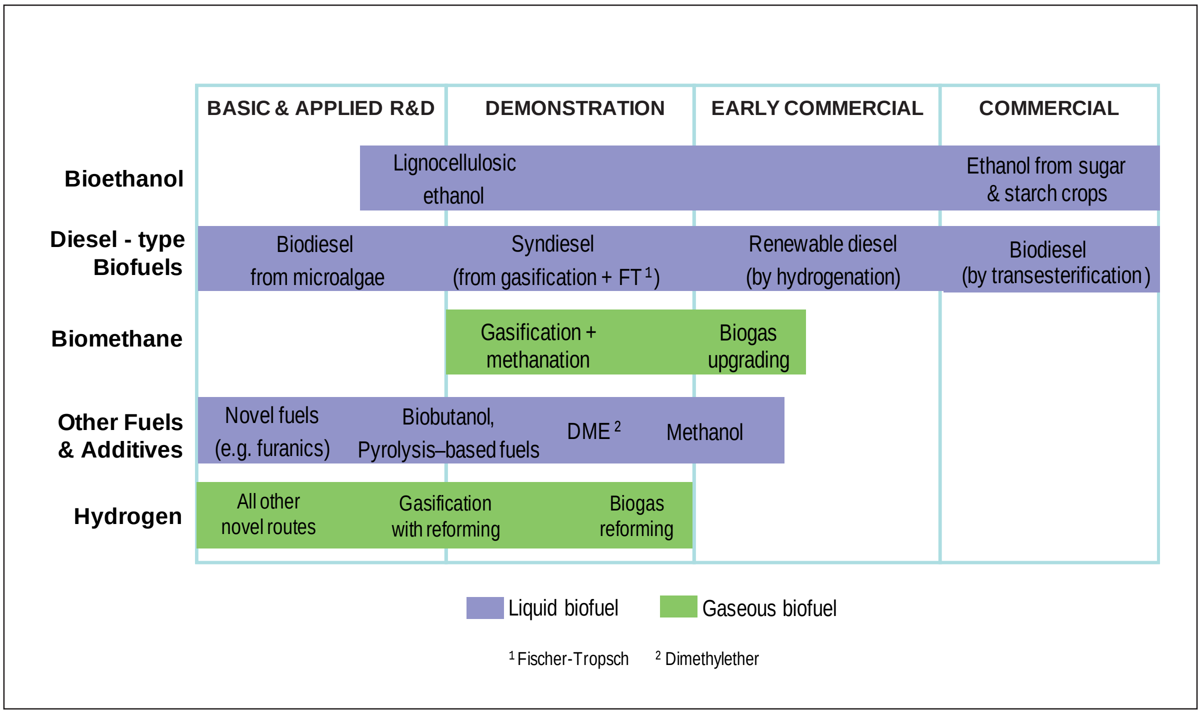


Figure 5. Development status of the main technologies to produce biofuels for transport from biomass. Source: E4tech, 2009.

BIOENERGY MARKETS

The predominant use of biomass today consists of fuel wood used in non-commercial applications, in simple inefficient stoves for domestic heating and cooking in developing countries, where biomass contributes some 22% to the total primary energy mix. This traditional use of biomass is expected to grow with increasing world population, but there is significant scope to improve its efficiency and environmental performance, and thereby help reduce biomass consumption and related impacts. See Figure 6.

In industrialised countries, the total contribution of modern biomass is on average only about 3% of total primary energy, and consists mostly of heat-only and heat and power applications. Many countries have targets to significantly increase biomass use, as it is seen as a key contributor to meeting energy and environmental policy objectives. Current markets, growing as a result of attractive economics, mostly involve domestic heat supply (e.g. pellet boilers), large-scale industrial and community CHP generation (particularly

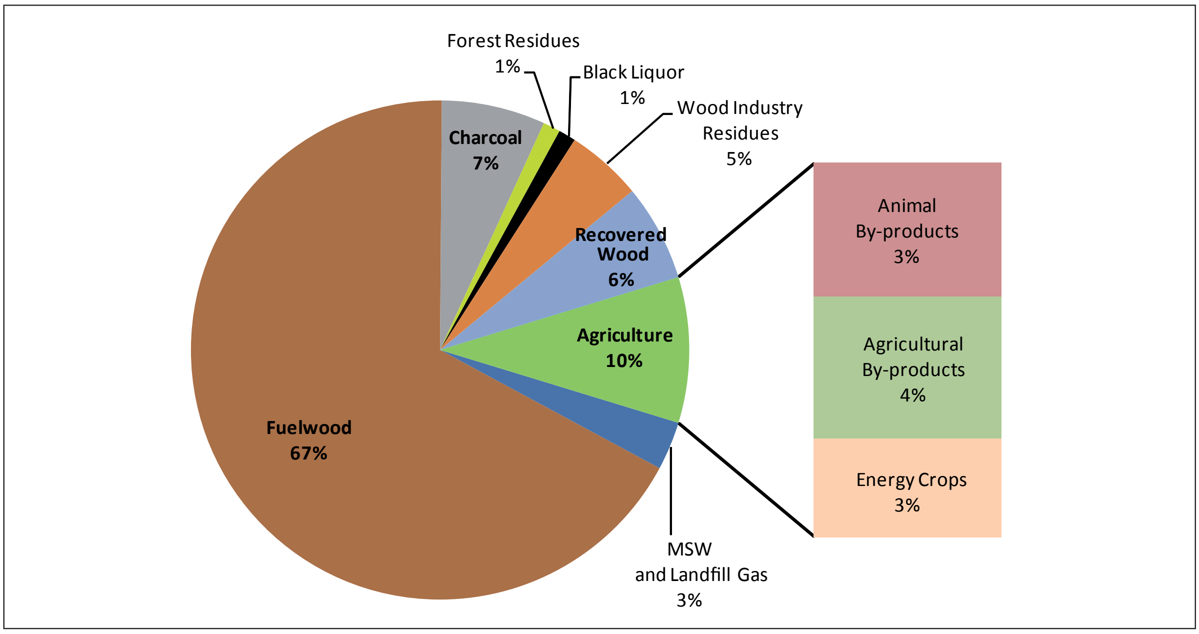


Figure 6: Share of the biomass sources in the primary bioenergy mix. Source: based on data from IPCC, 2007.

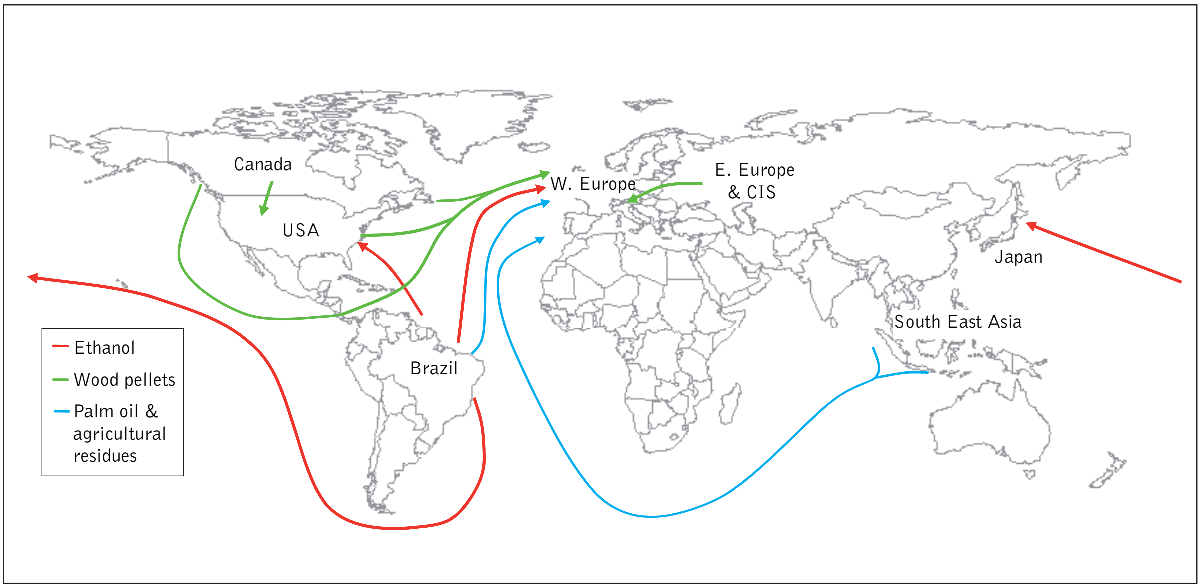


Figure 7: Main international biomass for energy trade routes. Intra-European trade is not displayed for clarity. Source: Junginger and Faaij, 2008.

where low cost feedstocks from forest residues, bagasse, MSW etc. are available), and co-firing in large coal-based power plants. The deployment of dedicated electricity plants has been mainly confined to low cost feedstocks in relatively small-scale applications, such as the use of biogas and landfill gas from waste treatment. Globally, the use of biomass in heat and industrial energy applications is expected to double by 2050 under business-as-usual scenarios, while electricity production from biomass is projected to increase, from its current share of 1.3% in total power production to 2.4 - 3.3% by 2030 (corresponding to a 5 - 6% average annual growth rate).

Transport biofuels are currently the fastest growing bioenergy sector, receiving a lot of public attention. However, today they represent only 1.5% of total road transport fuel consumption and only 2% of total bioenergy. They are, however, expected to play an increasing role in meeting the demand for road transport fuel, with 2nd generation biofuels increasing in importance over the next two decades. Even under business-as-usual scenarios, biofuel production is expected to increase by a factor of 10 to 20 relative to current levels by 2030 (corresponding to a 6 - 8% average annual growth rate).

Global trade in biomass feedstocks (e.g. wood chips, vegetable oils and agricultural residues) and processed bioenergy carriers (e.g. ethanol, biodiesel, wood pellets) is growing rapidly. Present estimates indicate that bioenergy trade is modest – around 1 EJ (about 2% of current bioenergy use). In the longer term, much larger quantities of these products might be traded internationally, with Latin America and Sub-Saharan Africa as potential net exporters and North America, Europe and Asia foreseen as net importers. Trade will be an important component of the sustained growth of the bioenergy sector. See Figure 7.

The quest for a sustainable energy system will require more bioenergy than the growth projected under the business-as-usual scenarios. A number of biomass supply chain issues and market risks and barriers will need to be addressed and mitigated to enable stronger sustained growth of the bioenergy sector. These include:

- **Security of the feedstock supply.** This is susceptible to the inherent volatility of biological production (due to weather and seasonal variations), which can lead to significant variations in feedstock supply quantity, quality and price. Risk mitigation strategies already common in food and energy markets include having a larger, more fluid, global biomass sector and the creation of buffer stocks.

- **Economies of scale and logistics.** Many commercially available technologies suffer from poor economics at a small-scale, but conversely larger scales require improved and more complex feedstock supply logistics. Efforts are required to develop technologies at appropriate scales and with appropriate supply chains to meet different application requirements.

- **Competition.** Bioenergy technologies compete with other renewable and non-renewable energy sources, and may compete for feedstock with other sectors such as food, chemicals and materials. Also, the development of 2nd generation biofuel technologies could lead to competition for biomass resources between bioenergy applications, and potentially with other industry sectors. Support needs to be directed at developing cost-effective bioenergy routes and at deploying larger quantities of biomass feedstocks from sustainable sources.

- **Public and NGO acceptance.** This is a major risk factor facing alternative energy sources and bioenergy in particular. The public needs to be informed and confident that bioenergy is environmentally and socially beneficial and does not result in significant negative environmental and social trade-offs.

However, the industry is confident such challenges can be met as similar challenges have been addressed in other sectors and appropriate technologies and practices are being developed and deployed.

INTERACTIONS WITH OTHER MARKETS

Developments in the bioenergy sector can influence markets for agricultural products (e.g. food and feed products, straw) and forest products (e.g. paper, board). However, this impact is not straightforward due to:

- other factors, such as biomass yield variations and fossil fuel price volatilities influencing markets just as much or more than biomass;
- other policy domains, including forestry, agriculture, environment, transport, health and trade, also having influence on bioenergy policies; and
- a lack of transparency in many product and commodity markets, especially in forest products, making it difficult to assess the impact of bioenergy development.

While all forms of bioenergy interrelate with agriculture and/or forest markets through their feedstock demand, the impact of 1^{st} generation liquid biofuels on food prices has been a topic of strong debate in recent years. Although different studies reveal a wide variety of opinions on the magnitude of these impacts, most model-based demand scenarios indicate a relatively limited risk of biofuels significantly affecting the price of food crops. In general, markets can work to dampen these effects.

Markets will need access to monetary and physical resources, and will need to function efficiently and transparently in order to counteract the pressure of increasing demand. There is therefore an important role for policy in providing support to an increasingly efficient industry, for example in terms of yields, use of residues and wastes, and land use, while providing regulation to avoid negative impacts associated with the exploitation of physical resources. This requires active coordination between energy, agriculture and forestry, trade and environmental policies.

BIOENERGY AND POLICY OBJECTIVES

Bioenergy can significantly increase its existing contribution to policy objectives, such as CO_2 emission reductions and energy security, as well as to social and economic development objectives.

Appreciating where bioenergy can have the greatest impact on GHG emissions reduction relies on both an understanding of the emissions resulting from different bioenergy routes and the importance of bioenergy in reducing emissions in a particular sector. Bioenergy chains can perform very differently with regard to GHG emissions. Substituting biomass for fossil fuels in heat and electricity generation is generally less costly and provides larger emission reductions per unit of biomass than substituting biomass for gasoline or diesel used for transport. However, the stationary bioenergy sector can rely on a range of different low carbon options while biofuels are the primary option for decarbonising road transport until all-electric and/or hydrogen fuel cell powered vehicles become widely deployed, which is unlikely to be the case for some decades. In the long-term, biofuels might remain the only option for decarbonising aviation transport, a sector for which it will be difficult to find an alternative to liquid fuels.

Land suitable for producing biomass for energy can also be used for the creation of biospheric carbon sinks. Several factors determine the relative attractiveness of these two options, in particular land productivity, including co-products, and fossil fuel replacement efficiency. Also, possible direct and indirect emissions from converting land to another use can substantially reduce the climate benefit of both bioenergy and carbon sink projects, and need to be taken into careful consideration. A further influencing factor is the time scale that is used for the evaluation of the carbon reduction potential: a short time scale tends to favour the sink option, while a longer time scale offers larger savings as biomass production is not limited by saturation but can repeatedly (from harvest to harvest) deliver greenhouse gas emission reductions by substituting for fossil fuels. Mature forests that have ceased to serve as carbon sinks can in principle be managed in a conventional manner to produce timber and other forest products, offering a relatively low GHG reduction per hectare. Alternatively, they could be converted to higher yielding energy plantations (or to food production) but this would involve the release of at least part of the carbon store created.

The use of domestic biomass resources can make a contribution to energy security, depending on which energy source it is replacing. Biomass imports from widely distributed international sources generally also contribute to the diversification of the energy mix. However, supply security can be affected by natural variations in biomass outputs and by supply-demand imbalances in the food and forest product sectors, potentially leading to shortages.

The production of bioenergy can also result in other (positive and negative) environmental and socio-economic effects. Most of the environmental effects are linked to biomass feedstock production, many of which can be mitigated through best practices and appropriate regulation. Technical solutions are available for mitigating most environmental impacts from bioenergy conversion facilities, and their

Tyseley Waste-to-Energy plant, Birmingham, UK. Built in 1996, the 28 MW plant with a 2-stream incinerator has a combined capacity of over 350,000 tonnes per year of municipal solid waste and a fifteen year Non-Fossil Fuel Obligation Contract. An award winning lighting system illuminates the plant at night.

Biomass contributes 12% of total energy consumption in Denmark and straw from agriculture is an important element. Consumption of biomass for energy production is now 100 PJ/year which is two-thirds of the total technical potential of domestic biomass resources. (Courtesy J. Bunger, Denmark).

use is largely a question of appropriate environmental regulations and their enforcement. The use of organic waste and agricultural/forestry residues, and of lignocellulosic crops that could be grown on a wider spectrum of land types, may mitigate land and water demand and reduce competition with food.

Feedstock production systems can also provide several benefits. For instance, forest residue harvesting improves forest site conditions for planting, thinning generally improves the growth and productivity of the remaining stand, and removal of biomass from over-dense stands can reduce the risk of wildfire. In agriculture, biomass can be cultivated in so-called multifunctional plantations that – through well chosen locations, design, management, and system integration – offer extra environmental services that, in turn, create added value for the systems.

Policy around bioenergy needs to be designed so that it is consistent with meeting environmental and social objectives. Bioenergy needs to be regulated so that environmental and social issues are taken into consideration, environmental services provided by bioenergy systems are recognised and valued, and it contributes to rural development objectives.

LESSONS FOR THE FUTURE

As the deployment of many bioenergy options depends on government support, at least in the short and medium term, the design and implementation of appropriate policies and support mechanisms is vital, and defensible, particularly given the associated environmental benefits and existing government support for fossil fuels. These policies should also ensure that bioenergy contributes to economic, environmental and social goals. Experience over the last couple of decades has taught us the following.

- A policy initiative for bioenergy is most effective when it is part of a long-term vision that builds on specific national or regional characteristics and strengths, e.g. in terms of existing or potential biomass feedstocks available, specific features of the industrial and energy sector, and the infrastructure and trade context.

- Policies should take into account the development stage of a specific bioenergy technology, and provide incentives consistent with the barriers that an option is facing. Factors such as technology maturity, characteristics of incumbent technologies, and price volatilities all need to be taken into consideration. In each development stage, there may be a specific trade-off between incentives being technology-neutral and closely relating to the policy drivers, and on the other hand creating a sufficiently protected environment for technologies to evolve and mature.

- There are two classes of currently preferred policy instruments for bio-electricity and renewable electricity in general. These are technology-specific feed-in tariffs and more generic incentives such as renewable energy quotas and tax differentiation between bioenergy and fossil-based energy. Each approach has its pros and cons, with neither being clearly more effective.

- Access to markets is a critical factor for almost all bioenergy technologies so that policies need to pay attention to grid access, and standardisation of feedstocks and biofuels.

- As all bioenergy options depend on feedstock availability, a policy strategy for bioenergy should pay attention to the sectors that will provide the biomass. For the agricultural and forestry sectors, this includes consideration of aspects such as productivity improvement, availability of agricultural and forest land, and access to and extractability of primary residues. For other feedstocks, such as residues from wood processing and municipal solid waste, important aspects are mobilisation and responsible use.

- A long-term successful bioenergy strategy needs to take into account sustainability issues. Policies and standards safeguarding biomass sustainability are currently in rapid development. Due to the complexity of the sustainability issue, future policy making and the development of standards will need to focus on integrated approaches, in which the complex interactions with aspects such as land use, agriculture and forestry, and social development are taken into account.

- Long-term continuity and predictability of policy support is also important. This does not mean that all policies need to be long-term but policies conducive to the growth of a sector should have a duration that is clearly stated and in line with meeting certain objectives, such as cost reduction to competitive levels with conventional technologies.

- The successful development of bioenergy does not only depend on specific policies which provide incentives for its uptake, but on the broader energy and environment legal and planning framework. This requires coordination amongst policies and other government actions, as well as working with industry and other stakeholders to establish a framework conducive to investment in bioenergy.

A SENSIBLE WAY FORWARD

Climate change and energy security are problems for which solutions need to be developed and implemented urgently. The scale of the challenge is such that it will require contributions from disparate sources of energy. Bioenergy already contributes significantly to addressing these problems and can contribute much further through existing and new conversion technologies and feedstocks. Furthermore, bioenergy can contribute to other environmental and social objectives, such as waste treatment and rural development. However, policy makers and the public at large will need to be comfortable that this expansion is sustainable.

Bioenergy can result in many external benefits but also entails risks. A development and deployment strategy needs to be based on careful consideration of the strengths and weaknesses, as well as the opportunities and threats that characterise it.

- Current bioenergy routes that generate heat and electricity from the sustainable use of residues and wastes should be strongly stimulated. These rely on commercial technologies, lead to a better use of raw materials, and result in clear GHG savings and possibly other emission reductions compared to fossil fuels. The development of infrastructure and logistics, quality standards and trading platforms will be crucial to growth and may require policy support.

- Further increasing the deployment of bioenergy, and in particular of biofuels for transport in the short-term, should be pursued by:
  - paying specific attention to sustainability issues directly related to the biomass-to-energy production chain, and avoiding or mitigating negative impacts through the development and implementation of sustainability assurance schemes;
  - incentivising biofuels based on their potential greenhouse gas benefits;
  - considering potential impacts of biomass demand for energy applications on commodity markets and on indirect land use change; and
  - defining growth rates that result in feedstock demands that the sector can cope with on a sustainable basis.

- Development of new and improved biomass conversion technologies will be essential for widespread deployment and long-term success. Public and private funding needs to be devoted to research, development and deployment as follows:
  - for liquid biofuels – advanced technologies that allow for a broader feedstock base using non-food crops with fewer (direct and indirect) environmental and social risks, and higher greenhouse gas benefits;
  - for power and heat production – more efficient advanced technologies, such as gasification and advanced steam cycles, and technologies with improved economics at a smaller scale to allow for more distributed use of biomass; and
  - for novel biomass – upgrading technologies and multi-product biorefineries, which could contribute to the deployment and overall cost-competitiveness of bioenergy.

- As the availability of residues and wastes will limit bioenergy deployment in the long-term, policies stimulating increased productivity in agriculture and forestry, and public and private efforts aimed at development of novel energy crops, such as perennial lignocellulosic crops, and other forms of biomass, such as algae, are essential for a sustained growth of the bioenergy industry. These efforts need to be integrated with sustainable land use policies which also consider making efficient and environmentally sound use of marginal and degraded lands.

CHAPTER 1: INTRODUCTION

Biomass consists of any organic matter of vegetable or animal origin. It is available in many forms and from many different sources e.g. forestry products (biomass from logging and silvicultural treatments, process residues such as sawdust and black liquor, etc.); agricultural products (crops, harvest residues, food processing waste, animal dung, etc.); and municipal and other waste (waste wood, sewage sludge, organic components of municipal solid waste, etc).

Biomass energy is solar energy stored in the chemical bonds of carbon and hydrogen chains as a result of photosynthesis or the metabolic activity of organisms. Biomass can be referred to as nature's solar battery reflecting its ability to store energy until required, which makes it more predictable and responsive than the sun or wind.

Biomass is the oldest fuel used by mankind and has been its main source of energy for cooking and keeping warm from the dawn of civilisation to the industrial revolution. However, over the last century its use has been supplanted by higher energy density, easier to handle and cheaper fossil fuels such as coal and oil.

Today, biomass (mainly wood) contributes some 10% to the world primary energy mix, and is still by far the most widely used renewable energy source (Figure 1-1). While bioenergy represents a mere 3% of primary energy in industrialised countries, it accounts for 22% of the energy mix in developing countries, where it contributes largely to domestic heating and cooking, mostly in simple inefficient stoves.

Over the last three decades, issues of energy security, increasing prices of fossil fuels, and global warming have triggered a renewed interest in biomass for the production of heat, electricity, and transport fuels. Many countries have introduced policies to support bioenergy, not least as a means of diversifying their agricultural sectors. This has been accompanied by significant developments in conversion processes, with several cleaner, more efficient technologies at the research, development, and demonstration stage, and others already introduced into the market. The biomass resource base is potentially large, and so are the opportunities for its increased use in different energy segments in industrialised and developing countries.

Bioenergy has become increasingly diversified in terms of final uses, and also in terms of resources. While biomass in the past was very much limited to woody feedstock, today's bioenergy landscape includes virtually all of the biomass types available, ranging from food industry residues (waste cooking oil, tallow) to energy crops such as corn, sugar-cane, and *Miscanthus*. New conversion technologies are being developed to account for the varied physical nature and chemical composition of the feedstocks available, as well as the energy service required. There is also growing interest and research in the production of chemicals from biomass, possibly in conjunction with the production of energy.
The multi-functional role of biomass, in terms of both the products and services it might provide, offers an opportunity to generate value beyond energy products.

As a result the bioenergy sector has witnessed significant growth in recent years, in particular in relation to biofuels for the road transport sector, which have grown considerably faster than heat and electricity uses (IEA 2008a). While the development of the bioenergy industry remains very

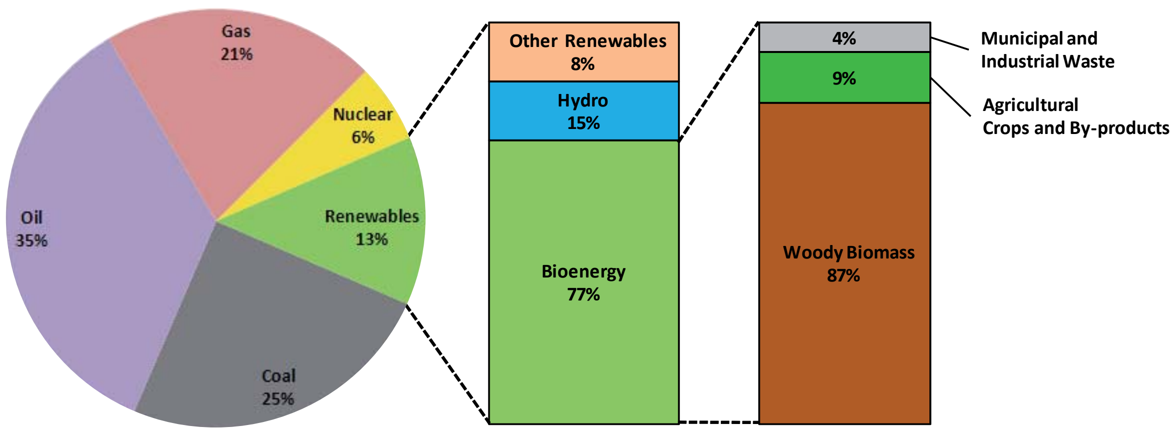


Figure 1-1. Share of bioenergy in the world primary energy mix. Source: based on IEA, 2006; and IPCC, 2007.

dependent on regional policies, it is becoming increasingly globalised as a result of an emerging global trade in biomass products such as pellets and bioethanol.

As bioenergy grows out of its niche position and becomes increasingly mainstream, its environmental and social performance has come under greater scrutiny. Public scepticism about the potential greenhouse gas savings biofuels might achieve has increased, alongside concerns about their broader environmental and social impacts. These issues have been further exacerbated by the potential indirect impacts of bioenergy use, i.e. the potential negative impacts of displacing biomass from other uses (such as food, feed, pulp and paper, etc.) and having to find substitutes for those uses.

To date, bioenergy is a very small part of the agricultural and energy sectors (about 3% of primary energy in OECD countries, and on average far less than 1% of agricultural land is used for energy crops), so while there may be some hotspots for environmental and social concern, its global implications should not be major at this stage. However, the development of a sustainable bioenergy industry will necessitate a better understanding of the risks posed by this growing sector and the development of practices and policies that minimise any environmental and social risks and maximise the multi-functional benefits that biomass can provide. The debate around bioenergy has often proved emotional in recent years. There is a need for this debate to become more informed by sound scientific evidence. This also means that more consistent approaches to assessing the impacts and opportunities of bioenergy are required.

While bioenergy needs to address environmental and social issues, it also faces other challenges relating to competition both with other energy sources and for biomass resources, market, and logistics issues associated with procuring increasing volumes of biomass, and the need for technological innovation for more efficient conversion of a more diverse range of feedstocks. The potential opportunities for bioenergy may be big, and its contribution to many of society's objectives (e.g. energy security, climate change mitigation, etc.) may be important, but numerous challenges need to be addressed for its untapped potential to be used in a sustainable way.

1.1 Objectives and Scope of the Report

This report provides a concise review on resource, technical, economic, environmental, social and policy aspects of bioenergy. It discusses the future potential for bioenergy and the main opportunities for deployment in the short and medium term. It also discusses the principal risks and challenges associated with the development of bioenergy, and how they may constrain its use. Its aim is to assist policy and other decision makers with information that is conducive to exploiting the opportunities and mitigating the risks associated with bioenergy, and which may help secure the sustainable development of the sector.

1.2 Structure of the Report

This review is structured along the value chain of bioenergy:

- Chapter 2 describes the availability and cost of feedstock as well as the environmental and social issues associated with their production.
- Chapter 3 reviews current and future technology pathways (R&D status and deployment horizon, preferred scale, feedstock, conversion efficiency, reliability and lifetime, cost, etc.).
- Chapter 4 provides an assessment of the global bioenergy market and biomass trade potential, and discusses deployment issues.
- Chapter 5 discusses the role of bioenergy in meeting policy objectives such as climate change mitigation, energy security and other environmental and socio-economic objectives.
- Chapter 6 reviews the different support mechanisms and regulatory frameworks affecting the bioenergy value chain, and discusses lessons relevant to bioenergy policy making.

Each Chapter is complemented by a set of annexes that provides additional reference materials and more in-depth discussion on specific key topics.

In Finland, the goal is to double the use of renewable energy sources by 2025 and thus contribute over one-third of total energy consumption. This increase will come almost entirely from bioenergy with forest residues being a significant component. The image above shows the Timberjack Slash Bundler manufacturing 'compacted residue logs' after final harvest. (Courtesy Dr Arto Timperi, Timberjack and J Tustin)

CHAPTER 2: BIOMASS RESOURCES AND POTENTIALS

Key questions addressed in this Chapter:

1. What are the most important current and future biomass feedstocks?
2. What are the main factors determining the long-term biomass potential for energy?
3. How significant could the contribution of biomass be to the global energy mix by 2050?
4. What logistical constraints do biomass supply chains have to tackle?
5. What are the potential implications of large-scale biomass production and use?

2.1 Overview of Biomass Feedstocks and Global Technical Potentials

Information about the long-term primary biomass potential is essential to understand the prospective role of bioenergy in the global energy mix. In the past fifteen years, a large number of studies have assessed the longer term (2050-2100) biomass supply potential for different regions, and globally. Since these studies used different approaches to consider determining factors – such as demand for food, soil and water constraints, biodiversity and nature preservation requirements, and a variety of other sustainability issues – they come to diverging conclusions regarding the biomass supply, ranging from roughly the current level of production (about 50 EJ) to levels above the current world primary energy consumption (about 500 EJ).

When assessing the biomass potential, one must distinguish between the technical potential, which is the unconstrained production potential limited only by the technology used and the natural circumstances, and the sustainable potential, which further considers a range of environmental and social constraints in order to guarantee sustainable feedstock production.

2.1.1 Technical biomass potential

When assessing global biomass potential, several key influencing factors prove uncertain. For this reason, assessments of the global technical potential cover almost three orders of magnitude, as shown in Table 2-1 which provides a synthesis of existing studies. This table presents the biomass categories most commonly considered in assessments. Currently most bioenergy feedstocks comprise:

- wood and agricultural wastes and residues (for heat and power production); and
- conventional food crops (for biofuel production).

Agricultural and wood-based residues and wastes form the vast majority of currently used biomass (IEA 2008b). Their long-term potential is mainly dependent on future developments in agricultural and forestry production, including the demand for the products of which they are the by-product.

Energy crops are potentially the largest supply source. However, it is difficult to narrow down the potential estimate for this category since it mainly depends on two parameters that are very uncertain:[2]

- land availability, which depends on food sector development (food demand growth and productivity development in agriculture), demand for other agricultural and forestry commodities (e.g. timber) and factors constraining access to land, such as nature protection; and
- the biomass yield levels that can be achieved on the available land.

In the category 'energy crop production on surplus agricultural land', the type of crop produced on this land has a large impact on the bioenergy potential. Typical examples of current cultivated crop use are confined to biofuels for transport, e.g. sugar-cane for ethanol production in Brazil, corn for ethanol production in the USA and various oil crops (rapeseed, sunflower, soy and oil palm) for biodiesel production. In the longer term, there is a common expectation that lignocellulosic crops will also be used, including both perennial herbaceous crops such as switchgrass and *Miscanthus*, and woody crops that can be either:

- coppice systems utilising tree crops such as willow, poplar and *Eucalyptus* species grown in multi-year rotations (3 to 6 years); or
- fast growing single stem plantations utilising species such as hybrid poplar and *Eucalyptus*, grown in short rotations (6 to 12 years).

Several lignocellulosic crops can be grown in less favourable soils and climatic conditions, so that large land areas could become available for these types of crops. The production of biofuels for transport can not however, take advantage of the favourable performance of lignocellulosic crops because the technologies for converting such feedstocks into biofuels have yet to become commercially available. Lignocellulosic feedstocks are therefore currently used for heat and power (see Chapter 3).

Even though conventional food crops for transport biofuels often produce high yields, the bioenergy output per hectare is commonly lower than expected with lignocellulosic crops[3].

[2] The expectations about future availability of forest wood and of residues from agriculture and forestry also vary substantially among the studies.

[3] A notable exception is sugar-cane, which can achieve high ethanol yields per hectare.

Table 2-1. Overview of the global technical potential of land-based biomass supply (primary energy) over the long-term for a number of categories (comprehensive version in Annex 2-1). For comparison, current global primary energy consumption is ca. 500 EJ.

Biomass category	Definition	Technical bioenergy potential year 2050 (EJ/yr)
Energy crop production on surplus agricultural land	Biomass that can be produced on future surplus agricultural land not required for food, fodder or other agricultural or forestry commodities production. Two types of energy crops can be distinguished: 1) conventional energy crops, normally used to produce food and animal feed (e.g. maize, sugar-beet, sugar-cane, rapeseed, oil palm, soybeans) 2) Lignocellulosic energy crops, composed of cellulose, hemicelluloses and lignin (e.g. poplar, willow, eucalyptus, miscanthus, switchgrass).	0 – 700
Energy crop production on marginal lands	Biomass that can be produced on deforested or otherwise degraded or marginal land that is still suitable for (for example) reforestation.	<60[4] – 110
Residues from agriculture	Residues associated with food production and processing, both primary (e.g. cereal straw from harvesting) and secondary (e.g. rice husks from rice milling).	15 – 70
Forest residues	Residues associated with wood production and processing, both primary (e.g. branches and twigs from logging) and secondary (sawdust and bark from the wood processing industry). In general, increased level of forest management, e.g. silvicultural thinning improving forest stands, makes it possible to utilise a larger part of the forest growth, which is well above the present level of biomass extraction in many countries.	30 – 150
Dung	Biomass from animal manure	5 – 55
Organic wastes	Biomass associated with materials use, e.g. waste wood (producers), municipal solid waste	5 – >50[4]
Total		<60 – >1100

One reason is that a smaller share of the aboveground growth of food crops is used as bioenergy feedstock compared to lignocellulosic crops, where most of the growth can be used. Another reason is that the lignocellulosic crops are often perennials and several species are grown in multi-year rotations, and they can therefore benefit from longer growing seasons. When considering the net energy output (i.e. energy output minus energy inputs in production) the difference becomes larger, since the lignocellulosic crops generally require fewer agronomic inputs per hectare (see also Annex 2.2 and Chapter 5).

In addition to the feedstocks mentioned above, by-products are often obtained when conventional food crops are used. For instance, straw can be used as animal fodder or as a fuel, and processing by-products (e.g. dry distillers grain with solubles (DDGS) from starch fermentation) can be used for animal feed or chemicals production. This use of by-products improves the situation with regard to land use since it substitutes for other production that would have claimed land elsewhere.

Relatively recently, algae have gained attention as a source of biomass for energy. This term can relate to both microalgae and macroalgae (or seaweed). Microalgae can be cultivated most cost-effectively in open ponds on land, and in offshore reservoirs (Florentinus et al., 2008). Potentially, they contain substantial concentrations of vegetable oil. Macroalgae could be cultivated in colonies in the open sea. Potentials for algae have not been studied as extensively as the land-based biomass resources indicated in Table 2-1, but they could reach up to several hundreds of EJ for microalgae and up to several thousands of EJ for macroalgae (Florentinus et al., 2008). All types of algae however, have relatively low dry matter content, so their applicability as a biomass feedstock is not straightforward. Other potential introduction barriers, such as logistical issues for offshore cultivation, have not yet been fully explored. Therefore, it is still difficult to assess the sustainability and economic competitiveness of algae options, and we have not taken them into detailed account in this review.

2.1.2 Key factors influencing technical biomass potential

Although assessments have not succeeded in providing narrow, distinct estimates of the biomass potential, they do indicate the most influential parameters that affect this potential, which enables strategies to improve the prospects of the longer term bioenergy supply to be formulated. The most important influencing factors are:

- Land availability for biomass production is particularly impacted by agricultural productivity, and the level of modernisation of agriculture that can be achieved globally, particularly in developing countries[5]. There is room for considerably higher land use efficiencies that can, in

[4] For an explanation of the '>' and '<' signs see Annex 2-1

[5] The expectations about future availability of forest wood and of residues from agriculture and forestry also vary substantially among the studies.

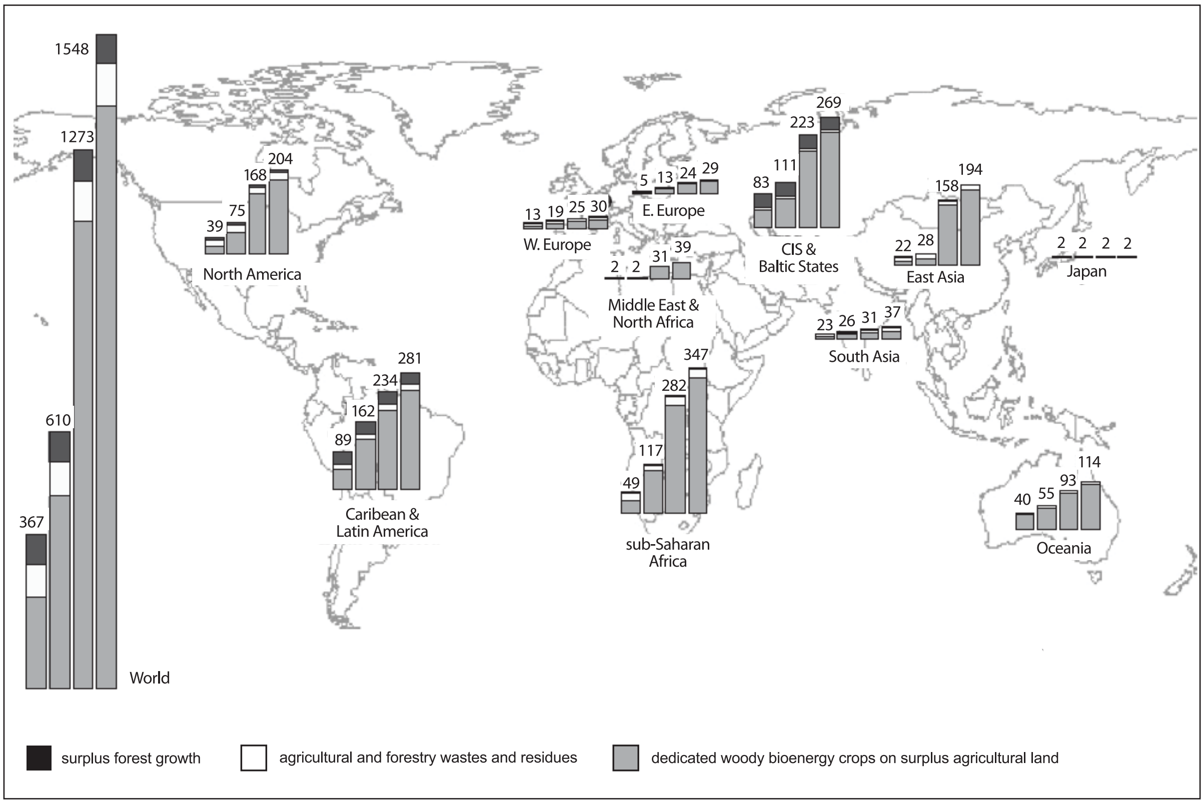


Figure 2-1. Illustration of the impact of different scenarios for agricultural productivity improvement on total technical bioenergy production potential in 2050, all other assumptions remaining equal (Smeets 2008). The two upper scenarios were not taken into account in the review of Table 2-1, as they were considered too optimistic in their assumptions. All numbers in EJ.

principle, more than compensate for the growing demand for food. For example, while average corn yields in industrialised countries such as the USA can reach up to 10 tonnes per hectare, in many developing countries with subsistence farming, average corn yields typically only achieve 1-3 tonnes per hectare.

- Under different assumptions for the level of improvements in agricultural technology, water supply and efficiency in use (rain-fed/irrigated), improvements in feed conversion efficiencies[6] in animal husbandry, and the animal production system used (pastoral, mixed, landless), a wide range of potentially available surplus agricultural land can be projected. For example, Smeets (2008) estimated that 0.7-3.5 billion hectares of surplus agricultural land could potentially become available for bioenergy by 2050, with especially large areas in sub-Saharan Africa and Latin America[7]. If the suitable part of this land was used for lignocellulosic crops, in addition to residues and forestry growth not required in the forest industry, technically over 1500 EJ could be produced (see Figure 2-1). This is even more than the upper limit of the review material presented in Table 2-1. Such a high level of bioenergy production would likely have negative environmental effects such as water stress in some regions, loss of biodiversity as well as possibly negative socio-economic consequences, and should thus be considered unrealistic.
- In a much less optimistic scenario for bioenergy – where agricultural productivity would remain at its current levels, population growth would continue at high rates and (biomass) trade and technology exchange would be severely limited – no land would then be available and only municipal solid waste (MSW) and some agricultural and forestry residues might be used. Such a scenario would leave the supply potential in the order of magnitude of the present level of biomass use, i.e. about 50 EJ.

2.1.3 Biomass potential taking into account several sustainability constraints

More moderate scenarios, taking into account a number of uncertainties and sustainability constraints can be summarised in the following three main categories of biomass:[8]

1. ***Residues from forestry and agriculture and organic waste, including MSW[9].*** In total, this category represents between 50 and 150 EJ/year, with a mean estimate of around 100 EJ/yr. This part of the potential biomass supply is relatively certain, although consumption changes (including diet) and competing applications may push the net availability for energy applications to the lower end of the range.

[6] For an explanation of the '>' and '<' signs see Annex 2-1.

[7] A notable exception is sugar-cane, which can achieve high ethanol yields per hectare.

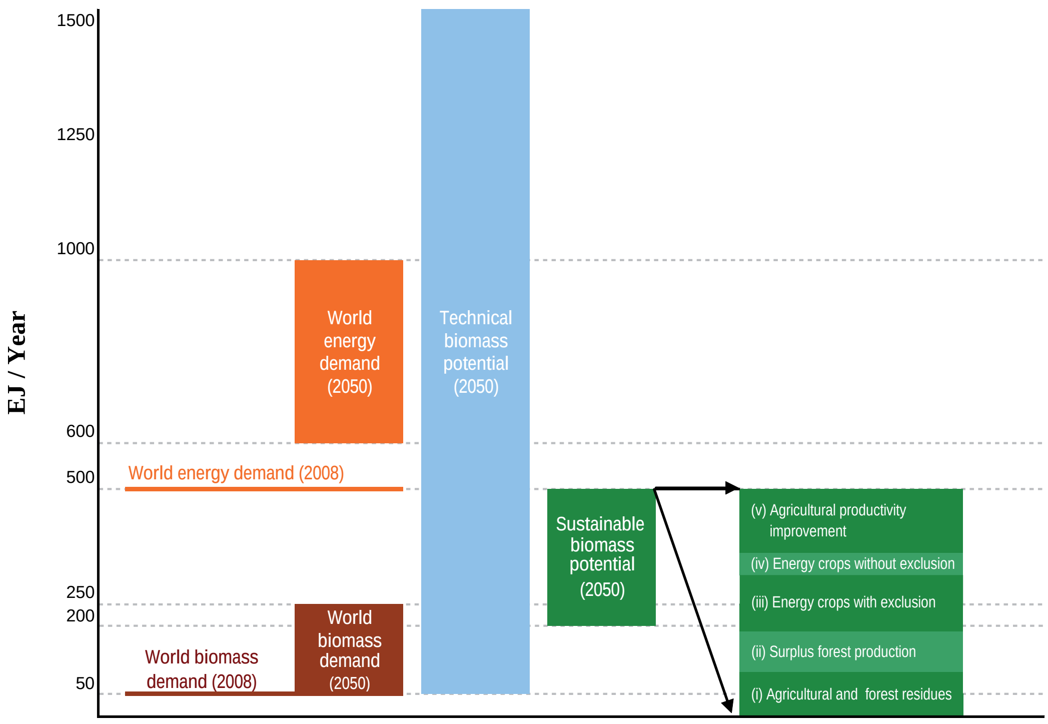
[8] Based on a recent analysis by Dornburg et al. (2008).

[9] The annual per capita generation of MSW varies from <100 kg in developing countries to >700 kg in industrialised countries, and is closely correlated with the gross domestic product (GDP) of a country.

2. *Surplus forestry.* In addition to forestry residues a further 60-100 EJ/yr of surplus forest growth could be available. The availability of this biomass category depends on the degree of restrictions set by sustainable forest management principles (which vary). These include requirements for protecting biodiversity and maintaining provision of various ecosystem services.

3. *Biomass produced via cropping systems.*
   - A more conservative estimate of energy crop production on possible surplus good quality agricultural and pasture lands, accounting for water scarcity, land degradation and new land claims for nature reserves amounts to an estimated 120 EJ/yr (potential indicated as 'with exclusion of areas' in Figure 2-2).
   - The potential contribution of water-scarce, marginal and degraded lands for energy crop production, could amount to an additional 70 EJ/yr. This would comprise a large area, which excludes current nature protection areas, where water scarcity provides limitations and soil degradation is more severe (additional potential indicated as 'no exclusion' in Figure 2-2).
   - Faster development of agricultural technology could add some 140 EJ/yr to the above values.

In summary, under the assumptions listed above, the three categories added together lead to a sustainable biomass supply potential of up to 500 EJ (see Figure 2-2). Under less favourable circumstances, if residues and surplus forestry supplies remain modest and crops only deliver feedstock from surplus existing agricultural lands without additional learning in agricultural practices, the biomass potential may remain in the order of 200 EJ. This wide range (200-500 EJ) illustrates that there is still considerable uncertainty about the potential availability of sustainable biomass.



- Current world energy demand (500 EJ/year).
- Current world biomass demand (50 EJ/year).
- Total world primary energy demand in 2050 in World Energy Assessment (600 - 1000 EJ/year).
- Modelled biomass demand in 2050 as found in literature studies (50 - 250 EJ/year).
- Technical potential for biomass production in 2050 as found in literature studies (50 - 1500 EJ/year).
- Sustainable biomass potential in 2050 (200-500 EJ/year). *Sustainable biomass potentials consist of: (i) residues from agriculture and forestry (~ 100 EJ); (ii) surplus forest production - net annual increment minus current harvest (~ 80 EJ); (iii) energy crops, excluding areas with moderately degraded soils and/or moderate water scarcity (~ 120 EJ); (iv) additional energy crops grown in areas with moderately degraded soils and/or moderate water scarcity (~ 70 EJ) and (v) additional potential when agricultural productivity increases faster than historic trends thereby producing more food from the same land area (~ 140 EJ).*

Figure 2-2. Technical biomass supply potentials, sustainable biomass potential, expected demand for biomass (primary energy) based on global energy models and expected total world primary energy demand in 2050. Current world biomass use and primary energy demand are shown for comparative purposes. Adapted from Dornburg et al., (2008) based on several review studies.

How much of the biomass supply potential could actually be realised will depend principally on the demand for bioenergy. Different energy models estimating how energy demand could be met cost-efficiently under different GHG emissions constraints, estimate that in 2050 between 50 and 250 EJ/yr of biomass would be used in the primary energy mix[10] (see Section 4.1 for a more elaborate discussion on market opportunities for bioenergy in different sectors).

Indicatively, the increasing cost of biomass feedstocks more often limits the biomass use rather than a shortage of technical potential. However, this does not imply that resource availability is never a limiting factor. Especially in world regions with high biomass demand and low technical potential, this can be the case. Also, up until 2100, energy models develop in contrasting ways – from bioenergy staying below 50 EJ/year to, in the highest case, reaching about 475 EJ/year by 2100 (IPCC 2001). In these cases, feedstock and land availability clearly are important limiting factors. For further details on the models compared, see Dornburg et al. (2008).

At the same time, scenario analyses predict a global primary energy use of about 600-1040 EJ/yr in 2050. Thus, up to 2050, biomass has the potential to meet a substantial share – between a quarter and a third – of the world energy demand.

2.2 Regional and Short-term Biomass Utilisation Scenarios

While the potential contribution of biomass could be substantial in the longer term, the question remains how much of this potential could be realised within the next two decades. As a complement to Figure 2-1, Table 2.2 shows selected studies that present how biomass feedstock production may develop in the short-to-medium term in different world regions and major countries, taking economic, environmental and other criteria into account (see Annex 2.3 for a short introduction of each study and more details on the study assumptions).

Biomass production costs. A key factor taken into account in almost all these studies is biomass production costs. Typically costs of US$3-4/GJ for primary biomass are seen as a threshold to compete with fossil fuel prices. Higher fossil fuel prices (especially gasoline) and policy incentives in favour of bioenergy can substantially enlarge the economically viable potential in the various studies (e.g. from 4 to 5.6 EJ in the EEA (2007) study).

Environmental constraints. Environmental restrictions can be considered in different ways. In the EEA (2007) study, a 30% share of 'environmentally orientated' farming is required, while the Refuel study (de Wit and Faaij, 2008) assumes strong agricultural efficiency increases and distributes the agricultural land that is consequently released between bioenergy production and land for nature conservation areas. See also Section 2.3.

Choice of crops. As shown in Annex 2.3, the projected primary biomass potentials and land requirements can vary substantially, and also depend on the choice of crops (sugar/starch, oil or lignocellulosic). All studies investigated assume that 1st generation food crops are likely to substantially contribute to the overall biomass production until 2030. In the studies for Europe and the USA, a mix of conventional and lignocellulosic crops is assumed, while in the ORNL study (Kline et al., 2008), almost all energy crops are conventional crops, requiring more land per EJ (e.g. for Latin American, about 70 out of 123 million hectares are used for soy cultivation). The choice of feedstock will also largely be determined by the commercial availability of advanced conversion technologies (see Chapter 3).

Logistical constraints. Finally, only one of the studies in Table 2-2 (Parker et al., 2008) takes spatially explicit logistical constraints into account (see also Section 2.4). The share that can be reached efficiently by existing infrastructure can in some cases reduce the technical potential significantly.

Table 2-2. Overview and short description of regional biomass production scenario studies. For additional assumptions, see Annex 2.3.

Region	Study / author	Time frame	Land use for energy crops (million hectare)	Primary biomass potential Energy crops + residues (EJ)#
Europe	Refuel / de Wit & Faaij (2008)	2030	66 arable land (+24 pasture)	12-15 + 9
	EEA (2007)	2030	25	3.4-5.0 + 1
USA (18 western states only)	Parker et al., (2008)	2015	20	2.1 + 0.8
Latin America	Kline et al., (2008)	2017	121	19.7 + 4.7
China & India	Kline et al., (2008)	2017	86	13.2 + 3.7
Australia	CEC (2008)	2020	ca. 0.05	0.003 + 0.15

When comparing these potentials to the ones presented in Table 2-1, it should be kept in mind that the values presented here are a) only for specific geographical regions, b) for a shorter time horizon, c) taking economic, environmental and other additional criteria into account, and d) based on different assumptions for energy crop use, yields, etc.

[10] In the IPCC-SRES main scenarios, biomass consumption in 2050 for energy varies between 50-120 EJ. However, these scenarios show the development mainly in the absence of ambitious climate policies. Given the additional requirement of low-carbon energy supply, these estimates can be considered as low compared to those that can be expected in a world striving for low stabilisation targets. This notion is strengthened by considering the recent debate in Nature where Pielke et al. (2008) argue that the reference scenarios used by the IPCC's fourth assessment report (AR4) – SRES – seriously underestimates the technological challenge associated with stabilising greenhouse-gas concentrations.

In summary, these studies show that with increased use of forestry and agricultural residues the utilisation of biomass can already be strongly increased over current levels. The short to medium term energy crop potential depends strongly on productivity increases that can be achieved in food production and on environmental constraints that will restrict energy crop cultivation on different land types. Achieving high yields will generally require that lignocellulosic crops rather than food crops are cultivated, though this will depend on the region and crop suitability. In the European scenarios with substantial dedicated lignocellulosic energy crops, the Refuel study shows that a substantial part of the long-term European technical potential (18-59 EJ as shown in Annex 2.3) may be realised by 2030, also considering economic and environmental criteria (but not explicitly considering logistics). Further considerations affecting dedicated biomass production are discussed in the following Section.

2.3 Environmental and Other Aspects of Energy Crop Production

When assessing biomass production potentials, it is important to acknowledge the complex linkages between the large-scale production and use of biomass for energy and materials, food production, energy use, water use, biodiversity and climate change. In Figure 2-3 this complexity is highlighted by showing some key relationships and assumptions. No single study or model has yet been able to describe these intricate relationships adequately. As stated in Section 2.1, it is to a certain extent possible to quantify the limitations for food requirements, water constraints, and nature reserves on the available biomass potential. For other factors, such as the use of GMO's or climate change, this is not currently possible.

The environmental impacts of conventional crop production have been researched in far greater detail than those of lignocellulosic crop production. However, in general lignocellulosic crops can be expected to cause fewer and lower impacts associated with agronomic inputs since they require less fertiliser and agro chemicals, and are perennial. In addition, bioenergy crop production can have positive impacts, for example, it can help to improve the soil structure and fertility of degraded lands.

On the other hand, the conversion of areas with sparse vegetation to high-yielding lignocellulosic plantations may lead to substantial reductions in downstream water availability, which may lead to deteriorating conditions in water scarce areas. The environmental impacts depend on local conditions, with the reference land use (i.e. the land use replaced by energy crops) being a crucial parameter.

A number of critical aspects affecting the prospects for biomass production are discussed in more detail below.[11]

2.3.1 Water availability and competition

Water is a critical resource for both food and biomass production and is in short supply in many regions. Large-scale expansion of energy crop production could lead to a large increase in evapotranspiration, potentially as large as the present evapotranspiration from global cropland. In some countries this could exacerbate an already stressed water situation. Outcomes for water depend on which biomass production systems are established and where.

Under strategies that focus on biofuels for transport and mainly lead to increased cultivation of conventional food crops, increasing global water use will resemble that driven by increasing food sector demand. Note that the geographical pattern may be different though, since the demand for crops for biofuels may vary geographically due to the increasing demand in the food sector. A shift to relying primarily on lignocellulosic feedstocks changes the situation in relation to water.

Firstly, to the extent that bioenergy is based on the utilisation of residues and biomass on processing by-products within the food and forestry sectors, water use would not increase significantly due to increasing bioenergy. The water that is used to produce the food and conventional forest products is the same water that will also produce the residues and by-products potentially available for bioenergy.

Secondly, a number of dedicated bioenergy crops are drought tolerant and relatively water efficient crops that are grown under multi-year rotations.[12] By adopting such crops farmers may better cope with a change in precipitation patterns and increased rates of evapotranspiration due to higher temperatures. If a larger fraction of the rainfall can be harnessed and consumed in plant production, a boost in productivity and total production can be accomplished without necessarily increasing the withdrawal of freshwater from rivers, lakes, and aquifers.

However, without proper planning at the hydrological catchment level, an increased allocation of freshwater flows to plant transpiration may lead to lowered groundwater levels, aggravate river depletion, and reduce downstream water availability. To assess the impact of land and water use and management, an integrated basin analysis is required; however, this is rarely done today. The impact of energy crops on changes in hydrology needs to be researched in order to advance our understanding of how the changes in water and land management will affect downstream users and ecosystems. In many cases such impacts can be positive. For example, local water harvesting and run-off collection upstream may reduce erosion and sedimentation loads in downstream rivers, while building resilience in the upstream farming communities.

[11] Note that in addition to the aspects described here, several other issues are described elsewhere in this report, such as the greenhouse gas (GHG) emissions due to use of fossil fuels in the production, transportation and use of bioenergy carriers, direct and indirect land use changes (see Section 5.3) and socio-economic aspects (see Section 4.3.3 and 5.5). Possible assurance mechanisms to safeguard sustainable biomass production are included in Chapter 6.
[12] As a drawback, these crops often however also have lower yields.

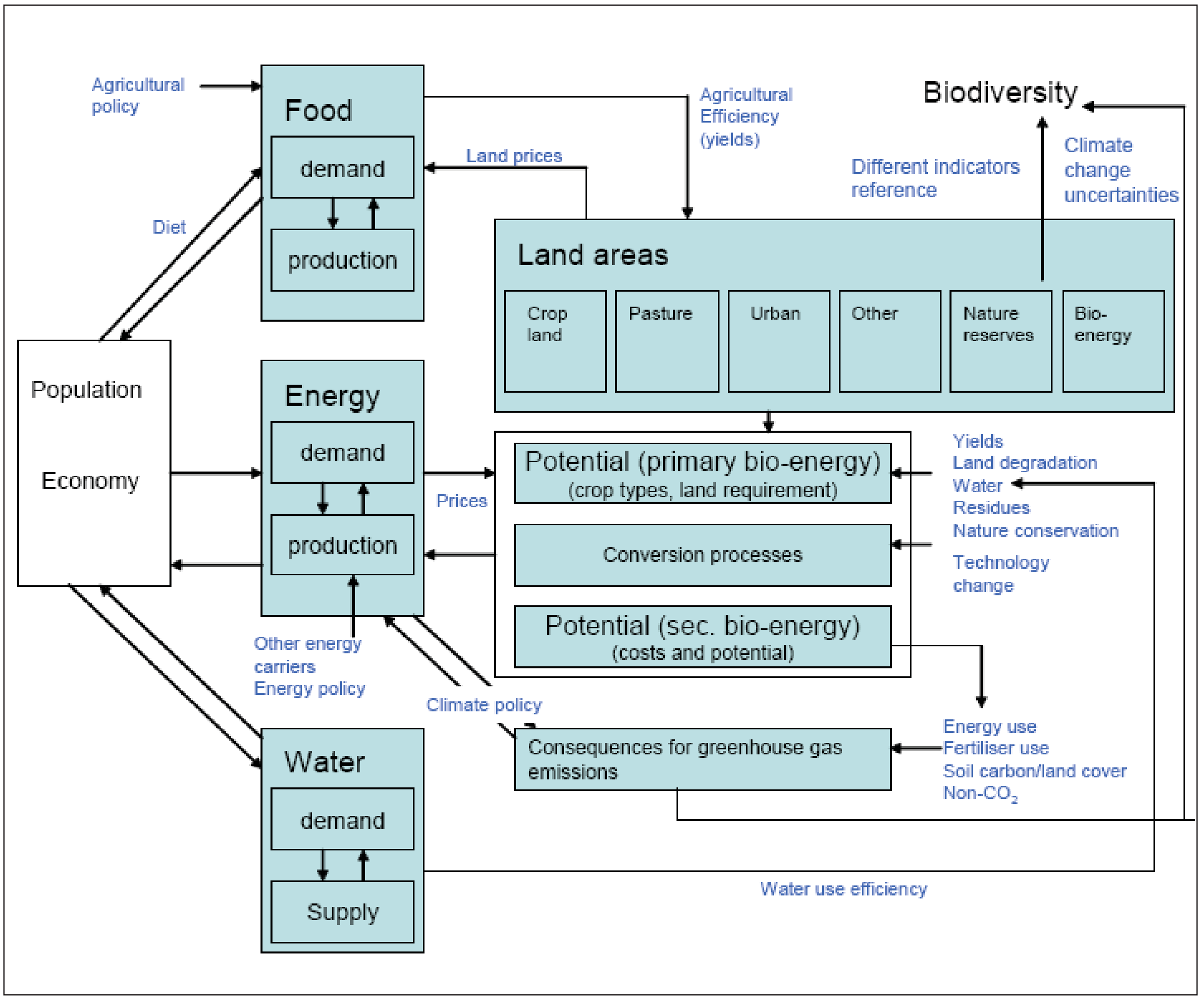


Figure 2-3. Overview of key relationships relevant to assessment of bioenergy potentials (Dornburg et al., 2008). Indirect land use issues and social issues are not displayed (see Chapter 5).

2.3.2 Environmental functions of bioenergy production

Much attention is presently directed to the possible negative consequences of land use change, such as biodiversity losses, greenhouse gas emissions, and degradation of soils and water bodies, referring to well-documented effects of forest conversion and cropland expansion to uncultivated areas. However, the production of biomass for energy can generate additional benefits.

For instance, forest residue harvesting also has environmental or silvicultural benefits. It improves forest site conditions for replanting. Stump harvesting (as practised in Nordic Countries) reduces risk of devastating root rot attack on subsequent stands. Thinning generally improves the growth and productivity of the remaining stand. Removal of biomass from over dense stands can reduce wildfire risk. In agriculture, biomass can be cultivated in so-called multifunctional plantations that – through well chosen location, design, management, and system integration – offer extra environmental services that, in turn, create added value for the systems.

Many such plantations provide water-related services, such as vegetation filters for the treatment of nutrient bearing water such as wastewater from households, collected runoff water from farmlands and leachate from landfills. Plantations can also be located in the landscape and managed to capture the nutrients in passing runoff water. Sewage sludge from treatment plants can also be used as fertiliser in vegetation filters. Plantations can be sited and managed to limit wind and water erosion, and will reduce the volume of sediment and nutrients transported into river systems. They may reduce shallow land slides and local 'flash floods'.

Contrary to annual crops, perennial crops can help reduce soil erosion, for example perennial grasses are used by the USA Conservation Reserve Programme to minimise soil erosion. Besides the onsite benefits of reduced soil losses, there are also offsite benefits such as reduced sediment load in reservoirs, rivers, and irrigation channels.

Perennial crops can also improve nutrient flows through the formation of an extensive root system that adds to the organic matter content of the soil and facilitates nutrient retention. Nutrient flow is a key issue for forest and agricultural production systems. When ploughed under or left on the field/forest, primary residues may recycle valuable nutrients to the soil and help prevent erosion, thus only a share may be available for extraction. Prevention of soil organic matter depletion and nutrient depletion is important to maintain site productivity for future crops.

2.3.3 Biodiversity

Although assessments of biomass potential commonly exclude nature conservation areas as not being available for biomass production, in the real world biodiversity impacts may still arise. In the short-term, impacts from existing agricultural and forest land for bioenergy are dominant. For example, the use of biomass from natural forests could reduce the quantity or quality of natural vegetation and availability of dead wood, and consequently biodiversity.

In the longer term, the pressure to convert natural ecosystems to energy crop cultivation could become very important. Expansion of intensive farming may have an impact on biodiversity through the release of nutrients and chemicals which can lead to changes in species composition in the surrounding ecosystems. Arable monocultures are commonly worse than mixed cropping systems and perennial crops in this respect and can have additional negative effects on biodiversity, e.g. animal-human conflicts.

Biodiversity loss may also occur indirectly, such as when productive land use displaced by energy crops is re-established by converting natural ecosystems into croplands or pastures elsewhere.

2.3.4 The agricultural sector, crop improvements and GMOs

Sound agricultural methods (agroforestry, precision farming, biological pest control, etc.) exist that can achieve major increases in productivity with neutral or even positive environmental impacts. However, such practices must be secured by sufficient knowledge, funds, and human capacity, which are often not present, especially in many developing countries. Other barriers to the sustainable production of biomass crops are the lack of social capital, land rights, market access and market power for small-scale landholders.

Dedicated energy crops have not been subject to the same breeding efforts as the major food crops. Selection of suitable crop species and genotypes for given locations to match specific soil types and climate is possible, but is at an early stage of development for some energy crops, and traditional plant breeding, selection and hybridisation techniques are slow, particularly in woody crops but also in grasses. New biotechnological routes to produce both non-genetically modified (non-GM) and GM plants are possible.

GM energy crop species may be more acceptable to the public than GM food crops, but there are still concerns about the potential environmental impacts of such plants, including gene flow from non-native to native plant relatives. As a result, non-GM biotechnologies may remain particularly attractive. On the other hand, GMO food crops have already been widely accepted in many non-EU countries. Finally, it is important to note that, especially for restoration of degraded soils, bioenergy crops must be optimised not maximised, as low input systems involve limited nutrients and chemical inputs.

2.3.5 Climate change impacts

Climate change is likely to change rainfall patterns while water transpiration and evaporation will be increased by rising temperatures. The net effect of this is not easy to predict, and large variations can be expected in different regions of the world. Semi-arid and arid areas are particularly likely to be confronted with reduced water availability and problems in many river basins may be expected to increase. Generally, the negative effects of climate change will outweigh the benefits for freshwater systems, thereby adversely influencing water availability in many regions and hence irrigation potentials.

Finally, biomass may pose environmental risks, but also environmental benefits if properly managed. Reaping the GHG abatement potential of biomass will involve understanding the risks and mitigating them, but also accepting some trade-offs in exchange for long-term benefits.

2.4 Biomass Supply Chains and Logistics

As was shown in the previous sections, biomass potentials are influenced by the development of the agricultural sector and various sustainability constraints. Additional constraints linked to the collection and distribution of dedicated energy crops and agricultural and forestry residues may further affect the realisable potential. These include:

- ***Equipment constraints.*** Collection methods may vary greatly between developed and developing countries, but also by region in developing countries. Mechanisation of the harvesting process and integration of residue collection may greatly influence the efficiency, but may also require significant investments.
- ***Current harvesting methods and practices.*** Often agricultural residues are burnt before the harvest (e.g. sugar-cane tops and leaves, to facilitate manual harvesting), burnt after harvest, or ploughed back into the field in order to improve soil quality or suppress the growth of weeds.
- ***Physical constraints.*** Steep slopes, wet soils, small size of fields and low-quality infrastructure can make the cropped area inaccessible to mechanical harvesters or may cause harvesting to be more inefficient. Specialised equipment may partially help overcome these constraints.

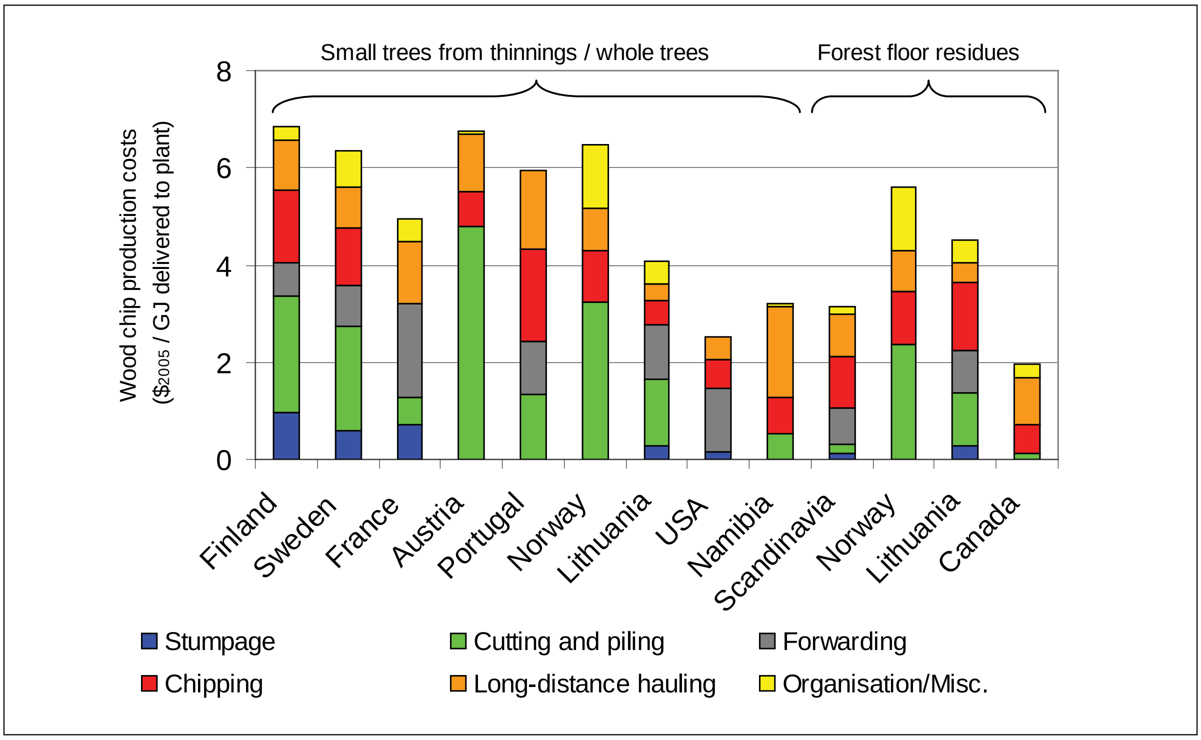


Figure 2-4. Typical cost structures in different countries for wood chips from whole trees, thinnings and forest residues delivered to a plant. Data from Alakangas and Virkkunen (2007), Bradley (2007), Energidata et al., (2005), Leinonen (2004), Leinonen (2007) and Mizaraite et al., (2007). Transport distances vary between different studies, typically between 50-100 kilometres.

These factors also influence the economics of biomass supply chains. The logistics associated with conventional food crops (such as sugar-cane, corn, rapeseed, and palm oil) and forestry products (such as round wood and pulp chips) are well established and cost-efficient. Experience with these crops can to some extent be applied to the new bioenergy crops, e.g. perennial grasses or fast-growing trees. However, for most field residues, the development of cost-efficient supply chains is a major challenge. The collection, pre-transport processing (such as chipping or baling) and transportation of woody and agricultural residues can add significantly to the overall feedstock costs, as can be seen in Figure 2-4 for woody biomass.

Also, cost structures are highly dependent on the available infrastructure and current harvesting practices, e.g. whether whole trees are skidded to the roadside, so residues are available at the roadside, or trees are cut to length in the forest and residues therefore need to be forwarded. Improving woody residue supply chains by reducing costs is an ongoing process, with much experience gained in Scandinavia over the last three decades. Over time, different production chains have been developed and deployed for the market to handle various raw and refined woody biomass fuels.

In general, when considering the logistics for large-scale bioenergy conversion plants, one has to take into account the following factors:

- Biomass has a low energy density, especially compared to fossil fuels, and often a high moisture content (up to 55%). Increasing the energy density by chipping, baling, bundling etc, and reducing the water content is crucial, to reduce transportation costs and improve the physical properties.
- The economics of biomass conversion plants generally become more favourable with increasing scale. Feedstock costs on the other hand typically rise as required feedstock volumes increase, due to longer transport distances. Typically, a trade-off between these two factors determines the economic optimal plant size. Advanced pre-treatment technologies such as further densification (briquetting or pelletising) or thermochemical treatment (such as pyrolysis or torrefaction) can further increase the energy density, which makes long transport distances more economical, and thus may allow larger plant sizes (see also Section 3.3).
- Seasonal availability and storability also impact feedstock supply for biomass conversion plants. For example, the harvesting season of sugar-cane is typically 6-7 months in a year, which limits the operational hours per year. In some cases, this may require storage of biomass (e.g. bagasse) for several months. The storability of biomass can also be problematic. Straw, for example, has a relatively short harvesting period, but its use is year long and storage is an important problem. As another example, sugar-cane cannot be stored for more than 24 hours due to decreasing sugar content, so storage of the final product (ethanol) is preferred. In general, storage of biomass feedstocks is problematic if moisture contents are high (e.g. >20%), as this generally increases the rate of dry matter loss and the risk of self-ignition. Advanced pre-treatment options can partially solve these issues. For more information, see the IEA Good Practice Guidelines (IEA, 2007c).
- In terms of both costs and energy requirements, transportation by boat is far superior to train or truck. The combination of high density biomass energy carriers (such as wood pellets or ethanol) and transport in large sea-going vessels has enabled the advent of intercontinental biomass

supply chains, and has to a large extent decoupled the production of electricity or biofuels from the geographical resource. For example, energy plants in Europe have been utilising wood pellets and other agricultural residues from North America, South America and Southeast Asia transported by ocean vessel (Marchal et al., 2004; Ryckmans et al., 2006, see also Section 4.2). Low density biomass energy carriers such as chips and bales are often transported by truck and maximum economic transport distances are typically limited to 100km.
- Finally, the optimal biomass supply chain also strongly depends on the quality requirements and required annual feedstock of the end-user.

2.5 Key Messages for Decision Makers

1. What are the most important current and future biomass feedstocks?

The most widely used feedstocks for the production of heat and electricity from biomass at present are forestry and agricultural residues and various organic wastes. Conventional sugar, grain, and vegetable oil crops are used for liquid biofuels production. In the longer term lignocellulosic crops (both perennial herbaceous and woody) could provide the bulk of the resource. Algae have high potential for the longer term, but are a relatively unexplored feedstock at the present stage of their development.

2. What are the main factors determining the long-term biomass potential for energy?

The availability of forestry and agricultural wastes and residues is mainly determined by future developments in agricultural and forestry production, including demand for the products of which they are a by-product. The main factors determining future bioenergy crop availability are:
- modernisation and technology development in agriculture, including productivity increases and technology exchange (directly influencing global food production and thus the amount of available land for biomass feedstock production);
- the biomass yield levels that can be obtained on the available land and the choice of crop;
- the efficiency of feedstock logistics;
- the sustainability constraints imposed on bioenergy crop production; and
- population growth, and resulting food and feed demand.

Other key factors determining the supply of bioenergy crops and other biomass in the coming decades will continue to be the costs of production or collection, the availability of suitable infrastructure, competing fossil fuel costs, and the levels of policy incentives in support of bioenergy. Finally, the potential development of aquatic species i.e. algae is a key factor. Depending on how these constraints are taken into account, various scenarios for North America and Europe show that moderate to substantial parts of the long-term technical potentials may be realised by 2030.

3. How significant could the contribution of biomass be to the global energy mix by 2050?

Moderate biomass potential scenarios, taking into account sustainability constraints, indicate an annual potential of between 200 and 500 EJ/year by the year 2050. Residues from forestry and agriculture, and organic waste (including MSW) represent between 50 and 150 EJ/year of this potential, with the remainder from surplus forest growth and energy crops. The biomass potential could be greater if algae prove to be successful.

Estimates of world energy demand by 2050 range between 600-1000 EJ/year, and indicate that bioenergy could contribute up to 250 EJ/year, in competition with other sources. Thus, the projected biomass supply should be able to meet this projected demand and potentially contribute between a quarter and a third of the global energy mix.

4. What logistical constraints do biomass supply chains have to tackle?

The critical issues in biomass logistics are:
- The specific properties of biomass: low energy density, often requiring drying and densification; and seasonal availability and problematic storage requiring further pre-treatment.
- Factors limiting the supply: availability and appropriateness of mechanised equipment; and inadequate infrastructure to access conversion facilities and markets.

The main solutions to these issues are the development of advanced densification and other pre-treatment technologies, diversifying procurement geographically and in terms of biomass types, and the optimisation of fuel supply chains from field to plant gate (including the development of specialised harvesting and handling equipment), leading to lowest delivered costs. These developments are crucial to the future deployment of large-scale biomass conversion plants and international bioenergy trade.

5. What are the potential implications of large-scale biomass production and use?

It is important to note that the impacts of large-scale energy crop production on environmental and socio-economic aspects can be both positive and negative, and are highly dependent on the specific situation and location of a project. In many cases, there may be tensions between economic, environmental, and social aspects. Potentially important positive implications of large-scale biomass production might include:
- reduction of greenhouse gas emissions and other pollutants;
- improved energy security for developed as well as developing countries;
- improvements in waste management and resource efficiency; and
- provision of environmental and socio-economic functions, e.g. soil restoration, vegetation filters, reduction of wildfire risk, rural diversification and development.

Risks or negative impacts from large-scale biomass production mainly relate to:
- environmental impacts, e.g. on water availability and quality, soil quality, biodiversity, net greenhouse gas emissions from land use change;
- competition for land and biomass with food and other products, and with other ecosystems; and
- social impacts related to, for example, land rights.

Best practice and appropriate regulation should be used to maximise benefits and minimise negative impacts.

CHAPTER 3: BIOENERGY ROUTES AND CONVERSION TECHNOLOGIES

Key questions addressed in this Chapter:

1. How does bioenergy differ from other renewable alternatives?
2. What are the bioenergy options to produce heat, power and transport biofuels from biomass and how do they compare in terms of development status?
3. What are the limitations of using biofuels for the transport sector?
4. What are the issues associated with 1st generation biofuels and to what extent can 2nd generation biofuels address these?
5. What is holding back 2nd generation biofuels from becoming commercial?
6. What are the main priorities for further development and improvement of the conversion technologies, and how would these assist deployment?

3.1 Biomass – A Unique Renewable Resource

In many ways biomass is a unique renewable resource.

- It can be stored and transported relatively easily in contrast to renewable options such as wind and solar, which create intermittent electrical power that requires immediate consumption and a connection to the grid.
- It has a cost. With the exception of waste and residues, the cost of biomass often represents a significant share (usually of the order 50-90%) of the production cost of bioenergy. This makes the economics of bioenergy fundamentally different from that of other renewable energy options that mostly rely on free resources (e.g. wind, sunlight, geothermal heat, wave, etc.).
- One or more conversion steps are needed to transform raw biomass into consumable bioenergy products and services. As it grows, plant biomass captures solar energy and converts it (through photosynthesis) to chemical energy stored in the chemical bonds of its molecular constituents. This chemical energy can be either directly released as heat via combustion (and subsequently transformed into power via an engine or turbine) or converted into a variety of marketable intermediate chemical and energy products. The latter biomass-derived energy products can be solid (chips, pellets, charcoal, etc.), liquid (biodiesel, bioethanol, etc.) or gaseous (biogas, synthesis gas, hydrogen, etc.) that, in turn, can be used in a variety of energy applications including use as transport fuels.
- Finally, biomass is a resource that is extremely varied in nature, which is again unlike all other renewable energy resources (e.g. the sunlight spectrum is the same all around the world). This requires specific technologies to be developed for each case, as explained in the following section.

3.2 Characteristics of Bioenergy Routes

A bioenergy chain, or route, consists of a series of conversion steps by which a raw biomass feedstock is transformed into a final energy product (heat, electricity, or transport biofuel). There are many potential bioenergy chains as a result of the wide range of raw biomass feedstocks (wood, grass, oil, starch, fat, etc.) and the variety of possible end-uses. An overview of bioenergy routes is given in Figure 3-1.

Different conversion technologies have been developed that are adapted to the different physical natures and chemical compositions of feedstocks, as well as to the energy service required (heat, electricity, transport fuel). While some routes are straightforward (e.g. direct combustion of forest wood for heat production), others necessitate several pre-treatment, upgrading and conversion steps, such as those required for the production of liquid fuels that can be used in an internal combustion engine.

Three main classes of conversion routes can be identified:

- Thermochemical conversion, by which biomass undergoes chemical degradation induced by high temperature. The four thermochemical routes are combustion, gasification, pyrolysis, and torrefaction which differ mainly in their temperature ranges, heating rate and amount of oxygen present in the reaction.
- Physicochemical conversion is used to produce liquid fuels (biodiesel or vegetable oil) from oil crop (rapeseed, soybean, *Jatropha*, etc.) by oil extraction possibly followed by a transesterification process.
- Biological routes use living micro-organisms (enzymes, bacteria) to degrade the feedstock and produce liquid and gaseous fuels. Biological routes are numerous, key mechanisms being fermentation from sugar (sugar-cane, sugar-beet, etc.), starch (corn/maize, wheat, etc.) and lignocellulosic (grass, wood, etc.) feedstock, anaerobic digestion (mostly from wet biomass), and the more recent bio-photochemical routes (e.g. hydrogen production using algae), which require the action of sunlight.

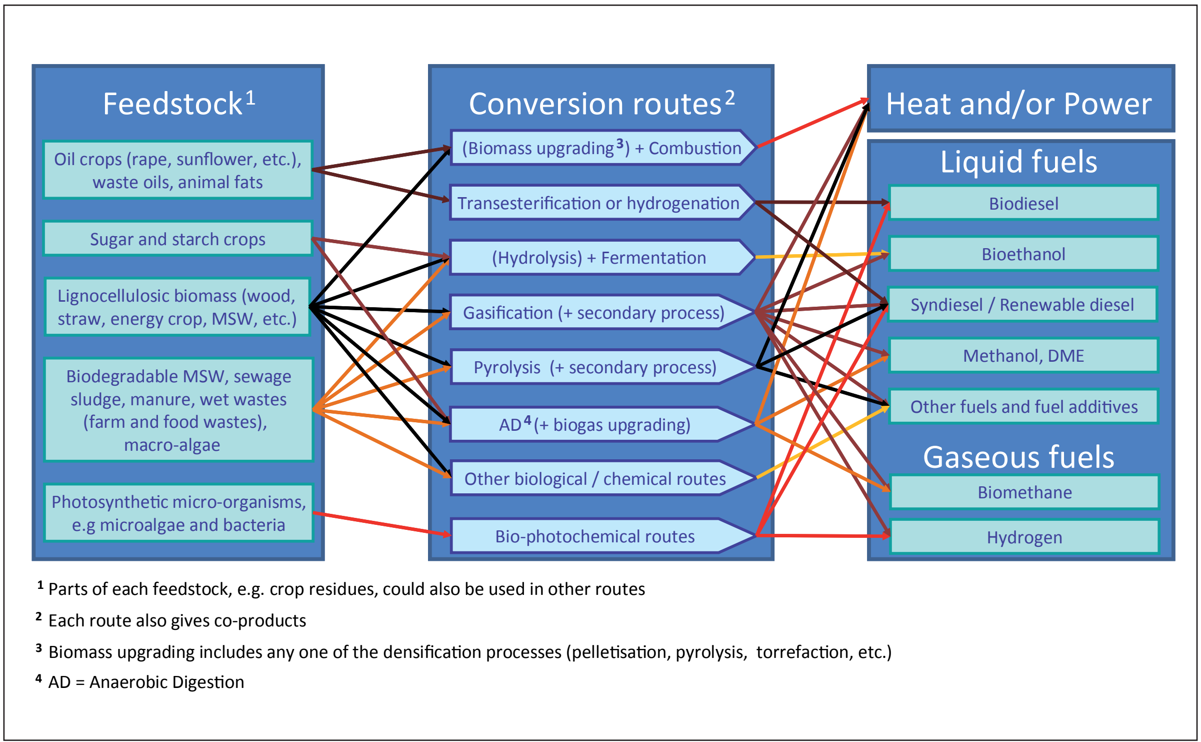


Figure 3-1: Synthetic view of the wide variety of bioenergy routes. Source: E4tech (2008).

A brief description of the main characteristics of the different conversion technologies is provided below, and a more in-depth description of these various bioenergy routes is available in Annex 3.

Every bioenergy conversion chain generates co-products, in addition to a principal energy product. Co-products may add substantial economic value to the overall process. Examples include animal feed, food additives, specialty chemicals, charcoal, and fertilisers. Further discussion on this topic is provided in the section on biorefineries (Section 3.7).

The preferred bioenergy route will depend on many considerations, including technology readiness, feedstock type and volumes available, as well as the energy service required. Different actors may have different objectives and hence favour varying technologies. Whilst project developers will be interested in maximising financial return, governments will be addressing additional considerations such as carbon saving potential, energy security, and nationwide economic return.

3.3 Biomass Pre-treatment and Upgrading Technologies

Although it has the great advantage of being a renewable source of energy, biomass has a number of disadvantages when compared with fossil fuels. It has a lower energy density (up to five times lower per unit volume) and is more variable in its physical nature, making handling, transport and storage more complex and more expensive than for fossil fuels. Also, the chemical composition and moisture content of biomass feedstocks may vary considerably, which may require pre-treatment in order to meet the requirements for quality and homogeneity of many conversion technologies.

For these reasons, biomass pre-treatment (or upgrading) techniques are used that convert raw biomass into easier to handle, denser and more homogeneous (solid or liquid) fuels, in order to reduce supply chain cost and increase the efficiency and reliability of downstream processes. Increasing the energy density of biomass may be attractive if it is necessary to decouple bioenergy production from its point of use, due to the increasing cost of transport. The main upgrading technologies used to increase the energy density of the biomass are, in order of development status: pelletisation, pyrolysis, torrefaction, and hydrothermal upgrading (see Figure 3-2). See Annex 3.1 for a more detailed description of these technologies.

3.3.1 Pelletisation

Pellets, which are simply made by compressing comminuted small particles of solid biomass, have become a common fuel in developed countries, both in households (in the increasingly popular pellet boilers) and industry. The adoption of quality standards is contributing to a rise in the use of pellets and their international trade. Pellets hold promise for supplying large volumes of standardised solid fuel, in particular for heating applications where they already represent a cost competitive alternative to fossil fuels such as heating oil and gas (EuBioNet2 2007).

However, pellets tend to absorb moisture during transport and storage, which can significantly reduce their net calorific value. This calls for various mitigation measures along the supply chain, including quality control. Today, pellets are mostly produced from sawdust, a co-product of sawmills, which may be a limiting factor in terms of the volume of pellets that can be easily introduced into the market.

3.3.2 Pyrolysis and hydrothermal upgrading

Pyrolysis is the controlled thermal decomposition of biomass occurring at around 500°C in the absence of oxygen (anaerobic environment) that produces a liquid bio-oil, a mixture of gas (syngas) and charcoal (biochar). There are two main types of pyrolysis processes: fast and slow. These are characterised by different residence times in the pyrolysis reactor, and lead to different proportions of the liquid, gas, and solid fractions. While slow pyrolysis favours the production of bio-char, which can be substituted in any applications using coal, fast pyrolysis is given more attention as it maximises the production of bio-oil.

Bio-oil should be cheaper to handle, store and transport compared to raw solid biomass. Also, the energy density (per unit volume) of bio-oil is higher than that of pellets or torrefied biomass, which gives it a competitive advantage in terms of transport cost. Potentially, bio-oil could be upgraded and used as a transport fuel, providing an efficient route to fuels that could be closely integrated with a petroleum infrastructure (see Section 3.6.3).

Bio-oils can also be produced by liquefaction in the presence of water, and possibly additional solvents (e.g. methanol), at high pressure (120-200 atmospheres) and relatively mild temperatures (300-400°C). This process is known as hydrothermal upgrading (HTU). One attractive feature of this process is that wet biomass can be used directly and that the bio-oil is less soluble in water in contrast to the bio-oil from fast pyrolysis.

However, in spite of these advantages and although considerable experience has been gained over recent decades, in particular for fast pyrolysis, these technologies are still at the demonstration stage. Only a few successful pyrolysis demonstration units have been realised (e.g. in Finland and Canada), and both economic and technical issues around quality, consistency and long-term stability of the bio-oil, which tends to degrade over time, remain to be addressed.

3.3.3 Torrefaction

Torrefaction is a high-efficiency thermal process occurring at 200-300°C by which biomass (usually wood) is chemically upgraded into a dry product that resembles coal in appearance. Torrefied biomass has a high energy density and is hydrophobic, which means it can be transported over long distances and stored outside without absorbing any significant amount of water, hence without reducing its calorific value. Torrefied biomass can also be pelletised to further reduce its handling and transportation costs. Torrefied pellets are expected to be even more cost competitive than traditional pellets.

The homogeneous and coal-like properties of torrified biomass make it an interesting feedstock in terms of compatibility with a range of conversion technologies. Torrefaction technology is currently at the demonstration stage, but could become commercially available in the near future. This would facilitate access to remote resources, such as residues from forest products industries and forests in remote regions.

3.4 Biomass for Heat Applications

The production of heat from biomass is the traditional energy use of biomass. Biomass-to-heat systems are all commercial (see Figure 3-2) and mostly cost-competitive, although the economic case will be context specific and depends on the cost of fossil alternatives.

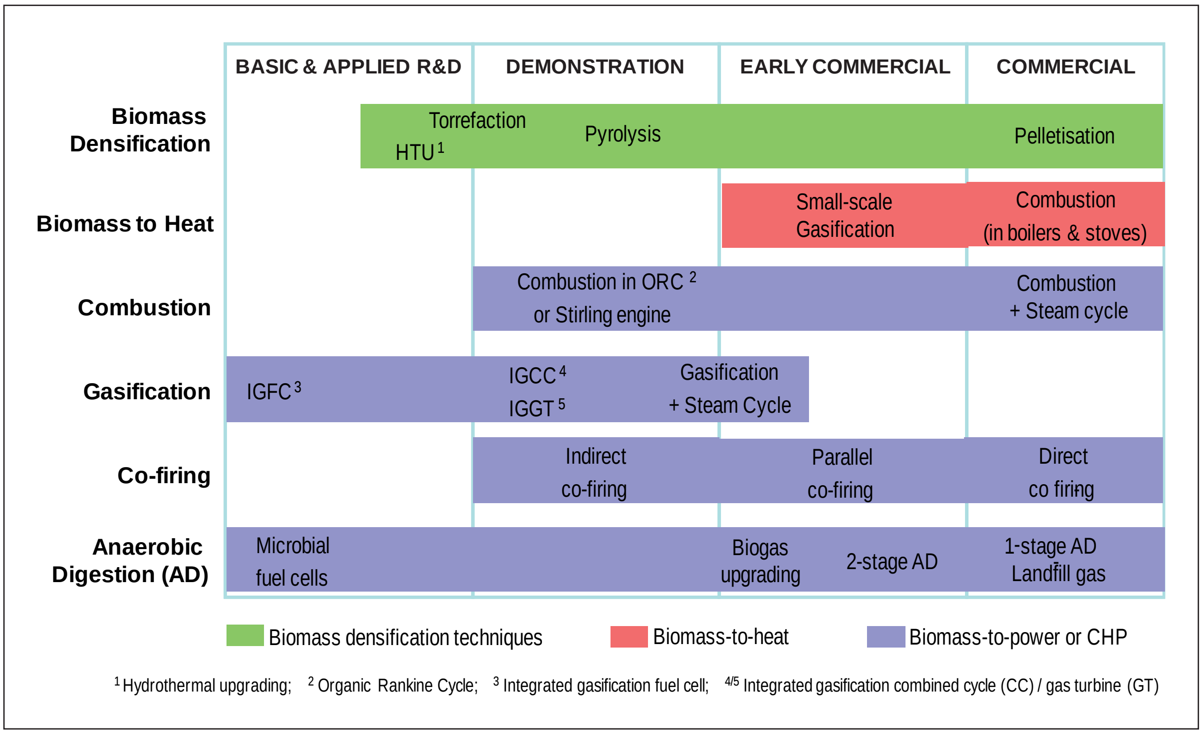


Figure 3-2. Development status of the main upgrading technologies (green), biomass-to-heat technologies (red) and biomass-to-power and CHP technologies (blue).

3.4.1 Combustion

The burning of biomass for heat is the oldest and most common way of converting solid biomass to energy. Because combustion is a straightforward and well understood process, there is a wide range of existing commercial technologies tailored to the characteristics of the biomass and the scale of the application (see Annex 3.2 for a more detailed description of the biomass-fuelled heating systems).

Domestic systems. The direct burning of woody feedstock has been used since the dawn of civilisation and is still by far the biomass conversion technology making the largest contribution to global energy supply (see Annex 4.1). Although modern units, such as increasingly popular pellet boilers, have an efficiency as high as 90%, the vast majority of domestic biomass devices in use are low efficiency (5-30%) traditional cooking stoves found mostly in developing countries (IEA 2008b). The potential for expanding biomass heating in industrialised countries and improving the use of biomass for heating in developing countries is considerable.

District heating and cooling. Although it is a proven technology, the economic case for biomass-based district heating depends on a number of complex technoeconomic parameters. Today, biomass-based district heating provides a significant share of the heating requirements in some countries (e.g. northern European countries). Although an economic case can be made for appropriately-scaled district heating networks, the high cost of new heat distribution networks and the difficulty of guaranteeing high overall efficiency are key issues hindering further deployment. Interest in district cooling systems (especially in combination with heat and electricity production, i.e. tri-generation) is on the rise. This could provide an efficient way of providing cooling services and improve the economic viability of biomass schemes through enhanced utilisation of plant and infrastructure.

Industrial systems. An increasing number of boilers in the 0.5-10 MW_{th} range are found in industries that consume large amounts of heat and have large volumes of biomass residues at their disposal. The industrial sector is potentially a large market for biomass heating, but it requires tailored solutions that meet the technical requirements of different industries, e.g. in terms of heating temperatures and flue gas quality.

3.4.2 Gasification

The use of gasifiers for direct heat application is mainly confined to emerging countries, while gasification for the production of higher value energy products (e.g. electricity and transport fuel) is of greater importance to developed countries (see Section 3.5.3). Hundreds of smaller size biomass gasifiers (10-500 kWth) are for example, being deployed mainly for intermittently operating thermal applications in China, India and South East Asia with viable pay-backs. However, reliability and maintenance of these units for continuous operation seems be an issue (see Annex 3.5 for further details).

3.5 Biomass for Power and CHP Applications

There are a multitude of feedstock and conversion technology combinations to produce power and combined heat and power (CHP), albeit at different stages of development and deployment. Figure 3-2 shows the development status of different routes that are explained further in this section.

The economic case of a bioenergy option for power and CHP depends not only on the actual technology (capital and operating costs, conversion efficiency, process reliability, economies of scale, etc.), but also crucially on the locally prevailing context for both biomass supply (quality, type,

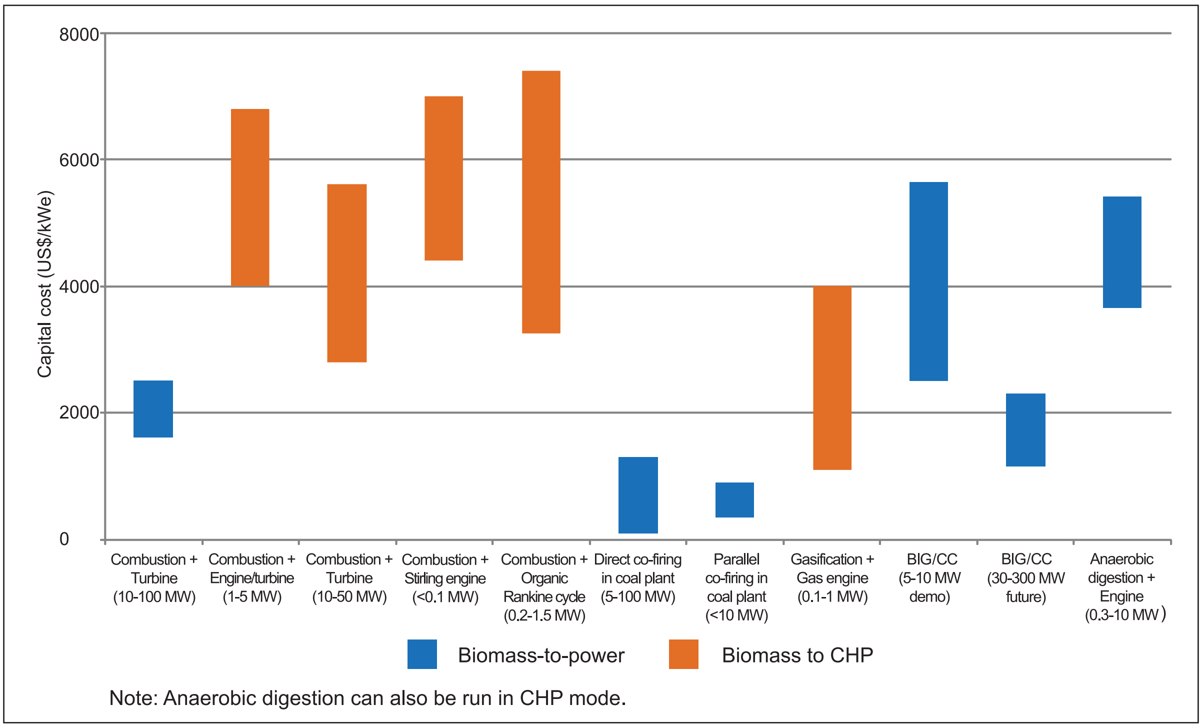
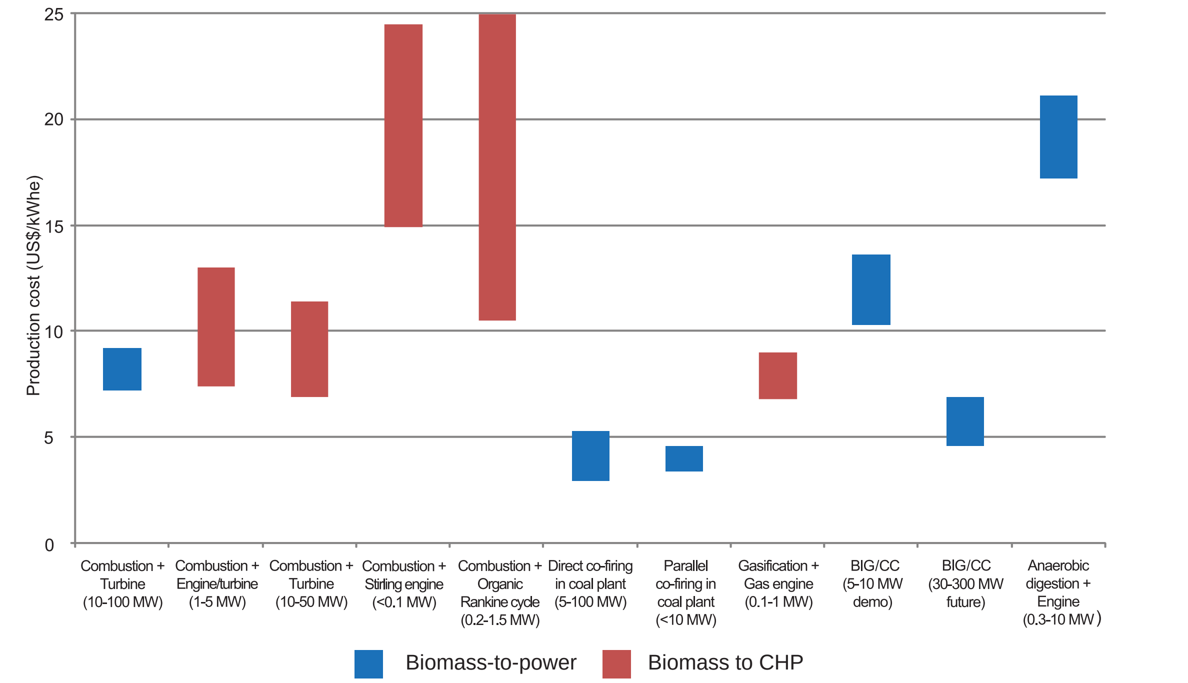


Figure 3-3. Capital cost for available biomass-fuelled technologies for power (blue bars) and CHP (orange bars). Sources: E4tech based on IEA (2007a, 2007b, 2008c, 2008e), Obernberger and Biedermann (2005), IEE (2007), and van Tilburg (2006, 2008).



Note 1: Anaerobic digestion can also be operated in CHP mode.
Note 2: Production cost can be reduced by 60-80% (depending on technology and plant size) if free biomass feedstock is used, such as MSW, manure, waste water etc.

Figure 3-4. Production cost for available biomass-fuelled technologies to power (blue bars) and CHP (red bars). For the sake of making comparison possible, the production costs have been calculated based on the capital costs given in Figure 3-3 and on the following assumptions for each of the technologies considered: (1) Plant lifetime = 20 years, (2) Discount rate = 10%, (3) Heat value=5US$/GJ (for CHP applications only), (4) Biomass cost=3 US$/GJ.

availability and cost) and final energy demand (cost of alternative energy production, heat demand and value, grid accessibility, support policies, etc.). Figure 3-3 and Figure 3-4 compare the capital cost and production cost for the main conversion technologies available for power and CHP applications. The wide range of costs found for most technologies indicates both that economies of scale are important (e.g. for steam turbines) and that most of these technologies are still in their demonstration stage (Stirling Engine, BIG/CC and Organic Rankine Cycle).

The advantages and disadvantages of each combustion-to-power technology are described in the following sections and in more detail in Annex 3.3.

3.5.1 Biomass combustion

Biomass-based power plants. The heat produced by direct biomass combustion in a boiler can be used to generate electricity via a steam turbine or engine. The electrical efficiency of the steam cycle is lower than that of alternative technologies such as gasification-based pathways (see below), but it is currently the cheapest and most reliable route to produce power from biomass in stand alone applications.

In a fragmented biomass supply market, the cost of purchasing large quantities of biomass may increase sharply as the distance to suppliers (and thereby logistical cost) increases. In this context, the importance of economies of scale for steam-cycle plants has meant that dedicated biomass power plants have generally only proven commercially viable at the larger scale (30-100 MWe) when using low cost feedstocks available in large volumes such as agricultural residues (e.g. bagasse), or wood residues and black liquor from the pulp and paper industry. However, a growing number of viable smaller scale plants (5-10 MWe) using other type of residues (wood, straw, etc.) are found throughout Europe and North America.

MSW waste-to-energy plants. Municipal solid waste (MSW) is a highly heterogeneous and usually heavily contaminated feedstock, which calls for robust technologies and rigorous controls over emissions, leading to relatively high costs associated with waste-to-energy facilities. Different technologies are available, and the choice usually depends on the degree of separation of the different MSW fractions. The generally uncompetitive cost at which electricity is generated means that, in the absence of an appropriate waste hierarchy and associated incentives, MSW remains a largely unexploited energy resource despite its significant potential in most countries.

Biomass-based cogeneration (CHP) plants. The principal means to significantly increase the overall efficiency of a power plant (and hence its competitiveness) is to find an economic application for its waste heat. Combined heat and power (CHP) plants, also called cogeneration plants, have typical overall (thermal + electric) efficiencies in the range of 80-90%, provided a good match can be found between heat production and demand (IEA 2008c). This is commonly the case, for example, in the sugar-cane industry.

Co-generation has been shown to reduce the cost of power production by 40-60% for stand-alone plants in the range of 1-30 MWe. However, for domestic and commercial heating applications, the scale of biomass CHP plants is often limited by the total local heat demand and by its seasonal variation, which can significantly affect economic returns unless absorption cooling is also considered (tri-generation).

Distributed cogeneration units. In the lower capacity range, the Stirling Engine (10-100 kWe) and the Organic Rankine Cycle (ORC) (50-2000 kWe) are promising technologies for distributed cogeneration. Currently at the demonstration stage, improvements are still needed, in particular concerning conversion efficiency, reliability, and cost. Developments in these technologies are, however, not focussing primarily on biomass-fuelled units, although some efforts in this direction have been made in Europe (Germany, Austria, the Netherlands, and Switzerland).

3.5.2 Co-firing

The co-combustion of liquid and solid biomass materials with fossil fuels in thermal processes for heat and power production can be relevant to all scales of operation. Biomass co-firing activities have expanded rapidly in recent years, particularly in Northern Europe, and the most popular approach has involved the direct co-firing of solid biomass with coal in existing large power station boilers. This has proved to be the most cost-effective and most efficient large-scale means of converting biomass to electricity and, where relevant, district heating. This is because this approach capitalises on the existing infrastructure of the coal plant and thus requires only minor investment in the biomass pre-treatment and feed-in systems. It also profits from the comparatively higher conversion efficiencies of these coal plants.

However, in spite of the great progress achieved in co-firing over the past decade, biomass properties pose several challenges to coal plants that may affect their operation and lifetime, in particular when a feedstock other than wood is used. This generally limits the amount of biomass that can be co-fired. The alternative option of indirect and parallel co-firing is designed to avoid these issues, but is much more expensive than direct co-firing (see Annex 3.4 for further details on co-firing technologies).

Carbon capture and storage (CCS) from fossil-fuelled power plant flue gases is being considered as a measure to reduce greenhouse gas emissions. In this context, CCS can also be applied to co-firing plants, which would enable the capture of carbon from biomass (biotic CCS), resulting in a net negative carbon emission or carbon sink associated with biomass combustion.

3.5.3 Gasification

Gasification is a thermo-chemical process in which biomass is transformed into fuel gas, a mixture of several combustible gases. It has two key advantages over direct combustion. First, gasification is a highly versatile process as virtually any biomass feedstock can be converted to fuel gas with high efficiency. Second, fuel gas can be used directly for heat or power applications or upgraded to syngas for biofuel production (see Figure 3-1 as well as Section 3.6.3 for conversion into liquid biofuels). Thus gasification technology could suit several possible applications in various market segments.

In combination with a power-generation device, gasification can offer higher overall conversion efficiencies compared to combustion-based routes. This is particularly true for small-scale plants (<5-10 MW_e) where relatively simple gasification systems could be coupled with gas engines, and where steam-based systems are disadvantaged by significant diseconomies of scale. At larger scales (>30 MW_e), gasification based systems are coupled with combined gas and steam turbines, again providing efficiency advantages compared to combustion. However, such plants require more skilled operation compared to combustion plants, and their efficiency and reliability still need to be fully established. Although several projects based on advanced concepts such as the Biomass Integrated Gasification Combined Cycle (BIG/CC) are in the pipeline in northern Europe, USA, Japan, and India, it is not yet clear what the future holds for large-scale biomass gasification for power generation.

Gasification can also co-produce a range of end-products, such as heat and electricity, together with liquid fuels and possibly other products in biorefineries. Such advanced concepts are currently being investigated in research and pilot plants. (See Annex 3.5 for further details).

3.5.4 Anaerobic digestion

Anaerobic digestion is the biological degradation of biomass in oxygen-free conditions. The main product of anaerobic digestion is biogas, a methane-rich gas. Biogas can either be burnt in power generation devices for on-site (co)generation, or upgraded to natural gas standards for injection into the natural gas network as biomethane or for use directly as gaseous biofuel in gas engine-based captive fleets such as buses.

Anaerobic digestion can biodegrade virtually all biomass that animals can digest (essentially any biomass excluding woody materials). It is particularly suited to wet feedstocks such as animal manure, sewage sludge from waste water treatment plants, wet agricultural residues and the organic fraction of MSW. Anaerobic digestion also occurs naturally underground in landfills and produces landfill gases which can be collected for use in energy applications.

Anaerobic digestion is a well established commercial technology, although its economic case relies heavily on the availability of very cheap or free feedstock such as sewage sludge, manure and some agricultural residues. Today, China is by far the biggest biogas producer in the world, with around 18 million farm households using biogas and about 3,500 medium to large-scale digester units (DEFRA 2007). In Europe, specific support mechanisms have resulted in Germany being the leader in this technology, with farm-based units totalling a combined 550 MWe installed capacity in 2006 (i.e. similar to that of a coal power plant). In order to increase productivity, decentralised farm-size units are increasingly relying on supplementary feedstock such as agricultural residues or crops. Sewage sludge digestion and use of landfill gas are both effectively supported by waste disposal fees, which means that these are globally the most common forms of anaerobic digestion generating energy at present (led by UK, Italy, and Spain). In contrast, deployment of biogas technology in the USA suffers from a reputation for poor reliability (EPA 2008).

The key co-product of anaerobic digestion is a nutrient-rich digestate, which can be used as a fertiliser. However, when using contaminated feedstock, contaminants may end up in the digestate, making it unsuitable for this and difficult to dispose of. Biomass pre-treatment and separation processes to remove these contaminants can help to avoid this, although these are processes which still need to be proven at larger commercial scale. (See Annex 3.6 for more details).

3.6 Biofuels for Transport Applications

3.6.1 Definitions and development status

Biofuels are commonly separated into different 'generations' according to their level of development and the feedstocks they use, though there is no universally agreed definition. Generally:

- 1st generation biofuels include mature technologies for the production of bioethanol from sugar and starch crops, biodiesel and renewable diesel from oil crops and animal fats, and biomethane from the anaerobic digestion of wet biomass.
- 2nd generation biofuels encompass a broad range of novel biofuels based on new feedstocks. These include:
  - Bioethanol and biodiesel produced from conventional technologies but based on novel starch, oil and sugar crops such as *Jatropha*, cassava or *Miscanthus*;
  - A range of conventional and novel biofuels (e.g. ethanol, butanol, syndiesel) produced from lignocellulosic materials (i.e. fibrous biomass such as straw, wood, and grass). These routes are based on biochemical and thermochemical technologies still at the demonstration stage.
- 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 from commercialisation (e.g. biofuels from algae, hydrogen from biomass).

The goal for 2nd and 3rd generation technologies is therefore to produce sustainable, low cost biofuels from a broad range of resources that do not compete with food production and that have significantly lower GHG emissions than 1st generation biofuels. An overview of the development status of the different bioenergy routes to biofuels is given in Figure 3-5.

3.6.2 1st generation biofuels

Bioethanol from sugar and starch crops. The biological fermentation process used to produce ethanol from sugars extracted from sugar and starch crops is technically mature and commercially available. However, technical improvements can still be made to commercial ethanol production routes, e.g. improved enzymes to convert starch to sugars (hydrolysis), improved bacteria (fermentation), water separation methods, process and plant optimisation, and greater value-added co-products (e.g. development of biorefineries – see Section 3.7 below).

Production costs vary significantly depending on the feedstock used and scale of the plant. The trend has been towards larger plants, with new plants generally of capacity greater than 200 million litres per year. Ethanol can be produced from Brazilian sugar-cane at less than US$0.31/l, whereas the production cost of ethanol from corn in the USA in close to US$0.75/l and that from wheat in the UK is about US$0.87/l (see Figure 3-6 below and Annex 3.7 and Annex 3.8 for yield and production cost figures). Feedstock costs account for approximately half of the cost of sugar-cane ethanol production, and for significantly more in the case of the other 1st generation bioethanol production pathways, such as corn ethanol.

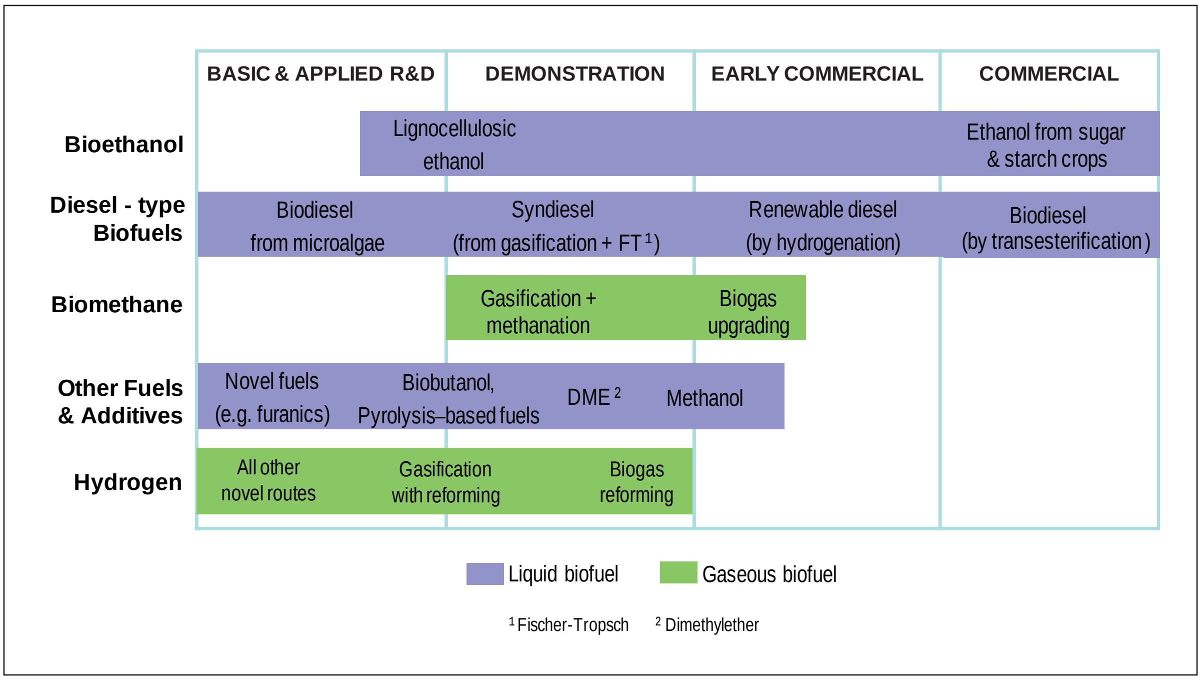


Figure 3-5. Development status of the main technologies to produce liquid and gaseous biofuels.

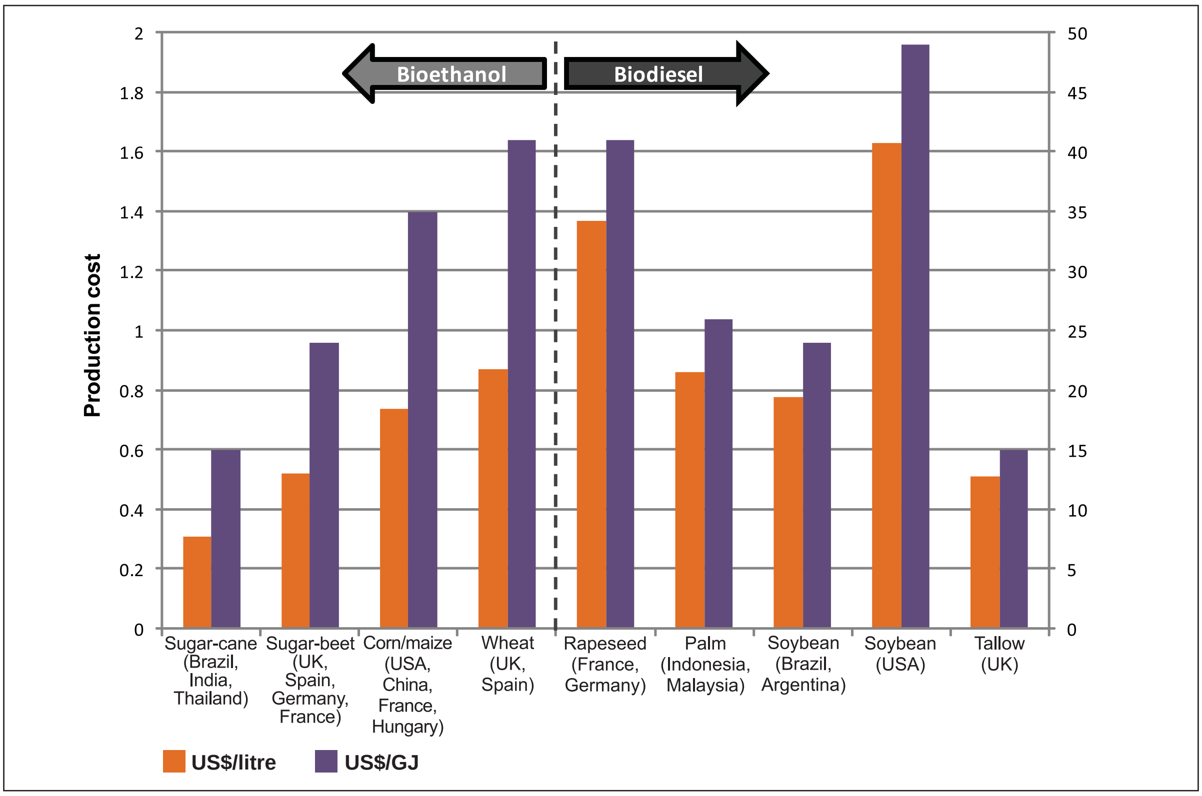


Figure 3-6. Indicative production costs of 1st generation bioethanol and biodiesel from different crops and from animal fat in the main producing regions in 2007. Source: E4tech (2008).

Biodiesel and renewable diesel from oil crops, waste oils and fats. There are various routes to produce diesel-type fuels from biomass (see Table 3-1). Transesterification and hydrogenation are technically mature and commercially available 1st generation technologies that produce biodiesel from vegetable oil and animal fats. Transesterification, a relatively straightforward catalytic process, is the dominant of the two technologies. So far there has been limited deployment of hydrogenation technology, a process resembling oil refining, although it produces a renewable diesel of superior quality (with higher blending potential) to that obtained via transesterification. This is a result of limited interest so far from oil companies and refineries in becoming involved in biofuels production, and the reluctance of the sector due to potential technical risks associated with the degradation of hydrogenation catalysts. However, continued interest in vegetable oils and animal fats as feedstocks could lead to greater deployment of hydrogenation. A description of the hydrogenation route is given in Annex 3.9.

As in the case of bioethanol, production costs of biodiesel vary significantly depending on the feedstock used and scale of the plant, and the trend has also been towards larger plants exceeding 200 million litres per year. Production costs range roughly from \$0.50/l to \$1.60/l, depending on whether waste feedstock or vegetable oil is used (see Figure 3-6 or Annex 3.7 and Annex 3.8 for yield and production cost figures). Production costs are dominated by feedstock cost in the case of vegetable oils.

Biomethane. As an alternative to combusting biogas to generate electricity (see Section 3.5.4), biogas can also be upgraded to biomethane and injected into the natural gas network for use in gas-powered vehicles. This route is experiencing significant deployment and development (see Section 4.1.3).

Table 3-1. Characterisation of routes to diesel-type biofuels.

Common name	Full name	Biofuel generation	Conversion Route	Product characterisation	Biomass used
Biodiesel	FAME or FAEE biodiesel (fatty acid methyl / ethyl ester)	1st	Transesterification of vegetable oils and animal fats	FAME biodiesel has lower energy content than fossil diesel and has blending limits in some applications	Rapeseed, palm, tallow, soybean, etc
Renewable diesel	Hydrotreated biodiesel	1st	Hydrogenation of vegetable oils or animal fats	Similar to fossil diesel	Same as FAME biodiesel.
Green diesel or syndiesel	Synthetic diesel	2nd	Gasification of biomass followed by Fischer-Tropsch (FT) synthesis	Similar to fossil diesel	Lignocellulosic biomass e.g. wood.

A number of known systems (e.g. membranes, absorption washers (water, glycole, amines, NaOH, etc) or pressure swing adsorption) are being improved to fulfil modern environmental standards and consume less process electricity. New systems such as cryogenic upgrading, in which the separated CO_2 can also be used in a pure form, are currently at the demonstration stage. Cost reduction and process simplification of this technology is still required.

Challenges for 1st generation biofuels. 1st generation biofuels face several challenges:

- *Economic case.* The profitability of biofuels is heavily dependent on the prices of both fossil oil and the commodity feedstocks used, both of which tend to fluctuate considerably, as well as on policy support.
- *Social issues.* The feedstocks used are generally also used for food, leading to increased competition as both biofuel and food demands continue to rise (see also Section 4.3).
- *Environmental issues.* The greenhouse gas benefits over conventional fossil fuels vary widely depending on the feedstock and process used (and can even be negative in certain cases – see also Section 5.3). Efforts need to be dedicated to developing more efficient processes, improving the greenhouse gas balance of biofuel chains, and extending the range of feedstocks that can be used, in particular residues and wastes.
- *Market and infrastructure.* The deployment of biomethane-fuelled vehicles suffers from the limited uptake of gas vehicles and related infrastructure.
- *End-use issues.* One advantage of biofuels is that they increase the so-called oxygenate levels of gasoline and diesel, thereby improving the combustion of the fuel. However, there are technical limits to the level at which bioethanol and biodiesel can be blended with gasoline and diesel for use in conventional cars. In most countries, car warranties generally limit biofuel blends with fossil fuels to between 5% and 10%. Going beyond 10% blend would require some changes to engine components and design.

In Brazil, ethanol is already blended in conventional vehicles up to 25% by volume and most new cars sold are flex-fuel vehicles which can function on any blend up to 85% or 100% ethanol depending on climate. These flex-fuel cars are now widely available in many countries. As far as biodiesel is concerned, blends of up to 30% have been used in fleet vehicles, and in some regions (e.g. Germany) vehicles that can be fuelled with 100% biodiesel used to be available on the market.

Advanced biofuels with properties closer to gasoline and diesel, such as syndiesel or renewable diesel, could be blended at much higher levels, or used in conventional vehicles to completely displace fossil fuels. These fuels can also be potentially more easily integrated in existing transport and distribution infrastructure.

3.6.3 2nd generation biofuels

Bioethanol from lignocellulosic feedstocks. Ethanol can be produced from lignocellulosic biomass; that is from any organic matter that contains a combination of lignin, cellulose and hemicelluloses. This includes agricultural wastes (e.g. straw), forestry products and wastes, energy crops (e.g. *Miscanthus*, poplar) and the biological component of municipal solid waste (MSW). Ethanol is produced by first breaking down the cellulose and hemicellulose into sugars, which can then be fermented using a mature 1st generation process. Lignocellulosic materials are more complex to break down than starch, and therefore require more advanced pre-treatment and conversion processes than those used in the production of 1st generation ethanol (see Annex 3.10 for more technical details on this conversion pathway).

There are many routes to produce 2nd generation bioethanol, lignocellulosic ethanol being at the most advanced stage of development and deployment despite still being at the demonstration stage. Although some of the individual stages involved in the process are already commercial (e.g. dilute acid pre-treatment, fermentation and distillation), technological advances are still needed in several process steps (e.g. enzymatic hydrolysis, fermentation of C5 sugars) in order to achieve the cost savings necessary to make lignocellulosic ethanol a competitive alternative. Most lignocellulosic ethanol R&D is currently taking place in the USA, but there is interest in Northern Europe (with its large forestry resources), and in Brazil (with its extensive 1st generation ethanol production from sugar-cane and associated availability of bagasse which could be used as a feedstock). Significant progress is being made in RD&D, and it is likely that commercial scale plants will be deployed over the next decade. See Figure 3-7 for estimated cost projections of 2nd generation bioethanol.

Biomass-to-Liquids (BTL). Using thermochemical conversion processes, a wide variety of biomass feedstocks can be converted into a range of liquid and gaseous transport fuels, such as synthetic diesel and gasoline, methanol, ethanol, dimethylether (DME), methane, and hydrogen.

Gasification-based routes. Combining gasification with the catalytic upgrading of the syngas to a liquid fuel (using, for example, the Fischer-Tropsch process) has the potential to produce a range of synthetic biofuels (synfuels) with low GHG intensity. These routes are particularly attractive and have therefore been given considerable attention both in Europe and North America.

Both biomass gasification and the Fischer-Tropsch process involve mature technologies, already used at commercial scale. However, there is very limited experience in integrating biomass gasification with downstream processes for the production of liquid or gaseous transport fuels. Also, each individual system is generally designed to work on a particular feedstock with narrow physical and chemical property ranges. Further R&D is needed to determine and optimise plant configurations that will be technically and economically viable based on a variety of feedstocks. Technologies are in the demonstration stage in Germany for the production of methanol from gasified mixed feedstock and for the production of green diesel (also known as syndiesel, see Table 3-1) from forest residue and waste wood (NNFCC 2007). Demonstration plants for ethanol production via gasification are being built in the USA. Successful demonstration could lead to the deployment of commercial scale plants over the next decade.

However, a key uncertainty for BTL is whether it will be possible to procure enough sustainable biomass to feed a plant at the scale needed for economic viability. With current technologies, it is expected that economic BTL plants will need to be very large (requiring around a million tonnes of dry biomass a year). Therefore the challenge is whether this process can be made to work technically and economically at a smaller scale, which would enable distributed production of synfuel, due to reduced feedstock procurement needs and reduced transport costs.

Pyrolysis-based routes. Pyrolysis technology (see Section 3.3.2) could be applied at small-scale (e.g. around 50 kt/yr biomass input) near to the feedstock source, followed by pyrolysis oil transport, or at a larger scale at a centralised location (possibly at around 150 kt/yr input or larger). Pyrolysis oils produced from current pyrolysis processes cannot be directly integrated into a conventional oil refinery, and would require upgrading to lower acidity and water content. This could be done at the point of pyrolysis, or after transport of the pyrolysis oil to a refinery. The upgraded pyrolysis oil could then be incorporated into an existing refinery process, such as hydrocracking or FCC (fluid catalytic cracking), producing conventional refinery products such as diesel or gasoline. Upgrading processes could also be developed that enable use of the pyrolysis oil directly in a diesel blend.

Pyrolysis technology is currently at the demonstration stage and technologies for upgrading the bio-oil to transport fuels are at the applied R&D and pilot stage. Main challenges concern the production of stable bio-oils (see Annex 3-1) and the development of cost effective catalytic upgrading processes.

Challenges for 2nd generation biofuels. Significant cost reductions are necessary if 2nd generation technologies are to compete with conventional fossil fuels and 1st generation biofuels. However, the cost reductions needed depend on the level of support such technologies would receive based on their GHG savings potential and other potential benefits (e.g. energy security), and the future cost of competing fuels. The GHG emissions reduction potential of 2nd generation biofuels is high, and generally better than most 1st generation biofuel routes. Further investment in 2nd generation biofuels is likely to rely on the recognition of their relative merits compared to other fuels and on the mitigation of technical risk by demonstration of reliable operation at scale. The availability of comparatively low-cost and sustainable feedstocks in significant quantity will also be key to their deployment (IEA 2008d).

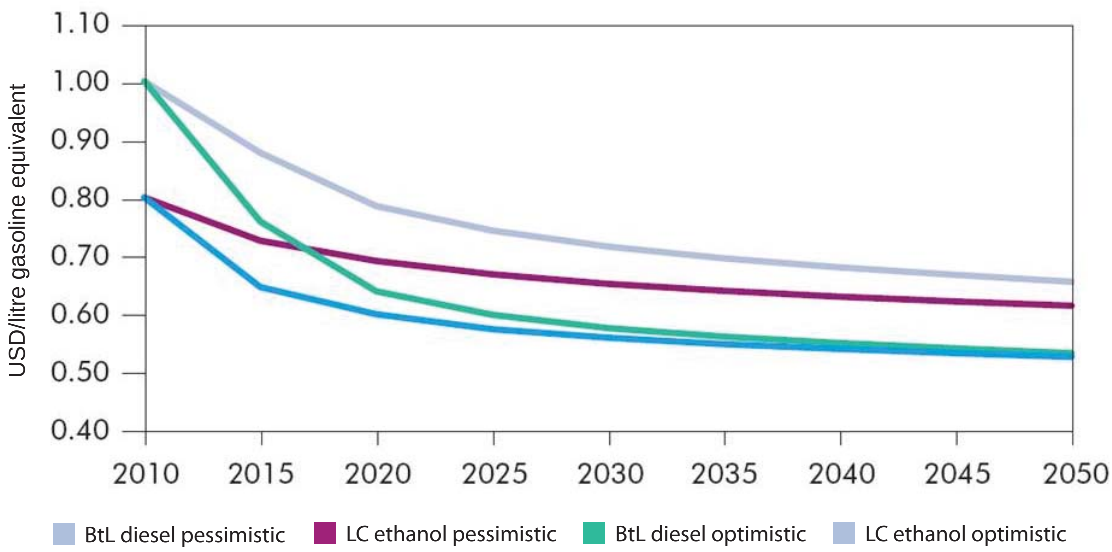
3.6.4 3rd generation biofuels

Biofuels from algae. Algae can be separated into two distinct groups: macroalgae and microalgae.

- Macroalgae (e.g. seaweed) are currently harvested mainly for non-energy purposes such as food, vitamins, and pharmaceuticals. They could potentially also be used as a source of biomass for heat and power, for example via anaerobic digestion to produce biomethane. Liquid biofuels could also be produced, for example via fermentation of sugars and starch to ethanol, via hydrothermal upgrading to an oil, or via gasification of dry biomass to a number of fuels (e.g. hydrogen).

  Macroalgae are still at an early stage of development with critical issues and controversial debate on the potential biomass yield. In some highly controlled environments, high yields were obtained (up to 45 dry tonnes/ha/yr), however, at costs excluding scale-up and commercialisation (EPOBIO 2007).

- Microalgae are microscopic photosynthetic organisms (e.g. diatoms, green algae, golden algae, blue-green algae), that produce chemicals and substances that can be harvested to produce a variety of useful products. Although many conversion routes are possible with microalgae, their high concentration of lipids, which can be extracted and esterified to produce a biodiesel, seems to be the most promising route for bioenergy.



Note: BtL = Biomass-to-Liquids; LC = Lignocellulose

Figure 3-7. Cost projections for lignocellulosic ethanol and BTL diesel. Source: IEA (2008c) and see also IEA (2008d) for data figures.

There has been a great deal of interest in microalgal biofuels due to their potentially very high oil yields per hectare. High yielding microalgae species have been quoted as having the potential to yield up to 20 times more oil per unit of land area devoted to their production than conventional crops such as oil palm (Christi 2007), although more realistic projections may be in the range of 6-10 times (Carbon Trust 2008).

Other reasons why microalgae are appealing is that some of the nutrients they require can be found in waste water, potentially enabling microalgae to be used for the dual purpose of cleaning waste water and producing biofuel feedstock. Microalgal production systems may also be linked to waste CO_2 streams, as this has been shown to improve the growth rate of the algae. Last but not least, they can be grown on non productive land.

The key challenge is to sustain microalgae populations over long periods, with both high productivity and high oil yields. Two types of cultivation systems are being investigated: open pond and photo-bioreactor. The latter is a closed system, which provides a highly controlled growing environment without infection by foreign species, but is obviously a much more costly approach.

There are still many technical challenges that need to be overcome before algae can be commercially grown for fuel production, and very large cost reductions must be achieved, which may prove to be a major challenge. As a result, the potential of microalgae to also produce high value co-products is likely to play an important role in improving the economics of biofuel production.

Liquid-phase catalytic processing of biomass-derived compounds. Sugars and other carbohydrates extracted from various biomass components can be biochemically or catalytically converted into hydrocarbons (e.g. hydroxymethylfurfural (HMF) or its derivates). These can serve as substitutes for the petroleum-based building blocks used for the production of fuels, plastics and fine chemicals (NSF 2008). These routes are potentially interesting, as they could produce high energy density liquid fuels, with potentially high yields via a limited number of chemical reactions, from a potentially wide range of biomass feedstocks. There has been much recent development activity, largely at the applied R&D stage, on these routes both in universities and companies, and in particular start-up companies.

Hydrogen from biomass. Hydrogen can be used to power vehicles, in fuel cells or dedicated internal combustion engines. Many expect hydrogen to play an important role in decarbonising the transport sector in the long-term, as it can be derived from many renewable sources including biomass and water. There are several different routes for the conversion of biomass to hydrogen. These include:

- biological routes, such as fermentation of biomass to hydrogen or anaerobic digestion with methane reforming;
- thermal routes, such as gasification followed by upgrading and reforming of syngas, aqueous phase reforming of biomass-derived solutions, and reforming of bio-oils; and
- photosynthetic routes, such as direct hydrogen production by photosynthetic organisms.

These routes vary in terms of commercial maturity and in the number of different conversion steps required. However, the one thing common to all of them is that they are not economically viable at present or even in the near future. Furthermore, the use of hydrogen as a transport fuel will require the deployment of hydrogen vehicles and a related fuelling infrastructure. Alternatively, biomethane and bioethanol, for which fuelling stations are already being deployed, could be used as hydrogen carriers and converted to hydrogen on board the vehicle using reformers, though this leads to significant additional vehicle complexity and cost.

3.7 Biorefineries

3.7.1 Concept and definition

One of the challenges for many bioenergy routes is their poor competitiveness compared with fossil energy. An option for making them more cost-competitive is to co-produce other high value products from the same feedstocks in biorefineries. Biorefineries are largely at the conceptual stage, with potentially interesting new products and routes still being identified. Even a clear definition of biorefineries is still lacking, and different definitions are being used depending on the type of activity and stakeholders involved. Within the framework of IEA Bioenergy Task 42 on biorefineries the following general biorefinery definition is being used: A biorefinery is the processing of biomass into a spectrum of marketable products and energy. This implies that biorefineries:

- are a cluster of facilities, processes, and industries;
- are sustainable: maximising economics, minimising environmental impacts, replacing fossil fuel, while taking socio-economic aspects into account;
- contain different processing steps: upstream processing, transformation, fractionation, thermochemical and/or biochemical conversion, extraction, separation, downstream processing;
- can use any biomass feedstock: crops, organic residues, agroresidues, forest residues, wood, aquatic biomass;
- produce more than one product, each with an existing (or shortly expected) market of acceptable volumes and prices;
- can provide both intermediate and final products, i.e. food, feed, chemicals, and materials; and
- can co-produce energy as fuels, power, and/or heat.

3.7.2 Development status and prospects

Some current biomass-based industries such as biofuels plants, pulp and paper mills and food processing plants could be considered to be the '1st generation' of biorefineries. Renewable materials like polylactic acid derived from corn starch are increasingly becoming commercially viable and could form an important part of future biorefineries.

New concepts of biorefineries are looking at extracting a much broader range of materials and chemicals from the rich variety of biomass building blocks (see Figure 3-8) for a schematic illustration of two biorefinery types.

The deployment of new biorefinery concepts, based largely on lignocellulosic feedstocks, will need to rely on the technical maturity of a range of processes to produce materials, chemicals, and energy. Considerable development work is

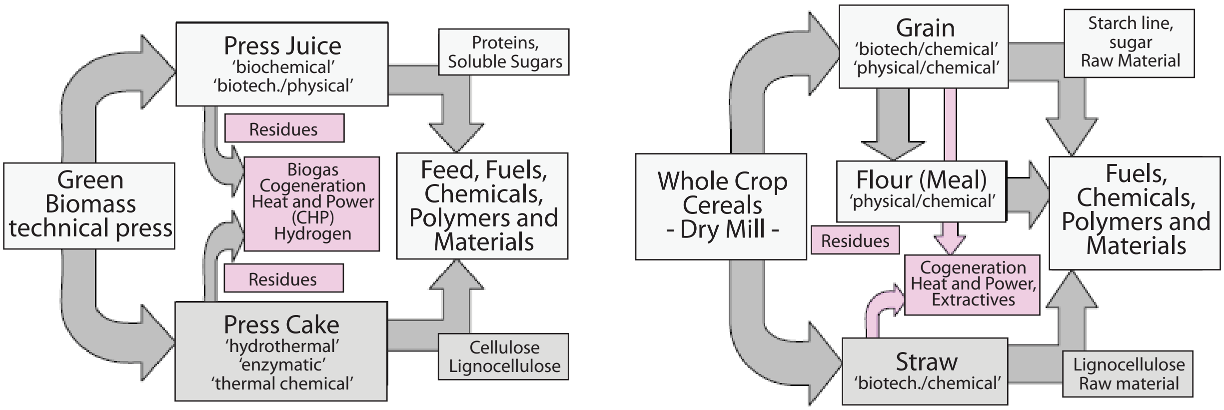


Figure 3-8. Illustrative scheme of a Green Biorefinery (left) and a whole crop biorefinery (right). Source: Kamm et. al. (2006).

underway and new biorefinery concepts are expected to be commercially deployed by 2020. The mix of market and government support for green materials and chemicals and for bioenergy will be an important factor in determining the type and rate of deployment of biorefineries.

3.8 Key Messages for Decision Makers

1. How does bioenergy differ from other renewable alternatives?
In contrast with other renewable energy options, biomass can generate carbon-based fuels, of a composition potentially very similar to that of fossil fuels, the basis for much of present-day energy technology. Furthermore, biomass is a form of stored solar energy which helps overcome the intermittency of the latter. This makes biomass very suitable for use in both heat and power generation, particularly in the transport sector where it is currently the principal renewable alternative to gasoline and diesel. However, biomass feedstock comes at a cost, unlike other renewable energy resources such as wind, hydro, geothermal, wave, and sunlight that are free 'fuels'.

2. What are the bioenergy options to produce heat, power and transport biofuels from biomass and how do they compare in terms of development status?
A multitude of technologies exist, or are being developed, to convert diverse biomass feedstocks to a wide range of solid, liquid and gaseous fuels, and to heat and electricity. Routes based on direct biomass combustion (to produce heat and/or power), anaerobic digestion (including landfill gas), and 1st generation biofuels processes are mature and commercially available.

More advanced options based on thermo- or biochemical processes are being developed and range between the research and demonstration stage. These include relatively well-developed technologies such as 2nd generation ethanol (i.e. lignocellulosic ethanol) and gasification-based power and biofuels. Gasification for power and CHP may offer scale, efficiency, logistics, and emissions advantages in the longer term if reliable and cost effective operation can be confirmed. Many other novel concepts to produce advanced biofuels (e.g. hydrogen from algae) are at an earlier stage of development.

3. What are the limitations of using biofuels in the transport sector?
There are technical limits to the level at which bioethanol and biodiesel can be blended with gasoline and diesel for use in conventional car engines (usually up to 5-10%). However, flex-fuel cars, which can be refuelled with any ethanol blend up to 85-100% ethanol, are now widely available in many countries. Also, dedicated vehicles are available on the market that can be fuelled with biodiesel blends, typically a 30% blend, or 100% biodiesel. Advanced biofuels such as syndiesel or renewable diesel could be blended at much higher levels, or used in conventional vehicles to completely displace fossil fuels. These fuels can potentially also be more easily integrated in existing transport and distribution infrastructure.

4. What are the issues associated with 1st generation biofuels and to what extent can 2nd generation biofuels address these?
1st generation biofuels face both social and environmental challenges. Being mostly based on food and feed crops, 1st generation bioethanol and biodiesel may have a direct impact on the price of food commodities. Also, depending on the agricultural practices and possible changes in land use, these biofuels may have very limited (or even negative) GHG reduction potential, and may result in other adverse environmental impacts, such as biodiversity loss. While such risks can be mitigated through regulation and sustainability assurance, technology development is also hard at work to develop next generation processes that rely on non-food biomass (wastes, residues, high yielding woody or grass energy crops or algae) that do not have an impact on land use or decrease the pressure on land use from biofuel production. These routes will have significantly lower GHG emissions than fossil fuels.

5. What is holding back 2nd generation biofuels from becoming commercial?

2nd generation technologies are not yet mature. Further developments are needed in order to reduce their production cost and demonstrate their reliability at substantial scale. Further investments are thus needed which will rely on the recognition of the relative merits of 2nd generation biofuels in terms of GHG reduction potential and, where appropriate, their ability to mitigate some of the impacts, e.g. on food markets, associated with 1st generation feedstocks.

6. What are the main priorities for further development and improvement of the conversion technologies, and how would these assist deployment?

Further development of bioenergy technologies is needed mainly to improve the efficiency, reliability, and sustainability of current bioenergy chains. The priorities for further development, however, depend on the sector. In the heat sector, improvement is needed to achieve cleaner more reliable systems linked to quality fuel supply. In the electricity sector, the development of smaller and more cost-effective electricity or CHP systems could better match resource availability. In the transport fuel sector, biofuels of improved quality and sustainability are needed.

CHAPTER 4: BIOMASS TRADE AND BIOENERGY MARKETS

Key questions addressed in this Chapter:

1. What is the market status and prospects for bioenergy in different market segments?
2. What are the main biomass feedstocks and products traded?
3. What are the current and potential trade volumes?
4. Does long distance transport of biomass use more energy than that embodied in the biomass itself?
5. Which commodity markets are going to be affected by an increasing use of bioenergy?
6. What is the impact of biofuels on the recent increase in food commodity prices?
7. What measures can be taken to minimise the impacts of bioenergy development on commodity markets?
8. What is hindering market penetration of bioenergy?

4.1 Bioenergy Markets and Opportunities

Today, biomass provides about 10% (~50 EJ) of the world's primary energy supplies (IEA 2008b). This share varies widely, however, between developing and industrialised regions. While bioenergy covers an average 22% of the primary energy consumption in developing countries, and can reach over 90% in rural countries such as Nepal (IEA 2008e), the total contribution of biomass to the primary energy mix is on average only about 3.4% in the OECD, although many of these economies have set targets to significantly increase this share.

Of the 50 EJ of bioenergy supplied worldwide, close to 90% is of woody origin, with fuelwood by far the largest contributor (Figure 4-1). Agriculture contributes 10% to the bioenergy mix, of which 30% is in the form of dedicated energy crops and the rest as by-products (dung, straw, bagasse, etc.). This means that dedicated energy crops currently only contribute 0.27% of the world energy mix. Municipal solid wastes and landfill gas currently contribute 3% of the bioenergy mix, but have a large untapped potential.

The IEA has established two scenarios for the future of the global primary energy consumption, which are based on different assumptions regarding the level of government intervention to 2030. While the reference scenario assumes that no new government policies are introduced during the projection period, the alternative scenario includes a set of policy measures addressing climate change and energy security issues (IEA 2006). In both these scenarios, the volume of bioenergy is expected to grow at an average rate

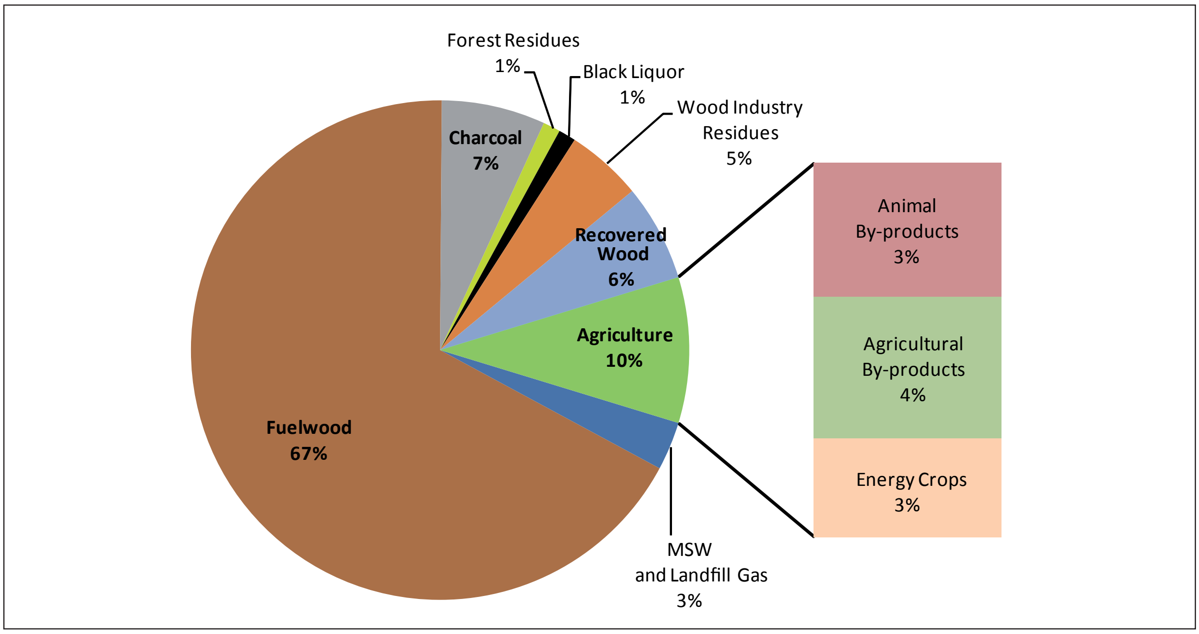
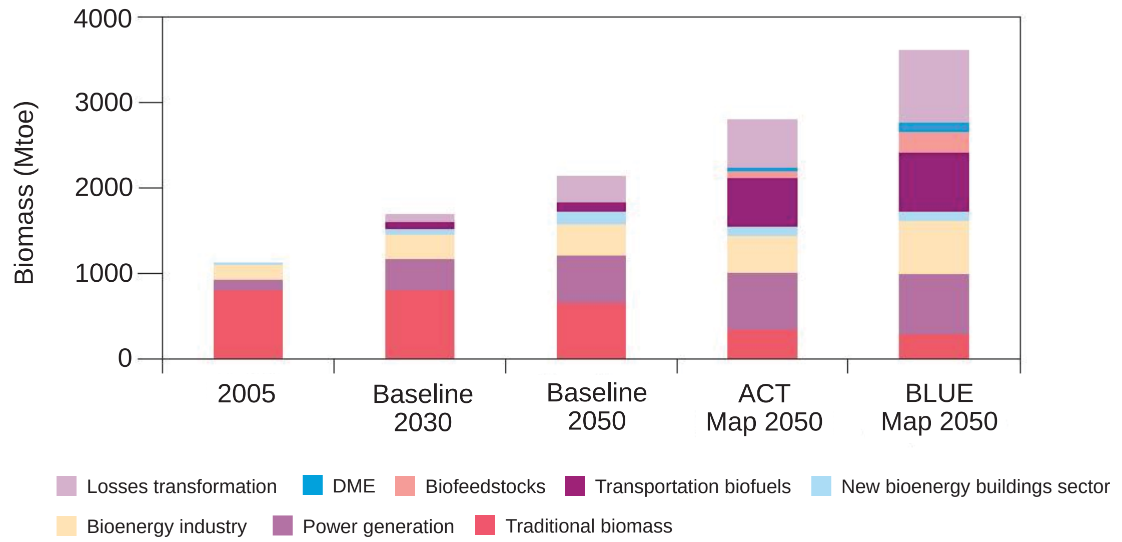


Figure 4-1. Share of the biomass sources in the primary bioenergy mix. Source: based on data from IPCC (2007).



Note: Transformation losses in the production of liquid biofuels from solid biomass are indicated and accounted for in the energy balances

Figure 4-2: Biomass end-use in 2030 and 2050 under various scenarios. Source: IEA (2008c).

of 1.3-1.4% per annum to 2030. Out to 2050, the volume of biomass used for energy purposes is projected to reach between 90 and 150 EJ (2100-3600 Mtoe) depending on the scenario considered (Figure 4-2), and could thus contribute up to 23% to the total world primary energy supply (IEA 2008b). The future share of bioenergy in the global energy mix, as well as the market share of the different bioenergy technologies within this mix, will depend on a number of context-dependent driving forces. These aspects are discussed in the following sections, while Annex 4.1 provides details of the current biomass flow into final energy applications.

4.1.1 Biomass-to-heat

Status. In spite of the versatile end-use potential of biomass, heat is by far the largest market segment for bioenergy. Of the 50 EJ of biomass supplied to the global primary energy mix in 2006 (IEA 2008b), an estimated 39 EJ (i.e. 87%) is burnt in traditional stoves for domestic heating and cooking primarily in developing countries (IEA 2008e). In 2005, an estimated 570 million wood or charcoal cooking stoves were in use worldwide, as well as some 21 million household-scale biogas digesters for cooking and lighting, mostly in China and India (REN 21 2006). In the developing world, hand-picked fuelwood is a free source of energy in rural areas, which makes it the cheapest option, irrespective of the poor efficiency of traditional stoves.

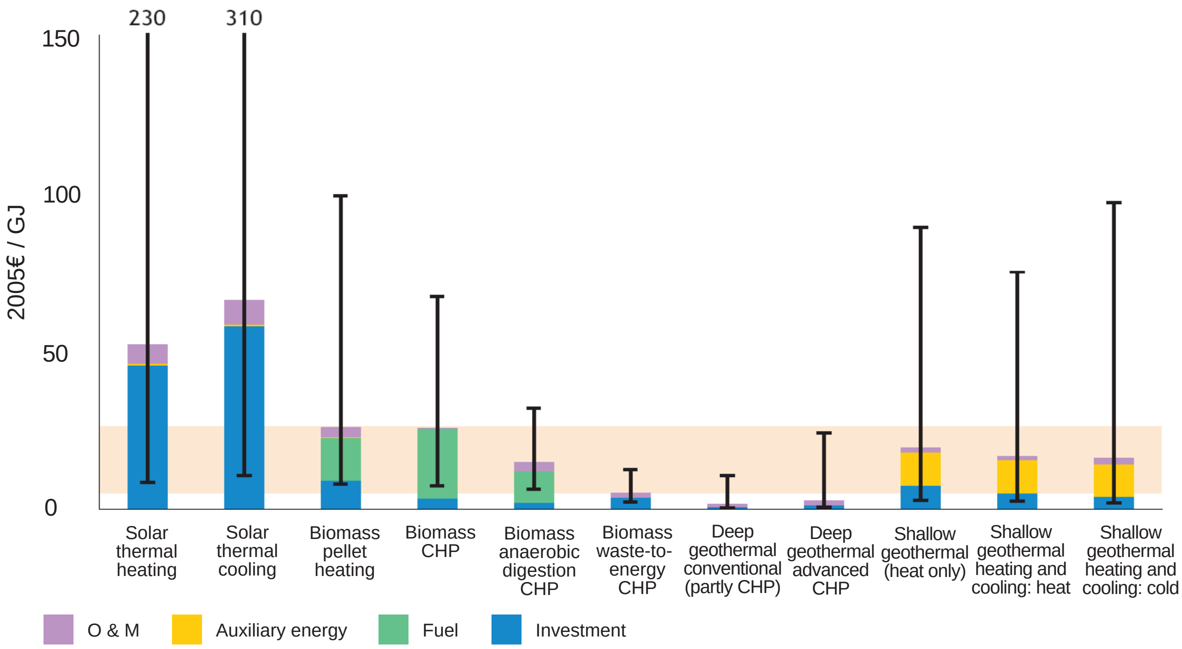
In industrialised countries, modern solid biomass technologies are in many cases cost competitive with conventional fossil-based options, in particular in the building sector (see Figure 4-3). For decades heating with wood has been considered as a poor, dirty, and inconvenient technology in industrialised countries. However, the advent of user friendly, efficient, and clean pellet boilers is now contributing to the increased acceptance and popularity of biomass-based heating in households.

In developed countries, biomass heating faces strong competition with natural gas and coal, which are convenient and widely available options. Biomass heating is particularly well developed in countries with good resource availability and where district heating systems are already in place e.g. Northern Europe. Sweden is the leader with biomass contributing close to 50% of its large-scale heat production, followed by Austria (24%), Finland (17%), Denmark (14%) and Norway (10%). On average 5% of large-scale heat is provided by biomass in the USA and 7% in the IEA member countries (IEA 2007b).

Prospects. In a 'business as usual' scenario, the demand for traditional biomass will grow from 34 EJ today to 36 EJ in 2030 due to population growth, with over 2.7 billion people relying on traditional cooking. This increase could however be largely offset by an increase in energy efficiency resulting from the introduction of efficient, modern stoves. Traditional biomass consumption could be globally reduced by up to 70% by 2050 in the event of fast market penetration of modern stoves and a large shift from traditional biomass to, for example, LPG (see Figure 4-2). Such a shift would further contribute to reducing the health issues related to toxic emissions from traditional stoves and alleviate unsustainable biomass harvesting, while generating a potential US$1.5 billion per year retrofit market for modern stoves to 2015 (IEA 2006).

In OECD countries the volume of biomass for residential heat is expected to grow by 40-90% to reach 3.2-4.3 EJ in 2030 (IEA 2006), mostly due to the growing market for modern boilers and stoves.

The global use of biomass and waste in the industrial sector is expected to increase slowly, in line with increased energy demand, by between 1.9% and 2.2% annually to reach close to 13 EJ by 2030. However, while this increase will be in



Notes: The conventional energy carrier costs are only based on fuel costs and conversion losses because investment and depreciation costs of appliances per GJ of heat are relatively small. Neither reference system nor avoided costs due to fuel savings are incorporated. Installation costs are included but heat distribution costs and costs allocated to electricity generation for CHP technologies are not.

Figure 4-3: Cost breakdown and ranges (excluding VAT) in 2005 for a selection of renewable heating and cooling technologies compared with the reference energy price range (shaded horizontal bar) for gas, fuel oil and electricity heat energy carriers for the domestic (top of range bar) and industrial (bottom) sectors. Source: IEA (2007b).

both developed and developing countries, an annual drop of 0.6-1% over this period is expected in transition economies (IEA 2006).

4.1.2 Biomass-to-power and CHP

Status. In 2006 biomass-based power and heat plants consumed a feedstock volume equivalent to 3.5 EJ, which represents a mere 7% of the global biomass used for energy purposes (IEA 2008b). Consumption in the OECD countries accounted for 82% of this volume, with Europe and North America leading with close to 1.3 EJ each.

Worldwide, the installed capacity for biomass-based power generation was about 45 GW in 2006 (IEA 2008b), with an estimated electricity production of some 239 TWh (roughly the annual total power consumption of Spain). This power production occurs mostly in:

- co-firing plants for those countries with coal plants;
- combustion-based CHP plants for countries that possess district heating systems (Nordic countries in Europe), large pulp and paper or food industries (e.g. Brazil, USA);
- MSW incineration plants, although a large potential is still untapped;
- stand-alone power plants where large amounts of residues are available (e.g. sugar-cane bagasse in Brazil); and
- anaerobic digestion units (e.g. in Germany) and landfill gas units (e.g. in the UK), as a result of increasingly strict environmental regulations on waste disposal and landfills at EU level.

In the EU, 55 TWh of electricity from biomass were produced in 2004 (roughly the annual consumption of Switzerland), mostly from wood residues and MSW. Finland is leading the way with 12% of its power consumption produced from biomass and wastes. In the United States some 85% of total wood process wastes (excluding forest residues) are used for power generation.

A proliferation of smaller-scale biomass-to-power or CHP projects throughout developed countries and emerging economies have been recorded in recent years. China, Brazil, Latin America, Thailand, and India are turning increasingly to biomass power plants alongside other renewable resources (IEA 2007a).

Biomass-based cogeneration of heat and power accounted for some US$5.2 billion global asset financing in 2008, which is about 9% of the $60 billion invested in renewable energy capacity worldwide in 2007 (NEF 2008). However, whilst the global renewable energy sector increased by 45% in 2006, biomass-to-power has seen the slowest growth with a mere 5.5% recorded. This can be explained by the increasing scarcity of cheap and easily accessible biomass feedstock, as well as by the poor economics of biomass-to-power plants at small-scale (this encourages large-scale projects, but these are slower to develop).

Prospects. According to most energy scenarios (IEA 2006), global electricity production from biomass is projected to increase from its current 1.3% share (231 TWh/year) to 2.4-3.3% by 2030 (~800-1000 TWh/year), corresponding to a 5-6% average annual growth rate. In absolute terms, the net increase would thus be about four times the current production, with a significant contribution to CO_2 emissions reduction. In spite of this rapid growth, this still represents a relatively small contribution from biomass compared with its technical potential. The main opportunities in the short to medium term are as follows:

- Co-firing remains a promising cost-efficient option for producing power from biomass, particularly due to the flexibility it offers to the power producers who can select the cheapest fuel on a day-to-day basis.
- It is estimated that the biogas production from farm-size and larger-scale biogas-to-power units will grow 55% in the EU by 2010 (EurObserv'ER 2007, 2008a). A boom in biogas is also expected in the USA, China, and India. MSW could potentially be a significant feedstock for biogas, but its use depends on linking energy and waste policies. Currently, there is limited industry interest in most regions in energy or fuel production.
- The economic case for stand-alone combustion-based biomass plants is more strongly dependent on local policy and regulatory conditions, but can offer interesting opportunities where biomass feedstock is available at an affordable cost.

In the medium term, the commercialisation of small-scale gasification could be of significant importance in the deployment of decentralised biomass power and CHP systems. However, it is currently unclear as to when this technology will become commercial. Similarly, the commercialisation of Stirling and ORC Engines could also enhance the prospects of small-scale biomass power and CHP generation, although the prime movers in these emerging technologies are not expected to focus on biomass-fuelled systems.

In the longer term, biomass integrated gasification gas turbines (BIG/GT) and combined cycles (BIG/CC) are promising technologies that could offer greater prospects for relatively large-scale power generation from dedicated biomass plants, thanks to their high overall efficiency. Again, the deployment horizons for these gasification-based technologies are difficult to predict, as significant cost reduction, as well as improvement of efficiency and reliability at larger scale are still required.

Long-distance transportation reduces the economic and environmental attractiveness of biomass, which has resulted in greater interest in energy densification techniques. While pelletisation is the only densification technique commercially available, it might lose market share to torrefaction and pyrolysis, which offer comparable advantages (see Section 3.3), in particular for large-scale power generation. Remote forestry companies (e.g. in Siberia) are envisaging torrefaction as potentially the most cost-effective way of transporting their fuelwood to very distant sale points in the near term (PC 2008). The advent of pyrolysis will depend on its ability to solve remaining technical and economic challenges, and sound market projections are thus not yet available for this technology.

4.1.3 Biomass-to-biofuels

Status. Biofuels are a fast growing bioenergy sector. Although Brazil has been producing bioethanol from sugar-cane since the late 1970s, it is only in the last decade that biofuel production has acquired global production significance.

However, biofuels today represent only about 1.5% of the total road transport fuel consumption (IEA 2008b), and only account for some 2% in the final bioenergy mix (in energy terms) (IPCC 2007). Nearly 80% of the global supply of biofuels is bioethanol from Brazil (from sugar-cane) and the USA (from corn/maize), where plants with capacities up to

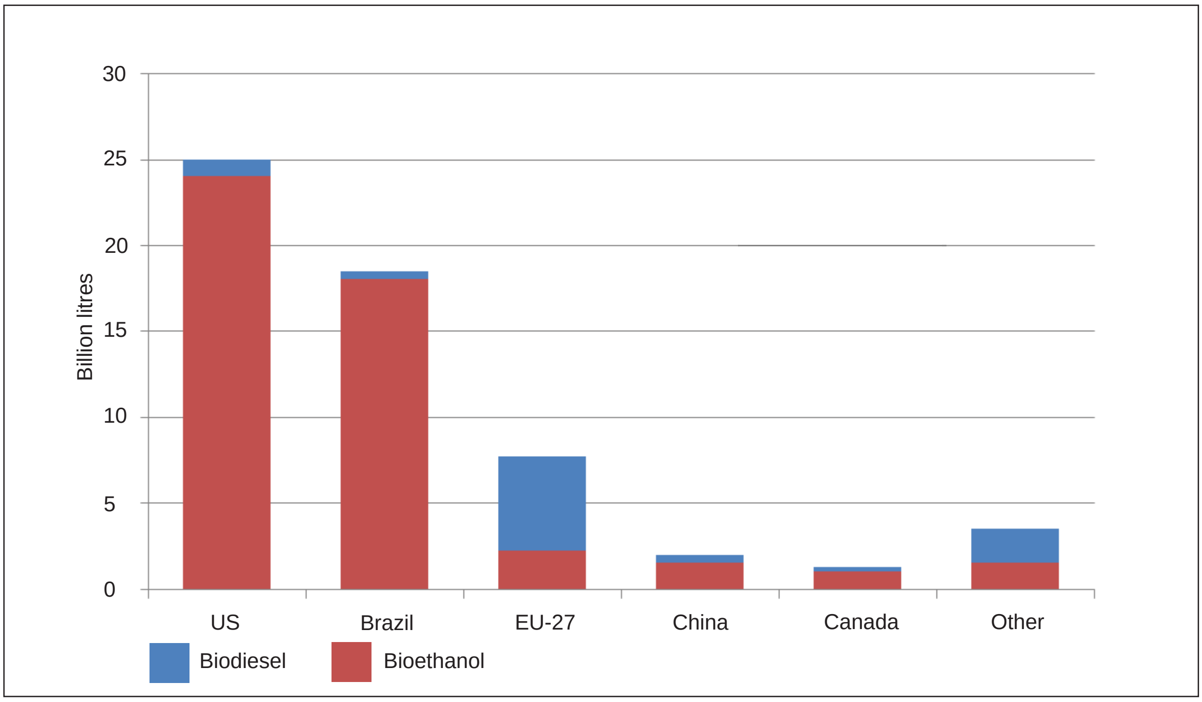


Figure 4-4: Major biofuel producers in 2007 (in billion litres). Source: Estimates based on Lichts (2007) and national sources.

more than 500 million litres per year are found (NNFCC 2007). China and India also produce significant quantities, mostly of ethanol (Figure 4-4). Bioethanol production has grown significantly, almost doubling in the period 2000 to 2005.

Global biodiesel production has also grown significantly, almost tripling between 2000 and 2005 (IEA 2006). Most production is based in Europe (Figure 4-4), with companies in Germany and Austria having established themselves as leading technology providers.

Bioethanol is used as a gasoline substitute, and is generally blended with gasoline to different extents depending on fuel and vehicle specifications. In Brazil alone, neat ethanol is sold for use in vehicles, in addition to gasoline and ethanol blends. In the USA, strong growth in ethanol output can largely be attributed to tax incentives and rising demand for ethanol as a gasoline-blending component (IEA 2006). In Brazil, demand for ethanol dropped due to falling oil prices in the 1980s, but it has recently experienced a resurgence as a result of falling production costs, higher oil prices and the introduction of flex-fuel vehicles that allow switching between ethanol and conventional gasoline.

Biodiesel is used as a diesel substitute, and is generally blended up to 5% with diesel, mainly as a result of limitations imposed by fuel and vehicle specifications. Higher biodiesel fuel blends are only used in the case of fleet vehicles (e.g. trucks and buses). The bulk of biofuel produced in the EU is biodiesel, which accounts for 87% of the global biodiesel supply (with Germany and France the largest European producers), as a result of past support for domestic biofuel production. However, total global production of biodiesel remains small compared with that of ethanol, amounting to approximately 4.1 Mtoe in 2006 (IEA 2008b).

Prospects. Demand for road transport fuels is expected to continue to increase significantly in the coming decades, especially in developing countries. Biofuels are expected to play an increasing role in meeting this demand, with a projected average production growth rate of 6-8% per year, reaching a 5% share of road transport fuel in 2030 (IEA 2008b). This implies a cumulative investment in biorefineries of between $160bn and $225bn in order to meet demand in the period 2005-2030 (IEA 2006).The biggest increase in biofuels consumption is expected to take place in the United States, in Europe, in China and in Brazil (IEA 2008b).

Energy security and climate change policy are the main drivers for the expansion of biofuel use. Agricultural policy has also been – and continues to be – an important driver. Oil and other commodity prices also have a strong influence on biofuels markets. Oil price increases make 1st generation biofuels increasingly cost competitive, although this effect may be counterbalanced by increases in agricultural commodity prices. Additionally, the prospects for biofuels depend on developments in competing low-carbon and oil-reducing technologies for transport, such as vehicle efficiency improvement and electric vehicles in the medium term and fuel cell vehicles in the longer term. In the longer run, a remaining market for biofuels will be aviation and heavy duty transport, as the alternatives mentioned have little prospects in these segments (IEA 2008a).

The growth of the biofuels industry will depend very much on its environmental and social sustainability. Recently, both the direct and indirect environmental and social effects of biofuels have come under increasing scrutiny (RFA 2008). Sustained government support is likely to depend very much upon understanding and mitigating any undesired impacts, such as emissions from indirect land use change or impacts on food prices.

While 2nd generation biofuels based on lignocellulosic feedstocks promise access to a greater resource and greater GHG reduction potential than current ethanol and biodiesel production from sugar, starch and oil crops, these routes are still a decade or two away from contributing a significant proportion of the world's liquid fuels (IEA 2008d). New biofuel technologies could also allow biofuels to penetrate other transport fuel markets such as aviation fuel (e.g. production of kerosene from Fischer-Tropsch routes).

Biogas upgrading to biomethane is undergoing a dramatic development, as a result of the worldwide exponential increase of natural gas vehicles (NGV). There were nine million units in 2007 compared with four million in 2004. Although somewhat optimistic, forecasts for NGV fleets in 2030 range between 100 and 200 million vehicles (IANGV 2008). The EU target for renewable energy used in road transport is 10% by 2020, a significant share of which could come from biomethane. Sweden, with a fleet of 15,000 natural gas vehicles has already reached a share of 55% biomethane in natural gas for transport, and Switzerland has reached ~35 %. Germany and Austria are both aiming for 20% by 2020 (IANGV 2008).

4.2 Trade in Biomass Energy Carriers

International bioenergy trade has developed rapidly over the past decade. Domestic biomass resources that are readily available in industrialised countries are often already exploited and the mobilisation of additional domestic resources often faces barriers such as lack of sufficient supply infrastructures or high production costs. In this context, bioenergy imports often represent a cost-effective alternative to diversify the energy mix, reduce CO_2 emissions and/or meet specific bioenergy or general renewable energy targets.

Many developing countries have a large technical potential for agricultural and forest residues and dedicated biomass production. Given the lower costs for land and labour in these countries, biomass production costs are often much lower than in industrialised countries, but the domestic demand is commonly not sufficient to realise the potentials. For these countries, bioenergy exports offer an opportunity for income generation and employment creation. In this regard, the development of international markets for biomass may become an essential component towards the realisation of these potentials. The main current commodities traded and trade routes are presented below.

4.2.1 Main commodities traded and trading routes

Wood pellets are among the most successfully traded biomass commodities, due to the techno-economic advantages they offer compared to other solid biomass fuels (see Section 3.3.1). These attractive properties have caused the demand for wood pellets to soar over the last years. A rough estimate indicates that between 2004 and 2006, traded wood pellet volumes have increased by about 50%. Most wood pellet production (and consumption) is currently taking place in Europe. It is estimated that in 2006 between 6-7 million tonnes of wood pellets were produced globally, with 3-4 million in Europe and two million in Canada and the USA. Estimating the size of global pellet trade is challenging, as there are currently no official statistics available for this immature and fast developing market. Intra-European trade (including refined wood fuels and briquettes) amounted to about 30 PJ in 2004 (approximately 1.7 million tonnes) and the major flows are from east to west, i.e. from Finland, the Baltic countries and eastern European countries to the rest of Scandinavia, the UK and the Benelux (Ryckmans et al., 2006). About 35% of all wood pellets produced in Europe are traded across a border. Turning to inter-continental trade, Canada is the largest pellet exporter followed by the USA (see Figure 4-5).

Further trade developments will depend on both government support measures (e.g. feed-in tariffs for co-firing wood pellets or pellet stove investment subsidies) and fossil fuel prices. Expectations are that demand for wood pellets will increase most strongly in Western Europe in the coming decades. Global production is estimated to reach 12 million tonnes by 2012, of which at least one third may be traded internationally.

Bioethanol is a commodity which has been produced and traded globally in large volumes for decades. The bioethanol market is well-developed, as is its infrastructure and logistics in many countries. The USA and Brazil are the world's largest bioethanol producers and consumers, covering almost 90% of the 40 million m³ produced globally in 2006. Estimates[13] indicate that bioethanol trade has steadily grown from about 3 million m³ in 2000 to 6 million m³ in 2005. Presuming that the rise in recent years was mostly due to increasing fuel ethanol trade, about 10% of the fuel ethanol consumed in 2005 was imported. The world's largest exporter by far is Brazil (48% of the total traded volume in 2005), followed by the USA (6%) and France (6%). As indicated in Figure 4-5, Brazil's major export markets for fuel ethanol are the USA, Japan and the EU.

Based on forecasts for gasoline consumption, it is estimated that ethanol demand would reach 272 million m³ by 2030 (from 33 million m³ in 2005) if targets/mandates for fuel ethanol use around the world are maintained and reached. This volume corresponds to about 10% of the estimated global demand for gasoline in 2030 (against less than 1% today). An estimated 24-46 million m³ could potentially be traded internationally in 2030 (Walter et al., 2007). Brazil alone could supply this volume, but other (mostly developing) countries have the potential to also become large-scale producers and exporters.

Other internationally traded biomass products include:
Wood chips, which are mainly traded as raw material for wood pulp production, with lower quality fractions utilised for energy applications despite their low bulk density and usually high moisture content.

Waste wood, which is mainly traded within Europe, e.g. between the Netherlands, Germany, and Sweden. This trade is driven by the introduction of a landfill ban on combustible materials in a number of EU countries, as well as by varying subsidies and combustion capacities across Europe.

Round wood, which indirectly contributes to bioenergy trade. For example, a significant share of Finnish bioenergy is based

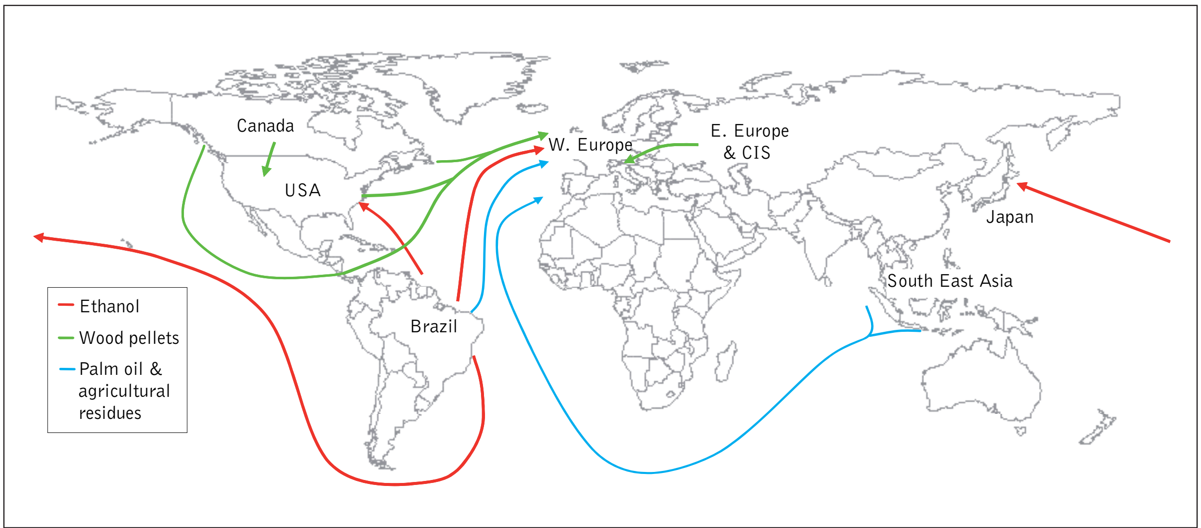


Figure 4-5. Main international biomass for energy trade routes. Intra-European trade is not displayed for clarity (Junginger and Faaij 2008).

[13] Data on traded ethanol volumes destined as transportation fuel are imprecise due to various potential uses of ethanol (fuel, industrial or for beverage use) and also because of the lack of proper codes for biofuels in the Harmonized System Commodity Description and Coding System.

on imported round wood. A fraction of the roundwood ends up in energy production (e.g. utilisation of saw dust or black liquor).

Various agricultural residues, including, for example, palm kernel expeller and shells (residues from palm oil production) exported to, amongst others, the UK, the Netherlands, and Italy. Many other residues are reported to be traded internationally, mainly for co-firing in coal power plants, such as rice and wheat husks, olive press cakes and cocoa and peanut shells.

Palm oil, soy bean oil and other vegetable oils, oil seeds and biodiesel, are increasingly traded on a global scale in response to increasing demand for biodiesel in the EU and many other world regions. These commodities are already traded on a large-scale for food and feed purposes. As liquid biofuel producers are generally reluctant to reveal the origin of their feedstock sources, estimates of traded volumes for energy purposes are uncertain. In 2004, an estimated 1 million tonnes (out of 23 million tonnes traded) of these commodities were used for energy purposes (Heinimö and Junginger 2009). There are indications that this volume has been increasing rapidly. Main producers and exporters of vegetable oils (and increasingly of biodiesel) are Malaysia and Indonesia for palm oil and Argentina for soy bean oil (see Figure 4-5).

4.2.2 Current and future trade volumes

Currently the global level of bioenergy trading is small compared to either trade in agriculture and forestry commodities (Heinimö and Junginger 2009) or to the global bioenergy use of approximately 50 EJ (see Table 4-1). In 2004 most trade in bioenergy was associated with indirect trade (e.g. roundwood of which elements such as bark, saw dust, and black liquor are later used for energy). However, the traded volumes of commodities such as wood pellets, bioethanol, and biodiesel for energy use are increasing rapidly. While reliable statistics are not available, it is estimated that since 2006, directly traded volumes are larger than those traded indirectly – on an energy basis

Table 4-1. An estimate of the scope of international trade of biomass and biofuels in 2006 (tall oil, ETBE and various waste streams excluded). Source: adapted from Heinimö and Junginger (2009).

	PJ	Million tonnes
Ethanol	160	6
Biodiesel	>90	>2.4
Fuelwood	40	3
Charcoal	20	0.9
Wood pellets	45	2.6
Palm oil	>60	>1.6
Direct trade	>380	>16.7
Industrial round wood	480	50
Wood chips and particles	150	16
Indirect trade	630	66
Total	>1000	>83

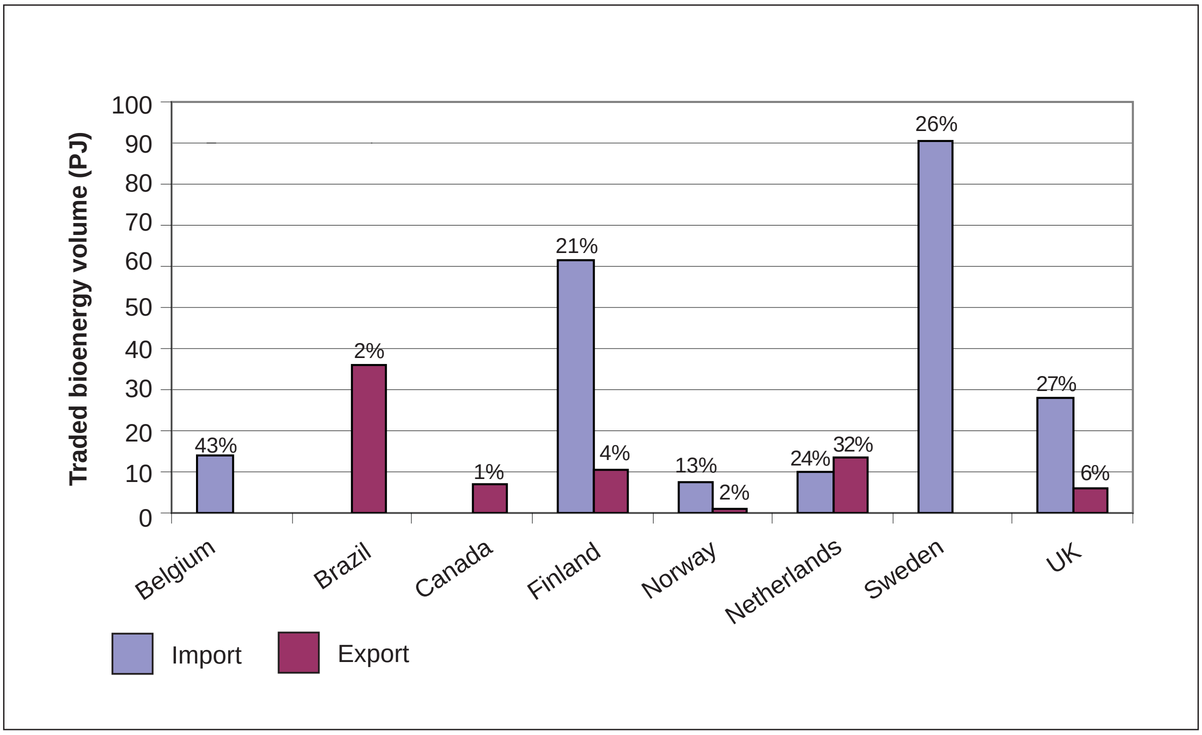


Figure 4-6. Overview of bioenergy imports/exports in IEA Bioenergy Task 40 member countries in 2004 (figures for Belgium and the UK refer to 2005). Percentages indicate the share of the traded volumes as part of the domestic primary biomass supply. Numbers should be considered as rough estimates. Source: Junginger et al., (2008).

(Heinimö and Junginger 2009). Biomass imports already contribute substantially to the overall biomass use in developed countries, e.g. 21-43% in North-West Europe and Scandinavia (see Figure 4-6). In the longer term, significant amounts (up to over 100 EJ) of biomass commodities might be traded internationally, with Latin America and Sub-Saharan Africa having the potential to become large net exporters and North America, Europe and South-East Asia large net importers (Hansson et al., 2006; Junginger et al., 2008; see also Chapter 2).

4.3 Bioenergy and Commodity Markets

4.3.1 Introduction

Developments in the bioenergy sector increasingly impact on the markets of several basic commodities. Every application of bioenergy represents a new demand for feedstock from the forestry and agricultural sectors. Effectively, the bioenergy sector now competes with other industries that use the same raw biomass materials. As a consequence, markets for transport fuels, agricultural commodities, and their intermediate and by-products become increasingly interdependent.

4.3.2 Bioenergy and agroforestry – relationships between competing sectors

Relationship between bioenergy and forestry-based sectors. Wood has many applications, both as the primary product of the forestry sector (logs) and as a residue from the wood processing industry (wood chips and sawdust). The forestry and wood processing sectors make a complex and intertwined system of industries and activities, in which a large number of wood types of different qualities are processed and used in a large variety of applications, including energy.

Furthermore, large volumes of wood are used virtually at the point of origin, which makes it hard to make any inventory of material flows and relative shares of the different applications. According to UNECE/FAO, there is a lack of data regarding volumes of wood resources mobilised both on the supply side[14] and on the consumption side[15], which makes any estimate of the flows of wood residues to different applications uncertain. Estimating trade flows of wood pellets used for co-firing proves particularly difficult, partly because of the lack of a clear definition of 'trade'.

In the EU, current use for sawn timber, pulp and paper, wood-based panels and other products accounts for about 58% of the total wood use (820 million m^3), while energy use accounts for the remaining 42% (mainly for heat production in private households and heat and/or power production in industries) (Mantau et al., 2007). This relatively balanced use of wood between industry and energy applications can be considered representative for most developed countries. In the developing world, most of the biomass used for energy is collected by hand and consumed directly by households for cooking and heating. There is limited and mostly informal trading, therefore structured consumption data are hardly available.

Assessments of the future use of wood predict a more rapid increase in use for energy than for materials applications. The level of demand from the energy sector will depend on three factors: bioenergy targets, the level of support the sector receives from governments, and the competitiveness of bioenergy options with other renewables. On the basis of the above data, by 2020 the combined shortfall of wood supply in Europe could reach 300 million m^3 (Mantau et al., 2007). The projected increase in the occurrence of extreme events caused by climate change, such as wildfire, major insect epidemics, and storm damage is expected to further increase this wood deficit.

Moreover, the forestry sector cannot respond to an increase in demand as rapidly as the agricultural sector, simply because forest trees have an average lifetime of several decades. Unless more wood resources in Europe are mobilised, the predicted deficit in wood supply will have to be compensated for by imports or shared by all industries. This will most likely result in higher wood prices and reduced growth rates for all the sectors that depend on wood as their main raw material.

In some countries (e.g. Sweden) the effect of the additional demand from the bioenergy sector has already become so strong that the paper and board industries are receiving subsidies from the government to enable them to compete with industries from countries that do not face such competition for feedstock. Elsewhere, the biomass-based heat and power generation sector is heavily dependent on government support to ensure sufficient purchasing power to secure the necessary feedstock volumes. Furthermore, potential suppliers of wood tend to lack appropriate market information on the developments in supply and demand, which makes it very difficult to achieve a new market balance because an increase in demand does not always lead to an increase in supply (Ericson et al., 2008).

Relationship between liquid biofuel for transport and agriculture-based sectors. In the case of liquid biofuels for transport and other industries that use the same agricultural raw material, the relationship is even more complex than the example of wood. Firstly, different agricultural crops respond to price movements on a year-to-year basis via farmers' decisions as to which crops to cultivate. Secondly, many crops can substitute for another in their applications, e.g. oilseeds (soy, oil palm, rapeseed) and cereals (wheat, barley, corn, rice). It must be noted that there are wide differences between biofuels with respect to their impacts on consumption of agricultural crops. These are summarised in Table 4-2.

Furthermore, an increase in production of liquid biofuels also results in an increased production of co-products and residues that are used as inputs to other sectors. The example of rapeseed-based biodiesel is typical. In 2005, the non-food use of rapeseed oil overtook its food use for the first time. This increased use of rapeseed oil for biodiesel production resulted in the increased availability of rapeseed cake, which is used as an animal feed. This resulted in an estimated drop of up to 40% of the price of rapeseed cake (EC 2007). Other sectors

[14] In particular on woody biomass outside the forest, post consumer recovered wood and logging residues.

[15] Especially on wood use for energy and on conversion factors calculating wood raw material equivalent from units of products.

Table 4-2. Feedstock consumption levels for different types of biofuels

Biofuel	From feedstock	Region	Current feedstock consumption level for biofuels as a share of total feedstock production
Bioethanol	Cereals	EU	1.4%
Bioethanol	Cereals (maize)	USA	20%
Bioethanol	Cereals	World	4.5%
Bioethanol	Sugar-cane	Brazil	50%
Biodiesel	Rapeseed	EU	60%
Biodiesel	Oilseeds	World	5%

that feel the effect of the developing biodiesel industry are:
- the food industry facing higher prices of rapeseed oil;
- the producers of vegetable oils (who are the main beneficiaries of increased prices for their product);
- glycerine producers facing lower prices for their product (glycerine is the main by-product of biodiesel production and large volumes have thus become available on the market); and
- the cosmetics and pharmaceutical industries, that are benefiting from availability of cheap glycerine.

A similar situation occurs when bioethanol is produced from cereals: this application is directly competing with grain for human and animal consumption, but at the same time increases availability of DDGS (distillers dried grains with solubles) which is used as animal feed. Such feedback loops can dampen the impact on cereal prices (Ericson et al., 2008).

4.3.3 Price impact estimates

Price impact on raw material (feedstock). Agricultural prices have always been impacted by energy prices. However, this impact has so far been limited to effects on agricultural inputs (e.g. fertiliser, pesticides and diesel). With rapidly rising energy prices and the increasing role of bioenergy, energy prices are also now directly affecting agricultural output prices (Schmidhuber 2006).

Price changes for woody biomass are very difficult to estimate because they are not traded on established trading platforms. Even markets for wood pellets (the most commonly used wood type by the stationary sector) are currently largely bilateral and highly volatile. With increasing oil prices, pellet prices are expected to increase, although no meaningful statistics are currently available regarding pellet production, trade, consumption and quality (Junginger et al., 2008).

There is a far more robust basis for quantitative assessment of the impacts of liquid biofuels for transport on agricultural commodities, as both are traded on established platforms and allow for gathering of consistent and reliable price data. However, very few comprehensive studies have focused on the immediate price impact of biofuels on agricultural commodities (FAO 2008). Most of the model-based studies are forward-looking and estimate a situation where biofuels develop to reach the different targets set by countries and world regions. Table 4-3 summarises the results of these studies and the reasons for their limited comparability.

Key conclusions that can be drawn from these studies are:
- The studies reviewed strongly disagree on the scale of impact that biofuels have had or will have on the price of agricultural commodities.
  - The IMF stated that biofuels 'at least in part' account for the food price increases in 2007 and 2008 (Johnson 2007)[16], while the World Bank believes this share to be around 70% for the period between 2003 and 2008 (World Bank 2008).
  - Most estimates based on agro-economic models predict that future price impacts will be in the order of a few percent to some tens of percent at the most in the years 2015 or 2020, when much higher production volumes of biofuels are assumed[17]. Extrapolated to the current situation, these results imply that the impact on commodity prices of the current production level of biofuels (2.6% of transport fuel based on energy content in the EU in 2007 according to EurObserv'ER (2008b)) would therefore be even smaller.
  - Studies that compare future scenarios with and without biofuels (Banse et al., 2008a and Schmidhuber 2006) estimate that, rather than increasing agricultural commodity prices, biofuels would only slow the trend of declining real agricultural prices in the long-term. Furthermore, these models do not consider in detail the biofuels-induced reductions in prices of co-products (e.g. glycerine), which would also have to be taken into account to estimate the net price effects on agricultural commodities.

- The impact of biofuels on the price of agricultural commodities is likely to grow as more countries adopt specific biofuels targets. National biofuel policies must therefore always take into consideration the global context and outlook for biofuels deployment when formulating their own targets.

- Finally, some of the studies point to spill-over effects into markets for agricultural commodities that are not directly consumed by the biofuel industry (or in negligible quantities only)[18]. This can happen for two reasons:
  - increased use of substitute crops by other sectors (e.g.

[16] In a BBC radio interview on April 14, 2008, Johnson suggested biofuels causing 20-30% of the price increase (Open Europe 2008).
[17] The latter are for cases where no or low productivity increases are expected and no 2nd generation biofuels are taken into account.
[18] Those impacts are estimated with the cross price effect.

Table 4-3. Summary of studies estimating price impacts of biofuels deployment on agricultural commodities.

Source	Geographical scope of target	Biofuel share (%)	Impact on global price of feedstock production		Cross-commodity price impact[19]	Comments
			Bioethanol	Biodiesel		
Banse et al., (2008a)	World	Various country targets for 2020	+18% cereals +10% sugar *Relative to no biofuels*	+20% oilseeds *Relative to no biofuels*		General equilibrium model; no 2nd gen assumed.
Schmidhuber (2005)	World	10 mio ton feedstock used for ethanol)	+2.8% maize +9.8% sugar *Relative to no biofuels*		+1.1% sugar, +0.2% veg oils, +0.9% wheat, +1.2% rice	Unspecified model; price changes expressed for every addition 10 mio tons of feedstock used for biofuel production. No 2nd gen assumed.
IFPRI (Rosegrant 2008)	World	2007 levels	30% price increase for grains between 2001-2007 *Relative to no biofuels*			Partial equilibrium model; no 2nd gen.
EC (2007)	EU	10% by 2020	+ 3-6% cereal *Relative to 2006 prices*	+ 8-10% rapeseed + 15% sunfl. seed *Rel. to 2006 prices*		Dynamic model; assuming 30% 2nd gen, and 20% imports.
Banse et al (2008b)	EU	10% by 2020	+6% cereals +2% sugar *Relative to no biofuels*	+9% oilseeds Relative to no biofuels		General equilibrium model; no 2nd gen assumed.
JRC (Edwards 2008)	EU	10% by 2020	+4% cereal	+24% veg oils		Unspec. model type; demand for food assumed in elastic, no 2nd gen. assumed.
Elobeid et al., (2006)	USA	20% by 2015	+58% maize *Relative to 2006 prices*		+ 5 soybean +20% soy oil +20% wheat	Partical equilibrium models, no 2nd gen. assumed. Price changes through demand elasticity.
Collins (2008)	USA	2008/09 levels	+40% maize *Relative to 2006/07 maize price level*			Price elasticity model; prices changes through demand elasticity.
OECD (2006)	USA, Brazil, Canada, EU	10% by 2014	+ 60% sugar + 4% cereals *Relative to no biofuels*	+2% oilseeds +20% veg oil *Rel. to no biofuels*		Partial equilibrium model; no 2nd gen. assumed. Static, no prod. increases, no int. trade, no marginal land.
IFPRI (Msangi et al., 2007)	China+USA +EU+India +Brazil	20% by 2020	+25-40% corn +40-65% sugar-cane +15-30% wheat *Relative to no biofuels*	+ 40-75% oilseeds *Relative. to no biofuels*		Partial equilibrium model; varying 2nd gen deployment; yield improvements account for.

19 Changes in the prices of agro-commodities affected by changes in prices of biofuels feedstocks.

the meat industry increasingly turns to using barley as animal feed when wheat becomes too costly); and
- competition for land: farmers will plant more of the most profitable crops, thus reducing the output of the existing ones – in a situation where they cannot expand the area of arable land.

Several studies also indicate other factors that will probably have a stronger impact on current food price dynamics than biofuels deployment:

- In the long-term, influential structural factors on the demand side of agricultural commodities include income and population growth, while on the supply side increase in agricultural yields and area of agricultural land are important (Banse et al., 2008a).

- In the short-term, sudden food price hikes are most often caused by weather effects, or a price hike in fossil energy, which is an important input in agricultural systems. These fundamental factors in the price volatility of agricultural commodities can then be exacerbated by more speculative responses, such as the entrance of hedge funds in agricultural commodity markets, and hoarding effects in a nervous market. Also, export taxes introduced by exporting countries to curb domestic inflation, lead to additional tightness in the global market.

Impact on retail food prices. The price impact on retail food products has to be approached from a different perspective to the impact on raw agricultural materials. To understand how an increase in the costs of inputs translates into price increases, it is important to look at the price structure of food commodities and its link to production costs.

In developed countries, the share of production costs in retail prices of food products has been steadily decreasing, while the shares of distribution, marketing, and margins have been increasing over time. In Western Europe, for example, production costs, on average, account for only 9% of the retail price of a loaf of bread, with cereal costs only contributing around 4% (EC 2007). Based on the estimates of the impact of biofuels on crop prices discussed above, even with significantly higher shares of biofuels on the market by 2020, the price of bread would increase by only a fraction of a percentage (if all else stays equal). Animal products are more affected by price increases since feed costs account for between 20% and 70% of total meat production costs, depending on the type of livestock, but on average only 25% of the retail price of meat.[20]

Estimates of the impact of biofuels on the consumer price index (CPI) in the USA range from 1% (USDA 2008 and Urbanchuk 2007[21]) to 9% (Lapp 2007). However, there have been cases of retailers disproportionately increasing food prices on account of increasing food production costs, especially where they hold large shares of the retail food market. Stimulating competition in the food retail sector can help curtail such practices.

In developing countries, where consumers tend to buy fewer processed products and food often accounts for more than 40% of total household consumption (UNDP 1997), higher food commodity prices are likely to increase hunger and chronic under nourishment among landless poor, potentially inducing political and social conflict. On the other hand, land-owning farmers may benefit from higher food prices. Thus the balance of distributional impacts is difficult to assess.

4.3.4 Policy implications

The complexity of the relationship between bioenergy and commodity markets means that both sectors are subject to influence from policies of various domains, not just energy, but also trade, agricultural, environmental, and competition policies. The possible role of governments in helping to limit pressure on commodity markets caused by bioenergy is discussed in the next section.

The role of government bioenergy support schemes. Because most of the demand for bioenergy is government-induced, the purchasing power of the sector relies heavily on the level of government support. This means that government policies on biofuels can have a direct effect on feedstock price.

The biofuels sector suffers most from high feedstock prices. In the case of food products, markets are often highly concentrated and the biofuel industry is thus mostly the price-taking sector, not the price-setter. Furthermore, the biofuels sector is particularly vulnerable to feedstock price increases, as feedstock costs represent 60% or more of total production costs of 1st generation biofuels (Deurwaarder et al., 2007). If prices of biofuels do not follow increases of feedstock price, the margins of producers get squeezed, capacity expansion is discouraged, and, subsequently, the impact on markets of agro-commodities is relaxed.

Impacts differ strongly between policies and countries. However, with governments switching to stronger policies (e.g. from indicative targets to tax-based systems and quota obligations), a less price-elastic demand for biofuels is being created and hence the sector's purchasing power is increased, inducing higher price levels in situations of scarcity. A study on the effects of the USA support system for biofuels estimates that the removal of a tax credit while keeping the mandate and tariff on imported ethanol would reduce corn prices in the year of removal by around 3.5%, while removing it in the absence of the mandate and tariffs would reduce them by 14.5% (McPhail and Babcock 2008a). Interestingly, the removal of the RFS[22] mandate would decrease corn prices in 2008/09 by only 3.9% (McPhail and Babcock 2008b). Thus it seems that different support policies have a different effect on the market for feedstock. Furthermore, impacts may differ substantially between countries, given their specific conditions in terms of, for example, agricultural systems, cropping traditions, and rural livelihoods. Any policy should take such considerations into account (BEFS 2008).

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[20] Although we can expect the situation in developing countries to be somewhat different, the higher share of agricultural inputs in retail food prices is most likely to come from lower costs of capital and labour, rather than higher share of feedstock inputs.

[21] Urbanchuk (2007) estimates that a 33% price increase in corn prices would cause a 0.3% increase in the CPI of food overall and a 0.7% increase in the CPI of meats and eggs.

[22] The Renewable Fuel Standard as part of the Energy Policy Act of 2005 mandates the use of 7.5 billion gallons of renewable fuels by 2012.

Unlike transport fuel prices that are global because fuel is a globally traded commodity, power and heat prices vary tremendously from country to country, creating differences in the competitiveness of biomass for power and heat between countries. This also means that the role of governments in supporting bioenergy can vary greatly depending on the individual situation.

The role of functioning markets and of international trade. In a completely free market, with perfect information, farmers all over the world would respond to global increases in prices for agricultural commodities by either bringing new land into production, switching to different crops, or improving yields. However, because agricultural markets are far from perfect, price signals often do not reach farmers. Even when they do, there are a number of barriers that prevent higher prices of agricultural commodities being translated into increasing agricultural output. Amongst the most significant barriers are the export-limiting measures adopted by governments in an effort to curb domestic inflation and protect consumers, but which also discourage farmers who are then unable to sell their crops at higher global market prices. To minimise the price impact of any additional demand for agricultural commodities, governments must ensure that all the institutions necessary to ensure proper functioning of the agricultural markets are in place, and abstain from any distortionary policies that prevent market signals from being translated into supply adjustments.

Residues supply for power and heat. The case of biomass used for power generation is fundamentally different from that of biofuels. Because most biomass-based power plants feed on waste or residues, an increased demand will not directly cause an increase in the production of round wood. Thus the supply stream of wood residues can be seen as independently determined by the demand for the main forestry product (roundwood). For example, the supply of residues (and therefore also of wood pellets) decreases significantly in the case of a downturn in the housing market, due to the reduced demand for construction wood. Government interventions are therefore limited in their ability to influence the supply of the raw material (sawdust). In a well functioning market, increased pelletising capacity would be established in regions where residues are not being utilised for energy production. Unfortunately, the pellet market has so far not been able to consistently pass market signals up through its value chain.

The importance of open and transparent trade. One of the most important conditions for efficient allocation of a scarce resource such as biomass amongst all its alternative applications is an open and transparent trade system. Agricultural commodities have long been traded on established platforms and the increased trade in biofuels has prompted the development of standardised contracts and other trading instruments for them. The development of wood and agricultural residues into global energy commodities has not yet reached this level, with few, mostly bilateral transactions, and consequently huge price variations and considerable price uncertainty. It can be reasonably expected that 2nd generation biofuels will suffer from similar problems once they reach large-scale production levels. If bioenergy targets are to be reached at least-cost, they must also be accompanied by efforts to increase the efficient and transparent trading of biomass.

4.4 Barriers to Deployment and Market Risks

There is a wide variety of existing and potential factors hindering the further deployment of bioenergy. These can be classified as factors relating to supply side, technologies,
and markets.

4.4.1 Supply side risks and barriers

Cultivation risks. Some essential supply side concerns, which the bioenergy sector shares with the food and forestry sectors, relate to the risks of biological production. For current 1st generation biofuels, these risks are directly related to crop production, while, for bioheat and biopower, the risks are generally associated with the supply of residues, mainly from the forest and wood industry. El Nino, drought and other weather-related impacts, fire and pests (including insects, plants diseases, and vertebrates) affect biomass production as well as food and fibre production and can drastically reduce the availability of biomass feedstocks. This is true for both dedicated energy crops and residues. The increases in prices for major food commodities in recent years illustrate the possible effects: adverse weather conditions in 2006 and 2007 in some major crop producing areas are cited as one of the major causes of this price increase.

The danger of pest and insect attacks, as well as susceptibility to fire, is a clear disadvantage of plantations – particularly monocultures. These risks can be reduced through proper planning and management (including continuously changing or rotating the genetic base in use), but they cannot be eliminated. In general, diversity is normally the best mechanism to minimise risk.

Longer term supply side concerns include uncertainties about the effects of climate change, in that increasing temperatures and shifting rain patterns could profoundly change the suitability of different parts of the world for the production of certain crops. In addition, soil, and water degradation, for instance due to improper irrigation practice or excessive crop residue removal, can also severely impact the productivity of cultivations and at worst make further production non-viable.

Procurement risks. The principal market needs from a feedstock supply perspective relate to securing quantity, quality and price (see Table 4-4). However the specific challenges are different for different bioenergy feedstocks. A distinction can be made between different categories:

- biomass feedstocks that are also produced for food, fibre and other material purposes;
- dedicated biomass crops that are specific to the bioenergy sector; and
- waste and residues.

The current production of biofuels for transport relies on food commodity feedstocks with established markets and logistics. These feedstocks have the advantage of being well known by farmers who have already invested in machinery and other facilities related to their production. To a large extent this also applies to agricultural residues.

Table 4-4. Major challenges for plant developers in relation to securing quantity, quality, and price of biomass feedstock.

Procurement risk factor	Major challenges
Quantity	• 'Chicken and egg' problem in joint development of biomass supply and demand. • Lack of fluid market in non-commodity biomass feedstocks. • Small supplier base. • Lack of adequate and integrated infrastructure.
Quality	• Biomass variability in physical characteristics and chemical composition. • Low density. • Lack of infrastructure to verify quality of supply.
Price	• Potential for variability because of limited supply base. • Difficulty in securing long-term contracts (longer than 2-3 years).

Similarly, much of the solid biomass that is used for heat and power in industrialised countries has been extracted from forests as part of well established forest industry practices. Extraction of new forest assortments, such as thinnings from silvicultural activities and felling residues, will require specially-adapted machinery, but could benefit from similar developments within the established forest sector.

For conventional feedstocks, i.e. forest materials and agricultural crops, price variability remains a risk. The feedstock competition with the food and forestry sectors makes the business situation more complicated, since the feedstock prices are also influenced by the supply-demand balances in these sectors. Apart from price competition, the food and forestry sectors can also affect the bioenergy supply through lobbying and other general strategic efforts to improve their own prospects.

The supply side challenges are quite different for dedicated bioenergy crops. Many of these feedstocks are largely unproven in production and face agronomic, technical, institutional, and, not least, cultural barriers. For many of the lignocellulosic grasses, the technologies and infrastructure present on farms can be used directly in their production. Woody crops, on the other hand, require either adapted agricultural or forestry equipment.

Biomass residues are co-products of the wood and agriculture industries. Hence, the availability (and price) of biomass residues is difficult to predict and secure as it is directly affected by the variability in production from these industry sectors, which in turn depends on both the cultivation risks described above and the variation in the demand for these primary products. For instance, the recent housing crisis in the USA, resulting in fewer houses being built and hence less timber consumed, has been interpreted as a possible cause of the sawdust shortage in the USA pellet industry.

Unlike dedicated crops and residues, wastes such as municipal solid waste (MSW) and sewage sludges suffer much less from procurement risks.

4.4.2 Technology risks and barriers

Although each bioenergy technology has its own technical challenges to overcome that depend mostly on their development status (see Chapter 3), a number of risks and barriers to deployment are common across the range of technologies. The principal concerns are discussed below, the majority of which relate to the physical properties and chemical composition of the biomass feedstock.

Ability to handle feedstock variability. Most bioenergy conversion technologies are not very flexible to changes in feedstock quality and moisture content. This may impact on both the performance and reliability of the plant, which in turn affects its economics.

Feedstock handling. Solid biomass feedstock generally has a low bulk density and comes in a variety of structures and types, which makes it technically difficult to handle and store. Reliability of the feeding systems into the boiler/reactor is a common issue and is considered one of the main technical challenges still to be overcome, particularly for gasification units that operate under pressure.

Economies of scale. Commercially available technologies, apart from technologies for heating applications, generally suffer from poor economics at small-scale. This is a particular problem because of the difficulty in supplying mainly lignocellulosic feedstocks to large plants due to insufficient resource availability, distribution, density and logistics. Addressing this risk will require the commercialisation of technologies with improved economics at small-scale and an improvement in the availability of biomass and its supply logistics.

Co-product contamination. The solid co-product fraction of bioenergy conversion (ash, digestate, etc.) may contain contaminants such as heavy metals. This is particularly the case when feedstocks such as short rotation crops, straw, grasses and husks, as well as waste wood are used, which usually contain higher concentrations of alkali metals than traditional wood fuel. In the context of increasingly strict environmental regulation, questions remain regarding the most affordable manner for treating and using these by-products and disposing of them in the most environmentally sound way.

Toxic emissions. Similarly, further R&D effort for flue gas cleansing will be required to meet increasingly stringent limits on toxic emissions (NOx, CO, particulates, etc.). This is particularly important for small-scale combustion units, as they need simple and affordable solutions (IEA 2008e).

4.4.3 Market risks and barriers

Competition and competitiveness. Bioenergy faces competition from alternative sources in all its market segments. While bioenergy is generally cheaper than most alternative renewable resources, it is usually not cost competitive with conventional fossil solutions without public support. The competitiveness of bioenergy is very much dependent on the cost of biomass (including any transport costs). Many local factors also affect the competitiveness of bioenergy such as infrastructure, cost of alternatives and regulatory aspects (e.g. grid accessibility). Some examples where bioenergy is competitive with conventional sources are: power generation from waste gases, certain heat applications based on woodchips and pellets, and ethanol production from sugar-cane.

Competition within the bioenergy sector. Within the bioenergy sector, there is no competition as yet between the commercial technologies that tend to be relatively similar in terms of the biomass types they can use; their regional availability; and the final product they can deliver. However, the advent of new technologies could change this. In particular, new technologies for the production of biofuels from lignocellulosic feedstock could lead to competition for biomass resources between transport fuel applications and heat and power applications. Technological advances in conversion technologies for biomass-fuelled heat, power, or transport would affect the competitiveness and use of bioenergy for those different applications, as would advances in the competitiveness of other renewable and non-conventional fossil sources of energy.

Policy and regulation. A stable and supportive policy environment is a prerequisite for the successful deployment of biomass in different applications. Similarly, there is a need for clarity and foresight in regulatory aspects, such as planning regulation and emissions standards.

Investor confidence. Supply side risks such as feedstock availability and price, and how these are affected by competing uses is a major source of concern for investors. Since feedstock costs represent 50-90% of the production costs of bioenergy, not being able to secure long-term supply contracts casts uncertainties over the viability of projects. The cost of feedstock is a key aspect that differentiates bioenergy from all the other renewable resources that feed on 'free' fuel such as sunlight and wind, etc.

On the technology side, feedstock variability and its impact on conversion processes also affects investors' confidence. Furthermore, the range of feedstock and technology options adds complexity to investment decisions, particularly considering the absence of a critical mass of knowledgeable investors (although this has changed somewhat in recent years). Also, the very high cost of first-of-a-kind demonstration plants, and the insufficient record of success stories, tends to restrain investments.

The interaction of biomass with other sectors, such as food and forestry, and the policies affecting them, is also a source of risk, placing further uncertainty on the future development of the bioenergy sector. Finally, the fragmented nature of policy support directed to bioenergy (focusing on feedstock production, conversion or end-use) enhances policy risk.

Public and NGO acceptance. Public and NGO acceptance is a major risk factor for all alternative energy sources, but bioenergy in particular. While concerns of NGOs and the general public are usually global (social justice, impact of land use change, deforestation and overall CO_2 balance), local public resistance is more likely due to local issues such as traffic movements, local air pollution, smells, noise, visual impacts, etc. In general, society needs to be informed and confident that bioenergy is environmentally and socially beneficial and does not result in negative environmental and social trade-offs on a global or local level.

4.5 Key Messages for Decision Makers

1. What is the market status and prospects for bioenergy in different market segments?

Bioenergy covers 10% of global primary energy consumption, of which around 90% consists of biomass for domestic cooking and heating in developing countries. Traditional biomass consumption could be globally reduced by up to 70% by 2050 by the widespread introduction of modern efficient stoves.

Electricity from biomass currently represents a mere 1.3% of the global power production, and this share is projected to increase to 3-5% by 2050 in most energy scenarios. The main opportunities in the short-term are co-firing with fossil fuels (the most cost-effective option), biogas-to-power units and MSW combustion plants, with other dedicated solid biomass requiring greater support for greater deployment. Gasification-based technologies could offer prospects in the longer term both at small- and large-scale.

Biofuels today represent less than 1% of the total road transport fuel consumption but this sector is expected to be the fastest growing bioenergy segment. A 6-8% annual growth rate for biofuels production is expected over the next decades. This rate will be strongly determined by what policies are put in place, which are likely to depend in turn on how the biofuel industry manages environmental and social sustainability challenges, and the development rate of other alternative fuel-vehicle technologies in transport.

2. What are the main biomass feedstocks and products traded?

The main biomass-based energy carriers traded today are:

- wood pellets (mainly from North America and Eastern Europe to Northern and Western Europe);
- ethanol (mainly from Brazil to Europe and the USA); and
- vegetable oils and biodiesel (mainly from South-East Asia and Latin America to the USA and Europe).

Many other bioenergy feedstocks are traded for energy use, such as wood chips, waste wood and agricultural residues. Furthermore, components of biomass commodities traded for other purposes (e.g. round wood) end up indirectly in energy use (e.g. bark, saw dust, and black liquor).

3. What are the current and potential trade volumes?

Current trade volumes are estimated to be around 1 EJ (in 2006) and growing rapidly. Compared to a global biomass use of 50 EJ and total energy demand of 500 EJ, this is relatively small. However, in the longer term, up to several hundred EJ of biomass commodities might be traded internationally, with Latin America and Sub-Saharan

Africa as potential large net exporters, and North America, Europe and South-East Asia as large net importers.

4. Does long distance transport of biomass use more energy than that embodied in the biomass itself?

Long distance transport of biomass takes place by sea in energy efficient bulk carriers. Especially when the biomass is pre-treated in order to increase the energy density, energy use due to long distance transport is very low compared to the energy content of the material transported. Long distance transport on land (particularly road transport) is significantly more energy intensive; for cost reasons, most biomass supply chains try to keep transport through these modes to a minimum.

5. Which commodity markets are going to be affected by an increasing use of bioenergy?

Increasing use of biomass for energy will affect commodity markets of agricultural and forestry products. This impact can be direct, e.g. bioenergy and food chains competing for the same product or same land, but can also be manifested in indirect ways, e.g. by co-products of bioenergy chains substituting feed crops. In general, the interactions between bioenergy and commodity markets are complex, and the impact may differ significantly for different bioenergy options.

6. What is the impact of biofuels on the recent increase in food commodity prices?

The use of biofuels is one of many factors affecting agricultural commodity prices. Although demand for biofuel might have a significant impact in the future, today it is far from being the dominant influencing factor in the case of most agricultural commodities. In the short-term, sudden food price hikes are mostly caused by weather effects, and price rises in fossil energy, which is an important input to agricultural systems. These fundamental factors affecting price volatility of agricultural commodities can be magnified by speculative market responses and by policy responses such as export taxes. In the long-term, influential factors on the demand side include population and income growth, and resulting increases in demand for food and feed. On the supply side, developments in agricultural yields and agricultural land area available are important factors. If the demand for biofuel feedstocks were to cause significant competition for land with food and feed crops, this could have a significant impact on food prices in the future.

7. What measures can be taken to minimise the impacts of bioenergy development on commodity markets?

Given that the biofuels market is largely policy driven, cautious target setting could limit disproportionate reactions from the market and minimise the impact of bioenergy development on commodity markets. Also, measures are needed to coordinate bioenergy policy with forestry, agricultural, competition, trade and environmental policies. This comprises policies aimed at:

- increasing agricultural yields, particularly in countries lagging in modern agricultural practices;
- creating selective incentives for biofuels produced from agricultural and forestry residues and crops from marginal and/or degraded land;
- reducing the share of fossil fuels in the total cost of crop production;
- critically reviewing trade-distorting government interventions (e.g. export bans); and
- facilitating the development of more transparent trading platforms for wood products.

8. What is hindering market penetration of bioenergy?

Major risks and barriers to deployment are found all along the bioenergy value chain and concern all final energy products (bioheat, biopower, and biofuel for transport). On the supply side, there are challenges in relation to securing quantity, quality, and price of biomass feedstock irrespective of the origin of the feedstock (energy crops, wastes, or residues). There are also technology challenges related to the varied physical properties and chemical composition of the biomass feedstock, and challenges associated with the poor economics of current power and biofuel technologies at small-scales.

On the demand side, some of the key factors affecting bioenergy deployment are cost-competitiveness, stability and supportiveness of policy frameworks, and investors' confidence in the sector and its technologies, in particular to overcome funding challenges associated with demonstrating the reliable operation of new technologies at commercial scale. In the power and heat sectors, competition with other renewable energy sources may also be an issue. Public acceptance is another critical factor closely related to the case for the sustainability of energy crops for biofuel production, especially conventional starch, sugar, and oil crops destined to biofuel production (woody biomass, wastes and residues are less of a public concern). Public percetion also can affect the planning approval for bioenergy facilities at a local level.

CHAPTER 5: BIOENERGY AND POLICY OBJECTIVES

Key questions addressed in this Chapter:

1. Is biomass best used to produce transport fuel or to generate heat and power?
2. If climate change mitigation in the energy sector is the objective, how can biomass be used most cost-effectively?
3. What is the impact of greenhouse gas emissions from direct and indirect land use change on the greenhouse gas balances of biofuels?
4. Is it better to use land for carbon sink creation than for bioenergy production?
5. Can biofuels play a role in improving energy security?
6. How can food insecurity and other socio-economic impacts be mitigated?

5.1 Introduction

Different bioenergy feedstocks and uses have different implications in terms of, for example, energy security, ecology, and climate. Consequently, different objectives and related policies lead to different prioritisation of bioenergy options, as well as biofuel chain configurations.

This chapter provides a strategic view on the relationship between bioenergy and policy objectives, taking into consideration the uncertainty of the longer term goals that will define sustainable energy and transport, and the strong influence of incumbent energy and transport infrastructures.

5.2 The Role of Bioenergy in the Stationary and Transport Energy Systems

The socio-economic context and the established industry, energy, and transport systems are major – and geographically varying – determinants of the technology response to government policies. Technologies that can be integrated with existing systems and do not require drastic changes in consumer behaviour have a clear advantage. In the case of bioenergy, examples of this are the blending strategy for biofuels in transport and the substitution of fossil fuels by biomass in the forest industry. Therefore, bioenergy deployment needs to consider existing and planned energy infrastructure, because new power plants, pipelines, etc. will stay in operation for many decades. Some specific illustrations:

- The large – and growing – installed capacity of coal-based power (see Figure 5-1) makes biomass co-firing with coal an interesting near-term option (IEA 2008b). The longer term prospects for this option depend on whether carbon capture and storage and/or high biomass shares in the fuel mix can provide competitive power when stringent climate targets are established.
- The large installed capacity of natural gas-based power generation, and the widespread natural gas grid in domestic areas for heating, warm water, and cooking, means that biomethane production could be an interesting option with large deployment potential. The build-up of a biomethane refuelling infrastructure for the transport sector could also rely on existing natural gas pipelines.
- There is significant potential to use surplus heat from biomass-based power and transport fuel production in domestic applications through heat distribution networks where these exist. Alternatively biomass energy conversion that requires heat input, e.g. ethanol production, could benefit from co-siting with energy plants and industries generating surplus heat.

The development of bioenergy will also be shaped by the presence of competing energy resources and technologies for meeting policy goals such as energy security improvement and climate change mitigation. As an illustration of this, model-based energy system studies report diverging findings on whether biomass should be used for transport or stationary energy. How biomass is to be used is to a large degree determined by the availability and cost of alternative transportation options that do not rely on biomass. If hydrogen or electric vehicles do not become technically viable or are too expensive, the only remaining supply-side option to reduce oil dependency and/or achieve very low emissions of CO_2 is to rely on biofuels for transport. In contrast, the stationary sector can rely on a range of different low carbon options, and has a huge potential for energy efficiency improvement. Thus, the focused use of biomass for heat and power rests on the argument that other climate friendly transport options will become commercially available soon and make biofuels for transport irrelevant.

Individual countries differ in their existing energy infrastructure and the sources of energy (including bioenergy) that they have access to. Therefore, they will probably prioritise biomass use differently. Technology development will also affect the use of bioenergy, and while region-specific factors may influence energy technology development, this will largely follow global trends. Standards, e.g. fuel standards for engines, also influence technology development and deployment.

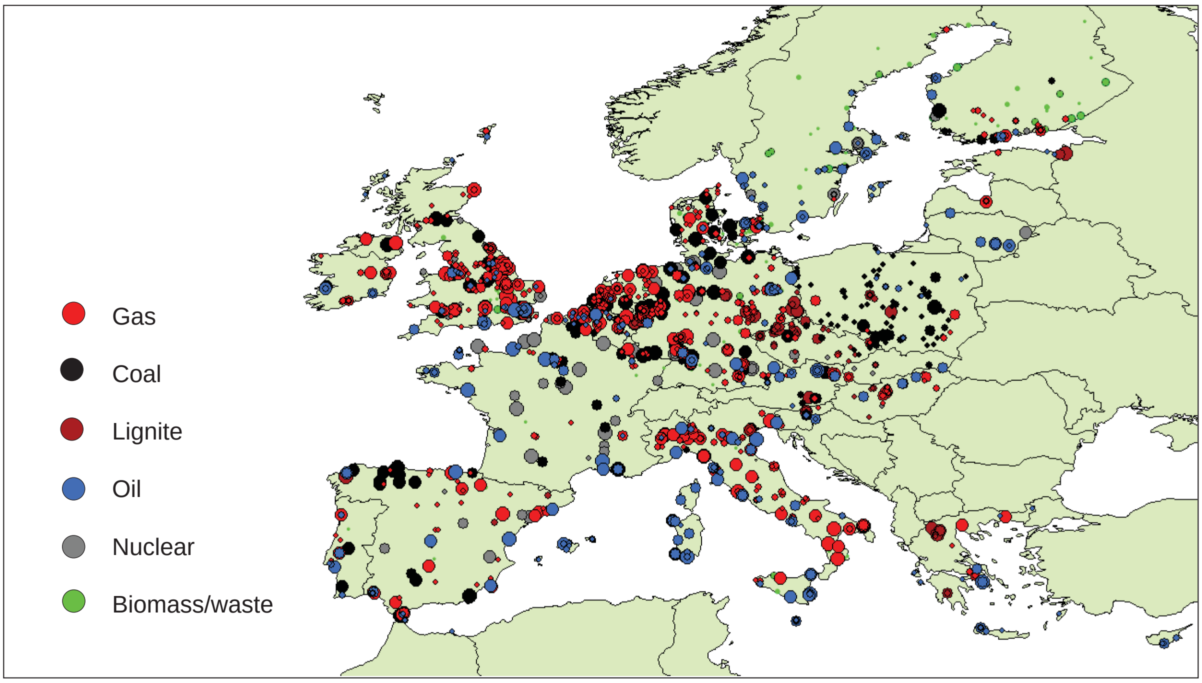

Figure 5-1. Thermal power plants in EU25 exceeding 10 MW. A 10-15% biomass share in all existing coal plants under 40 years old would correspond to ca 900 PJ of biomass, or 90 TWh, or almost 20% of the renewable electricity generation in EU27 in 2005. Source: Kjärstad and Johnson (2007).

5.3 Bioenergy and Climate Change Mitigation

An essential feature of bioenergy as a climate mitigation option is that it requires land for biomass feedstock cultivation. Land can be used for climate change mitigation in two principal ways:

- By increasing the land's biospheric carbon (C) stocks (soils and standing biomass) and thereby withdrawing CO_2 from the atmosphere[23](here denoted carbon sink option).
- By supplying biomass as a substitute for fossil-based fuels and other products and thereby reducing the emissions of fossil CO_2 to the atmosphere (here denoted bioenergy option).

These two options are not mutually exclusive. The establishment of bioenergy systems in themselves often leads to (positive or negative) changes in the biospheric carbon stocks. Both the bioenergy and the carbon sink option can also induce indirect land use change (LUC) when they are implemented. The possible emissions from direct and indirect LUC can substantially influence the climate benefit of bioenergy systems as well as carbon sink projects.

The remainder of this section provides an overview of the GHG reduction potential of different bioenergy options, with and without consideration of LUC effects. The option of using land for carbon sinks is then compared to the bioenergy option.

5.3.1 Conclusions from lifecycle assessments and well-to-wheel analyses

In lifecycle assessments of GHG emissions, the benefits of bioenergy are estimated in terms of the reduction of GHG emissions compared with conventional fossil routes. However, the lack of solid empirical data for some parameters, and of a commonly agreed methodology (e.g. how by-products are taken into account) contributes to uncertainties in the climate impact of bioenergy chains and to the diverging results provided by studies (see, for example, IEA 2008d). Despite the uncertainties in the data and methodologies, some conclusions can safely be drawn.

Biomass-to-heat and power generally leads to larger greenhouse gas emission reductions and biomass cascades are better than single-product systems. Bioenergy will be most effective for GHG mitigation when it is adopted in association with other products i.e. by utilising biomass wastes of primary product chains or biomass that has already served one or more functions. When used for energy, biomass that substitutes for fossil fuels in heat and electricity generation in general provides larger and less costly CO_2 emissions reduction per unit of biomass than substituting biofuels for gasoline or diesel in transport. The major reasons for this are:

- the lower conversion efficiency, compared to the fossil alternative, when biomass is processed into biofuels and used for transport, and
- the higher energy inputs in the production and conversion of biomass into such fuels, when based on conventional arable crops.

At the same time, the stationary sector can rely on a range of different low carbon options, while biofuels may be the major option for climate change mitigation and energy security improvement in the transport sector. Future fossil fuels in the transport sector may also yield higher GHG emissions,

[23] Reducing the present rate of deforestation and other ecosystem degradation can be regarded as a third option as it leads to a deviation from trends in atmospheric CO_2 accumulation (due to biospheric C losses) in the same way as bioenergy substituting fossil fuel use reduces the rate of atmospheric CO_2 accumulation (due to reduced fossil C emissions). Preservation of biospheric C stocks differs from bioenergy in the same way as C sink creation: it does not require any energy system changes.

and improve the case for biofuels. Transport fuels from less conventional oil resources and coal based Fischer Tropsch diesel both have higher lifecycle GHG emissions than the gasoline and diesel used today.

The question whether to use biomass for transport or stationary energy purposes may become less relevant in the longer term, when bioenergy systems may increasingly consist of biorefinery technologies that produce liquid/gaseous biofuels for transport in combination with power, heat, solid biofuels, chemicals and other products (see also Section 3.7). The driving factors are the synergies available with the higher total energy efficiency and resource efficiency obtained by combined approaches, and the potential added value from producing a range of products.

Greenhouse gas emission reductions vary strongly between chains but choice of methodological approach also strongly influences the outcome of analyses. Greenhouse gas emissions of bioenergy systems (and thus the GHG reduction potential) vary widely with changing feedstock growing conditions and process options, and changing calculation methodologies.

Typically, Brazilian sugar-cane ethanol achieves GHG emission reductions of 85% whereas the GHG emissions from ethanol made from conventionally grown maize in the USA are reported to be slightly more or slightly less than those from gasoline per unit of energy. Another example is wheat ethanol produced in Sweden which reduces GHG emissions by some 80% compared to gasoline. It has also been estimated that cellulosic ethanol could achieve roughly the same emissions reduction in the future as Brazilian sugar-cane ethanol (Farrell et al., 2006).

Process options such as, for example, the choice of fuel for the conversion process, have an important influence on the final result of GHG calculations. Recent analyses using updated values for crop management and yields, conversion process configuration, and by-product utilisation found emissions reductions of roughly 50-60% for maize ethanol in USA (Liska et al., 2009). As stated above, earlier studies showed almost no reduction and sometimes a slight increase. The choice of fuel for the conversion process is one major reason for this difference. High climate benefit also requires that nitrous oxide emissions are minimised by means of efficient fertilisation strategies using commercial nitrogen fertiliser produced in plants that have nitrous oxide gas cleaning.

Finally, the choice of method for the allocation of impacts between main product and by-product(s) strongly affects the performance.

Figure 5-2 exemplifies the wide range of results that can be obtained for one bioenergy production system (wheat ethanol in Sweden) by varying three different factors: the fuel combusted in the conversion process, the time horizon and the

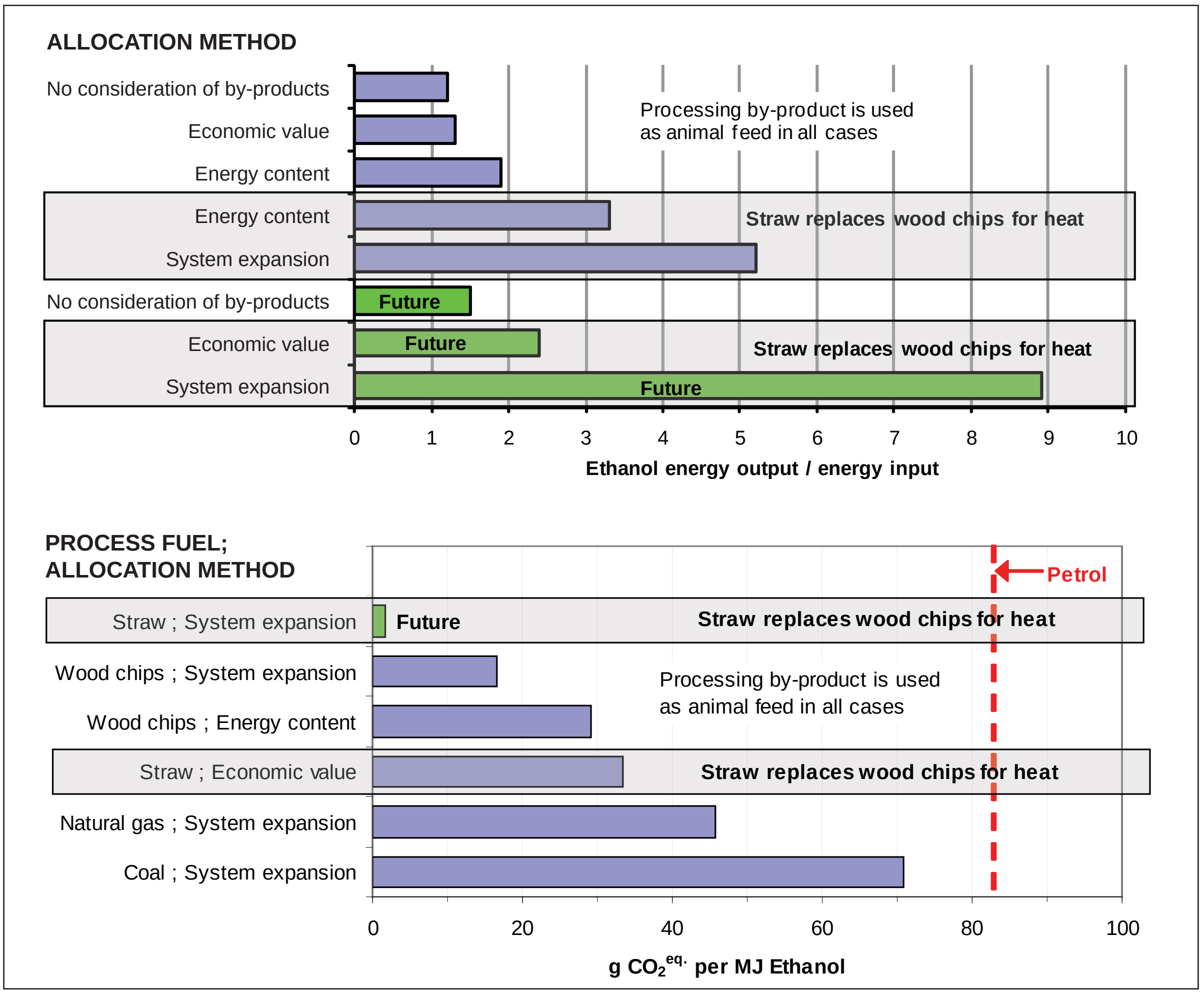

Figure 5-2. Energy balances (upper diagram) and GHG emissions (lower diagram) for wheat-based ethanol production, taking into account various methods for considering by-product uses. System expansion refers to the assumption that the use of by-products leads to reduced production of an alternative product with the same use. The bars designated 'Future' show how the systems can improve due to development in both the feedstock production and the conversion to ethanol. Based on Börjesson (2008).

allocation method. The upper diagram of Figure 5-2 shows the ratio of ethanol produced to external energy invested in the process and the lower one presents the net GHG emissions, including a comparison with gasoline.

Results are given for allocation by economic value, by energy value, and 'system expansion' where the avoided impacts of a substitute product that the by-product replaces are accounted for. If by-products are utilised efficiently so as to maximise their energy and climate benefits, the performance of the bioenergy system improves substantially. However, economic realities may lead to uses that contribute less to climate benefits. Note also that the use of by-products as animal feed – which leads to significant GHG reductions in Figure 5-2 when by-product is assumed to replace soy protein imports in the system expansion method – is limited by the relatively small size of this by-product market, corresponding to a few percent of the transport fuel demand.

A key message from this is that, although the same bioenergy chain can perform very differently, most bioenergy options can deliver significant GHG savings if high LUC emissions are avoided.[24] There is a clear potential for improvement of the current production of ethanol and other biofuels worldwide, leading to increased GHG savings. However, policies must be put in place that stimulates such improvement (see Chapter 6).

5.3.2 Impact of direct and indirect land use change on greenhouse gas emissions

Modelling studies have shown that the possible direct and indirect emissions from converting land to an alternative use can substantially reduce the climate benefit of bioenergy initiatives (Leemans, et al., 1996; Fargione et al., 2008; Searchinger et al., 2008; Gibbs et al., 2008; RFA 2008). The promotion of biofuels for transport in recent years is being questioned because of concerns that they may result in a marginal or even negative contribution to greenhouse gas emissions reduction, in part due to large CO_2 emissions from induced LUC.

The quantifications reported so far are based on model projections of LUC. These involve a significant degree of uncertainty, for example in relation to causal chains and the carbon stock changes linked to LUC. The effects are complex and difficult to quantify in relation to a specific bioenergy project (see Figure 5-3):

- Brazilian sugar-cane plantations are primarily established on pastures, displacing cattle ranching (Sparovek et al., 2008). This may lead to intensified cattle production on existing pastures or establishment of new pastures elsewhere. If a substantial part of the pasture expansion were to take place in the Amazon region, CO_2 emissions from deforestation would severely reduce the climate benefits of Brazilian ethanol.
- Oil palm expansion (predominantly for food production purposes) has caused significant deforestation in SE Asia and large CO_2 emissions, especially from peatland forests. Historically, increased palm oil production has largely been achieved by establishment of additional plantations rather than by increasing yields, but concern about the negative impacts of expanding oil palm plantations may shift focus to increasing plantation productivity. But, to avoid indirect impacts, yield increases would have to outstrip increases in demand.
- If European biofuel demand leads to pastures and grasslands being converted to croplands for rape seed (or other annual crops), soil C emissions from these lands may be high. But even if biodiesel comes from rape seed cultivated on the present cropland, rising demand for this feedstock may lead to increasing prices, which may in turn lead to increased palm oil production (and possibly deforestation) for rape seed oil substitution in the food sector. Another illustrative example is the shift from soy to corn cultivation in response to increasing ethanol demand in the USA, which has induced increased expansion of soy cultivation in Brazil and other countries (Laurance 2007).

If biofuel crops are grown on previous agricultural land which has been taken out of production, soil C losses may be minimal. Similarly, planting short or long rotation forestry on grasslands with limited C and ecosystem value may result in limited C loss or possibly C gains, depending on the planting and management techniques used. In many cases, bioenergy initiatives could lead to a net increase in biospheric C stores if perennial grasses or short rotation woody crops are established on land with sparse vegetation and/or C depleted soils on degraded and marginal lands. In this context, land application of bio-char produced via slow pyrolysis offers an option where the C is sequestered in a more stable form and also improves the structure and fertility of soils (Lehman et al., 2006; Gaunt et al., 2008).

Despite the substantial degree of uncertainty, if the expansion of crops for 1st generation biofuels results directly or indirectly in the loss of permanent grasslands and forests it is likely to have negative impacts on GHG emissions. This conclusion clearly highlights the need for land development strategies that reduce the risk of displacement, along with accompanying policies reducing the pressure on ecosystems with large C stocks. Such policies may also be preferred for reasons other than climate change, for instance nature conservation and biodiversity preservation (see also Chapter 6), even in the absence of ambitious bioenergy programmes.

The question whether land should be used for biomass production for fossil fuel substitution or for the creation of biospheric carbon stores has been subject to substantial debate and scientific effort.[25] The lack of uniform and comprehensive evaluation standards and varying limitations in scope for studies (e.g. studies commonly disregard the effects of indirect land use change) has resulted in a diverse set of studies that are difficult to compare and whose comparison does not provide clear answers. Also, as has been stated above, the two principal land use options for climate change mitigation are not mutually exclusive: bioenergy systems have carbon stocks associated with them and forests established as carbon sinks can deliver products for various uses, including bioenergy.

[24] There are examples of bioenergy systems that are unlikely to give a positive contribution to climate change mitigation, regardless of process configuration. The common feature is that their establishment involves conversion of carbon-rich ecosystems to bioenergy plantations. This is further discussed in Section 5.3.2.

[25] IEA Bioenergy Task 38 is one example of thematic research networks involved with these issues.

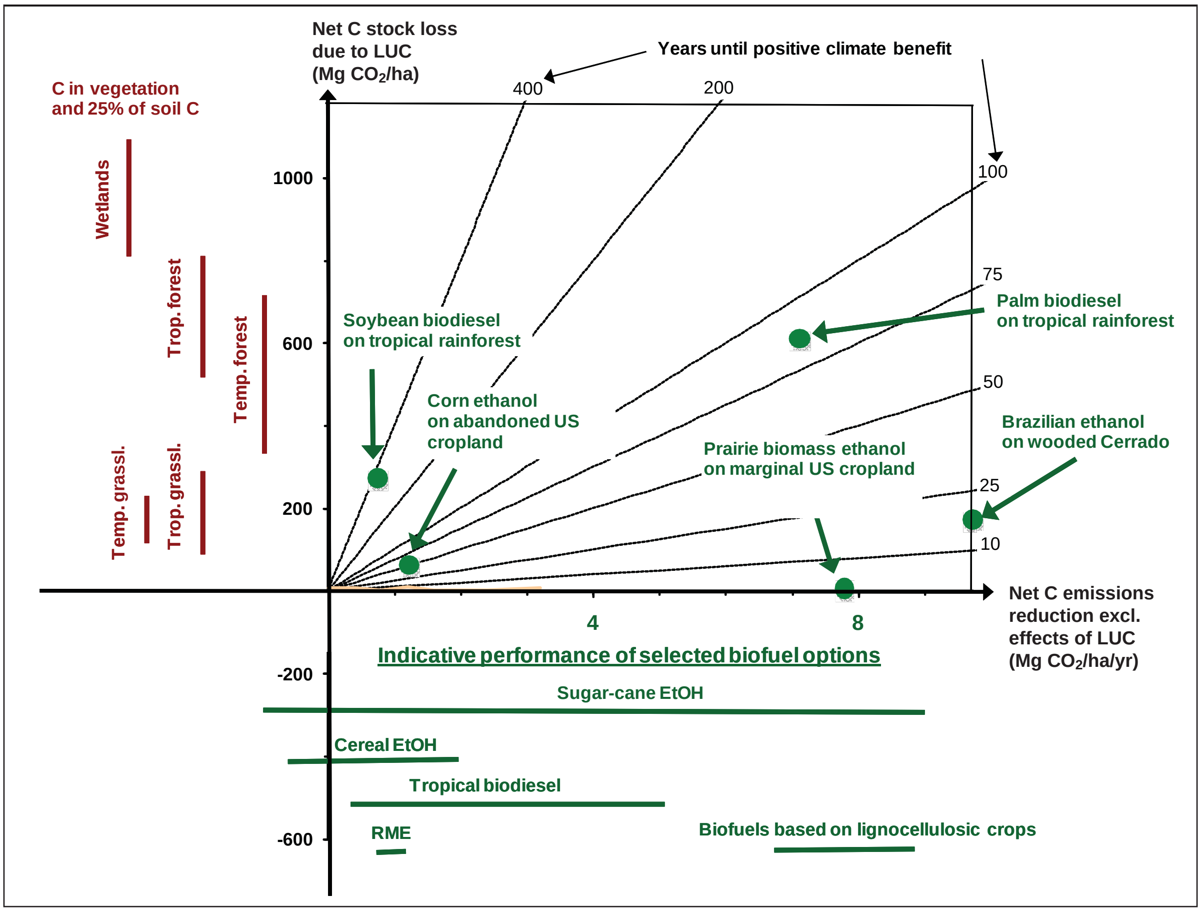

Figure 5-3. Illustration of how LUC emissions can influence the climate benefit of biofuels. The x-axis shows the net GHG emissions reduction (CO_2eq.) of using biofuels (excluding LUC effects), with typical performance (green bars) indicated based on biofuel output per hectare in IEA (2008c) and GHG emissions reduction in RFA (2008). Different use of process fuel is one major explanation for the range for the sugar-cane and cereal ethanol cases, for tropical biodiesel the specific crop causes the range, with palm biodiesel performing better than soybean biodiesel. The y-axis shows the net loss of carbon in soils and vegetation when different ecosystem types are converted to bioenergy plantations: the bars to the left of the y-axis indicate the ranges for C content in different ecosystem types (IPCC 2001; Searchinger 2008). The dashed lines indicate how many years of biofuels production and use that is required to fully compensate for the C emissions due to land conversion to bioenergy plantations. The dots represent specific cases reported in Fargione et al., (2008).

Ranking of land use options based on their contribution to climate change mitigation is also complicated by the fact that the performance of the different options is site-specific and is determined by many parameters. Among the more critical parameters are:

- Biomass productivity and the efficiency with which the harvested material is used – high productivity and efficiency in use favour the bioenergy option. Low productivity land may be better used for carbon sinks, given that this can be accomplished without displacing land users to other areas where their activities lead to indirect CO_2 emissions. Local acceptance is also a prerequisite for the long-term integrity of sink projects.
- The fossil fuel system to be displaced – the GHG emissions reduction is for instance higher when bioenergy replaces coal that is used with low efficiency and lower when it replaces efficient natural gas-based electricity or gasoline/diesel for transport.
- The initial state of the land converted to carbon sinks or bioenergy plantations (and of land elsewhere possibly impacted indirectly) – conversion of land with large carbon stocks in soils and vegetation can completely negate the climate benefit of the sink/bioenergy establishment.

The relative attractiveness of the bioenergy and carbon sink options is also dependent on the timescale that is used for the evaluation. A short timeframe (a few decades) tends to favour the sink option, while a longer timeframe favours the bioenergy option. The reason is that the accumulation of carbon in forests and soils cannot continue endlessly – the forest eventually matures and reaches a steady state condition. This is also the case for soils. In contrast, bioenergy can be produced repeatedly and continue to deliver greenhouse gas emissions reduction by substituting fossil fuels.

The bioenergy and carbon sink options obviously differ in their influence on the energy and transport systems. Bioenergy promotion induces system changes as the use of biofuels for heat, power, and transport increases. In contrast, the carbon sink option reduces the need for system change in relation to a given climate target since it has the same effect as shifting to a less ambitious climate target. The lock-in character of the sink option is one disadvantage: mature forests that have ceased to serve as carbon sinks can in principle be managed in a conventional manner to produce timber and other forest products, offering a relatively low GHG reduction per hectare. Alternatively, they could be converted to higher yielding energy plantations (or to food production) but this would involve the release of at least part of the carbon store created. On the other hand, carbon sinks can be viewed as a way to buy time for the advancement of climate-friendly energy technologies other than bioenergy. Thus, from an energy and transport systems transformation perspective, the merits of the two options are highly dependent on expectations about other energy technologies.

5.4 Bioenergy and Energy Security

Biomass provides a diverse source of energy, potentially improving energy security through the substitution of oil and natural gas. The use of domestic bioenergy resources would generally contribute to the diversification of the energy mix. Biomass imports, from widely distributed international sources, also contribute to energy diversification, especially if lignocellulosic resources and bioenergy products derived from them are considered. The international bioenergy market is expected to have a wide range of net suppliers from several world regions (see also Chapter 2) and import of bioenergy is therefore not affected by the same geo-political concerns as oil and natural gas imports are. There may be other problems however.

El Nino drought and other weather-related impacts, fires and pests can drastically reduce the availability of bioenergy feedstocks. The increases in prices of major food commodities in recent years illustrate these effects (for further discussion of its causes see Section 4.3.3). Supply-demand imbalances in the food and forestry sectors could lead to increases in biomass prices for energy, and vice-versa.

Furthermore, the contribution of bioenergy to improving energy security largely depends on decoupling the bioenergy system from oil and gas inputs. The use of coal as a fuel for the conversion process may be less of an issue from the perspective of energy security, but it drastically reduces the climate benefit of biofuels. In relation to energy crops, energy security will be improved through systems that achieve high energy outputs per unit of land used. Figure 5-4 illustrates these points for the Swedish case, showing the net production of vehicular fuels, i.e. the gross biofuel yield less the amount of vehicular fuels used for the cultivation, harvest, and transportation of biomass to the processing plant.

Figure 5-4 also shows how biofuels differ in terms of additional energy use, i.e. energy inputs other than vehicular fuels. From the perspective of GHG emissions reduction, an assessment of biofuel alternatives on the basis of Figure 5-4 should consider types of energy inputs required. For example, using sugar-beet as feedstock requires relatively more energy but also produces a large amount of net vehicular fuel per hectare. It matters greatly how the required energy is produced. If it is generated from biomass instead of fossil fuels, replacing gasoline with beet ethanol leads to higher GHG emissions reduction. If biofuel plants are located close to activities with excess heat, 'free' process heat may be utilised.[26]

Oil is commonly thought of as a transport fuel but in many places in the world oil is more commonly used for space heating and power generation than for transportation. The transport sector currently consumes about half of the oil used globally. Thus, biofuels may replace oil in the stationary energy system as well (see Figure 5-1). Using biomass to

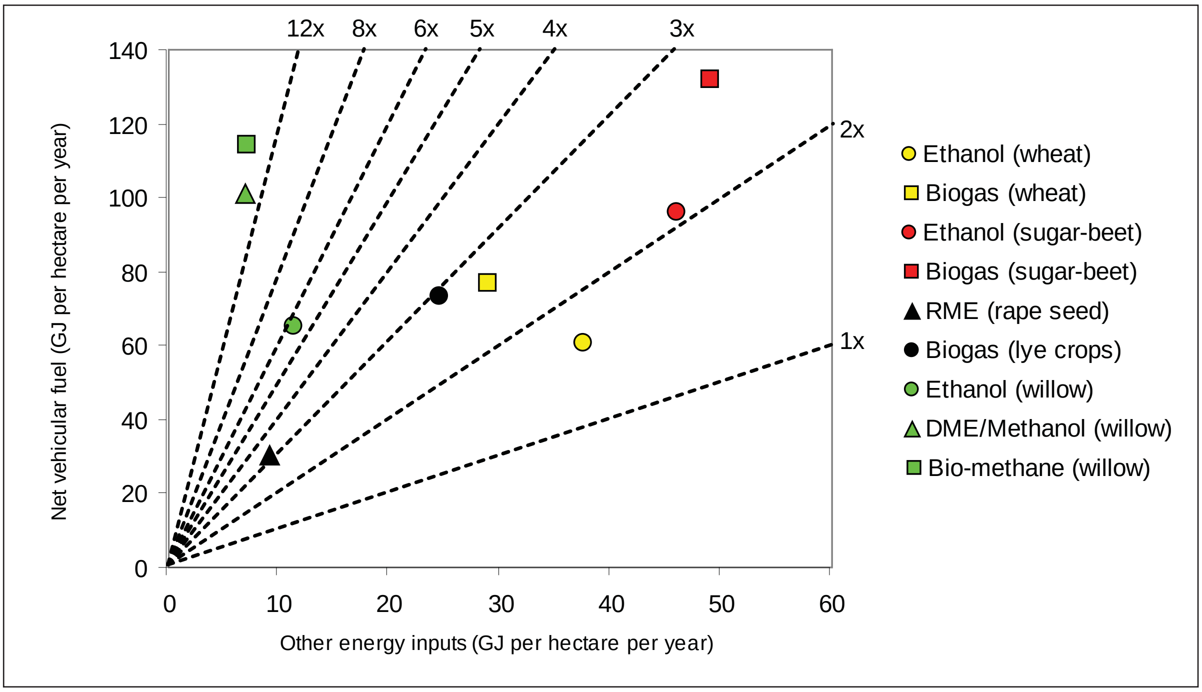

Figure 5-4. Net production of vehicular fuel per hectare per year and other non-vehicular energy inputs, for various biofuel alternatives to be produced in Sweden. The dashed lines indicate how the alternatives compare to the energy quotient, net vehicular fuel production/other energy input. Source: Berndes et al., (2008).

[26] The heat can be considered 'free' if no other use is possible, and the heat therefore in the absence of the vehicular biofuels plant would not have yielded any other utility.

replace oil is in general cheaper in the stationary sector and the net oil replacement per unit of biomass is generally higher than in the transport sector, since solid biofuels – produced with fewer energy inputs and conversion losses than liquid biofuels – can be used. In countries where natural gas import dependency is a concern, the promotion of bioenergy could also mitigate the increasing gas dependency and – where gas-based electricity is growing particularly quickly – could also improve the security of supply for electricity. As for other renewable options, bioenergy promotion in the stationary energy system influences the development of stationary energy towards a higher degree of diversity with respect to technology and fuel choice. It also reduces the investment in fossil energy plants that, once built, can be expected to be in operation for several decades.

On a more strategic systems level, the use of biofuels in gasoline/diesel blends can reduce oil imports but may not induce the kind of development that can act as a bridge to a more radical decoupling of transport from oil. The biofuels presently used in low-level blends – ethanol and biodiesel – are channelled through the established oil industry infrastructure, and are not conducive to a large-scale substitution of fossil fuels. This would require either the development of an infrastructure and vehicles that would accept higher quantities of ethanol and biodiesel, or the development of fuels that would be compatible with the existing distribution and vehicle infrastructure in large quantities (e.g. Fischer Tropsch fuels).

The Brazilian biofuel strategy with higher-level blends has reduced the country's oil dependency drastically, but Brazil is so far an isolated case. Low-level blending is more commonly favoured due to compatibility with the existing vehicle stock. Sweden is possibly one exception where E85 car sales are increasing rapidly[27] and an extensive network of dedicated pumps at fuelling stations has been established. Another example of prospective developments that might act as a bridge to a drastic decoupling of transport from oil can be seen in the further development of hybrid vehicles into plug-in hybrid vehicles – a large-scale penetration of plug-in hybrids could dramatically reduce the requirements of transport fuels (be it gasoline/diesel or biofuels).

5.5 Other Environmental and Socio-economic Aspects

In addition to providing a possible strategy for addressing the twin challenges of energy security and climate change, the production and use of bioenergy can also result in other (positive and negative) environmental, health and socio-economic effects. Most of the environmental effects are connected to feedstock production. The environmental impact from fuel processing is usually lower (Zah 2007). Solutions are available to mitigate the environmental impacts that result from biofuel plants, although they may not be installed in regions with lax environmental regulations or limited law enforcement capacity.

Bioenergy strategies that mainly focus on biofuels for transport and lead to increased cultivation of conventional agricultural crops for the production of 1st generation biofuels amplify the risk of further expansion of agricultural land into forests and other land with high biodiversity values, potentially causing continued ecosystem conversion and biodiversity loss (RFA 2008, Thow and Warhurst 2007). They may also intensify concerns about the capacity of the agricultural resource base (soils, freshwater) to sustainably support an increasing agricultural output, due to the well-documented degradation of soils and water bodies that typically accompanies intensive agricultural practices (MEA 2005; CA 2007).

Increased bioenergy use does not necessarily lead to increased competition for food and feed crops. As has been described in Chapter 3, there are a multitude of conversion options that generate energy from biomass and which can use many different feedstocks other than food/feed crops. Under strategies that shift demand to alternative – mainly lignocellulosic – feedstocks, bioenergy expansion could use other sources such as agriculture and forestry residues that would not require additional land or water, although these could potentially cause negative effects if extraction rates are excessive (see Chapter 2). Lignocellulosic crops could also be grown on a wider spectrum of land types. Marginal lands, pastures and grasslands, which are not suitable for 1st generation biofuels due to environmental and greenhouse gas implications, could become an additional resource for feedstock production under sustainable management practices. The cultivation of perennial energy crops also presents an opportunity for increasing water productivity, by decreasing the proportion of rainfall lost through unproductive evaporation.

Marginal/degraded areas could also be considered for lignocellulosic feedstock production. However, marginal lands may also have alternative uses, implying that the current land users must be involved to ensure positive local socio-economic development. In many cases, this may require approaches other than monoculture plantations, such as agroforestry systems integrating bioenergy production with food crop cultivation and cattle production. Furthermore, biomass production on marginal/degraded land may not be the automatic outcome of increasing biomass demand. As bioenergy use increases and farmers adopt bioenergy crops, they will consider developments in both the food and bioenergy sectors when planning their operations. The economic realities at farm level may then still lead to bioenergy crops competing with food crops, since it is the good soils that also result in higher yields for the bioenergy crops. Biomass plantations may eventually be pushed to marginal/degraded land due to increasing land costs following increased competition for prime cropland, but this competition will probably also be reflected in increasing food commodity prices.

Rules and regulations may dictate that certain bioenergy crops should be produced on certain soils not suitable for food/feed crops production (such as wastelands in India) or on lands where the cultivation of food/feed crops causes significant

[27] During the first half of 2008 E85 cars accounted for roughly 20% of new car sales. Since July 5, regulations also allow for conversion of gasoline/diesel cars to ethanol or gas.

environmental impacts (such as sloping soils susceptible to erosion on the Loess Plateau in China). Regulations may also prevent farmers from using more than a certain share of their land for energy crop production (see Chapter 6). There are also many examples of how integrating technical, ecological, and social knowledge at a local level makes it possible to produce biomass for energy while minimising any risks and generating additional benefits, such as environmental services and improved productivity in agriculture and forestry (see Chapter 2).

Rural development is commonly cited as one of the major benefits of increased bioenergy use. This is viewed differently in developing and industrialised countries. In industrialised countries rural development is seen as a way of differentiating and supporting the agricultural sector and rural areas in general. In developing countries rural development is seen in a broader livelihood context providing employment, much needed income and helping to develop the agricultural system. The link between bioenergy and food security is predominantly a concern for developing countries where the vulnerability to rising food prices is higher, which may have effects beyond those parts of the population that could directly benefit from bioenergy. Sustainability concerns also include direct and indirect socio-economic aspects, including land conflicts and human rights violations.

It is beyond the scope of this report to comprehensively report on mitigating measures in agriculture and land use in general. However, it is increasingly acknowledged that the model that drove agricultural development in industrialised countries and the spread of the green revolution must be revised so that agricultural knowledge, science, and technology effectively meet the challenges of reducing hunger and poverty, improving rural livelihoods and facilitating equitable and environmentally, socially, and economically sustainable development (IAASTD 2008). In this context, increasing bioenergy demand presents challenges but also opportunities for promoting more sustainable land and water uses around the world. As was described in Chapter 2, several biofuel crops can provide important environmental services in agricultural landscapes, such as erosion reduction and microclimate regulation, thereby enhancing the overall agricultural productivity. If domestic and international investors in developing countries can effectively engage local communities and make them partners in the development of a biofuels industry that integrates with food production, reaping the benefits of the inflow of technology, infrastructure and capital for the benefit of both food and bioenergy production, positive rural development may be realised.

Summing up, bioenergy can help meet environmental and energy policy objectives but can also have highly undesirable side effects. Policy around bioenergy needs to be designed so that it contributes to consistent energy and environmental policy objectives. Bioenergy also needs to be regulated so that broader environmental and social issues are taken into consideration and environmental services provided by bioenergy systems should be recognised and valued. Chapter 6 discusses how these challenges can be addressed.

5.6 Key Messages for Decision Makers

1. Is biomass best used to produce transport fuel or to generate heat and power?

The use of biomass is guided by its competitiveness relative to other options in different sectors, its fit with existing technologies and energy infrastructure, and its contribution to complying with energy and environmental regulations. Given that the uptake of biomass is largely dependent on policy incentives, the best use is likely to be one that cost-effectively contributes to energy and environmental policy objectives, e.g. in terms of least cost per tonne of avoided CO_2. This in turn depends on the level of energy and environmental objectives, and how other energy alternatives can help meet them in different sectors (e.g. new technologies for the transport sector, and carbon capture and storage (CCS) in power).

So, the best use of biomass will depend entirely on the policy priorities and how these can be met in different sectors. Since individual countries differ in their energy infrastructure and the sources of energy they have access to, each will probably prioritise and incentivise its biomass use differently.

2. If climate change mitigation in the energy sector is the objective, how can biomass be used most cost-effectively?

Producing heat and power are in general more cost-efficient and land-efficient ways of using biomass to reduce greenhouse gas emissions than producing transport fuels, especially if coal use is replaced. However, while there are other renewable and low carbon options for producing heat and power, biofuels are very well placed to contribute to the reduction of transport emissions, as there are currently limited cost-effective abatement options available.

If other options do not mature and become more cost effective, then this may be the best way to use biomass, though it still may be of interest as a complement to other transport abatement options, such as hybrid vehicles. This is also true if there is the ambition to achieve large reductions in GHG emissions in the short to medium term, implying a need to tackle the transport sector.

3. What is the impact of greenhouse gas emissions from direct and indirect land use change on the greenhouse gas balances of biofuels?

Emissions from direct and indirect land use change can substantially reduce the GHG benefit of biofuels that are based on cultivated feedstock, and potentially lead to very long greenhouse gas payback times to make up for those emissions. The extent of the impact of land use change depends on the land that is converted, the type of crop that is planted, and the efficiency with which it is used. The use of waste and residues from agriculture and forestry largely avoids this problem, although there may be instances where this use also leads to indirect land use change if the previous users of the biomass are forced to shift to using cultivated biomass.

4. Is it better to use land for carbon sink creation or for bioenergy production?

On a short timescale, carbon sinks can provide cheaper and larger greenhouse gas reductions per hectare of land than bioenergy production – especially if low efficiency bioenergy use is the alternative. However, the sink option is constrained by saturation (only a limited amount of carbon can be stored on a hectare of land), whereas bioenergy can be produced repeatedly, from harvest cycle to harvest cycle, thus accumulating emissions reductions in time. Longer timescales therefore tend to favour bioenergy production. The impacts of the two options other than on greenhouse gas emissions also need to be considered. Finally, these two options are not mutually exclusive: depending on where and how they are established and managed, bioenergy systems are themselves net sources or sinks of carbon, and a forest established for the purpose of sequestering carbon can be managed to produce timber and other forest products.

5. Can biofuels play a role in improving energy security?

The use of domestic biomass resources improves energy security. Also, biomass imports from widely distributed international sources would generally contribute to a diversification of the energy mix and improved energy security. However, the effective contribution largely depends on the extent to which the bioenergy production system is decoupled from oil and gas inputs. The best use of biomass to address energy security concerns will vary – some countries may prioritise the substitution of natural gas imports while other countries see oil import dependency as the major concern.

6. How can food insecurity and other negative socio-economic impacts be mitigated?

At the macro level, policies causing rapidly increasing and price-inelastic demand for biofuel feedstocks should be avoided, as they can result in negative impacts on food security and other socio-economic aspects. Instead a cautious approach to biofuels expansion is needed that mitigates potential risks through an understanding of the elasticity of the system and by stimulating the use of resources and technologies that limit the impact on basic food production. At the implementation level, companies investing in developing countries need to effectively engage local communities and make them partners in the development of a biofuels industry that is integrated with food production, thus reaping the benefits of the inflow of technology, infrastructure, capital, and income for the benefit of both food and bioenergy production.

CHAPTER 6: MAKING POLICY FOR BIOENERGY DEPLOYMENT

Key questions addressed in this Chapter:

1. Why is bioenergy dependent on policy support, and what considerations justify this support?
2. What are the ingredients for successful bioenergy policies?
3. Which policy instruments can be applied to promote and deploy bioenergy?
4. What are the main instruments that are characteristic of bioenergy policy making in the heat, electricity, and biofuels sectors?
5. Should feed-in tariffs or quota systems be preferred?
6. How can sustainable production and use of bioenergy be guaranteed?

6.1 Introduction

The external costs and benefits of energy production options are not sufficiently reflected in energy prices, an important reason why most bioenergy solutions are not (yet) economically competitive with conventional fossil fuel options. Policy support is therefore essential for almost all bioenergy pathways. Furthermore, specific policies may be needed for removing bioenergy introduction barriers as described in Section 4.4.

The specific formulation of bioenergy policies can have major consequences for bioenergy options and can make or break business opportunities. Furthermore, their specific formulation influences the extent to which introduced technologies contribute to the underlying policy objectives, such as greenhouse gas emission reduction, energy security improvement, economic development, and overall sustainability. Strategies need to be well-designed if bioenergy options are to be developed, introduced and deployed. Biomass is an energy source that offers important large-scale solutions, but can also contribute to local energy supply. Therefore, successful deployment of bioenergy requires not only a national policy strategy, but also energy planning and incentives at local administrative levels (see Table 6-1).

Table 6-1. Key motivations for bioenergy policy, as stated in country summaries and key policy documents. Source: GBEP (2007).

Country	Objectives						
	Climate change	Environment	Energy security	Rural development	Agricultural development	Technological progress	Cost effectiveness
Brazil	X	X	X	X	X	X	
China	X	X	X	X	X		
India			X	X		X	X
Mexico	X	X	X	X		X	
South Africa	X		X	X			
Canada	X	X	X			X	
France	X		X	X	X		
Germany	X	X		X	X	X	X
Italy	X		X		X		
Japan	X	X			X	X	
Russia	X	X	X	X	X	X	
UK	X	X	X	X			X
US		X	X	X	X	X	
EU	X		X	X	X	X	

A main driver behind bioenergy policies is the cost reduction that can be achieved through market introduction of bioenergy technologies (learning by doing), which can finally lead to competitive cost levels. A long-term structural cost gap may be defendable taking external benefits of bioenergy into account. The valuation of these external benefits may differ between countries and regions. As Chapter 5 shows this may lead to different emphases in policy making, both in terms of sectors supported and in the specific policy measures applied. In this chapter, we summarise knowledge and experience in setting up successful bioenergy policies.

6.2 Common Lessons for Bioenergy Policy Making

On the basis of current knowledge and experience (Menanteau et al., 2003; Sawin 2004; GBEP 2007; IEA 2007b; Junginger 2007; Lehtonen 2007; IRGC 2008; Neeft et al., 2007), several general recommendations can be given for sensible bioenergy policy making:

- A policy initiative for bioenergy is most effective when it is part of a long-term vision for bioenergy. Such a vision should be clear about its motivation (see Chapter 5). Furthermore, the vision should identify the specific national or regional strengths that bioenergy options could build on, e.g. in terms of existing or potential available feedstocks, the trade and infrastructure context, and specific features of the industrial sector. Almost all successful bioenergy policies were able to open up opportunities that were already partly available in the country.
- Long-term continuity and predictability of policy support appears to be pivotal for successful development of bioenergy options. This implies that, from the start, policies should take into account the specific characteristics of the options involved (e.g. in terms of the key factors affecting their competitiveness) and provide sufficiently long-term measures to address them. This does not mean that all policies need to be maintained forever, however it improves policy predictability when the duration of a policy regime is clearly stated in the beginning. For further details see Section 6.4.
- Bioenergy policies should take into account the development stages of specific bioenergy technologies, and provide incentives consistent with the barriers that an option is facing. The best-fit type of policy support for early markets, be it quantity-based obligations or subsidies reducing production costs, strongly depends on the characteristics of the option and its market development. Factors such as technology maturity, market transparency, the allocation of market power and the split between investment and variable costs need to be taken into consideration. Further details are provided in Sections 6.3 and 6.5.
- Access to markets is critical for almost all bioenergy technologies. For biomass-to-power, connection to the grid is the key issue that needs to be addressed at the power distribution network level. For biofuels, standardisation of biofuels and of vehicles (in the case of higher blends) is essential for reliable market access. As biofuels are increasingly becoming a globally traded commodity (see Section 4.2), national standards will need to converge into internationally acknowledged ones.
- As all bioenergy options depend on feedstock availability, a policy strategy for bioenergy should pay attention to the agricultural, forestry and waste sectors from which feedstock is expected to come. In the long-term, specific support for productivity improvement in these sectors will be pivotal for reconciling feedstock demand from, for example, the food, feed, and wood processing industries and the bioenergy sector. This is also key for the reduction of impacts in agricultural commodity markets (see Section 4.3).
- As with any policy related to technology development or otherwise, a policy strategy on bioenergy should meet several standard criteria such as credibility, enforceability, clarity, simplicity, and transparency.
- A long-term successful bioenergy strategy will also need to take into account sustainability issues. Policies safeguarding bioenergy sustainability are currently in rapid development. Important issues are energy and greenhouse gas balances, direct and indirect impacts on land use, and other environmental, social, and economic impacts. Due to the complexity of the sustainability issue, future policy making on bioenergy will need to focus on integrated approaches, in which the complex interactions with other policy domains such as land use, agriculture and forestry, and human development are taken into account. For further details see Section 6.6.
- Finally, bioenergy support policies are a precondition, but not a guarantee for the successful development of bioenergy. Other critical factors include the legal, administrative, technological, and cognitive framework. Unforeseen barriers can affect the introduction of installations, and also the set-up of feedstock supply and reliable logistics; both essential for successful bioenergy initiatives. As such factors are often affected by other governmental departments, internal streamlining and checking of policies for consistency are crucial.

6.3 Bioenergy Technology Support Instruments for Different Development Stages

As with any technology, several stages can be identified in the development of bioenergy, and for each stage, specific policy instruments apply. Figure 6-1 gives an overview of instruments, roughly structured by development stage, based on a wide set of reviews (Sawin 2004; van der Linden et al., 2005; Ros et al., 2006; GBEP 2007; IEA 2007b; Neeft et al., 2007; OECD 2008a). In the different phases, support needs to be directed at:

- RD&D – learning by searching: invention by R&D efforts, pilot and demonstration projects, and assessment of market prospects.
- Early market – learning by doing: improving competitiveness with established options, and building practical experience.
- Mass market – deploying: incentives for further technology and production cost reduction, broader regulation, and policies enabling wide deployment of sustainable bioenergy projects and products.

6.3.1 Policies related to the RD&D phase

We can distinguish between two main mechanisms for taking bioenergy options through the RD&D phase: direct or indirect R&D funding, and measures aimed at reducing investment risks.

- RD&D funding is a very common way for governments to encourage technology development in its initial development phase. This provides support for options that are considered promising by researchers and/or market actors. Apart from direct funding, RD&D funding can also be carried out indirectly under Public-Private Partnership (PPP) arrangements.
- Investment related subsidies, e.g. for the realisation of pilot and demonstration projects, have a direct impact on reducing the initial barrier of investment costs. Government support can help overcome this threshold by direct investment subsidies, soft loans, and fiscal measures decreasing investment costs. In particular soft loans and fiscal measures may be extended to the initial market phase of a technology.

6.3.2 Policies related to early markets

After bioenergy options have passed the demonstration phase, there often remains an excess cost in comparison with existing commercial technologies. In the early market stages, a key objective of policies is to reduce this cost gap by allowing the technology to be introduced and by building up experience (learning by doing). Three categories of instruments are applied in this context:

- Measures reducing production costs, in the form of feed-in tariffs, feed-in premiums, and tax exemptions. These incentives can be targeted at different parts of the supply chain – feedstock producers, energy producers, and distributors. To create an incentive for cost reduction and avoid structural 'addiction' to subsidies, the level of financial support can be reduced over the years (albeit in a gradual and well-planned manner). The level of support can also be differentiated to reflect the cost of different technologies. Costs of such policies can be carried by the government (the taxpayer ultimately paying the cost), or they can be redistributed among consumers by, for example, a levy on non-renewable energy, making the policy budget revenue neutral for the government.
- Quantity-based instruments, in the form of quota obligations and tendering schemes. Quota obligations are minimum shares of bioenergy imposed by governments on consumers, suppliers, or producers, and include a penalty for non-compliance. An obligation can be combined with a system of tradable certificates in order to improve cost-efficiency and provide a compliance mechanism. Generally, an obligation system does not require additional governmental spending: costs are borne by the parties to which the obligation applies. In the case where the obligation is placed on a producer or a supplier, the costs are generally passed on to the consumer. In tendering schemes, an obligation (e.g. to produce bioenergy) is sold in an auctioning mechanism to the bidder who offers the best price, e.g. the lowest required subsidy level to meet the obligation.
- Measures related to market access can facilitate early market penetration of new technologies by giving them preferred access to markets or infrastructure (e.g. public procurement, preferential access to the grid), or by standardising the product. These are typically measures that act as a prelude to early markets.

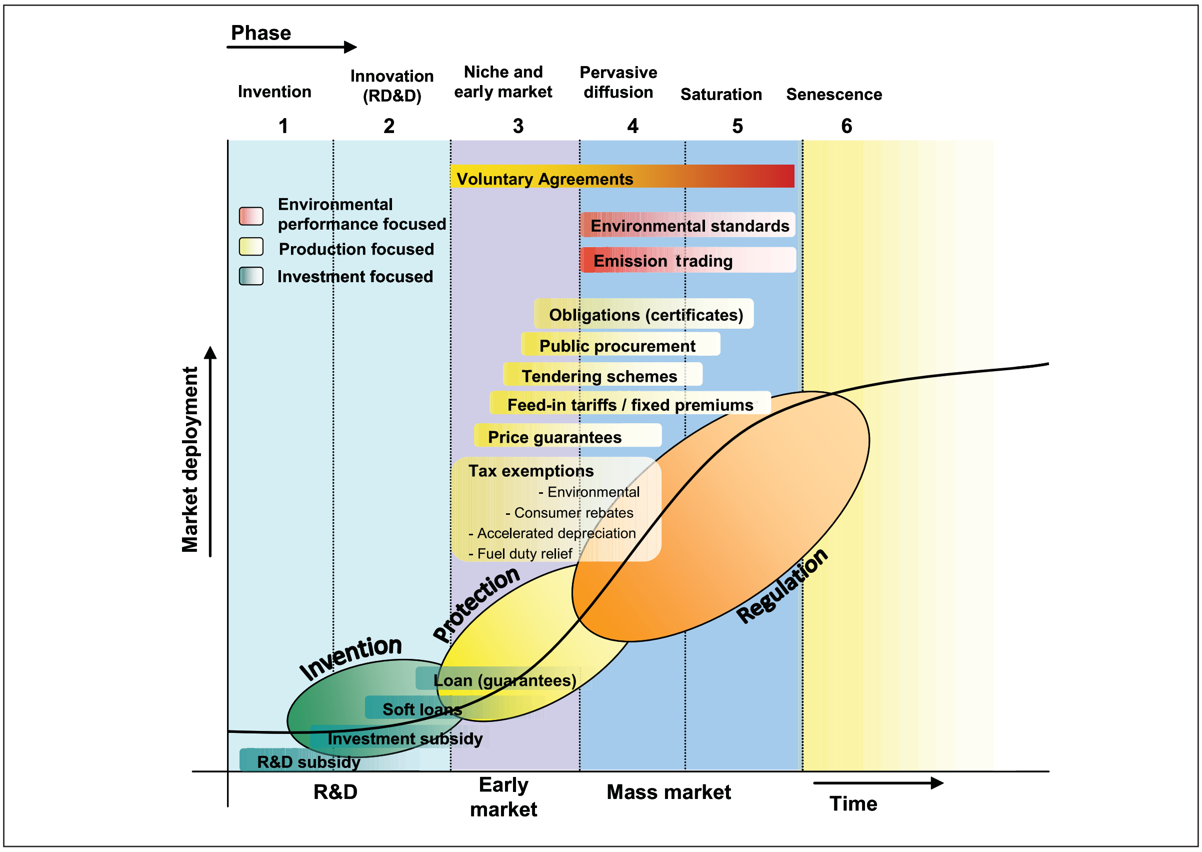

Figure 6-1. Overview of policy instruments for each technology development stage. Adapted from Ros et al., (2006).

The different support instruments categorised above have their specific strengths and weaknesses.

- Feed-in tariffs and premiums, if well designed usually provide more long-term certainty of support for investors, reducing investment risks compared to quota obligations. Although feed-in tariffs and premiums allow for technology-specific support, thereby reducing windfall profits for low cost technologies, there is still a need for governments to have sufficient information on technology costs in order to set an appropriate support level.
- An obligation entails more certainty for a government that a target will be met, but requires sufficient players to create a liquid certificate market. Furthermore, a generic obligation set to, for example, renewable power generation will not distinguish between different technologies, and will thereby only encourage short-term low-cost technologies to enter the market, not options that are currently expensive but have a substantial cost reduction potential. Tradable certificate markets are usually more complex to design than feed-in systems, and operators have to be active in two markets; the energy market and the certificate market. In tendering systems, in which technology developers compete for contracts (and corresponding support) and the most competitive bids are awarded, it is possible to set the quantity to be achieved and the price to be paid for this quantity. If applied properly, tendering stimulates competition between producers and results in cost-efficiency and price reduction. However, the procedures for successful tendering can be complex and therefore difficult to implement. In many countries it is common to promote bioenergy using a combination of instruments, e.g. a quota obligation combined with a moderate production subsidy or tax exemption.

6.3.3 Policies related to mass markets

After the early market entry of a new technology, structural support may be required and should be defendable on the basis of its positive external effects. However, sustained support for bioenergy on a sheer production basis has its drawbacks, as it does not guarantee that the bioenergy options applied align best with the background motivations for promoting it (think of a generic biofuels policy that also provides incentives for biofuels that hardly reduce greenhouse gas emissions). Furthermore, pursuing diverse objectives such as energy security, climate change abatement, and economic development by a single (bioenergy) policy is rarely efficient (IRGC 2008). Policies can then provide incentives directly related to the external effects, for example in the form of CO_2 emission taxes or trading systems that are technology neutral.

6.4 Key Characteristics of Bioenergy Policies by Sector

For each sector, the optimal policy mix depends on the characteristics of specific bioenergy technologies. The current application of different instruments by sector for G8 + 5 countries can be found in Table 6-2. This section, reviews current experiences in heat, power and biofuels.

Table 6-1. Key motivations for bioenergy policy, as stated in country summaries and key policy documents. Source: GBEP (2007).

Country	Energy Policy							
	Binding targets/ Mandates[1]	Voluntary targets[1]	Direct incentives[2]	Grants	Feed-in tariffs	Compulsory grid connection	Sustainability criteria	Tariffs
Brazil	E,T		T					Eth
China		E,T	T	E,T	E,H	E,H		n/a
India	T,(E*)		E	E,H,T	E			n/a
Mexico	(E*)	(T)	(E)			(E)		Eth
South Africa		E,(T)	(E),T					n/a
Canada	E**	E**, T	T	E,H,T				Eth
France		E*,H*,T	E,H,T		E			As EU below
Germany	E*,T		H	H	E	E	(E,H,T)	As EU below
Italy	E*	E*,T	T	E,H	E	E		As EU below
Japan		E,H,T				E		Eth, B-D
Russia		(E,H,T)	(T)					n/a
UK	E*,T*	E*,T	E,H,T	E,H	E		T	As EU below
USA	T	E**	E,H,T	E,T	E			Eth
EU	E*,T	E*,H*,T	T	E,H,T		E	(T)	Eth, B-D

E: electricity, **H:** heat, **T:** transport, **Eth:** ethanol, **B-D:** biodiesel
*: target applies to all renewable energy sources, **: target is set at a sub-national level
(..) policy instrument still under development/awaiting approval
1 blending or market penetration
2 publicly financed incentives: tax reductions, subsidies, loan support/guarantees

6.4.1 Heat [28]

Although it is by far the most widespread application, the use of small-scale biomass for heating has been generally overlooked by policy makers. In developing countries, policies relating to biomass for heat mostly focus on the introduction of more efficient stoves and other appliances with reduced emissions or local air pollutants. In developed countries, biomass heat applications may be competitive in some situations, depending on the alternative heating source and the availability of relatively low cost local wood or agricultural residues, but they will generally require some form of support. In some countries, biomass application to domestic heating in modern stoves has been stimulated by investment subsidies or fiscal measures reducing investment costs, and by standardisation of appliances in order to improve their reliability and efficiency, and reduce their emissions (BERR 2008).

The majority of successful policies in biomass for heat in recent decades have focused on more centralised applications for heat or combined heat and power, in district heating and industry. For these sectors, a combination of direct support schemes with indirect incentives has been successful in several countries. In Sweden, for example, several measures that spurred biomass-based district heating and CHP were implemented gradually (Junginger 2007):

- Some aiming at taxation of fossil energy use (e.g. carbon and fossil energy taxes in 1991, an increase in carbon tax in 2000, a tax on electricity of fossil origin for households and services in 2004, an increase in the carbon tax level to about €100/t CO_2 in 2006), providing indirect but strong support to biomass for heat (and power).
- Some specifically aiming at biomass-based CHP (e.g. investment subsidies for new installations between 1997 and 2002, and a Green Electricity Certificate system from 2003).

In particular the continuity and the complementary character of the various measures seem to have been key factors to their success (Junginger 2007). The existence of district heating systems and the availability and reliability of biomass supply chains also seem to have been critical factors in the success of centralised biomass-to-heat and CHP.

Finally, quality and continuity of biomass supply is an important potential barrier that policies can reduce. As heat demand is usually of a constant nature, the stability of supply is particularly crucial for heat applications. For example, the UK allocated several million pounds between 2005 and 2008 to develop the supply chain and market infrastructure for wood and straw fuels under its Bioenergy Infrastructure Scheme. This policy specifically aims to develop the supply chain required to harvest, store, process and supply the biomass for CHP plants.

6.4.2 Power generation

In the power sector, feed-in tariffs have gradually become the most popular incentive for bioenergy and for renewables in general. Mostly, tariffs are differentiated between types of technologies even within bioenergy (e.g. co-firing in coal-fed plants, stand-alone biomass combustion/gasification, and anaerobic digestion). Most systems guarantee an investor a fixed tariff level over a given number of years. In some countries, future tariffs for new projects are also set in advance. In contrast, quota systems have so far been less successful in getting renewables (and bioenergy) off the ground (van der Linden et al., 2005). It seems that an effective quota system requires careful planning in order to prevent its main pitfall, a lack of investment security for producers. For tendering schemes, the critical issue is avoidance of situations with a limited number of bidders, as full competition is essential for this mechanism.

The success of any feed-in tariff strongly depends on the tariff being set at a sufficiently attractive level for an investor to make a profit. In contrast to other renewable technologies such as wind and solar, in which capital costs dominate production costs, bioenergy projects can come with a substantial share of variable costs in the form of feedstock costs. This complicates the calculation of feed-in tariffs, and makes projects vulnerable to fluctuations in feedstock prices. Co-firing of biomass pellets in existing coal-fed power plants is the clearest example: investment costs are relatively minor, and the attractiveness of co-firing almost solely depends on the costs of biomass versus those of coal (sometimes with the addition of a CO_2 tax). As large-scale power plants purchase commodities on the global market, their costs may fluctuate on a daily basis, and so will the financial gap between them. A feed-in tariff may need to take such dynamics into account, e.g. by regular adjustment or by making the subsidy dependent on coal and pellet prices.

Next to feed-in tariffs or quotas, almost all countries that have successfully stimulated bioenergy development have applied additional incentives relating to investment support, such as fiscal measures or soft loans (GBEP 2007). Such measures reduce the initial financial hurdle and reduce private investment risks.

Additionally, grid access for renewable power is an important issue that needs to be addressed. This can be a particular bottleneck for distributed, medium-scale technologies such as biogas-to-power. Priority grid access for renewables is applied in most countries where bioenergy technologies have been successfully deployed (Sawin 2004).

Even when bioenergy-related policies create a favourable climate for new initiatives, other barriers may cause policy failure. For example, biogas-based power production from manure and co-substrates evolved very differently in Germany and the Netherlands, although both countries have regions with intensive animal husbandry and both adopted policies for this technology.

- In Germany, biogas production has increased rapidly in the past decade, mainly due to the attractive feed-in tariffs for this technology, including a bonus for the use of cultivated crops, such as corn, as co-substrates[29]. The country now accounts for almost 80% of total EU power generation by co-digestion-based biogas production (Eurobserv'ER 2008a).

[28] Unless mentioned otherwise, information in this sub-section derived from IEA (2007).

[29] The German success was also due to a very simple pragmatic approach to digester design, which, together with good technical support, decreased capital and ongoing costs and enabled farmers to operate plants successfully.

- Austria had a comparable feed-in tariff to Germany resulting in an equal growth in biogas plants per capita. However, when the high feed-in tariff reached the cap in 2006, the construction of new plants halted.
- In the same period, the Dutch renewables feed-in premium system was also open to biogas-to-power, but in practice manure handling regulations prevented the use of co-substrates, thereby decreasing biogas profitability to unattractively low levels. In 2004, the application of co-substrates was allowed, leading to new projects being initiated. However, the country has not caught up from its initial slow start: In 2007 the agricultural biogas production per capita in Germany was still about four times higher than in the Netherlands (Eurobserv'ER 2008a). This example shows that initial policy failure can have long-term impacts.

6.4.3 Biofuels

Globally, three regions have led the way in biofuels policy until now (GBEP 2007; Neeft et al., 2007):

- Brazil, starting with the ProAlcool programme in 1975; mainly triggered by energy security considerations, and making use of the existing sugar-cane production infrastructure.
- The USA, starting with the Energy Security Act in the 1980s, followed by the 1992 EPACT and the EPA Clean Air Amendments, and developed further in the 2002 Farm Bill; mainly triggered by energy security, air pollution and rural support considerations, and making use of the existing corn production infrastructure.
- The EU, member state support policies starting in the 1990s, major EU-level policies starting with the 2003 Biofuels directive; first triggered by rural support considerations, followed by climate change and energy security considerations, with production mainly based on oil seeds (especially rapeseed). The renewables directive, adopted by the European Parliament in December 2008, recognises all these policy drivers for biofuels and contains several criteria for biofuels sustainability (EP 2008).

Although policies in these regions were developed in different times with different motivations, there are some similarities:

- In many countries, the policy mix consists of a combination of obligations, mostly applied to fuel suppliers, and financial incentives, either in the form of a tax exemption at the pump or as production and investment subsidies to biofuel or feedstock producers (GBEP 2007; OECD 2008b). Their combination seems to be most effective: an obligation creates demand for biofuels, while financial incentives facilitate the development of production capacity.
- Additionally, all three regions have supported major efforts in RD&D. In Brazil, ProAlcool covered R&D programmes on all parts of the supply chain (Lehtonen 2007), now the USA and the EU are strongly supporting R&D, mostly in 2nd generation biofuels (GBEP 2007).
- Recently, new policies have been developed that provide an incentive for biofuels on the basis of their climate merits, and simarlarly differentiate between specific biofuels on this basis. This is the basis of the California Low Carbon Fuel Standard and the proposed update of the EU Fuel Quality Directive. Generally, several studies stipulate that biofuels policies should not strive for biofuels development as such, but for the introduction of biofuels that best comply with the motivations that drive biofuels policy (Sawin 2004; Londo and Deurwaarder 2007; Lee et al., 2008; OECD 2008a).

Additionally, two policy-related issues have appeared to be crucial for successful implementation of biofuels: adaptation of vehicles and fuel standardisation.

- While minor shares of ethanol and biodiesel can be blended with their fossil equivalents without problems, use of these biofuels as higher blends or in pure form does require specific vehicle alterations. Policies have gradually shifted from vehicles that could run on pure biofuel (such as the E100 vehicles in Brazil in the 1980s and the B100 guarantees of several German car brands in the early 2000s (Neeft et al., 2007) to vehicles that run on a range of fossil/biofuel blends, such as the ethanol flexi-fuel vehicle. This was mainly motivated by the need to increase the flexibility in biofuels end-use.
- Additionally, biofuels themselves need to be standardised to ensure their reliability. Therefore, governments have guided standard setting processes for ethanol and biodiesel along with the introduction of policies. As a next step, normalisation authorities of Brazil, the USA, and the EU have started integrating their standards into a single global standard for ethanol.

Several examples show the importance of an integrated set of incentives for a successful introduction of biofuels:

- In Brazil, Sweden and the USA, incentives for the introduction of ethanol flexi-fuel vehicles (FFVs) have contributed to 6.5 million of these vehicles being on the road by 2008. However, as the introduction of E85 in fuelling stations was not encouraged centrally in the USA, only a limited number of stations have started providing these fuels there (mainly in the Mid-West), and the number of FFVs regularly running on E85 is probably modest. In contrast, in Sweden and Brazil E85 is sold at many stations throughout the country.
- India set out an ambitious biofuels vision in 2003, mainly motivated by air quality considerations. However, a specific incentive, in the form of an obligation on fuel distributors, was only introduced in 2007. Due to discussions on the possible competition between food and fuels, the introduction of policies supporting domestic biofuels production lagged behind, therefore the incentive only spurred limited biofuels growth. In 2008, measures to support feedstock production were introduced, including oil crops such as *Jatropha* that provided a possible solution to the food-fuel conflict in the country. With the disputes on policy formulation and delayed attention to feedstock availability, the period between 2003 and 2007 was basically lost.

6.5 Other Policy Domains Relevant for Bioenergy

Apart from instruments aimed at the introduction of bioenergy technologies themselves, several other policy domains are highly relevant to bioenergy. In this section we focus on agricultural, forestry, trade, and environmental policies, and communication and public support.

6.5.1 Agricultural policies

The link between bioenergy and agricultural policy is strong, especially for conventional 1st generation biofuels, which make use of food crops (OECD 2008b). Reverse effects, i.e. the impact of biofuels policies on agricultural markets, are discussed in Section 5.3. As agricultural markets are strongly regulated in most OECD countries, almost all developments in this policy domain affect the competitiveness of biofuels. There are a wide range of policies in this area: subsidies or intervention prices for specific crops, maximum production quotas, or direct support to farmers (GBEP 2007; OECD 2008a). Other known measures are direct supply-regulating schemes such as the EU's set-aside scheme, and the energy crop support scheme (a hectare-based subsidy) that was operational in the EU for several years (EC 2006a). Also the introduction of advanced bioenergy technologies that use lignocellulosic material as feedstock will have long-term implications for agricultural policy as increasing demand for this type of feedstock may call for dedicated woody or herbaceous cropping systems, and their inclusion into agricultural policy.

An important aspect that policy needs to consider is the productivity development in agriculture that is needed to meet demand for food, feed, and bioenergy in the long-term, without causing conversion of natural areas to new agricultural land. This will require a continuous increase in agricultural yields in mainly developing countries. Fundamentals are discussed in Sections 2.1 and 4.3. For agricultural policy, the challenge is to support agricultural development, by measures such as supporting investments by farmers and enhancing technology R&D in the sector.

By increasing yield potentials, GMOs can increase both the resource base for energy crops as well as the yields of energy crops themselves. Future developments depend strongly on the global policy debate on GMOs.

6.5.2 Forestry policies

For the generation of heat and power, bioenergy routes mostly use woody biomass, predominantly forestry, and wood processing residues. Therefore policies that affect productivity of forests and the wood-processing industry have a direct impact on feedstock availability for bioenergy. Measures can be directed to a wide range of objectives (EC 2006b; OECD 2008b): increasing physical productivity (e.g. by improvement of management practices); removing practical barriers (e.g. by improving access, or clearing forest ownership issues); but also to other uses of forests (e.g. biodiversity and recreational functions) that may interfere with productivity and harvestable shares.

6.5.3 Land use planning policies

Closely related to agricultural, forestry and environmental policies, land use planning and spatial policies can also strongly affect bioenergy, mainly in terms of feedstock availability. Land evaluation and land use planning are proven instruments for improving the physical basis of agriculture, e.g. by improving water management and transport infrastructure, increasing parcel size, and identifying the most appropriate crops and cropping systems. Comparable approaches can be used to improve prospects in forestry.

Spatial policies also influence bioenergy. For example, they can regulate urbanisation so that urban sprawl does not excessively convert agricultural land. Furthermore, nature reserves are usually protected through spatial policies. This is particularly relevant within the sustainability discussion, as the conversion of nature reserves into land for energy crops can lead to significant penalties in terms of biodiversity and soil carbon losses.

6.5.4 Trade policies

Several aspects of trade policy also affect bioenergy. Import and export tariffs can be applied to feedstocks as well as end products such as liquid biofuels. Almost all OECD countries apply import tariffs to agricultural commodities and products (GBEP 2007). Generally, tariffs on end products are higher than those on feedstocks, favouring industrial processing in the importing country. Additionally, quotas of duty-free trade may be opened to specific exporting countries, on the basis of bilateral agreements. As mentioned in Section 4.3, trade policy can also be applied to exports. For example, an export tariff applied by major feedstock producing countries protects their domestic markets from a price hike, but reduces the incentive of a high feedstock price for farmers in these countries to increase their production. Several grain producers imposed such taxes during the 2007/2008 food price hike. Indirectly, a Russian export tariff on unprocessed roundwood, to be gradually implemented between 2007 and 2009 (USDA 2007), will have a stimulating effect on the availability of wood pellets from Russia, as the tariff provides an incentive for the Russian wood processing industry and thereby increases the availability of wood processing residues for pellets in the country. The overall system of trade policies and tariffs is an ongoing source of dispute within the World Trade Organisation.

Another issue related to trade is the absence of a trading platform for bioenergy feedstocks, and corresponding quality standards. In particular, trade in woody materials such as pellets could benefit significantly from the introduction of a trading platform, as this usually makes the market more transparent and liquid. Furthermore, heterogeneous streams such as woody residues need standardisation of material characteristics (Alakangas et al., 2006).

6.5.5 Environmental policies

Bioenergy technologies can have environmental impacts at different stages of their production chain: in feedstock production, conversion, end-use and in logistics. Obviously, existing regulations are in place to address environmental issues, for example, in agricultural production, industrial facilities, and emissions from vehicles. However, the introduction of new bioenergy routes often calls for dedicated measures. In the case of new conversion technologies, for example, the lack of experience in best practices and achievable emission limits can be a barrier to introduction, as local regulators would lack reference material for an environmental permit. Guidelines from central government can help to reduce this implementation obstacle. Certification initiatives for safeguarding sustainability of imported biomass and biofuels are further discussed in Section 6.6.

6.5.6 Communication with the public and education of relevant professional groups

Communication about bioenergy is essential to build public support (IEA 2007b). Furthermore, information and education should be directed to professional groups that need to get acquainted with different bioenergy technologies. This applies, for example, to technical personnel who need to obtain the skills for correct installation of domestic biomass-based heating systems.

6.6 Sustainability Policies and Certification[30]

With the rapid development of bioenergy, attention to its potentially negative impacts is also increasing (see FAO 2008). For example, production of biomass energy crops and excessive removal of biomass residues from forest and agricultural systems for energy production can result in negative ecological impacts, changing land use patterns, socio-economic impacts, and GHG emissions. With considerable further increase in bioenergy expected, sustainability of bioenergy is becoming a key concern and is currently being considered as a possible requirement for market access.

Defining sustainability criteria and setting standards are logical strategies to help ensure that biofuels are produced in a sustainable manner. Sustainability has environmental, social, and economic dimensions, and in all parts of the bioenergy chain, safeguarding sustainability is complex and multi-dimensional. Currently, much discussion is focussing on sustainability safeguarding mechanisms, particularly certification. Certification is the process whereby an independent third party assesses the quality of management in relation to a set of predetermined requirements (standards). In this section we describe the most common principles or criteria that have been proposed for the safeguarding of sustainability, currently proposed mechanisms to meet these principles, implementation strategies, and key implementation issues.

6.6.1 Sustainability principles relating to bioenergy

Sustainability is a multi-dimensional concept. In the context of sustainable bioenergy, several initiatives aiming at bioenergy certification (see Annex 6-1) have been elaborated into a set of key principles. These are commonly:

- Greenhouse gas balance: Bioenergy chains should reduce greenhouse gas emissions compared to their fossil reference. This also includes emissions of soil carbon induced by land use changes.
- Energy balance: Bioenergy chains should generate more energy than that needed for feedstock production, conversion, and logistics.
- Biodiversity impacts: Bioenergy chains should not negatively affect biodiversity.
- Impacts on production of food: Bioenergy chains should not endanger the supply of biomass for food, materials, and other applications.
- Other environmental impacts: Bioenergy chains should not lead to negative impacts on soil, water, and air quality.
- Impacts on economic development: Bioenergy chains should contribute to local prosperity.
- Impacts on welfare: Bioenergy chains should contribute towards social well-being for employees involved and for the local population.

These principles need to be converted into criteria and indicators, against which bioenergy can be measured. Full-chain lifecycle approaches provide the framework to perform such assessments.

6.6.2 Key characteristics of bioenergy certification systems

Spurred by increasing concerns about undesired impacts of the rapid introduction of bioenergy, several platforms are currently developing certification systems. Some initiatives come from governments with obligations on bioenergy uptake, e.g. the UK system for its Renewable Transport Fuel Obligation (RTFO), the Dutch 'Cramer Criteria' for its national biofuels and biomass-to-power schemes, and the EU efforts related to the Renewable Energy Directive. Others are initiated by private parties, in an effort to implement their social responsibility on a voluntary basis. Examples are the biomass labels introduced by power producers Essent and Electrabel, and the efforts made by several roundtable groups, such as the roundtables for sustainable palm oil (RSPO), for responsible soy (RTRS), and for sustainable biofuels (RSB). All of these initiatives differ in the specific sustainability issues they try to address, and in their practical elaboration. A key challenge is the GHG calculation.
A detailed table with the key characteristics of several initiatives can be found in Annex 6-1.

From principles to criteria and indicators. After defining the general principles, the next step is their translation into concrete criteria and measurable indicators. For some principles, translation into indicators is relatively easy, and most certification initiatives propose comparable methodologies. However, some other principles are difficult to translate into measurable quantities. Generally, there is also a clear trade-off between obtaining perfect information and practical limitations in data gathering: an ideal set of indicators may require data gathering efforts that significantly increase the costs of bioenergy or their feedstocks.

Level of implementation. Certification schemes can be implemented on several levels in the bioenergy supply chain. They can cover the impacts of the entire supply chain, including feedstock production, conversion, end-use, and logistics. Other initiatives, however, focus on the feedstock production step. This is particularly related to schemes that are inspired by the impacts of increasing biomass trade.

Accounting mechanisms (chain of custody). Obviously, a certification system requires a mechanism to account for the bioenergy produced under the scheme. Generally, three types of accounting can be distinguished:

- 'Track and trace sourcing': A flow of information accompanies the physical flow of biomass along the supply chain. Most 'fair trade' products have a track and trace system.

[30] Unless specified otherwise, this section is based on van Dam et al. (2008) and Marchal et al. (2008).

- 'Book and claim': A certified producer of biomass receives a quantity of certificates, which are traded independently from the physical flows of biomass. Renewable power certificates work this way.
- An intermediate system of 'mass balancing', in which the biomass is traceable to the source but can be blended along the supply chain. The FSC certification system for construction wood works this way, and the EU renewable energy directive also opts for this mechanism.

The strength of the first approach is that the sustainability characteristic is bound with the specific batch of biomass. But it comes with an additional administrative burden and it complicates trade. As biomass trade flows become more complex and intermingled, a book and claim system may be more robust and cost-effective. There is no clear tendency in current certification initiatives as to which mechanism is preferred. Any type of accounting is accompanied by a verification mechanism, often under the responsibility of an independent verifier or 'clearing house'.

Implementation issues. A sustainability scheme in bioenergy faces several implementation issues. Largely, these issues are consistent with problems that earlier certification systems have experienced. At least, a sustainability scheme can therefore (at least partly) build further on experiences in existing schemes (e.g. FSC wood, fair trade food products, and organic products). Key issues are summarised in Annex 6.2.

6.6.3 Addressing indirect effects

Certification is a powerful instrument for checking the impacts of bioenergy that can directly be attributed to a specific production chain. However, bioenergy also has indirect, or 'leakage' impacts. Mostly, they are related to indirect changes in land use (see Section 5.3.2). For example: an existing palm oil plantation is rerouting its production from food to biofuels markets. As an indirect result, a new palm oil plantation is founded in tropical rain forest in another region, leading to deforestation and loss of soil carbon. Alternatively, new palm oil plantations are established on land already in use for agriculture (e.g. coconut plantations), which in turn triggers establishment of new coconut plantations in tropical rain forests. Impacts on global food prices and on regional economic development and welfare may also take place via such indirect routes. Such indirect effects may have unsustainable impacts such as deforestation, loss of soil carbon and greenhouse gas emissions, without them being directly attributable to a specific bioenergy production chain. Therefore, it is difficult to assess such impacts by chain-based approaches. Essentially, nationally or even globally induced land use changes need to be taken into account. This can only be achieved if an integral land use planning vision and strategy are established for entire regions.

Although several studies indicate that indirect effects can truly break the greenhouse gas emission profile of almost any bioenergy feedstock (Eickhout et al., 2008; Searchinger et al., 2008), it is also clear that methods to assess these effects are still poorly developed, and outcomes strongly depend on specific assumptions. In the context of policy making, indirect effects are currently put forward as an argument against too rapid introduction of bioenergy options that strongly depend on cultivated crops, where the bioenergy application directly competes with food production. In looking to develop more sophisticated approaches that address this issue, two options are currently being explored:

- Within a certification system: indirect effects may be taken into account by applying a 'risk adder' to, for example, chain-based calculations on greenhouse gas emissions (Fritsche 2008). In such an approach, a first-order estimation is made of potential leakage effects, which are then added to the production chain.
- Additional to a certification system: Measuring leakage effects is complex and can only be done on national or even international levels. They require macro-level monitoring of changes in land use and changes in markets (Eickhout et al., 2008). In an ideal case, observed leakage effects in the recent past would lead to an additional penalty on specific biomass feedstocks or on specific producing regions. In addition, a bioenergy policy might be connected to an integrated policy vision on land use, in which energy crop production is stimulated with due regard to considerations of food security, biodiversity and the other sustainability criteria mentioned above. However, as indirect effects can occur globally, they can hardly be controlled on a national level.

Conversely, there are also arguments against both approaches. For instance, their compatibility within the WTO is unclear and probably problematic. Also, price and volume effects are spread throughout the world and among several commodities. It is therefore difficult to monitor all possible effects.

6.7 Support for Bioenergy Policy

Several platforms exist to exchange local and regional experiences and best practices in policy making. Some of these are functioning within broader international bodies, such as the IEA and its Bioenergy Agreement, others are dedicated fora, such as the Global Bioenergy Partnership (GBEP), Renewable Energy Network for the 21st century (REN21), and the Renewable Energy and Energy Efficiency Partnership (REEEP). These platforms are open to national and regional/local governments and chiefly aim to accelerate learning processes. Often, exchange of experiences and best practices is facilitated by websites, databases of literature and policy measures in place, and by organising workshops on specific topics. A concise overview of key networks and their contact details can be found in Annex 6.3.

6.8 Key Messages for Decision Makers

1. Why is bioenergy dependent on policy support, and what considerations justify this support?

Several bioenergy routes have been commercial for decades. However others deserve policy support as their technologies still need development before they become competitive. Also, the external benefits of bioenergy (e.g. greenhouse gas emission reduction, reduction of fossil energy dependence) are not appropriately reflected in the market, justifying policy intervention.

2. What are the ingredients for successful bioenergy policies?

Consideration of national strengths in biomass supply and of the characteristics of the energy system, a stable long-term framework, differentiation based on technology development status, and attention to sustainable feedstock supply, are key ingredients of a successful bioenergy policy.

3. Which policy instruments can be applied to promote and deploy bioenergy?

A wide range of policy instruments can be applied to spur bioenergy growth, from R&D support and investment grants to quota obligations and feed-in tariffs, and more technology neutral instruments that reward the performance towards, for example, a greenhouse gas emission reduction objective. The appropriate instrument depends on the development stage of the technologies considered. In each development stage, there may be a specific trade-off between incentives being technology-neutral and closely relating to the policy drivers, and on the other hand creating a sufficiently protected environment for technologies to evolve and mature.

4. What are the main instruments that are characteristic of bioenergy policy making in the heat, electricity, and biofuels sectors?

A multitude of policy instruments and combinations thereof are applied worldwide. Feed-in tariffs seem to be the most popular instrument in the power generation sector, while biofuels are often stimulated with quota obligations and fuel tax reductions. In both sectors, additional measures are often applied, such as investment subsidies (or soft loans) for conversion installations or enhanced capital allowances. Bioenergy policies for heat mostly focus on purchase subsidies on appliances and incentives for bio-CHP.

5. Should feed-in tariffs or quota systems be preferred?

Both feed-in tariffs and quota systems can function or fail. Feed-in tariffs have the advantage of creating a relatively stable investment climate, but do not contain a direct incentive for cost reduction. Theoretically quota systems are better suited to achieve least-cost solutions, however their introduction has proven to provide little stimulus to biomass electricity production whereas the quota applies broadly to renewable electricity generation. Ultimately, the effect of an instrument largely depends on its judicious design and implementation. Combinations of instruments can often be used to compensate for their individual weaknesses.

6. How can sustainable production and use of bioenergy be guaranteed?

At the bioenergy production chain level, sustainability can be safeguarded by certification mechanisms, which are currently under development. Indirect effects, such as impacts on commodity prices and indirect land use change are more difficult to deal with, and will need appropriate regulation of bioenergy chains, bioenergy markets (e.g. levels of quotas and incentives) and land use. In the short-term, it is crucial that these macro impacts are being monitored, analysed and reported.

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ANNEX 1: UNITS AND CONVERSION FACTORS

Annex 1.1: Energy Conversion Factors

To:	GJ	Gcal	Quad (= 10^{15} BTU)	GWh	Mtoe
From:	*Multiply by*				
GJ	1	0.239	9.479×10^{-10}	2.778×10^{-4}	2.4×10^{-8}
Gcal	4.184	1	3.968×10^{-9}	1.163×10^{-3}	1×10^{-7}
Quad	1.055×10^{9}	2.52×10^{8}	1	2.931×10^{5}	25
GWh	3.6×10^{3}	860	3.412×10^{-6}	1	8.6×10^{-5}
Mtoe	4.2×10^{7}	1×10^{7}	4×10^{-2}	11.6×10^{3}	1

Annex 1.2: Metric System Prefixes

Factor	in full digits	in words: one...	SI prefix	Mtoe
$1.0 * 10^{24}$	1 000 000 000 000 000 000 000 000	septillion	yotta-	Y
$1.0 * 10^{21}$	1 000 000 000 000 000 000 000	sextillion	zetta-	Z
$1.0 * 10^{18}$	1 000 000 000 000 000 000	quintillion	exa-	E
$1.0 * 10^{15}$	1 000 000 000 000 000	quadrillion	peta-	P
$1.0 * 10^{12}$	1 000 000 000 000	trillion	tera-	T
$1.0 * 10^{9}$	1 000 000 000	billion	giga-	G
$1.0 * 10^{6}$	1 000 000	million	mega-	M
$1.0 * 10^{3}$	1 000	thousand	kilo-	k
$1.0 * 10^{2}$	100	hundred	hecto-	h
$1.0 * 10^{1}$	10	ten	deca-	da
1.0		one		
$1.0 * 10^{-1}$	0,1	tenth	deci-	d
$1.0 * 10^{-2}$	0,01	hundredth	centi-	c
$1.0 * 10^{-3}$	0,001	thousandth	milli-	m
$1.0 * 10^{-6}$	0,000 001	millionth	micro-	μ
$1.0 * 10^{-9}$	0,000 000 001	billionth	nano-	n
$1.0 * 10^{-12}$	0,000 000 000 001	trillionth	pico-	p
$1.0 * 10^{-15}$	0,000 000 000 000 001	quadrillionth	femto-	f
$1.0 * 10^{-18}$	0,000 000 000 000 000 001	quintillionth	atto-	a
$1.0 * 10^{-21}$	0,000 000 000 000 000 000 001	sextillionth	zepto-	z
$1.0 * 10^{-24}$	0,000 000 000 000 000 000 000 001	septillionth	yocto-	y

Annex 1.3: Currency Conversion Approach Adopted in this Report

For this review, financial data have been used that were expressed in different currencies, US Dollars (US$), UK pounds (UK£) and EU Euros (EU€), and from different years. In order to translate all of this data into the chosen reference year (US$ 2005), the following conversion was carried out:

- First, the UK£ and EU€ currencies were inflated or deflated to 2005 levels, using a domestic output price index (in national currency) for total industry, excluding construction and energy, obtained from Eurostat (www.europa.eu/eurostat)
- Second, UK£ (2005) and EU€ (2005) currencies were converted to US$ using the 2005 year-average exchange rate, which were 1.8189 US$/UK£ (www.bankofengland.co.uk) and 1.2441 US$/EU€ (www.dnb.nl), respectively.

These two steps are summarised in the following conversion table:

Year of source data	2000	2001	2002	2003	2004	2005	2006	2007	2008
1 EU€(year) = US$(2005)	1.331	1.308	1.302	1.292	1.267	1.244	1.210	1.172	1.132
1 UK£(year) = US$(2005)	1.940	1.938	1.938	1.914	1.869	1.819	1.770	1.715	1.658

ANNEX 2: BIOMASS RESOURCES AND POTENTIALS

Annex 2.1: Overview of the Long-term Global Technical Potential of Bioenergy Supply

An overview of the global potential of bioenergy supply over the long-term for a number of categories and the main pre-conditions and assumptions determining these potentials.[1]

Biomass category	Definition	Main assumptions and remarks	Potential bioenergy supply up to 2050 (EJ yr-1)[2]
Energy crop production on surplus agricultural land	Biomass that can be produced on future surplus agricultural land, after the demand for food and fodder is satisfied. Two types of energy crops can be distinguished: 1) conventional energy crops, normally used to produce food and animal feed (e.g. maize, sugar-beet, sugar-cane, rapeseed, oil palm, soybeans) 2) Lignocellulosic energy crops, composed of cellulose, hemicelluloses and lignin (e.g. poplar, willow, eucalyptus, miscanthus, switchgrass).	Potential land surplus: 0–4 billion ha (Most studies find 1-2 billion ha). A large surplus requires intensive agricultural production systems (i.e. modernisation of all aspects). When this is not feasible, the bioenergy potential could be reduced to zero. On average higher yields are likely because of better soil quality: 8-12 dry tonne ha-1 yr-1are assumed. See also Table 3-2.	Low – 700
Energy crop production on marginal lands	Biomass that can be produced on deforested or otherwise degraded or marginal land that is still suitable for, e.g. reforestation	On a global scale a maximum of 1.7 Gha could be used. Low productivity of 2–5 dry tonne ha-1 yr-1. The supply could be low or zero due to poor economics or competition with food production.	<60 – 150
Residues from agriculture	Residues associated with food production and processing, both primary (e.g. cereals straw from harvesting) and secondary (e.g. rice husks from rice milling)	Potential depends on yield/product ratios and the total agricultural land area as well as type of production system. Extensive production systems require re-use of residues for maintaining soil fertility. Intensive systems allow for higher utilisation rates of residues.	15 – 70
Forest residues	Residues associated with wood production and processing, both primary (e.g. branches and twigs from logging) and secondary (sawdust and bark from the wood processing industry)	The sustainable energy potential of the world's forests is unclear. Part of the considered potential stems from natural forest (reserves). Low value: figure for sustainable forest management. High value: technical potential. Figures include processing residues.	30 – 150
Dung	Biomass from animal manure	Low estimate based on global current use. High estimate: technical potential. Utilisation (collection) over longer term is uncertain.[3]	5 – 55
Organic wastes	Biomass associated with materials use, e.g. waste wood (producers), municipal solid waste	Estimate on basis of literature values. Strongly dependent on economic development, consumption and the use of bio-materials. Figures include the organic fraction of MSW (typically >= 50% of the entire energy content) and waste wood. Higher values possible by more intensive use of bio-materials.	5 – >50[4]
Total		Most pessimistic scenario: no land available for energy farming; utilisation of residues only. Most optimistic scenario: intensive agriculture concentrated on the better quality soils.	<50 – >1000

[1] The overview is based on Berndes et al., (2003), Smeets et al., (2007) and Hoogwijk et al., (2005).

[2] A lower limit of zero implies that potential availability could be zero, e.g. if global agriculture is not modernised and additional land is needed to meet the world's food demand.

[3] Note that traditional use of dung as fuel should be discouraged. The dung potentials shown here mainly stem from intensive agriculture, which offers opportunities for fermentation and production of biogas.

[4] The energy supply of bio-materials ending up as waste can vary between 20-55 EJ (or 1100-2900 Mt dry matter) per year. This range excludes cascading and does not take into account the time delay between production of the material and 'release' as (organic) waste.

Annex 2.2: Biomass Yields of Food and Lignocellulosic Crops

Indicative biomass yields and possible subsequent transportation fuel production per hectare per year. Starch and sugar crops require conversion via fermentation to ethanol and oil crops to biodiesel via esterification (commercial technology at present). The woody and grass crops require either hydrolysis technology followed by ethanol or gasification to syngas to produce synthetic fuel (both not yet commercial conversion routes, see also Chapter 4).

Crop	Crop yield (fresh tonne/ha/yr)	Net Energy yield in fuel (GJ/ha/ yr) [3]	By-products
Conventional energy crops [1]			
Wheat	5.1	~ 15	Straw
Corn	9.2	19- 37	Stover, straw, DDGS
Sugar-beet	58.5	~ 111	Sugar-beet pulp
Sugar-cane	73.1	84-152	Bagasse, tops and leaves
Soy beans	2.7	12-13	Glycerine, seed cake
Palm oil (fresh fruit bunches)	19.2	~ 140	Palm kernel shells, PFAD, glycerine
Rape seed	2.9	28	Glycerine, seed cake
Jatropha seeds	4-7	~ 40	Seed cake
Lignocellulosic energy crops [2]			
Woody crops, e.g. poplar, willow, *Eucalyptus*	10 – 15	90-110	
Perennial herbaceous crops, e.g. *Miscanthus*, switchgrass, reed canary grass	10 – 30	140 – 230	
Prairie grasses (low-input system, degraded lands)	3 – 6	18-28	

[1] Yields are generally based on current average agricultural practices in industrialised countries. Numbers are based on a 5 year average (2002-2006) yields, for wheat, sugar-beet and rape seed based on average EU-27, for corn and soy beans on USA, for sugar-cane on Brazil (all FAOSTAT, 2008); for palm oil on average yield 2005-2007 Malaysia (MPOB, 2008), for *Jatropha* based on a literature review by Jongschaap et al., (2007).

[2] Yields based on Sims et. al. (2006), EEA (2007), Berndes (2001) Tilman et al., (2006) and Smeets (2008).

[3] The net energy yield is obtained by taking into account the gross energy yield per hectare, and subtracting all energy inputs during the production process. Sources: Sims et al., (2006) for wheat, corn, sugar-beet and rape seed, Smeets et al., (2008) for sugar-cane, Donato and Huerga (2007) for soy, Wicke et al., (2008) for palm oil, Berndes (2001) & Fischer et al., (2007) for lignocellulosic energy crops, Tilman et al., (2006) for corn and prairie grasses. In some cases, own estimates for the net energy yield were made.

Annex 2.3: Overview of Regional Biomass Production Scenario Studies

Region	Study / author	Time frame	Land use for energy crops	Primary biomass potential	Remarks
Europe	De Wit & Faaij (2008)	2030	66 Mha arable land (+24 Mha pasture)	12 EJ (+3 EJ) crops + 9 EJ residues	Potentials of highest yielding crops (grass) on arable (+ pasture) land and maximum residue use EU-27+ Switzerland, Norway & Ukraine feedstock cost 2.9-9.3 $ / GJ
	EEA (2007)	2030	25 Mha	3.4-5.0 EJ crops + 1 EJ residues	Varying mix of conventional & lignocellulosic feedstocks over time EU-25 (excl. Romania & Bulgaria)
USA	Parker et al., (2008)	2015	20 Mha	2.1 EJ crops + 0.8 EJ residues & MSW	18 Western USA states only Mainly corn, herbaceous crops, forest & agricultural residues Feedstock cost range to produce liquid biofuels < 24 $/GJ
	Perlack et al., (2005)	2050	30 Mha	7.4 EJ crops + 10.8 EJ residues	Entire USA Including forest & agricultural residues (grains & perennial crops)
Latin America	Kline et al., (2008)	2017	121 Mha	19.7 EJ crops + 4.7 EJ residues	Argentina, Brazil, Colombia, Mexico and CBI Crops: sugar-cane, corn, soy bean, wheat, palm oil and cellulosic residues
China & India	Kline et al., (2008)	2017	86 Mha	13.2 EJ crops + 3.7 EJ residues	Crops: sugar-cane, corn, soy bean, wheat, palm oil and cellulosic residues
Australia	CEC (2008)			0.07 EJ residues	Based on process residues, (mainly bagasse and wood) and waste streams (MSW, sewage sludge and landfill gas) Resource assessment for solid biomass only

For **Europe**, the resource assessment of Refuel study (de Wit & Faaij, 2008) comprises an estimation of future arable and pasture land area requirements for food and livestock sectors, the surplus being potentially available for bioenergy production while accounting for agricultural land converted to urban use and land for nature conservation areas. Both cultivated arable land and pasture are potentially considered as areas for growing dedicated bioenergy crops. Land becoming available for bio-fuel production is a result of future consumption and technological progress, e.g. through yield increases and improved feed conversion efficiencies. The resulting estimate can be interpreted as the land that becomes available without compromising food and feed production. Also explicitly taken into account is the area reserved for nature conservation areas, complying with the Pan European Ecological Networks. Finally, a bottom-up costs analysis is executed, considering 13 dedicated bioenergy crops. Note that also the potential in the Ukraine is taken into account, which contributes about one third of the total available land in the Refuel study. In contrast, the EEA study (2007) aims at determining the environmentally 'compatible' arable land area, and uses a fixed set of sugar, starch and lignocellulosic crops. It also assumes that selection of these energy crops and their management at farm level would follow environmental best-practice (adaptation to bio-physical constraints and ecological values of a region, appropriate crop mixes and rotations, low use of inputs, double cropping practices etc.). Furthermore, it is assumed that for the maintenance or further development of 'environmentally orientated farming' in the EU, the present share of 'environmentally orientated' farming would need to increase to about 30% of the utilised agricultural area in most Member States by 2030; at least 3% of present intensively used farmland should be set aside by 2030 for nature conservation purposes; and no conversion of permanent grassland, dehesas and olive groves through ploughing for targeted biomass crops. Two scenarios (with low and high fossil fuel prices) are used to model the economic biomass potential (4-6.6 EJ).

For the **USA**, a study by Parker et. al. (2008) for the Western Governors' Association analysed the potential contribution of biofuels for the transportation sector in the western USA by 2015 by combining a spatially-explicit resource inventory and assessment, models of conversion technologies, and transportation costs into an integrated model of biofuel supply chains. Geographic Information System (GIS) modelling was used in conjunction with an infrastructure system cost optimisation model to develop biofuel supply curves using biomass feedstocks throughout the western USA. All routes delivering fuel price between $2.40 and $3.00 per gasoline gallon equivalence (gge) were considered economically viable. A diverse resource base is relied on to provide this fuel with significant contributions from municipal solid waste, agricultural residue, herbaceous energy crop, forest thinning, corn, and lipid resources. The biofuel potential estimated in this way is significant, but substantial uncertainties remain, including the economic performance of the different conversion technologies and the overall sustainability of many of the biomass resources considered. Perlack et al., (2005) performed a study to determine whether by 2050 the land resources of the United States are capable of producing a sustainable supply of biomass sufficient to displace 30% or more of the country's present petroleum consumption - requiring approximately 1 billion dry tonnes of biomass feedstock per year. This was shown to be possible, using forestry and agricultural residues, and dedicated conventional and lignocellulosic energy crops. Major assumptions were that inaccessible forestland and all environmentally sensitive areas were excluded, yields of corn, wheat, and other small grains were increased by 50% until 2050, and residue recovery was enhanced.

For selected **Latin American** countries and **China and India**, Kline et al., (2008) performed a study to develop 'supply curves' for selected countries and feedstocks. Such supply curves permit more detailed analysis of feedstock variables when modelling future global biofuel markets. They focused on Argentina, Brazil, Canada, China, Colombia, India, Mexico, and the Caribbean Basin Initiative (CBI). Future feedstocks are divided into two groups: traditional crops that can be converted to biofuel and cellulosic materials such as crop and forest residues. Crop feedstocks selected for study were sugar-cane, corn, wheat, soybeans, and palm oil. Historic production trends and the structure of average production costs were analysed by state (or province) to develop supply curves for each selected crop-country combination. To estimate the amount of feedstock available for export and or biofuel production, the total potential production in the baseline case was reduced based on the percentage of production used to meet domestic food, feed, and fibre demands in the most recent year with reported data (usually 2006). In the table above, the main results for the baseline scenario for 2017 are presented (the study also presents high and low scenarios, for the years 2012 and 2027).

Finally, for **Australia**, CEC (2008) developed a road-map for increasing the utilisation of biomass for stationary applications until 2020. The aim was to focus on those resources where there is a prospect that the resource can be matched with an appropriate technology to contribute sustainably and economically to stationary energy supply. Therefore, the analysis only considers solid, process-based residues from agriculture and forestry and various waste streams (e.g. MSW and sewage sludge). It does not include any substantial quantities of field-based residues or energy crops.

Annex 3.1: Biomass Upgrading Technologies

There are numerous possible pre-treatment techniques ranging from well-established mechanical techniques that consist of simply chopping, chipping or milling the raw feedstock into ready to use material for subsequent conversion, to less well established thermomechanical or thermochemical upgrading techniques that also increase the energy density of the biomass. Pelletisation, torrefaction and pyrolysis technologies are such examples.

3.1.1 Pelletisation and briquetting

Pellets are small wood-based cylinders 6-12 mm in diameter and 10-30 mm in length. They are produced by compressing wood sawdust through a die. The high pressure of the press causes the temperature of the wood to increase greatly which causes the lignin content of the wood to form a glue that binds the pellet together as it cools.

Pellets have quality standards in Europe (CEN, DIN) that guarantee a moisture content below 10% (against 20%-25% for commercial wood chips), a uniform density and hence calorific value irrespective of the wood used, as well as strict physical and chemical characteristics. Pellets can be made from virtually any type of woody feedstock, as well as from herbaceous biomass, fruit biomass, and peat. However, the use of such alternative feedstocks might result in pellets with ash or contaminant contents that do not comply with the above standards.

Pelletising is an efficient energy densification technique as pellets typically have a bulk density of 650 kg/m^3, that is some 3.3 times higher than industrial softwood chips. Moreover, due to their very low water content, pellets also have a high net calorific value (or lower heating value) of about 17 MJ/kg, that is 17% higher than wood chips. This property alone can make it economically viable for material to be pelletised to reduce transport and storage costs. In Sweden for instance, where pellets are primarily used to substitute for coal in large power plants, pellets are manufactured from sawdust at the sawmill, before being transported to the power plant where they are milled before combustion.

Pellets thus have the great advantage over other woody feedstocks of being a homogeneous, dense, and easy to handle solid fuel, which explains its increasing popularity both at domestic and industrial scale. However, pellets are hygroscopic, i.e. they tend to absorb moisture during transport and storage, which can significantly reduce their net calorific value – down to below 10 MJ/kg (PC 2008).

Pellets have become a common fuel in developed countries. Some 442 pellet producers were identified worldwide in 2007, spread throughout Europe, Russia and North America (Bioenergy Int. 2007). Quality standards are increasingly contributing to the development of international trade in pellets. Canada produced close to 1.5 million tonnes of pellets in 2007, most of which were exported to Europe, while Russia has a production capacity of 600,000 tonnes and exports most of its production to Europe, China and Japan (Bioenergy Int. 2007).

Since pellets are mostly produced from sawdust, which is a co-product of sawmilling, the volume of pellets produced may depend on the volume of timber consumed in the wood industry. The recent housing crisis in the USA, resulting in fewer houses being built and hence less timber consumed, has been interpreted as a possible cause of the sawdust shortage. In Canada, on the other hand, large amount of wood unsuitable for the processing industry has been available for pelletising due to the massive destruction of the forest by the pine beetle (Bioenergy Int. 2007).

In Europe, average production cost of wood pellets is estimated to be in the range 50-80 Euro/tonne (EuBioNet2 2007), compared to $60-84/tonne in Canada (Urbanowski 2005, Mani et. al. 2006). Costs of switch grass pellets are some 40% higher (Mani et. al. 2006). The competitiveness of wood pellets with alternative fossil options differs from country to country depending on the tax system and market price of pellets. The latter ranged roughly from 120 to 270 Euro/tonne in 2007 in the 17 European countries that use pellets (Junginger et al., 2007), where the lower limit corresponds to industrial volumes for co-firing applications, and the upper limit is small volumes for household boilers. Market price to the final customer was around 184 Euro/tonne in Germany at the end of 2007 (after climbing above 250 Euro/tonne in 2006), which makes pellets much cheaper (~4 Euro cents/kWh) than heating oil and gas (EuBioNet2 2007). There is no apparent correlation yet between the pellet price and oil price.

Further research is still necessary to increase the stability and resistance to abrasion of pellets, as well as to reduce the dust emission during handling in domestic applications (IEA 2008e).

Biomass briquettes are fabricated in a similar way as pellets and have a typical dimension of 30-100mm. Unlike pellets, which can be used for automatically-charged stoves and boilers, briquettes require manual charging, which makes it a far less user-friendly fuel. Briquettes are mainly produced and used in Southern India.

3.1.2 Pyrolysis

Pyrolysis is the thermal decomposition of biomass occurring in the absence of oxygen (anaerobic environment) that produces a solid (charcoal), a liquid (pyrolysis oil or bio-oil) and a product gas. The respective fraction of these three co-products depends on the operating temperature and on the residence time of the hot vapour used in the process. Moderate temperatures (around 500°C) and short residence time (around 1 second) used in so-called fast pyrolysis (or flash pyrolysis) are optimal conditions for maximising the production of the liquid fraction (up to 75% of the output energy content).

The production of wood charcoal using slow pyrolysis (also known as carbonisation) has been used for centuries throughout the world (e.g. in traditional stoves in developing countries, in barbecues in Western countries, as well as in industry such as the Brazilian steel industry). However, it is only in the last 30 years that fast pyrolysis has been given extensive development effort because liquid fuels are generally easier (and thus cheaper) to handle, store and transport than solid biomass. In spite of considerable experience gained over the last decades, fast pyrolysis is still in its demonstration stage. Although fast pyrolysis units are used in niche applications such as the production of food flavourings, only a few successful demonstration units have been realised for bioenergy (e.g. in Finland and Canada), and both economic and technical challenges must be resolved before commercialisation is feasible. Bio-oil could either be burnt directly for power in CHP applications (in boilers, stationary engines and turbines, co-firing), or upgraded to transport fuel.

The deployment of pyrolysis technology still faces technical and economic challenges. A key challenge remains the improvement of the quality and consistency of the pyrolysis oil in terms of moisture content, contaminants, corrosiveness and viscosity, as well as in terms of stability, as bio-oil tends to degrade and separate over time. Reactor design and bio-oil upgrading techniques can address these technical challenges but are expensive.

Also, current bio-oil production technology is not very selective, resulting in a bio-oil composed of more than 300 chemicals. These prove mostly incompatible with the upgrading of bio-oil into transport biofuels, which require precise, highly selective composition. New techniques for increasing the control of bio-oil composition are thus required to make this technology more attractive. Among the technological advances needed are better characterisation of the thermal reactions and greater understanding of how catalysts can be incorporated into the reaction environment to produce the preferred bio-oil compositions (NSF 2008).

There are also technical challenges relating to scale-up, particularly concerning heat transfer which is crucial in this technology. Several types of reactors are under investigation, but no prevailing design has emerged yet.

The by-products of fast pyrolysis are mainly char and a product gas, which can typically be recycled (burnt) in the process to produce the heat necessary for the conversion process. Alternatively, applications for the char including soil amendment, use as combustion fuel (possibly added to the pyrolysis oil in co-firing applications), or gasifier feedstock have been proposed but not yet extensively studied.

While bio-oil has a calorific value of about 17.5 MJ/kg, which is comparable to that of pellets, its energy density is about 20-30 GJ/m^3 – about twice that of pellets and 4-5 times that of torrefied biomass (but still only half that of diesel oil) (Uslu 2008). This gives pyrolysis a competitive advantage over pelletisation and torrefaction in terms of transport cost. However, this advantage is not sufficient to offset the higher cost of bio-oil. Investment costs have been calculated in the range 1900-4200 Euro/kW_{th} for 25 MW plants, while production costs (excluding feedstock cost) are estimated to be 50-100% higher than those of pelletisation or torrefaction plants (Uslu et. al., 2008).

Fast pyrolysis has mainly been considered as a biomass densification step before long distance transport. Demonstration CHP plants integrating pyrolysis and gas turbine exist, but it is as yet unclear whether this direct combination can prove economic as it is competing with more efficient technologies such as gasification and simply direct combustion. Potentially interesting opportunities may be provided by the integration of pyrolysis processes or oils in conventional refineries or in biorefineries (see Section 3.7).

3.1.3 Torrefaction

Torrefaction is a thermal process that involves slowly heating the biomass at 200-300°C in the absence of oxygen. This degrades the biomass into a completely dry coal-like product that has lost the fibrous structure of the original biomass, hence significantly improving its grindability, as well as net calorific value (19-23 MJ/kg) and energy density. Torrefaction can be a highly efficient means of densification, with torrefied products retaining some 92% of the original feedstock energy (Uslu et. al., 2008).

In addition, torrefaction transforms hygroscopic feedstocks into a hydrophobic material. This represents a significant advantage over traditional dried biomass such as pellets, since torrefied feedstock can be transported over long distances and stored outside without absorbing any moisture, hence without seeing its calorific value drop.

Although torrefaction is an old technique, it is not commercially available as a means of pre-treating biomass for biomass-to-energy production chains. Although torrefied biomass can be produced from a wide variety of biomass while yielding similar product properties, this upgrading technique is mostly applied to wood. Torrefied wood can be subsequently pelletised, which could reduce logistics cost by as much as 50% as compared to traditional pellets, This is expected to compensate largely for their higher production cost (approximately 10% higher) (Bergman 2005).

Annex 3.2: Biomass-to-Heat Technologies

The direct burning of wood and other solid biomass feedstock for domestic heating and cooking purposes is the oldest and most accessible energy technology used by man, and it is still by far the largest contribution of biomass to global energy supply today.

Depending on the socio-economic context and environmental legislation in place, domestic biomass combustion technologies range from very inefficient devices such as open fire places (efficiency ranging from -10% to 10%[31]) or traditional cooking stoves found primarily in developed countries (efficiency 10-15%), through to very efficient and increasingly

[31] Because of the large amount of cool outdoor air dragged inside by the combustion process (and thus removing warm air from the heated space), open fireplaces can actually consume more energy than they produce when the outdoor temperature is low (typically below 0°C), and thus have a negative thermal efficiency

popular modern chip-burners, heat storing stoves and pellet-boilers with efficiencies of up to 90% (IEA 2008e). Advanced biomass boilers can even reach efficiencies of 105-110% (define on LHV basis)[32] if flue gas condensation and humidification of combustion air is applied, or if the waste heat is used for absorption cooling (Westermark 2006).

A range of biomass combustion systems is available for heat production on a larger scale for industrial purposes or district heating. Grate boilers and underfeed stokers are the most common technologies for small- to medium-scale applications (200 kW-20 MW) as these offer low investment and operating costs. Fluidised bed technologies, which became commercial in the 1970s, offer higher thermal efficiency and lower toxic emissions (CO, NOx) than fixed bed approaches due to better control over combustion conditions. Fluidised bed technologies also offer the further advantage of a greater tolerance of moisture content and type of biomass used. However, fluidised bed technologies have higher capital and operating costs, and require significant economies of scale, so that only larger plants (>20-30 MW) are economically viable. Over 300 fluidised bed installations have been built worldwide to date (IEA 2008e).

Production costs of biomass-based heating systems vary widely with size and fuel cost. Heat production costs in pellet boilers in the range 5-100 kW range from 8 to 99 Euro/GJ, with an average of 26 Euro/GJ – about competitive with fossil resources. A mere 4-6% cost reduction is expected through to 2030 (at a constant fuel price) by increasing lifetime and efficiency. Combustion of wood chips for district heating is more commonly applied than pellet burners. These can have higher investment costs but lower fuel prices (IEA 2007b).

The economic case of district heating depends on a number of complex technoeconomic parameters. The cost of heat distribution networks accounts for 35-55% of the total investment cost of district heating plants, which calls for a high annual utilisation rate (>75%) and concentration of customers to reach economic viability. This can prove difficult to attain as demand is, in general, not constant throughout the year (IEA 2008e). Moreover, thermoeconomic optimisation of the network efficiency is necessary, by trading-off network losses against the cost of expensive pipe insulation (IEA DHC 2005). Although large-scale district heating networks can prove economic, a significant number of failures have been reported due to the complexity pf optimising these systems properly.

Further R&D on combustion technologies will focus mainly on increasing thermal efficiency, and the need to develop small-scale technologies that can burn biomass other than wood (e.g. energy crops, tree residues, etc.). Also, as the combustion process *per se* is associated with toxic emissions of volatile compounds (in particular NOx and particulates), continuous effort is needed to further reduce these harmful emissions in order to meet increasingly stricter emission regulations. This is particularly the case for biomass fuels rich in nitrogen and ash. Small-scale combustion units are of special concern, as they need simple and affordable solutions. Finally, questions remain regarding the most environmentally sound and affordable manner for processing ash from contaminated biomass sources in the context of increasingly strict landfill regulations.

Annex 3.3: Biomass Combustion-to-Power Technologies

The heat produced by direct combustion in boilers can be used to produce electricity in a separated steam turbine or engine. Overall electrical efficiency is limited by the relatively low efficiency of the steam cycle. The efficiency of electrical generation alone typically ranges from about 10% for small CHP plants (<1 MW_e steam-engine) up to 40% (electricity-only mode) for >50 MW_e steam-turbine combined with the most advanced fluidised bed combustion technology (IEA 2008e). The rest of the energy from the combustion (60-90% of the energy contained in the feedstock) is lost into the air or water as waste heat.

The main way to increase the overall efficiency of a power plant (and hence its competitiveness) significantly is to use this heat. By making use of waste heat, combined heat and power (CHP), or cogeneration, plants have typical overall efficiencies in the range 80-90% provided a good match can be found between heat production and demand (IEA 2008c). However, recycling the waste heat has a slightly detrimental impact on the efficiency of the power production, which is a few percentage points lower in CHP plants than in power-only plants.

Municipal solid waste (MSW) incineration plants are generally large in scale but corrosion problems limit the process steam temperature and thus reduce the electrical conversion efficiency to about 22%. New generation CHP plant designs using MSW are, however, expected to reach 28%-30% electrical efficiency (IEA 2007a).

Economies of scale are very important. Investment cost is about 3,500 Euro/kW_e for a 5 MW_e plant, but drops to about 2,000 Euro/kW_e for a 25 MW_e plant. Until recently, dedicated biomass power plants have only proved competitive when using large quantities of free waste that had to be disposed of, such as MSW, black liquor from the pulp and paper industry and agriculture residues such as bagasse. However, a growing number of viable smaller scale plants using other type of residues (forestry, straw, etc.) are found throughout Europe and North America. Co-generation has been shown to reduce the cost of power production by 40-60% for stand-alone plants in the range 1-30 MW_e. However, the scale of biomass CHP plants is often limited by the total local heat demand and by its seasonal variation, which can significantly affect economic returns unless absorption cooling is also considered.

[32] Since energy is required to vaporise water, energy is conversely released (in the form of heat) when water vapour is condensed. Efficiencies above 100% can be achieved if the air used in the combustion is humidified prior to entering the boiler and the flue gas naturally condensed when exiting the boiler. This condensation energy is extra energy that adds to the combustion energy of the biomass.

As an alternative to conventional steam plants in the range 0.5-2 MW, the Organic Rankine Cycle (ORC) engine[33] can offer technical and economic advantages (e.g. lower process temperature, low operating cost, and the potential to use a thermal oil boiler instead of a more expensive high temperature-proof steam boiler) (Obernberger and Biedermann 2005). The gross efficiency of ORC engines can reach 17%, which is slightly higher than a steam turbine of equivalent size. However, the net efficiency can be significantly lower due to the relatively high power consumption of ORC units (IEA 2008e). Although ORC is a well-proven technology (e.g. in geothermal applications), only a few ORC plants operate on biomass at this stage (e.g. Switzerland, Austria, the Netherlands). Work is still needed to improve efficiency and reliability, and to reduce costs.

In the lower capacity range (10 -100 kW_e), the Stirling engine is a promising technology for domestic cogeneration. Currently at the demonstration stage (e.g. in Denmark, Germany, UK, Switzerland, Austria, and New Zealand), improvements are still needed, in particular to improve the current 12-20% conversion efficiency, which could reach up to 28% by improving process and scaling up to 150 kWe. Developments on Stirling units operated on biomass are very few, with some efforts under way in Germany with pellets.

Feedstock handling and storage management, excessive equipment wear, bottlenecks in the feed system, heavy metal contamination, and wide fluctuations in fuel moisture content into the boiler are common technical issues with biomass combustion plants that need to be addressed. Furthermore, biomass often contains heavy metals, the combustion of which can cause corrosion and deposit formation on the heat transfer surfaces, thus reducing plant efficiency and increasing maintenance requirements.

Annex 3.4: Co-firing Technologies

Biomass co-firing (or co-combustion) involves supplementing existing fossil-based (mostly pulverised coal) power plants with biomass feedstock. There are three types of biomass co-firing:

- direct co-firing, where the biomass is combusted directly in the existing coal furnace;
- indirect co-firing, where the biomass undergoes a preliminary gasification conversion before the resulting syngas is combusted in the coal furnace; and
- parallel co-firing where the biomass is combusted in a separate boilers, with utilisation of the steam produced within the main coal power station steam circuits.

Over the past decade, direct co-firing has been successfully demonstrated with many technology options and with a wide range of biomass feedstocks (wood and herbaceous biomass, crop residues, and energy crops). In the main, direct co-firing has been achieved in two ways:

- the raw solid biomass is pre-mixed, generally in granular, pelletised or dust form, with the coal in the coal handling system; or
- the biomass is milled to a topsize around 1-5 mm and is directly injected into the pulverised coal firing system.

These approaches to co-firing are now in full commercial operation in over 150 installations worldwide, of which 100 are located in Northern Europe, 40 in the USA and a few in Australia. A very large 400 MWe capacity biomass co-firing plant is currently being built in the UK at the existing 4 GWe Drax coal plant. Direct co-firing can thus be considered fully commercial. The direct co-firing of a range of liquid biomass materials (e.g. vegetable oil, tallow) in existing plants is also practised on a commercial basis, albeit at much smaller scale than for the solid materials.

In most cases, the biomass co-firing ratio is limited to around 5-10% on a heat input basis, and this is controlled by the availability of biomass and in some cases, by site-specific plant constraints. In one or two cases, co-firing ratios of up to 25% have been achieved.

Direct co-firing in large-scale modern coal plants is today the most cost effective use of biomass for power generation. This technology only requires minor investment to adapt handling and feeding equipment without noticeably affecting boiler efficiency, provided the biomass is not too wet and has been pre-milled to a suitable size. Furthermore, electric efficiencies for the biomass-portion range from 35% to 45%, which is generally higher than the efficiency of biomass-dedicated plants (IEA 2007a).

In spite of the significant progress achieved in co-firing over the last decade, biomass properties pose several challenges to coal plants that may affect their operation and lifetime. Most of the potential issues faced by co-firing are associated with the biomass ashes which are very different from coal ashes. Problems arise mainly at increased co-firing ratios and with biomass materials with high ash contents. The technical risks are mainly associated with the increased ash deposition on surfaces in the boiler and in SCR catalysts (thus reducing the efficiency of the system), and with the impact of flue gas on gas cleaning equipment. The contamination of ashes by alkaline metals is relatively well understood and, in Europe, this has largely been recognised in performance standards for the utilisation of ashes in the manufacture of building products.

Indirect and parallel co-firing options are designed to avoid biomass-related contamination issues, but have proven much more expensive than the direct co-firing approach as additional infrastructure is needed. Parallel co-firing units are mostly used in pulp and paper industrial power plants. The indirect option faces issues regarding the cooling and cleaning of the syngases.

Indirect co-firing with pre-gasification of the biomass has now been demonstrated in both pulverised coal power plant and in coal gasification plants (demonstration projects in e.g. Austria, Finland, the Netherlands). The highest efficiencies (up to 50%) and economies of scale can be obtained with indirect co-firing in a Biomass Integrated Gasification

[33] The ORC engine is similar to steam engine but works with low boiling temperature organic oil as a process fluid instead of steam.

Combined Cycle (BIG/CC). Although promising, more R&D and cost reduction efforts are needed for this technology to reach commercial status (further information on this topic in the gasification Section below). The calorific value of the syngas generated is an important consideration when co-firing with coal syngas in gas turbines.

Co-firing with pre-pyrolysis of the biomass is still in its early stages, but could potentially become a cost-effective bioenergy route for countries with large distances between the fossil plants and the regions of biomass production. This route would be competing with other densification technologies, i.e. pellets or torrefied biomass.

Annex 3.5: Biomass Gasification Technologies

Gasification occurs when biomass is heated under sub-stochiometric combustion conditions. This results in the production of a combustible gas mixture (called producer gas or fuel gas) rich in carbon monoxide (CO) and hydrogen (H_2), which has an energy content of 5-20 MJ/Nm^3 (depending on biomass and whether gasification is conducted with air, oxygen, or indirect heating), that is, roughly 10-45% of the heating value of natural gas. Fuel gas can then be upgraded to a higher quality gas mixture called syngas.

Gasification was originally developed in the early 19th century to produce town gas from coal for lighting and cooking, before it was supplanted by natural gas and electricity. Wood gasification-based engines called gasogene were also used to power vehicles in Europe and elsewhere during the fuel shortage of World War II. Gasification regained interest in the early 1980s and has undergone significant RD&D both in Europe and North America, with several competing reactor designs and gas cleaning processes.

Gasification is a highly versatile process. Virtually any biomass feedstock can be converted into syngas with a very high carbon conversion and thermal efficiency of 85-95%. Furthermore, syngas is an intermediate product that offers a large range of possible secondary conversion and final energy uses (see Figure 3-1 in Chapter 3). Heat application of gasification is mainly confined to countries with emerging economies. Hundreds of small and medium size biomass gasifiers (< 1 MW_{th}) are, for example, being deployed mainly for heat applications in China, India, and South-East Asia with attractive pay-backs (IEA Bioenergy 2007). These gasifiers are operated intermittently and may not conform to the environmental guidelines generally practiced in OECD countries. Their reliability and lifespan in continuous operation may be an issue.

Raw syngas can also be cleaned of its particulates and condensable hydrocarbons and burnt in an internal combustion gas engine, which offers electrical efficiency in the range 22-35% (IEA 2008c), that is, slightly higher than for steam engines used in conjunction with biomass combustion. Demonstration CHP and co-firing plants based on this principle are widespread in Europe and the USA in the range 1-15 MW_{th} (IEA 2008c). Higher electrical efficiencies are reached if the syngas is combusted in gas turbines (up to 40% efficiency), or in gas and steam turbine combined cycles (up to 42%) (IEA 2008e). Due to their high conversion efficiencies, these technologies offer greater CO_2 emission reduction potential than direct combustion-based approaches.

However, these pathways rely on pressurised operations which have not yet been adequately demonstrated at large-scale (IEA 2008c). The first pressurised (1.8 to 2.5 MPa) biomass integrated gasification combined cycle (BIG/CC) plant running on 100% biomass (9 MW_{th} and 6 MW_e plant based on wood and straw) has been successfully demonstrated in Sweden since 1995 and technical issues (process integration, tar formation, real-time process monitoring, etc.) appear to have been overcome. However, other projects have not succeeded (e.g. the ARBRE project in the UK) due to inadequate support to resolve process shakedown and system integration issues. Several commercial scale BIG/CC projects are in the pipeline in northern Europe, USA, Japan and India, with respective operational start-ups ranging from 2006 to 2011.

The syngas can be converted to hydrogen-rich gas or pure hydrogen that could be electrochemically converted in fuel cells to produce electricity. The integrated gasification fuel cell (IGFC) technology is expected to yield high electrical efficiencies – 50 to 55% (Watanabe and Meada 2007). However, significantly more RD&D is needed to develop, demonstrate, and commercialise IGFC systems in the near future.

Instead of being directly combusted for heat and power, the syngas can be further processed into a methane-rich gas called substitute or synthetic natural gas (SNG), the composition of which makes it suitable for blending in the natural gas network, thus offering enhanced flexibility as to the final use. Such projects are in their demonstration stage (Austria), with the first commercial size projects under development in Sweden and Switzerland. The syngas can also be converted into a liquid fuel (e.g. Fischer Tropsch or FT-diesel, DME, methanol, or mixed alcohols) using different methods employing the proven catalytic conversion process. These biomass-to-liquid (BTL) routes are discussed in Section 3.6.3.

Gasification of coal and oil residues has been used for decades at industrial scale for strategic reasons (e.g. Sasol plants in South Africa). Biomass gasification technologies struggle for market entry due to limited plant capacities because of the cost of collection and transportation of biomass to central energy conversion plants. For this reason, out of the ~5.25 GW_e of existing global IGCC plant capacity in 2006, only 0.15 GW_e run on biomass fuel, mostly in the EU with a negligible capacity in North America and Asia.

Further support and development of certain biomass gasification processes is required to address and resolve issues related to sensitivity to feedstock quality and moisture content, reliability of feedstock feeding systems into the reactors, gas clean-up (tar formation, process monitoring, and tar, alkali, chloride, ammonia, etc. removal), and process scale-up with first-of-a-kind plants (Babu 2005). Due to inadequate opportunities to replicate commercial applications, it is difficult to obtain performance and reliability guarantees from many technology developers, which poses a financial risk to investors (IEA 2007c).

Since process developers cannot obtain or do not provide adequate resources for first-of-a-kind demonstration plants the production costs are usually 3-4 times higher than conventional alternatives (IEA Bioenergy 2007). Under certain site-specific situations claims have been made that BIG/CC plants could be commercially viable, such as in co-production mode using black liquor from the pulp and paper industry (IEA 2007a).

The evolving lignocellulosic and other biofuel processes, including algal fuels, do not convert the entire feedstock to the desired products and leave behind a significant portion of carbonaceous matter that could be effectively utilised in closely integrated biomass gasification processes, to improve overall process performance. It is noteworthy that for many countries, demand for electricity may be comparable to security of supply of transportation fuels in importance. With adequate incentives, biomass gasification offers prospects for the market entry of distributed power generation to meet future needs. Whatever form biomass gasification may evolve into, it should play a critical role in building a 'bridge' for sustainable energy for the future.

Annex 3.6: Anaerobic Digestion Technologies

Anaerobic digestion is the biological degradation of biodegradable organic matter under exclusion of oxygen/air conditions. The main product of anaerobic digestion is biogas, a gas mixture of methane (the main component of natural gas) and carbon dioxide (CO_2). The biogas produced can either be cleaned for on-site use in heat and power generation units or be separated from the carbon dioxide, compressed and injected into the natural gas network for use in heat or electricity generation elsewhere or as a transport fuel.

Anaerobic digestion applies to almost any biodegradable waste materials such as grass clippings, leftover food, sewage, animal waste, or industrial waste. Anaerobic digesters can also be fed with specially grown energy crops to boost biodegradable content and hence increase biogas production. However, lignin can not be degraded by anaerobic digestion, which makes woody biomass not suited for this conversion route.

Both dry and wet processing are well-established technologies, have a good track record and have been proven at a commercial scale. Anaerobic digestion is happening both in centralised plants (typically for the treatment of sludges in waste water treatment plants or landfill gas recovery facilities close to urban areas) and in small and distributed biodigester units, usually in rural areas on farms or even in small households where mostly manure and agricultural wastes are being digested. Anaerobic digestion is also part of the mechanical biological treatment of municipal solid waste (MSW), where the waste is sorted into refuse derived fuels going into waste-to-energy plants (combustion), while the organic fraction undergoes anaerobic digestion.

There are two main classes of proven technologies that differ in their process temperatures. Thermophilic digestion (50-70°C) systems offer faster throughput and better pathogen and virus reduction than mesophilic processing (25-40°C), but require more expensive technology and a higher degree of hands-on operation and monitoring. Thermophilic units are thus mostly used for centralised production. Most such plants are found in Switzerland and to a smaller extent in Sweden.

China is by far the biggest biogas producer and user in the world, with around 18 million farm households using biogas (about 7 million Nm^3 per year) and about 3,500 medium to large-scale digester units (about 250 million Nm^3 per year) (DEFRA 2007). In Europe, Germany is the leading country with some 3700 units in operation corresponding to some 1270 MW_e total capacity installed in 2007 (mostly small cogeneration units running on agricultural residues) generating 8.9 TWh of electricity annually. About 50 new plants are installed each month. This success is mostly explained by the support provided by the feed-in tariff targeted to farm-scale systems. The UK, Italy, and Spain are leading landfill gas production, while less successful in stimulating farm-based anaerobic digestion (see production map below). The Danish centralised AD plants are also a technical success and are more cost-efficient than the German plants thanks to economies of scale. In the USA, the deployment of biogas technology suffers from a poor reputation due to a high failure rate. As of April 2008, a mere 114 farm-scale digesters were in operation in the USA (EPA 2008).

The economic viability of biodigesters is highly sensitive to unit size and feedstock price. Small-scale plants are often uneconomic, but centralised digestion may be limited because of the distances over which manure has to be transported, which increases both the price of feedstock and the biosecurity issues in the case of manure handling (CCTP 2005). Also, the rural context of farm-based biogas digestion is often associated with difficulty in selling the surplus process heat and high cost of grid connection in remote areas. Finally, the anaerobic digestion process cannot easily accommodate changes in feedstock properties and thus requires significant technical know-how and commitment to operate effectively. Failure rate has been very high in the past decades, with a detrimental impact on the economic viability of these units, due to the complexity of design and operation. German manufacturers largely overcame this issue with simpler designs and good technical support.

Although anaerobic digestion has long been commercial, further technology optimisation and cost reduction are still possible that could significantly improve the economic viability of smaller units. The main areas of need are to improve biomass pre-treatment to reduce fermentation time, to reduce costs and to improve reliability of two-stage technologies[34], to

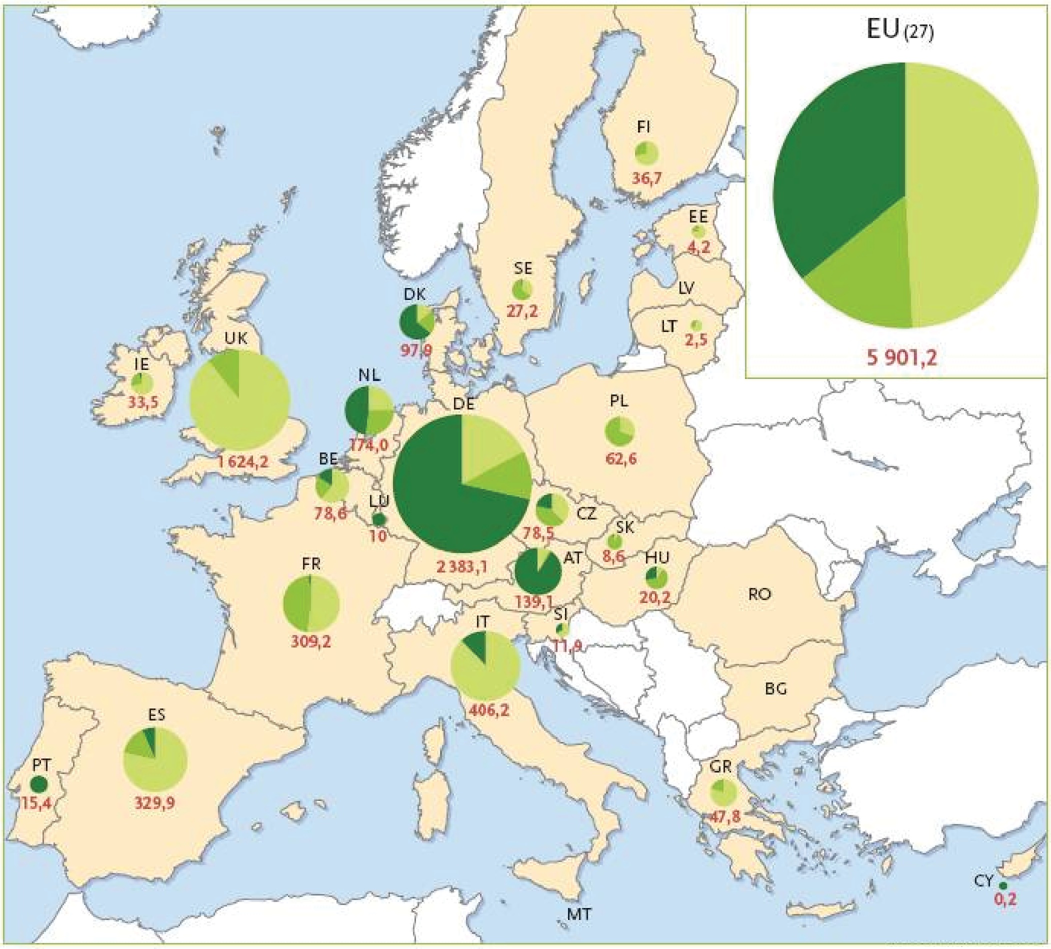
[34] The mechanism of anaerobic digestion involves two steps: 1) hydrolysis and acetogenesis processes, which convert bio-degradable feedstock into glucose and amino-acid, and then into fatty acids, hydrogen and acetic acid, and 2) conversion by methanogenesis of acetic acid into a product gas rich in methane (biogas) according to the biochemical reaction $CH_3COOH \rightarrow CH_4 + CO_2$. These two steps can take place in a single reactor (single-stage AD) or in two separated reactors (two-stages AD). The latter solution allows for individual optimisation of each process, thus potentially increasing the overall system performance, but is associated with more complex process control and higher capital cost.

improve biogas cleansing processes (mainly of corrosive H_2S) and to increase the robustness of the thermophilic process. Techniques to improve the biological digestion process (through ultrasonic treatment or enzymatic reactions) are currently at the R&D stage. These approaches could increase biogas output by several percentage points.

The co-product of anaerobic digestion of source-separated wastes is a nutrient-rich digestate that may contain pollutants if the separation is not properly done. This may make this co-product unsuitable for use as fertiliser depending on the regulations in place. Biomass pre-treatment and separation processes to remove these contaminants could prove cheaper than capital intensive cleansing processes, but these processes still need to be proven at a larger commercial scale. If anaerobic digestion is part of an industrial waste process the digestate is often aerobically polished or dried and used in a waste-to-energy plant.

The alternative route, of microbial fuel cells, could have interesting prospects in the longer term. The concept of microbial fuel cells, by which the micro-organisms that digest the biomass are selected to generate a hydrogen-rich 'biogas' that can in turn be used in fuel cells is still at an early stage of development. Although feasibility has been proven, this technology requires a lot more R&D before it could reach demonstration stage.

PRIMARY ENERGY PRODUCTION OF BIOGAS IN EUROPE IN 2007*



KEY

Primary energy production of biogas of the European Union in 2007 (in ktoe)

- Landfill gas
- Sewage sludge gas
- Other biogases (decentralised agricultural plant, etc.)

5 901,2 Red figures show total production in ktoe

* Estimate

Source: EurObserv'ER (2007)

Annex 3.7: Feedstock Yields for Sugar and Starch Crops Used for Bioethanol Production

Region - Biofuel	Feedstock	Yields, 2005(l/ha)		Average	Resulting yields in 2050 (lge/ha)
		Nominal	Gasoline/diesel equivalent		
Europe – ethanol	Wheat	2500	1650	0.7%	2260
Europe – ethanol	Sugar-beet	5000	3300	0.7%	4520
Europe – FAME biodiesel	Oilseed rape	1200	1080	0.7%	1480
US/Canada – ethanol	Corn	3000	1980	0.7%	2710
US/Canada – FAME biodiesel	Soybean/oilseed rape	800	720	0.7%	990
Brazil – ethanol	Sugar-cane	6800	4490	0.7%	6140
Brazil – FAME biodiesel	Soybean	700	630	1.0%	990
Rest of world - ethanol	Sugar-cane	5500	3630	1.0%	5680
Rest of world - ethanol	Grain	2000	1320	1.0%	2070
Rest of world - biodiesel	Oil palm	2500	2250	1.0%	3520
Rest of world - biodiesel	Soybean/oilseed rape	1000	900	1.0%	1410
Second generation					
World - ethanol	Lignocellulose	4300	2840	1.3%	5080
World – Btl biodiesel	Biomass	3000	3000	1.3%	5360

Note: FAME = Fatty acid methyl esters; lge/ha = litres gasoline equivalent per hectare; l/ha = litres per hectare; ethanol converted to gasoline equivalent (ethanol 67% the energy content of gasoline), biodiesel converted to diesel equivalent (biodiesel 90% the energy content of diesel, except BTL biodiesel with 100% the energy content of petroleum diesel).

Source: IEA (2008a)

Annex 3.8: Production Costs for Different Biofuels

Biofuel	Feedstock	Producing country	Year	Size of plant considered [million l biofuel/yr]	Feedstock costs [$ feedstock / GJ biofuel]	Conversion costs (capex + opex), [$/ GJ biofuel]	Revenue from co-products [$/GJ biofuel]	Total cost [$/GJ biofuel]	Total cost [$/l biofuel]
Conventional bioethanol	sugar-cane	Brazil	2008	250	7.7	7.0	0.0	14.7	0.31
	corn	USA	2008	250	29.4	6.0	0.0	35.4	0.75
	sugar-beet	UK	2008	250	21.6	11.0	8.2	24.4	0.52
	wheat	UK	2008	250	36.2	10.5	6.0	40.7	0.87
	maize	France	2008	250	29.3	10.5	5.0	34.7	0.74
Conventional biodiesel	soybean	US	2008	220	100.6	4.2	55.6	49.2	1.63
	soybean oil	Brazil Argentina	2008	220	22.6	2.7	1.7	23.5	0.78
	rapeseed	UK	2008	220	35.6	4.2	11.3	28.5	0.94
	rapeseed oil	France	2008	220	40.5	2.7	1.7	41.4	1.37
	palm oil	Indonesia / Malaysia	2008	220	25.1	2.7	1.7	26.1	0.86
	tallow	UK	2008	220	13	4	2	15.3	0.51
Lignocellulosic ethanol	cellulosic feedstocks	UK	2015	90	14	14	0	28.0	0.60
			2022	360	14	10	0	23.5	0.50
Syndiesel	cellulosic feedstocks	UK	2015	80	12	17	0	29.5	1.01
			2022	280	12	8	0	20.0	0.69

Source: E4tech (2007)

Annex 3.9: Renewable Diesel by Hydrogenation

The hydrogenation of vegetable oil and animal fat yields a bio-diesel fuel that can be blended in any proportion with petroleum-based diesel. The process involves reacting vegetable oil or animal fats with hydrogen (typically sourced from an oil refinery) in the presence of a catalyst. Although at an earlier stage of development and deployment than transesterification, hydrogenation of vegetable oils and animal fats can still be considered a 1st generation route as it is demonstrated at commercial scale.

Two main types of hydrogenation plant exist: stand-alone or co-processing.

- Stand-alone plants include their own dedicated hydrotreating equipment, and produce biodiesel that can subsequently be blended with conventional diesel from oil refineries.
- Co-processing hydrogenation plants use the hydrotreating capacity of existing conventional oil refineries, and produce a single, blended diesel output. This reduces the capital costs of the hydrogenation plant, but also reduces the refinery's output of petroleum-based diesel.

Hydrogenation potentially enables greater feedstock flexibility and lower production cost than transesterification. The technology is at the demonstration stage, and currently requires integration with an oil refinery to avoid building a dedicated hydrogen production unit and to maintain a high level of fuel quality. However, production costs are dominated by feedstock costs in the case of vegetable oils.

Key areas for improvement include improving understanding of catalysts for hydrogenation. Deployment of hydrogenation technology has been slow because of the limited interest so far of oil companies and refineries to become involved in biofuels production. There has also been reticence from the sector due to potential technical risks associated with hydrogenation catalysts degrading. However, continued interest in vegetable oils and animal fats as feedstocks could lead to greater deployment of hydrogenation.

Annex 3.10: Conversion Pathway of Lignocellulosic Material into Bioethanol

The conversion of lignocellulosic materials to ethanol involves five key processes:

1. Feedstock Production – growth and harvesting of lignocellulosic biomass (crops/residues).
2. Pre-treatment to separate the biomass into cellulose, hemicellulose and lignin (and partially hydrolysing the hemicellulose).
3. Hydrolysis of the cellulose and hemicellulose to produce sugars. This stage can be chemical, (e.g. acid hydrolysis - a well established process) or biological (using catalytic enzymes - cellulases, which are in development).
4. Fermentation of the sugars to produce ethanol.
5. Separation of the ethanol from co-products of fermentation.

Each stage in the conversion process has potential for improvement:

Feedstock production could benefit from current research into crops with higher yields, lower inputs, lower lignin content and crops that produce the enzymes that break down lignocellulosic biomass.

Pre-treatment is currently achieved by dilute acid and alkaline hydrolysis and, more recently, steam explosion. Research today focuses on the development of chemical (e.g. ionic liquids) and biological (e.g. fungal) pre-treatment processes, which are currently at an early stage of development. The development of microbes which can pre-process lignocellulosic material, decrystalise the cellulose and ferment the sugars to ethanol all in a single step could provide great cost savings.

Hydrolysis. Acid hydrolysis is a well established process and nearing commercialisation. Enzymatic hydrolysis is at the later stages of R&D, and is starting to be demonstrated at larger scale.

Fermentation of C6 sugars (hexose) to produce ethanol has reached commercialisation. C5 sugars (pentoses), on the other hand, are more difficult to ferment, and R&D is underway to produce organisms that will ferment them, some nearing demonstration at large-scale.

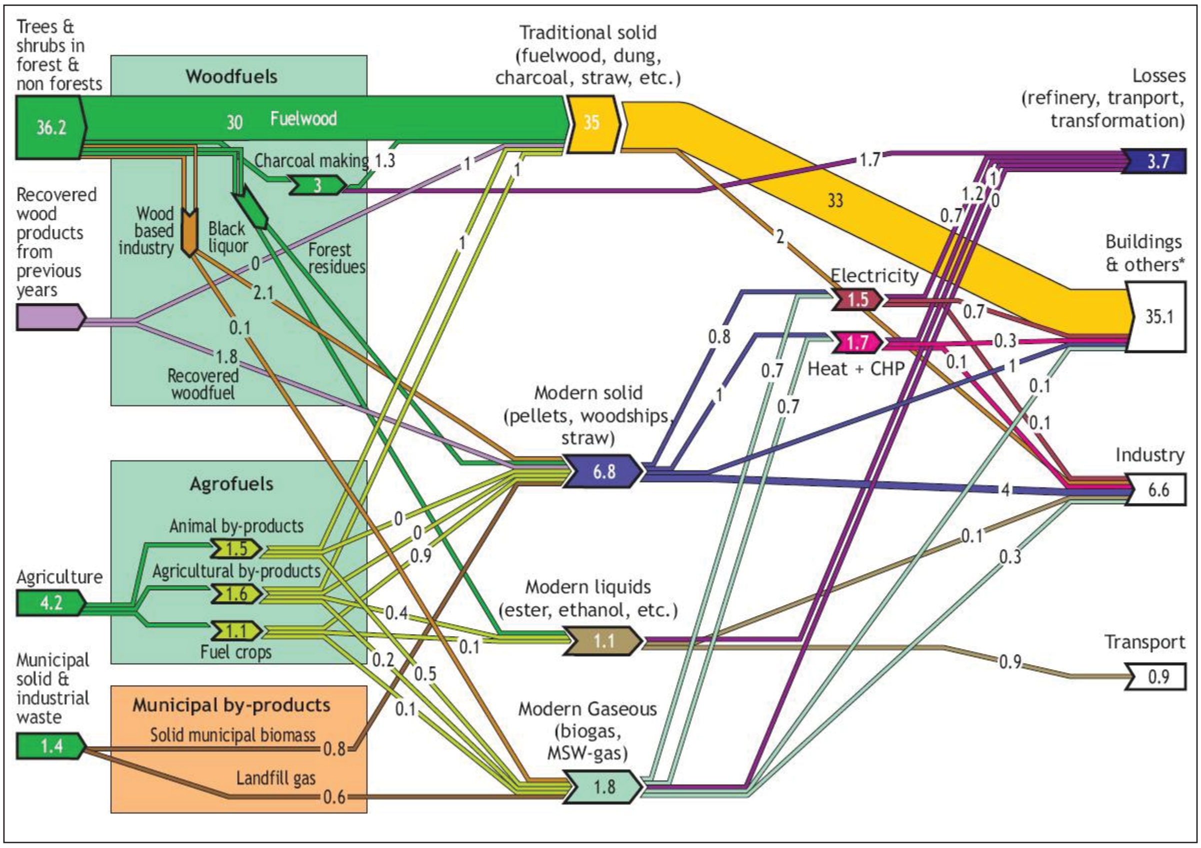
Separation can be performed by distillation. However, since this is very energy intensive, other novel, less energy intensive options are being explored.

The process whereby hydrolysis enzyme production, cellulose hydrolysis, hexose fermentation and pentose fermentation all take place in different steps (i.e. in different bioreactors) is called 'separate hydrolysis and fermentation' (SHF). Processes exist which combine these steps are in development to make the overall process potentially quicker and cheaper:

- Simultaneous Saccharification and Fermentation (SSF), where cellulose hydrolysis and hexose fermentation are combined.
- Simultaneous Saccharification and Co-fermentation (SSCF), where cellulose hydrolysis, hexose and pentose fermentation all take place simultaneously.
- Consolidated Bioprocessing (CBP) where all are combined in a single reactor.

ANNEX 4: BIOMASS TRADE AND BIOENERGY MARKETS

Annex 4.1: Overview of Bioenergy Flows into Final Applications



Source: IPCC (2007)

ANNEX 5: BIOENERGY AND POLICY OBJECTIVES

Annex 5.1: Bioenergy, Land Use and GHG Emissions

Direct land use emissions may result from the production of biomass for bioenergy. These can occur from the clearing of vegetation including forests to establish the bioenergy crop, the application of synthetic and natural fertilisers and the use of fossil fuels during the cultivation and harvesting of the bioenergy crop. The emissions from the clearing of vegetation are predominantly CO_2 from the loss of biomass, but may include CH_4 and N_2O emissions if the vegetation is burnt during clearing. The use of fertilisers produces N_2O emissions.

Indirect emissions come from three main sources: (i) emissions associated with the consumption of fossil fuels outside the project boundary during establishment and management of the bioenergy system; (ii) emissions associated with the production of fossil fuels, fertilisers or other soil additives used during cultivation; and (iii) emissions that result from the displacement of land use activities.

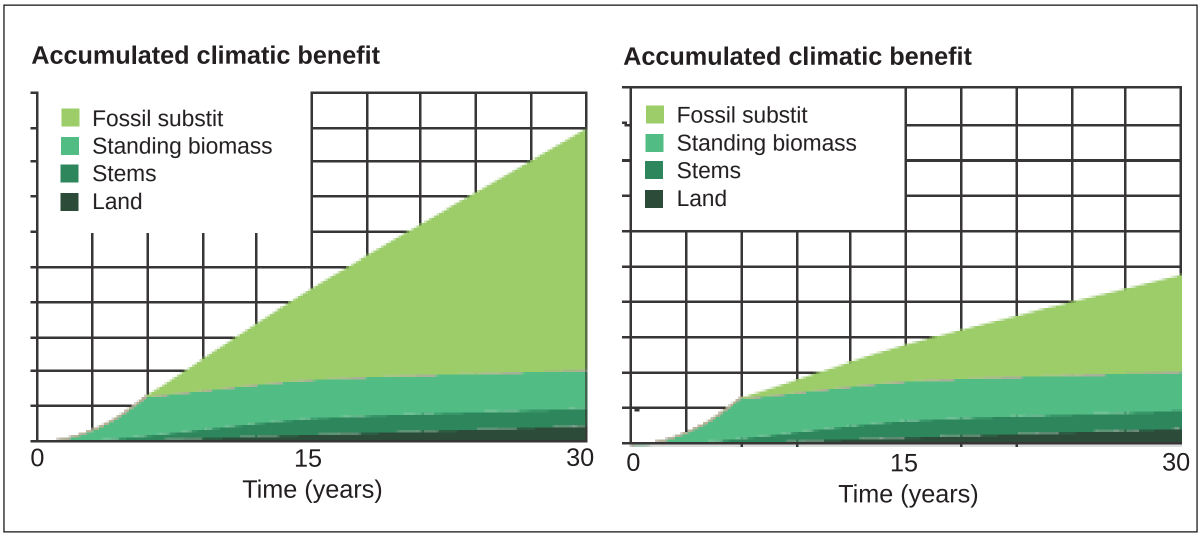
The first two tend to be small components of total project emissions. The third component – emissions that result from the displacement of the land use activities – is more significant and both the direct and indirect emissions from land use change are presently a major concern for scientists, policy makers and other parties.

Land management associated with the production of biomass may result in decreased terrestrial carbon stocks in above-ground biomass, below-ground biomass, dead wood, litter, and soil. For example, the production of biofuels from palm oil plantations causes large decreases in carbon stocks if the land was deforested to enable the establishment of the palm oil plantation. Similarly, a project that increases the collection of dead wood in an existing forest will lead to reduced carbon stocks if this practice depletes the carbon pool of dead wood in the forest. The planting of an annually tilled bioenergy crop such as rapeseed on grassland is a third example: the annual tillage of the soil could cause a systematic decrease in the soil carbon stocks.

On the other hand, bioenergy systems may also function as carbon sinks, or conversely afforestation, reforestation and revegetation can enhance carbon stocks in plants and soils, while at the same time contributing to a future biomass resource. The figure below shows two illustrative bioenergy cases where the relative importance of fossil fuel substitution and increases in carbon stocks differ. The diagram on the left could represent the case where the heat and electricity from modern biomass-fired combined heat and power plants substitute heat from a coal-fired boiler and electricity from a coal-fired condensing plant. The right hand diagram could represent the case where instead the fossil alternative would be a modern natural gas-based CHP plant. The increases in carbon stocks could for instance result from establishment of short rotation tree plantations on cropland historically used for cereal production. These diagrams were produced using the GORCAM model (see endnote in this Annex) and do not consider possible indirect effects.

It is not possible to assign a general ranking of land use options based on their contribution to climate change mitigation. The climate benefit of a specific option is determined by many parameters that are site-specific and can differ substantially depending on cultivation practice, conversion system configuration and the energy infrastructure context of its establishment (and the nature of direct and possibly indirect land use change).

Generally, the relative merits of the two principal options bioenergy and carbon sinks are dependent on:
- Efficiency with which biomass energy can substitute for fossil fuel energy. This efficiency is high if:
  - biomass is produced and converted efficiently;
  - the replaced fossil fuel would have been used with low efficiency; and
  - a carbon intensive fossil fuel is replaced.

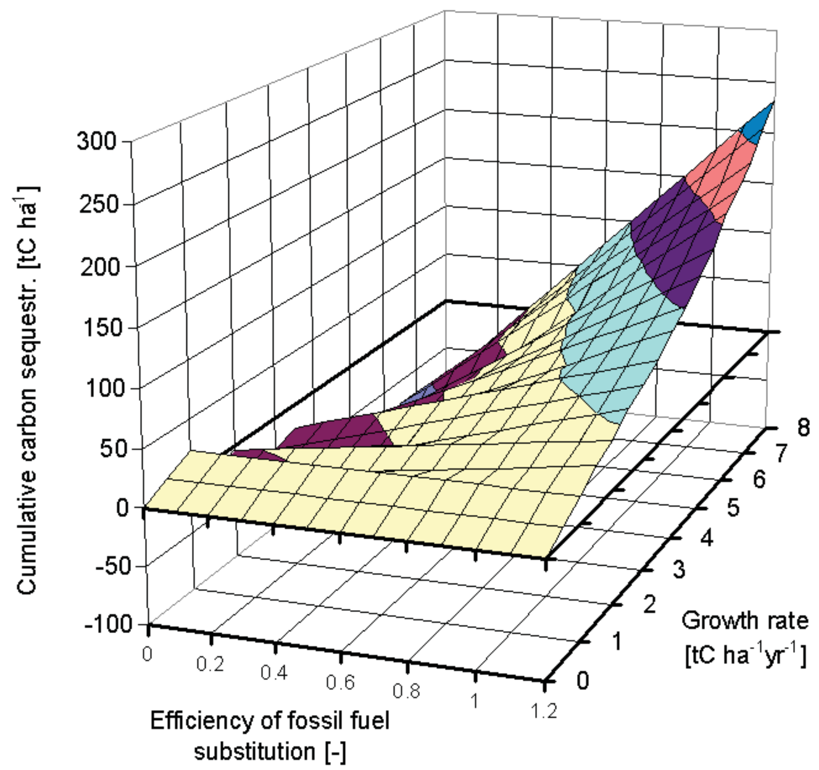


- Time period of consideration: the longer the timeframe of the analysis, the more attractive biomass energy is in comparison with carbon sequestration, because the latter is constrained by saturation (only a limited amount of carbon can be stored on a hectare of land), whereas bioenergy can be produced repeatedly, from harvest cycle to harvest cycle.
- Growth rate of the site: the higher the growth rate, the sooner the saturation constraints of carbon sequestration will be reached.

The figure below shows the difference after 40 years between a scenario where land is reforested with fast growing species to produce biomass for energy (fossil fuel substitution), and a scenario where land is reforested with the main purpose of storing carbon (carbon sequestration). The coloured surface (vertical axis) depicts cumulative carbon benefits of substitution over sequestration as a function of the efficiency of bioenergy use, and the growth rate. Positive values indicate that management for biomass energy is the better choice.

As can be seen, a combination of high yielding species and efficient use of the biomass to replace fossil fuels makes substitution management the preferable option over sequestration management. In the back right corner of the diagram the benefits of substitution management exceed those of sequestration management by almost 250 tonnes of carbon/ha after 40 years. On the other hand, low-efficiency biomass use, independent of growth rate, means that the land is better used for carbon sequestration. Where biomass is used efficiently, but growth rates are low, the relative merits of substitution management are limited.

Endnote: Material provided by IEA Bioenergy Task 38 was one important basis for Chapter 5 as well as for this Annex. Task 38 analyses and integrates information on bioenergy, land use, and greenhouse gas mitigation; thereby covering all components that constitute a biomass or bioenergy system, i.e. from biomass production to bioenergy conversion and end-use. More information about products and activities of Task 38 can be found at www.ieabioenergy-task38.org.



Annex 6.1: Key Characteristics of Several Biomass Sustainability Certification Initiatives

The list of initiatives and schemes described in the Table below is based on the publication by van Dam et al., (2008), updated to July 2009 for the present report. In addition, the RED and RSB schemes have been added. This list is only a selection of key initiatives.

Check list:	Green Gold Label	Electrabel Label	Government (BE)	RTFO (UK)	NTA 8080 (NL)	RSPO	RED (EU)	RSB
Type of biomass	All biomass for heat and electricity	All biomass for heat and electricity	All biomass for heat and electricity	Biomass for biofuels	All biomass	Palm oil	Biomass for biofuels	Biomass for biofuels
Status	Certification in implementation, also in development	Certification in implementation, also in development	Green certificates linked to GHG / energy criteria	Implemented since 2008	Principles developed, testing phase C&I (pilot studies)	Principles developed, testing phase C&I (pilot studies)	Standards developed; detailed design through 2009.	In development
GHG and/or energy balance	+ (included in GGLS8)	+	+	+	+	+	+	+
Biodiversity	+	-	-	+	+	+	+	+
Competition with food	-	-	-	-	+	-	-	+
Leakage	-	-	-	-	-[35]	-	-	+
Economic well-being	-[36]	–	–	+	+	+	-[37]	+
Welfare / social criteria	-	-	-	+	+	+	- [39]	+
Environmental criteria	+	+	-	+	+	+	- [39]	+
Type of system[38]	Track-and-trace Sourcing	Track-and-trace Sourcing	Cooperation with e.g. Electrabel, SGS	Meta-standard	Track-and-trace, mass balance or book-and- claim, currently under consideration.	Track-and-trace, mass balance or book and claim	Mass balance	Not yet determined
Organisation	Established by company Essent, now open for 3rd parties	Label is developed by company Electrabel	Government provides Green Certificate based on criteria compliance	Administered by Renewable Fuels Agency, a UK government body	Initiated by government, organisational structure in process	Roundtable with stakeholders in palm oil production	Evolving – probably mixture of government and private schemes.	Roundtable with multi-stakeholder participation
Verifier	Control Union	SGS	Independent 3rd party verification	Independent 3rd party verification	Requirements not yet determined	Verifier working group (in progress)	Independent 3rd party verification	Not yet determined
Relation to national policies	Stimulated by policy	Required by law	In regional policy (in development)	Embedded in national policy	NTA 8080 will be coupled to subsidy (only) for biomass for heating and electricity)	On voluntary basis	Will be embedded in national policies	Not yet determined
(Plans to) make use of existing systems	FSC, 'Organic' certification	Yes (e.g. FSC)	See Electrabel	Yes – meta-standard approach	Will apply e.g. FSC, and GGL	Makes use of existing systems	Will make use of existing systems	Yes – meta-standard approach

[35] How leakage could be taken into account is currently being investigated.

[36] The monitoring of living conditions in general is included.

[37] The scheme only includes a reporting requirement.

[38] Track-and trace implies the physical traceability of the traded biomass. Under book-and-claim, production and redemption of a certificate is separated (and the certificates can be traded separately from the physical biomass). Similar systems exist for example for renewable electricity, where Certificates of Origin are traded. For some of the initiatives described here, this choice has not yet been made, but the requirement to calculate GHG and energy balances makes a track-and-trace requirement likely.

Annex 6.2: Key Issues in Certification System Implementation

A sustainability scheme in bioenergy faces several implementation issues[39].

6.2.1 Criteria and indicators

Criteria and indicators have already been developed for some principles, while others are more difficult to put into practice. A robust strategy could be to start a system with available indicators and develop additional ones on the way, making use of practical experience gained in implementation.

6.2.2 Control and monitoring systems

Any successful system should be accompanied by an effective system of accounting and sufficient mechanisms for control and monitoring. Furthermore, such a system is complex given the differences in production conditions over the world, leading to different requirements for 'sustainable' production. Here, experiences with other certification systems clearly give good and bad examples. On one hand, checks such as field visits are indispensable, but on the other, these also lead to increased costs. Furthermore, the certifying body clearly functions best if it is fully independent. For example, its financial position needs to be independent of the number of certificates issued.

6.2.3 Compliance with trade law

Certification schemes can affect international trade and competitiveness, and are therefore subject to WTO regulations. This particularly applies to certification of feedstocks when applied compulsorily in the context of governmental bioenergy policies. Trade measures based on environmental considerations that distinguish between identical products on the basis of their process and production methods (PPM) may violate the WTO's regulations as laid down in the Technical Barriers to Trade (TBT) Agreement. However, jurisprudence on the exact implications of this agreement is still unclear. Two criteria seem to come forward: a trade policy should not systematically advantage domestic production over imports, and measures based on environmental considerations or conservation of exhaustible natural resources may be allowed. Indicatively, the following can be said about the different principles. Setting standards for greenhouse gas emissions and other impacts on soil, water and air seem to be feasible under WTO law. They refer to environmental issues, and greenhouse gas emissions are one of the most important motivations for bioenergy policy in the first place. On the other hand, standards for economic prosperity, social welfare, and food security are generally considered impossible under WTO law. On the other principles, the situation is less clear and much will depend on the specific formulation of the policy.

6.2.4 Barriers for small stakeholder entry

Smallholders, often operating with limited resources and technical skills, may lack the capacity to meet the requirements for certification. Therefore, there is a risk that only larger producers will apply for certification, involving a risk for market power concentration. While a certification scheme should be thorough and reliable, it should not create a hurdle for developing industries. This can be overcome by pairing a certification scheme with assistance and incentives, and supporting group certification to guarantee that small producers are not excluded. Using existing certification systems in the development of a biomass certification system, at least for the short-term, may also promote the involvement of smaller stakeholders.

6.2.5 Cost levels

Additional costs for certification are composed of two types: cost related to changes in management needed to meet the requirements, and costs related to monitoring compliance. Usually, the first type is more substantial than the second, but for smallholders this balance may differ.

6.2.6 Stakeholder involvement

Expert judgment can flag the issues, alert stakeholders to major concerns and provide methodologies for measuring, valuating, and monitoring the different aspects. However, experts should not unilaterally decide which sustainability criteria to include and how to prioritise them. To a large extent, the judgment of local stakeholders is also crucial to take into account the circumstances and needs in specific situations. An adequate understanding and involvement of primary processors and workers in the field, often the ones controlling and monitoring the criteria, is required for successful implementation of a biomass certification system. Especially for developing countries, this is not easy, as groups with relevant grassroots expertise may not be the most influential ones, and also lack access to modern communication channels.

6.2.7 Limitations to national legislation and governance

Obviously, a certification system assumes producer's compliance with national legislation. However, in countries with weak governmental enforcement, a certification system may not fully rely on this legislation. Particularly in land use planning and clarity about land owner's rights, this may be an issue. A certification system may create initiatives to support national governments to improve their laws and enforcement systems, or include additional requirements on these issues.

Annex 6.3: Overview of Intergovernmental Platforms for Exchange on Renewables and Bioenergy

Several platforms exist in which policy makers can find advice, support, and the possibility to exchange experiences on policy making for bioenergy. The main ones are:

6.3.1 International Energy Agency (IEA)

The International Energy Agency (IEA) acts as energy policy advisor to 27 member countries in their effort to ensure reliable, affordable and clean energy for their citizens. Founded during the oil crisis of 1973-74, the IEA's initial

[39] Based on van Dam et al (2008).

role was to co-ordinate measures in times of oil supply emergencies. As energy markets have changed, so has the IEA. Its mandate has broadened to incorporate the 'Three E's' of balanced energy policy making: energy security, economic development and environmental protection. Current work focuses on climate change policies, market reform, energy technology collaboration and outreach to the rest of the world, especially major consumers and producers of energy like China, India, Russia and the OPEC countries. As an example, IEA hosts an international renewables policies database (http://www.iea.org/textbase/pm/?mode=re).

Associated with IEA, the IEA Bioenergy Agreement provides an umbrella organisation and structure for a collective effort in the field of bioenergy where national experts from research, government and industry work together with experts from other member countries. For policy makers and decision makers, IEA Bioenergy provides opportunities to gain an international perspective on progress in bioenergy; to compile guidelines and standards; to gain new perspectives on deployment opportunities and issues.

Geographical scope. Mainly OECD countries
Participating countries: *Australia, Japan, Austria,* Republic of Korea, *Belgium*, Luxembourg, *Canada*, *The Netherlands*, Czech Republic, *New Zealand*, *Denmark*, *Norway*, *Finland*, Portugal, *France*, Slovak Republic, *Germany*, Spain, Greece, *Sweden*, Hungary, *Switzerland*, *Ireland*, Turkey, *Italy*, *United Kingdom*, *United States*. (Italics indicate the Member Countries of IEA Bioenergy. Non-OECD Members who also participate in IEA Bioenergy are Brazil, Croatia, the European Commission, and South Africa)

Further info: www.iea.org; www.ieabioenergy.com

6.3.2 Global Bioenergy Partnership (GBEP)

The Global Bioenergy Partnership (GBEP) provides a forum to develop effective policy frameworks to suggest rules and tools to promote sustainable biomass and bioenergy development, facilitate investments in bioenergy, promote project development and implementation, and foster R&D and commercial bioenergy activities. GBEP's main functions are to promote global high-level policy dialogue on bioenergy and facilitate international cooperation, support national and regional bioenergy policy-making and market development, favour efficient and sustainable uses of biomass and develop project activities in the bioenergy field, foster exchange of information, skills and technologies through bilateral and multilateral collaboration and facilitate bioenergy integration into energy markets by tackling specific barriers in the supply chain.

Geographical scope. Global
Participating countries. Brazil, Canada, China, France, Germany, Italy, Japan, Mexico, Netherlands, Russian Federation, Spain, Sudan, Sweden, Tanzania, United Kingdom, United States of America, FAO, IEA, UNCTAD, UN/DESA, UNDP, UNEP, UNIDO, UN Foundation, World Council for Renewable Energy (WCRE) and European Biomass Industry Association (EUBIA). Countries that participate as observers are: Angola, Argentina, Austria, Colombia, India, Indonesia, Israel, Kenya, Malaysia, Morocco, Mozambique, Norway, Peru, South Africa, Switzerland, Tunisia, European Commission, European Environment Agency (EEA), International Fund for Agricultural Development (IFAD), the World Bank and the World Business Council on Sustainable Development (WBCSD).

Further info: www.globalbioenergy.org

6.3.3 Renewable Energy Network for the 21st Century (REN21)

The Renewable Energy Network for the 21st Century (REN21) is a global policy network that provides a forum for international leadership on renewable energy. Its goal is to bolster policy development for the rapid expansion of renewable energies in developing and industrialised economies. Open to a wide variety of dedicated stakeholders, REN21 connects governments, international institutions, non-governmental organisations, industry associations, and other partnerships and initiatives. Linking the energy, development, and environment sectors, REN21 strengthens the influence of the unique renewable energy community that came together at the 'Renewables 2004' conference in Bonn. REN21 is the network in which ideas are shared and action is encouraged to promote renewable energy worldwide.

Geographic Scope. Global
Participating countries: Brazil, China, Denmark, European Community, Germany, India, Italy, Morocco, Netherlands, South Africa, Uganda, United Arab Emirates, United Kingdom of Great Britain and Northern Ireland, United States of America, supported by several other research organisations, NGO's and intergovernmental bodies

Further info: www.ren21.net

6.3.4 Renewable Energy and Energy Efficiency Partnership (REEEP)

The mission of the Renewable Energy and Energy Efficiency Partnership (REEEP) is to accelerate the global market for sustainable energy by acting as an enabler, multiplier, and catalyser of changing energy systems. The lack of long-term and reliable policies and regulatory measures to support renewables and energy efficiency and a corresponding lack of finance are the principal obstacles to the development of sustainable energy markets. The removal of market barriers is urgently needed to achieve long-term transformation of the energy sector, including creation of attractive investment environments.

REEEP projects concentrate on the following themes:
- Policy and regulation: robust policies and favourable, transparent, and stable regulatory frameworks to attract investors and to guarantee affordable energy services to consumers.
- Innovative finance mechanisms: new forms of financing, risk mitigation and finance models to make small sized renewable and energy efficient projects bankable and economically attractive.

Geographical scope. Global
Participating countries: Australia, Spain, UK, Ireland, Canada, EU, Germany, Austria, New Zealand, Norway, the Netherlands, Italy

Further info: www.reeep.org

6.3.5 Environment and Development Network for Africa (AFREPREN/FWD)

The key objective of the Energy, Environment and Development Network for Africa (AFREPREN/FWD) is to strengthen local research capacity and to harness it in the service of energy policy making and planning. Initiated in 1987, AFREPREN/FWD is a collective regional response to the widespread concern over the weak link between energy research and the formulation and implementation of energy policy in Africa. AFREPREN/FWD, brings together over 300 African energy researchers and policy makers from Africa who have a long-term interest in energy research and the attendant policy-making process.

Geographical scope. Africa
Participating countries: AFREPREN/FWD has initiated policy research studies in 19 African countries namely: Angola, Botswana, Burundi, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mauritius, Mozambique, Rwanda, Seychelles, Somalia, South Africa, Sudan, Tanzania, Uganda, Zambia and Zimbabwe. AFREPREN/FWD also maintains close collaborative links with energy researchers and policy makers from Côte d'Ivoire, Ghana, Nigeria, Sierra Leone, and Senegal.

Further info: www.afrepren.org

ANNEX 7: GLOSSARY OF TERMS AND ACRONYMS

ABREVIATIONS	DESCRIPTION
1st generation biofuels	1st generation biofuels include mature technologies for the production of bioethanol from sugar and starch crops, biodiesel and renewable diesel from oil crops and animal fats, and biomethane from the anaerobic digestion of wet biomass.
2nd generation biofuels	2nd generation biofuels are novel biofuels or biofuels based on novel feedstocks. They generally use biochemical and thermochemical routes that are at the demonstration stage, and convert lignocellulosic biomass (i.e. fibrous biomass such as straw, wood, and grass) to biofuels (e.g. ethanol, butanol, syndiesel).
3rd generation biofuels	3rd generation biofuels generally include advanced biofuels production routes which are at the early stage of research and development or are significantly further from commercialisation (e.g. biofuels from algae, hydrogen from biomass).
Agricultural residues	Agricultural residues include arable crop residues (such as straw, stem, stalk, leaves, husk, shell, peel, etc.), forest litter, grass and animal manures, slurries and bedding (e.g. poultry litter).
Anaerobic digestion	Decomposition of biological wastes by micro-organisms, usually under wet conditions, in the absence of air (oxygen), to produce biogas.
Animal residues	Agricultural by-products originating from livestock operations. It includes among others solid excreta of animals.
Ash	Residue obtained from the combustion of a fuel.
Bagasse	Fibre left over after the juice has been squeezed out of sugar-cane stalks. It is commonly used as a source of heat supply in the production of bioethanol.
Bark	The outermost sheath of tree trunks, branches, and roots of woody plants. It overlays the wood and consists of inner bark (living tissue) and outer bark (dead tissue). Bark is usually a by-product (residue) from conventional wood processing.
BIG/CC	Biomass integrated gasification and combined cycle.
Biobutanol	Alcohol with a 4 carbon structure and the molecular formula C_4H_9OH produced from biomass. Biobutanol can easily be added to conventional petrol and can be blended up to higher concentrations than bioethanol for use in standard vehicle engines. Biobutanol can also be used as a blended additive to diesel fuel to reduce soot emissions.
Biodiesel	Biodiesel refers to a diesel-type fuel produced by transesterification of vegetable oils or animal fats. Biodiesel can be blended (with some restrictions on the level of blending) with conventional diesel for use in unmodified diesel-engine vehicles. Its full name is FAME (Fatty Acid Methyl Ester) biodiesel.
Bioenergy	Renewable energy produced from the conversion of organic matter. Organic matter may either be used directly as a fuel or processed into liquids and gases.
Bioethanol	Alcohol with a 2 carbon structure and the molecular formula C_2H_5OH, produced from biomass. Bioethanol can be blended with conventional gasoline or diesel for use in petroleum-engine vehicles.
Biofuel	Fuel produced directly or indirectly from biomass. The term biofuel applies to any solid, liquid, or gaseous fuel produced from organic (once-living) matter. The word biofuel covers a wide range of products, some of which are commercially available today, and some of which are still in the research and development phase.
Biogas	A combustible gas derived from decomposing biological waste under anaerobic conditions. Biogas normally consists of 50-60% methane, 25-50% carbon dioxide, and other possible elements such as nitrogen, hydrogen or oxygen. See also Landfill Gas.
Biomass	Organic matter available on a renewable basis. Biomass includes forest and mill residues, agricultural crops and wastes, wood and wood wastes, animal wastes, livestock operation residues, aquatic plants, fast-growing trees and plants, and municipal and industrial wastes.
Biomass energy	See Bioenergy above.
Biomass feed system	Electromechanical system (e.g. conveyors, pumps) to feed the biomass feedstock into the boiler of a biomass-based plant.
Biomethanol	Simplest possible alcohol with the molecular formula CH_3OH. Biomethanol can be blended into gasoline, but the substance is more volatile than bioethanol.
Bioreactor	A bioreactor is a vessel in which a biochemical process occurs. This usually involves organisms or biochemically active substances derived from such organisms.

ABREVIATIONS	DESCRIPTION
Biochar	Biochar is charcoal created by pyrolysis of biomass.
Bio-SNG	Bio Synthetic Natural Gas is syngas (produced from gasification of biomass) that has been upgraded to meet the quality standard of natural gas. Bio-SNG is often called simply SNG.
Black liquor	Black liquor is a by-product of the kraft process during the production of paper pulp. It is an aqueous solution of lignin residues, hemicelluloses, and the inorganic chemicals used in the process.
Briquette	Densified solid biofuel in the shape of cubiform or cylindrical units, produced by compressing biomass. The raw material for briquettes can be biomass of various origins (e.g. woody, herbaceous, fruit). Biofuel briquettes are usually manufactured in a piston press. The total moisture content of the biofuel briquette is usually less than 15 % of mass.
BTL	Biomass-to-liquid is a (multi-step) process to produce liquid biofuels from biomass. The first step is gasification, while the second step may, for example, be Fischer Tropsch.
Bulk density	Mass of a portion of a solid fuel divided by the volume of the container which is filled by that portion under specific conditions.
By-product	A by-product, or co-product, is a substance, other than the principal product, generated as a consequence of producing the main product. For example, a by-product of biodiesel production is glycerine. Every bioenergy conversion chain generates co-products. These may add substantial economic value to the overall process. Examples include animal feed, food additives, specialty chemicals, charcoal, and fertilisers.
Calorific Value (Q)	Amount of heat released during the complete combustion of a given amount of a combustible.
Capacity	The maximum power that a machine or system can produce or carry safely. The maximum instantaneous output of a resource under specified conditions. The capacity of energy generating equipment is generally expressed in kilowatts (for devices) or megawatts (for plants).
Capital cost	The total investment needed to complete a project and bring it to a commercially operable status. The cost of construction of a new plant. The expenditures for the purchase or acquisition of existing facilities.
Catalyst	A catalyst is a substance that increases the rate of a chemical reaction, without being consumed or produced by the reaction. Enzymes are catalysts for many biochemical reactions.
Cellulose	Polysaccharide (long chain of simple sugar molecules) with the formula $(C_6H_{10}O5)_n$. Cellulose is the fibrous substance which is contained in leaves, stems, and stalks of plants and trees. It is the most abundant organic compound on earth and can be used to produce biofuels.
Cellulosic ethanol	Cellulosic ethanol is ethanol fuel produced from lignocellulosic material such as wood. Cellulosic ethanol is chemically identical to ethanol from other sources, such as corn or sugar, and is available in a great diversity of biomass including waste from urban, agricultural, and forestry sources.
Char	The remains of solid biomass that has been incompletely combusted, such as charcoal resulting from wood that is incompletely burned.
Charcoal	Solid residue derived from carbonisation distillation, pyrolysis, and torrefaction of fuelwood.
Chips	Woody material cut into short, thin wafers. Chips are used as a raw material for pulping and fibreboard or as biomass fuel.
Circulating fluidised bed (CFB)	A type of furnace in which the emission of sulphur compounds is lowered by the addition of crushed limestone in the fluidised bed thus obviating the need for much of the expensive stack gas clean-up equipment. The particles are collected and recirculated, after passing through a conventional bed, and cooled by boiler internals.
CHP	Combined Heat and Power. See cogeneration below.
CO_2	Carbon dioxide.
Cogeneration	The simultaneous production of electricity and useful thermal energy from a common fuel source. Surplus heat from an electric generating plant can be used for industrial processes, or space and water heating purposes (topping cycle).
Combined cycle	Two or more energy generation processes in series or in parallel, configured to optimise the energy output of the system.
Combined Heat and Power (CHP)	See Cogeneration above.
Combined Cycle Power Plant	The combination of a Brayton-Joule Cycle (gas turbine) and a Rankine Cycle (steam turbine) in an electric generation plant. The waste heat from the gas turbine provides the heat energy required for the steam cycle. This is also called combined cycle gas turbine.
Combustion (of biomass)	The transformation of biomass fuel into heat, chemicals, and gases through chemical combination of hydrogen and carbon in the fuel with oxygen.

ABREVIATIONS	DESCRIPTION
Compressed Natural Gas (CNG)	CNG is made by compressing natural gas to less than 1% of its volume at standard atmospheric pressure. It is used in traditional gasoline internal combustion engine cars that have been converted into bi-fuel vehicles (gasoline/CNG).
Co-product	See By-product.
Density	Ratio of mass to volume. It must always be stated whether the density refers to the density of individual particles or to the bulk density of the material and whether the mass of water in the material is included.
Dimethyl ether (DME)	Liquid biofuel with the molecular formula CH_3OCH_3. DME is produced by the dehydration of methanol and can be used as a fuel in diesel engines, petrol engines, and gas turbines. It works particularly well in diesel engines due to its high cetane number.
District heating	District heating is a system for distributing heat generated in a centralised location for residential and commercial heating requirements, such as space and water heating.
Digester	An airtight vessel or enclosure in which bacteria decompose biomass in wet conditions to produce biogas.
Discount rate	A rate used to convert future costs or benefits to their present value.
Dry basis	Condition in which the solid biofuel is free from moisture.
Dry matter	Material after removal of moisture under specific conditions.
Dry matter content	Fraction of dry matter in the total material on mass basis.
E85	Mix of 85% ethanol and 15% petrol. E85 is a common bioethanol blend used in flex-fuel vehicles. Other blends exist such as E5 and E100. The number always refers to the percentage of ethanol blended in the petrol.
EC	European Commission.
Effluent	The liquid or gas discharged from a process or chemical reactor, usually containing residues from that process.
EJ	Exajoules (1EJ = 10^{18}J). See also Joule.
Emissions	Waste substances released into the air or water. See also Effluent.
Energy crops	Crops grown specifically for their fuel value. These include food crops such as corn and sugar-cane, and non-food crops such as poplar trees and switchgrass.
Energy density	Ratio of net energy content and bulk volume.
Engine	A device that converts the energy of a fuel into mechanical power. The combination of an engine and an alternator converts heat from combustion (e.g. of biomass) into power.
Enzyme	A protein or protein-based molecule that speeds up chemical reactions occurring in living things. Enzymes act as catalysts for a single reaction, converting a specific set of reactants into specific products.
EtOH	See Bioethanol.
Ethyl-tertio-butyl-ether (ETBE)	Organic compound with the formula $C_6H_{14}O$. ETBE is commonly used as an oxygenate gasoline additive in the production of gasoline from crude oil.
EU	European Union.
Externality	A cost or benefit not accounted for in the price of goods or services. Often 'externality' refers to the cost of pollution and other environmental impacts.
FAME Biodiesel	Fatty Acid Methyl Ester Biodiesel. See Biodiesel.
Feed System	See Biomass Feed System.
Feed-in tariff	Subsidy mechanism by which the regional or national electricity companies are obligated to buy the electricity generated from renewable resources by decentralised producers at fixed prices (the feed-in tariffs) set by the government, The higher price helps overcome the cost disadvantages of renewable energy sources.
Feedstock	A feedstock is any biomass resource destined for conversion to energy or biofuel. For example, corn is a feedstock for ethanol production, soybean oil may be a feedstock for biodiesel and cellulosic biomass has the potential to be a significant feedstock source for biofuels.
Fermentation	Conversion of carbon-containing compounds by micro-organisms for production of fuels and chemicals such as alcohols, acids or energy-rich gases. It is a biochemical reaction that breaks down complex organic molecules (such as carbohydrates) into simpler materials (such as ethanol, carbon dioxide, and water). Bacteria or yeasts can ferment sugars to bioethanol.

ABREVIATIONS	DESCRIPTION
Firewood	Cut and split oven-ready fuelwood used in household wood burning appliances such as stoves, fireplaces and central heating systems. Firewood usually has a uniform length, typically in the range 150 mm to 500 mm.
Fischer Tropsch (FT) Process	Catalysed chemical reaction in which syngas from gasification is converted into a liquid biofuel of various kinds.
Flex-fuel vehicle (FFV)	Vehicles that can use either biofuels and/or petroleum interchangeably.
Fluidised-bed combustion (FBC)	Fluidised-bed combustion is a technology that improves the chemical reactions and heat transfer of boilers in power plants, and hence its overall efficiency, as compared to traditional fixed-beds. FBC plants are more flexible than conventional plants because they can be fired on coal and biomass, among other fuels. FBC also reduces the amount of sulphur emitted in the form of SO_X emissions.
Fly ash	Small ash particles carried in suspension in combustion products.
Forest residues	Material not harvested or removed from logging sites in commercial hardwood and softwood stands as well as material resulting from forest management operations such as pre-commercial thinnings and removal of dead and dying trees.
Fossil fuel	Solid, liquid, or gaseous fuels formed in the ground after millions of years by chemical and physical changes in plant and animal residues under high temperature and pressure. Oil, natural gas, and coal are fossil fuels.
Fuel cell	A device that converts the energy of a fuel directly to electricity and heat, without combustion.
Fuel gas	See Producer Gas.
Fuel handling system	A system for unloading biomass feedstock from vans or trucks, transporting the feedstock to a storage location (e.g., pile, silo), and conveying it from storage to the boiler or other energy conversion equipment.
Fuelwood	Wood fuel where the original composition of the wood is preserved.
Furnace	An enclosed chamber or container used to burn biomass in a controlled manner to produce heat for space or process heating.
Gas turbine	A turbine that converts the energy of hot compressed gases (produced by burning fuel in compressed air) into mechanical power. Often fired by natural gas or fuel oil.
Gasification	A thermochemical process at elevated temperature and reducing conditions to convert a solid fuel to a gaseous form (CO, H_2, CH_4, etc.), with char, water, and condensibles as minor products.
Gasifier	A device for converting solid fuel into gaseous fuel.
Gha	Gigahectares (1Gha = 10^9ha).
GHG	Greenhouse gas. Gases that trap the heat of the sun in the Earth's atmosphere, producing the greenhouse effect. The two major greenhouse gases are water vapour and carbon dioxide. Other greenhouse gases include methane, ozone, chlorofluorocarbons, and nitrous oxide.
GIS	Geographic Information System. An information system for capturing, storing, analysing, managing, and presenting data which are spatially referenced (linked to location).
GJ	Gigajoule (1GJ = 10^9J).
GJ_e	Gigajoule electrical.
GJ_{th}	Gigajoule thermal.
GMO	Genetically Modified Organism.
Green diesel	See Syndiesel.
Greenhouse effect	The effect of certain gases in the Earth's atmosphere in trapping heat from the sun.
Grid	An electric utility company's system for distributing power.
GW	Gigawatt. A measure of electrical power equal to one billion watts (1,000,000 kW). A large coal or nuclear power station typically has a capacity of about 1 GW.
Heating value	Amount of heat released during the complete combustion of a given amount of a combustible. See Higher Heating Value and Lower Heating Value for more details.
Hectare (Ha)	Common metric unit of area, equal to 2.47 acres. 1 hectare equals 10,000 square meters. 100 hectares = 1 square kilometre. Abbreviated as ha.
Herbaceous biomass	Biomass from plants that has a non-woody stem and which dies back at the end of the growing season.
Higher heating value (HHV)	Amount of heat released during the complete combustion of a given amount of a combustible (initially at 25°C) and the cooling of the combustion products back to 25°C. Thus, the HHV includes the latent heat of vaporisation of the water contained in the combustion products.

ABREVIATIONS	DESCRIPTION
Hydrocarbon	Any chemical compound containing hydrogen, oxygen, and carbon.
Hydrogen	Simplest molecule conceivable, with a molecular formula of H_2. Gaseous fuel that can be produced from fossil fuels, biomass and electricity.
Hydrogenation	Process which typically constitutes the addition of pairs of hydrogen atoms to a molecule. Biodiesel manufactured from the hydrogenation of vegetable oil and animal fat can be blended in any proportion with petroleum-based diesel.
Hydrolysis	Hydrolysis is a chemical reaction that releases sugars, which are normally linked together in complex chains. In bioethanol production, hydrolysis reactions are used to break down the cellulose and hemicellulose in the biomass.
Hydrotreated Biodiesel	See Renewable Diesel.
IEA	International Energy Agency.
Incinerator	Any device used to burn solid or liquid residues or wastes as a method of disposal. In some incinerators, provisions are made for recovering the heat produced.
Indirect liquefaction	Conversion of biomass to a liquid fuel through a synthesis gas intermediate step.
IPCC	Intergovernmental Panel on Climate Change.
Jatropha	*Jatropha curcas* is a non-edible evergreen shrub found in Asia, Africa and the West Indies. Its seeds contain a high proportion of oil which can be used for making biodiesel.
Joule	Metric unit of energy, equivalent to the work done by a force of one Newton applied over a distance of one metre (= 1 $kg.m^2/s^2$). One joule (J) = 0.239 calories (1 calorie = 4.187 J).
kW	Kilowatt. A measure of electrical power equal to 1,000 watts. 1 kW = 3.413 Btu/hr = 1.341 horsepower. See also Watt.
kWh	Kilowatt hour. A measure of energy equivalent to the expenditure of one kilowatt for one hour. For example, 1 kWh will light a 100-watt light bulb for 10 hours. 1 kWh = 3.413 Btu.
kW_e	Kilowatt electrical. See also kW.
kW_{th}	Kilowatt thermal. See also kW.
Kyoto Protocol	UN-led international agreement aimed at reducing GHG emissions.
Landfill gas	Biogas generated by decomposition of organic material at landfill disposal sites. Landfill gas is approximately 50% methane. See also Biogas.
Lifecycle Assessment (LCA)	Investigation and valuation of the environmental impacts of a given product or service caused or necessitated by its existence. The term 'lifecycle' refers to the notion that a fair, holistic assessment requires the assessment of raw material production, manufacture, distribution, use and disposal including all intervening transportation steps necessary or caused by the product's existence.
Lower Heating Value (LHV)	Amount of heat released during the complete combustion of a given amount of a combustible (initially at 25°C) and the cooling of the combustion products down to 150°C. Thus, the LHV excludes the latent heat of vaporisation of the water contained in the combustion products.
Lignin	Structural constituent of wood and (to a lesser extent) other plant tissues, which encrusts the cell walls and cements the cells together.
LNG	Liquefied natural gas.
Log wood	Cut fuelwood, with most of the material having a length of 500 mm and more.
LPG	Liquefied Petroleum Gas.
MeOH	See Biomethanol.
Methane	Methane is a combustible chemical compound with the molecular formula CH_4. It is the principal component of natural gas.
Miscanthus	*Miscanthus* or elephant grass, is a genus of about 15 species of perennial grasses native to subtropical and tropical regions of Africa and southern Asia. The rapid growth, low mineral content and high biomass yield of *Miscanthus* makes it a favoured choice as a bioethanol feedstock.
MJ	Megajoule (1MJ = 10^6J). See also Joule.
Moisture content	The quantity of water contained in a material (e.g. wood) on a volumetric or mass basis.
Monoculture	The cultivation of a single species crop.
MSW	Municipal Solid Waste.
MTBE	Methyl tert-butyl ether. MTBE is used as an oxygenate additive to raise the octane number of gasoline.

ABREVIATIONS	DESCRIPTION
MW	Megawatt. A measure of electrical power equal to one million watts (1,000 kW). See also Watt.
MW_e	Megawatt electrical.
MW_{th}	Megawatt thermal.
N_2	Nitrogen.
N_2O	Nitrous oxide or laughing gas. Powerful greenhouse gas that can be emitted from soils with intensive (nitrogen) fertilisation.
Nitrogen Oxides (NO_x)	Nitrogen oxides are a product of photochemical reactions of nitric oxide in ambient air, and are one type of emission produced from fuel combustion.
O_2	Oxygen.
Octane number	Measure of the resistance of gasoline and other fuels to detonation (engine knocking) in spark-ignition internal combustion engines. The octane rating of a fuel is indicated on the pump. The higher the number, the slower the fuel burns. Bioethanol typically adds two to three octane numbers when blended with ordinary petroleum, making it a cost-effective octane-enhancer.
Organic compounds	Chemical compounds based on carbon chains or rings and also containing hydrogen, with or without oxygen, nitrogen, and other elements.
Organic matter	Matter that comes from a once-living organism.
Organic Rankine Cycle (ORC)	A Rankine Cycle is a closed circuit steam cycle to convert heat into mechanical energy in an engine. An organic Rankine Cycle uses an organic fluid with a high molecular mass instead of steam, allowing heat recovery from low temperature sources such as industrial waste heat, geothermal heat, solar ponds, etc.
Particulate	A small, discrete mass of solid or liquid matter that remains individually dispersed in gas or liquid emissions. Particulates take the form of aerosol, dust, fume, mist, smoke, or spray. Each of these forms has different properties.
Pellet	Densified biofuel made from pulverised biomass with or without pressing aids usually with a cylindrical form, random length typically 5 to 30 mm, and broken ends. The raw material for biofuel pellets can be woody biomass, herbaceous biomass, fruit biomass, or biomass blends and mixtures. They are usually manufactured using a die. The total moisture content of biofuel pellets is usually less than 10% of mass.
Photosynthesis	Process by which chlorophyll-containing cells in green plants convert incident light to chemical energy, capturing carbon dioxide in the form of carbohydrates.
Pilot scale	The size of a system between the small laboratory model size (bench scale) and a full-size system.
Process heat	Heat used in an industrial process rather than for space heating or other housekeeping purposes.
Producer gas	The mixture of gases produced by the gasification of organic material such as biomass at relatively low temperatures (700-1000°C). Producer gas is composed of carbon monoxide (CO), hydrogen (H), carbon dioxide (CO_2), Nitrogen (N_2) and typically a range of hydrocarbons such as methane (CH_4). Producer gas can be burned as a fuel gas in a boiler for heat or in an internal combustion gas engine for electricity generation or combined heat and power (CHP). It can also be upgraded to Syngas for the production of biofuels.
Pyrolysis	The thermal decomposition of biomass at high temperatures (greater than 400°F, or 200°C) in the absence of air. The end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), and gases (methane, carbon monoxide and carbon dioxide) with proportions determined by operating temperature, pressure, oxygen content, and other conditions.
Renewable diesel	Hydrotreated biodiesel produced by the hydrogenation of vegetable oils or animal fats. Its fuel characteristics are similar to fossil diesel.
Reforming	Chemical process used in the petrochemical industry to improve the octane rating of hydrocarbons, but is also a useful source of other chemical compounds such as aromatic compounds and hydrogen. Steam reforming of natural gas or syngas sometimes referred to as steam methane reforming (SMR) is the most common method of producing commercial bulk hydrogen. At high temperatures (700 – 1100°C) and in the presence of a metal-based catalyst (nickel), steam reacts with methane to yield carbon monoxide and hydrogen. $CH_4 + H_2O \rightarrow CO + 3\ H_2$ Additional hydrogen can be recovered by a lower-temperature gas-shift reaction with the carbon monoxide produced. $CO + H_2O \rightarrow CO_2 + H_2$.
Refuse-derived fuel (RDF)	Fuel prepared from municipal solid waste. Non-combustible materials such as rocks, glass, and metals are removed, and the remaining combustible portion of the solid waste is chopped or shredded. RDF facilities process typically between 100 and 3,000 tonnes of MSW per day.

ABREVIATIONS	DESCRIPTION
Residues	By-product of agricultural cultivation (e.g. bagasse), farming activities (e.g. manure) or forestry industry (tree thinnings).
RME	Rape methyl ester. Esterified rape-oil commonly used as biodiesel.
Sawdust	Fine particles created when sawing wood.
Short rotation crop	Woody biomass grown as a raw material and/or for its fuel value in short rotation forestry.
Sludge	Sludge is formed in the aeration basin during biological waste water treatment or biological treatment process and separated by sedimentation. Sludges can be converted into biogas via anaerobic digestion.
SNG	Synthetic natural gas. Gas mixture that contains varying amounts of carbon monoxide and hydrogen generated by the gasification of a carbon-containing fuel to a gaseous product with a heating value.
Solid biofuel	Solid fuels (e.g. pellets, wood charcoal) produced directly or indirectly from biomass.
Steam turbine	A device for converting energy of high-pressure steam (produced in a boiler) into mechanical power which can then be used to generate electricity.
Stirling engine	Closed-cycle regenerative heat engine with a gaseous working fluid. The working fluid, the gas which pushes on the piston, is permanently contained within the engine's system.
Switchgrass	Perennial energy crop. Switchgrass is native to the USA and known for its hardiness and rapid growth. It is often cited as a potentially abundant 2nd generation feedstock for ethanol.
Syndiesel	Synthetic diesel produced through Fischer-Tropsch synthesis from lignocellulosic biomass (e.g., wood). Its fuel characteristics are similar to fossil diesel.
Syngas	Syngas (from the contraction of synthesis gas) is a mixture of mainly carbon monoxide (CO) and hydrogen (H_2), which is the product of high temperature steam or oxygen gasification of organic material such as biomass. Following clean-up to remove any impurities such as tars, syngas can be used to produce organic molecules such as synthetic natural gas (mainly CH_4) or liquid biofuels such as synthetic diesel (via Fischer Tropsch synthesis).
Synthesis gas	See Syngas.
Synthetic Diesel	See Syndiesel.
Torrefaction	Mild pre-treatment of biomass at a temperature between 200-300°C. During torrefaction of the biomass, its properties are changed to obtain a better fuel quality for combustion and gasification applications.
Transesterification	Process of exchanging the alkoxy group of an ester compound with another alcohol. Biodiesel is typically manufactured from vegetable oils or animal fats by catalytically reacting these with methanol or ethanol via transesterification.
Tri-generation	Tri-generation is the simultaneous production of mechanical power (often converted to electricity), heat and cooling from a single heat source such as fuel.
Turbine	A machine for converting the heat energy in steam or high temperature gas into mechanical energy. In a turbine, a high velocity flow of steam or gas passes through successive rows of radial blades fastened to a central shaft.
VOC	Volatile organic compounds are air pollutants found, for example, in engine exhaust.
Watt	The common base unit of power in the metric system. One watt equals one joule per second, or the power developed in a circuit by a current of one ampere flowing through a potential difference of one volt. 1 Watt = 3.413 Btu/hr. See also Kilowatt.
Wood chips	Chipped woody biomass in the form of pieces with a defined particle size produced by mechanical treatment with sharp tools such as knives. Wood chips have a sub-rectangular shape with a typical length 5-50 mm and a low thickness compared to other dimensions.
Wood fuel	All types of biofuels derived directly or indirectly from trees and shrubs grown on forest and non-forest lands, from silvicultural activities (thinning, pruning, etc.), and from industrial activities (harvesting, logging or primary and secondary forest industries).
Woody biomass	Biomass from trees, bushes and shrubs.
Yeast	Yeast is any of various single-cell fungi capable of fermenting carbohydrates. Bioethanol is produced by fermenting sugars with yeast.

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IEA Bioenergy

IEA Bioenergy is an international collaboration set up in 1978 by the IEA to improve international co-operation and information exchange between national RD&D bioenergy programmes. IEA Bioenergy's vision is to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis, thus providing increased security of supply whilst reducing greenhouse gas emissions from energy use. Currently IEA Bioenergy has 22 Members and is operating on the basis of 13 Tasks covering all aspects of the bioenergy chain, from resource to the supply of energy services to the consumer.

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