Biomass and biofuels.

A background report for the Energy Council of the Netherlands (Algemene EnergieRaad – AER)

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Datum: 29 januari 2007

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Background

The ‘Raad voor Verkeer en Waterstaat’, the ‘Algemene Energieraad’ and the ‘VROM-raad’ were requested by the Minister of Verkeer en Waterstaat to prepare an advice on mobility CO_2 halfway 2007. A crucial question for this advice how the CO_2 emission mitigation policy should be designed to achieve far reaching emission reduction on longer term (i.e. 2050). The Council should take into account the societal and political support and feasibility, international context and technical possibilities in its recommendations.

A committee with members from the three councils involved, prepares this advice. The committee requested background papers on various topics (including passenger road transport, aviation and international shipping and biofuels for the transport sector). The background papers serve as ‘quick scans’ and are ment to provide the committee an overview of the state-of-the-art in the fields mentioned, including ongoing (policy) debate. The target group consists of committee members, who are not experts but knowledgeable on the field in general.

The **objective** of this background report is to offer a compact overview on the current status, boundary conditions and future perspectives for biofuels for the transport sector. This report is based on publicly available information and recent (international and scientific) literature.

Discussed are the current status on production and use of biofuels, technological options and their performance, biomass resources and potentials, sustainability criteria, competition for resources, policy development and issues around implementation and strategy. The latter is in particular focused on the Netherlands.
Important for the content of this report is the explicit attention for production and supplies of biomass resources. The supply and production of biomass (for transport fuels, power or heat generation or use of biomaterials alike) is usually a major component of the total production costs as well as the total ecological (and socio-economic) impacts of biomass use for energy and materials. The current debate on the sustainability of biofuels is largely focusing on the biomass resource base and (additional) land use for its’ production. In addition, for a country as the Netherlands, with a small land base, high population density, high energy use per capita and high intensity agriculture, possibilities to produce and supply biomass within the country are limited (as is explained in section 4 of this report). Therefore, biomass resources are increasingly imported, either as raw or pre-treated material or directly as biofuel (e.g. ethanol). In particular for the Netherlands, biomass imports will be the key for large scale deployment of biomass and biofuels. Subsequently, the development of international and sustainable biomass markets is therefore a crucial factor. Therefore, this report has a global perspective. This also allows a, brief, comparison with developments on biofuels between different key countries and regions. Throughout the report, specific remarks on the Netherlands are included when applicable and relevant.

1. Current status of biofuels

(largely based on reviews from: WWI, 2006, UNCTAD, 2006, IEA- WEO, 2006]

Recent Developments in the Biofuel Industry

Interest in biofuels – liquid transport fuels derived from biomass – is soaring in many countries. Biofuels hold out the prospect of replacing substantial volumes of imported oil with indigenously-produced fuels in the coming decades. Such a development would bring energy-security benefits to importing countries. It could also bring environmental benefits, including lower greenhouse-gas emissions, because the biomass raw materials for producing biofuels are renewable. Biofuels can also contribute to rural development and job creation. The recent surge in international oil prices – together with lower biofuels production costs – has made biofuels more competitive with conventional petroleum-based fuels, though further reductions in costs will be needed for biofuels to be able to compete effectively with gasoline and diesel without subsidy in most cases. New biofuels technologies being developed today, notably based on ligno-cellulosic feedstock, promise such reductions. Until recently, most biofuels programmes were conceived as part of farm-support policies, but a growing number of governments are now looking to expand or introduce such programmes for genuine energy-security, economic and environmental reasons.

There are several types of biofuels and many different ways of producing them. Today, the overwhelming bulk of biofuels produced around the world are ethanol and diesters – commonly referred to as biodiesel. Ethanol is usually produced from starchy crops, such as cereals and sugar, while biodiesel is produced mainly from oil-seed crops, including rapeseed and sunflowers. Other crops and organic wastes can also be used. Each fuel has its own unique characteristics, advantages and drawbacks. Ethanol, in an almost water-free anhydrous form, is usually blended with gasoline (either pure or in a derivative form, known as ethyl tertiary butyl ether, or ETBE).[1] Biodiesel obtained from vegetable oils can be used easily in most existing engines in its pure form or in virtually any blended ratio with conventional diesel fuel. Ethanol in a hydrous form (containing up to 5% water) and some types of biodiesel can be used unblended only with modifications to the vehicle engine. Almost all biofuels are used in cars and trucks, though small quantities of ethanol are used for aviation purposes.

Global production of biofuels amounted to just under 26 million tonnes of oil equivalent (Mtoe), or 840 thousand barrels per day (kb/d) in 2005 – equal to 1% of total road-transport fuel consumption in energy terms. Brazil and the United States together account for 70% of global supply. The United States overtook Brazil in 2005 as the world's largest producer of biofuels (Table 1.1). In both countries, almost all biofuels are ethanol. Most US bio-ethanol is derived from corn (maize). US production has surged in recent years as a result of tax incentives and rising demand for ethanol as a gasoline-blending component. In Brazil, production of bio-ethanol peaked in the 1980s, but declined as international oil prices fell back. Falling production costs and, more recently, the rebound in oil prices have led to a renewed surge in output. Production of biofuels in Europe is growing rapidly thanks to strong government incentives. More than half of EU production is biodiesel, which in turn makes up almost 87% of world biodiesel output. Elsewhere, China and India are the largest producers of biofuels, mostly in the form of ethanol and mostly used in industry. In no other country other than Brazil, Cuba and Sweden does the share exceed 2% (Figure 1.1). Only Brazil exports significant volumes of biofuels.

Table 1.1: Biofuels Production per Country, 2005

	Ethanol		Biodiesel		Total	
	Mtoe	kb/d	Mtoe	kb/d	Mtoe	Kb/d
Brazil	8.17	277	0.05	1	8.22	278
China	1.92	65	negligible		1.92	65
European Union	1.39	47	2.54	56	3.93	103
Germany	0.18	*6*	*1.50*	33	1.68	39
France	0.47	*16*	*0.41*	9	0.88	25

[1] ETBE has lower volatility than ethanol, but there are health concerns about its use as a gasoline blending component.

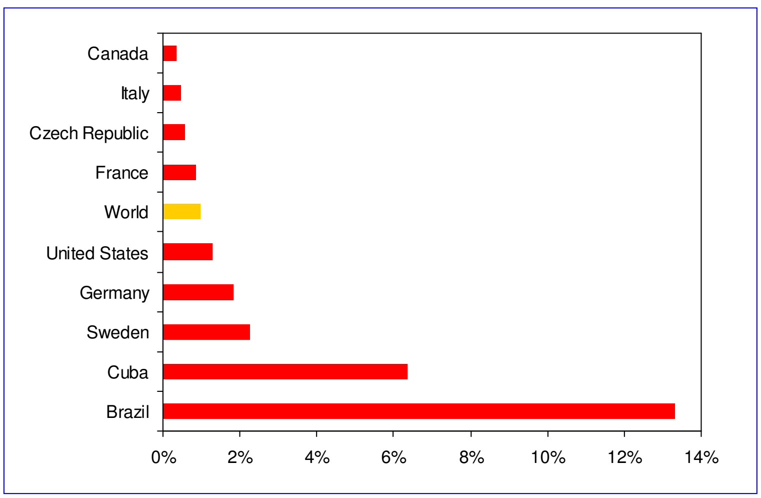
Italy	0.09	*3*	*0.18*	4	0.27	7
Spain	0.18	*6*	*0.05*	1	0.22	7
United States	8.23	279	0.23	5	8.46	284
India	0.86	29	negligible		0.12	29
Russia	0.38	13	negligible		8.46	13
Canada	0.12	4	negligible		0.12	4
Total World	22.80	**773**	**2.91**	**64**	25.71	837

Note: Includes ethanol produced for industrial use.
Source: F.O.Lichts (2006); IEA analysis.

Ethanol

Conventional ethanol production technology involves fermenting sugar obtained directly from sugar cane or beet or indirectly from the conversion of the starch contained in crops. The ethanol produced is then distilled to produce fuel grade. In OECD countries, most ethanol is produced from starchy crops like corn, wheat and barley, but ethanol can also be made from potatoes, sorghum and cassava or directly from sugar beet. In tropical countries like Brazil, ethanol is derived entirely from sugar cane. The process of converting starchy crops starts with the separation, cleaning and milling of the feedstock. The grains are soaked and broken down either before the starch is converted to sugar (dry milling) or during the conversion process (wet milling). The starch is converted into sugar in a high-temperature enzyme process. The sugar produced in this process or obtained directly from sugar cane or beet is then fermented into alcohol using yeasts and other microbes. At the end of both processes, ethanol is distilled to the desired concentration and separated from water. The grain-to-ethanol process yields several co-products, including protein-rich animal feed. Co-products reduce the overall cost of ethanol, as well as the greenhouse-gas emissions associated with its production.

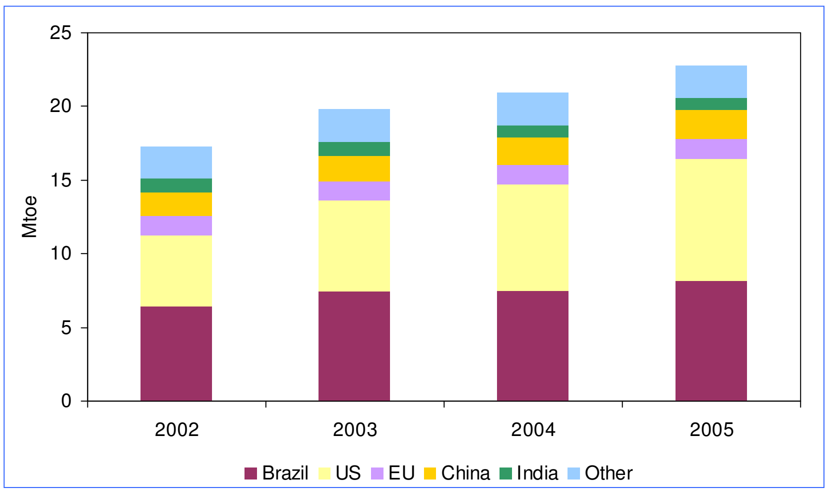
Figure 1.2: Share of Biofuels in Total Road-Fuel Consumption in Energy Terms by Country, 2004



Efforts to introduce ethanol into the market for road-transport fuels for spark-ignition engines have focused on low-percentage blends, such as ethanol E10, a 10% ethanol and 90% gasoline blend (known as gasohol in Brazil). Such blends, which are already marketed in many countries, do not require engine modifications and can be supplied in the same way as gasoline through existing retail outlets. However, blended ethanol cannot be transported by pipeline over long distances, as it tends to separate out. Higher-percentage blends, with more than 30% ethanol, or pure ethanol can only be used with some modifications to the vehicle engine. Ethanol has a high octane value, which makes it an attractive blending component, and generally good performance characteristics, though its energy content by volume is only two-thirds that of gasoline. Demand for ethanol as an octane enhancer is rising in several countries, especially the United States, where methyl-tertiary-butyl-ether (MTBE) – the most commonly-used oxygenate – is being phased out or discouraged for health and environmental reasons. The fuel economy of a vehicle with an engine adjusted to run on pure ethanol can be as good as that of a gasoline-only version of the same vehicle.[2] In Brazil and several other countries, "flex-fuel" vehicles that allow consumers to switch freely between any blend of ethanol and gasoline have recently become available. This protects the consumer from any sudden jump in the price of ethanol relative to gasoline that might result from a supply shortage or a drop in gasoline prices.

Ethanol production is rising rapidly in many parts of the world in response to higher conventional oil prices, which are making ethanol more competitive, as well as government incentives and rules on fuel specifications. Global production reached 577 kb/d in 2005, almost double the level of 2000 (Figure 2). The United States accounted for most of the increase in output over that period. In most cases, virtually all the ethanol produced is consumed domestically. Brazil accounts for half of global trade in ethanol.

Figure 1.3: World Ethanol Production



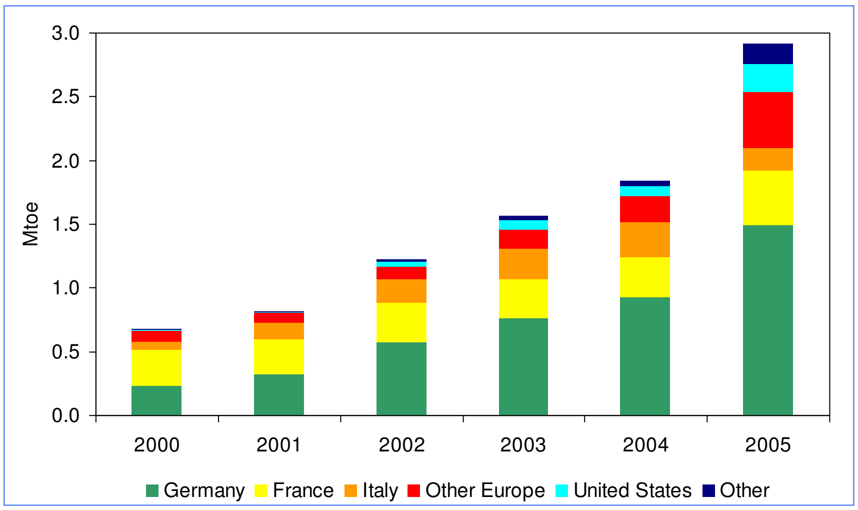
[2] This depends on whether the engine is optimised to run on ethanol. The high octane number of ethanol-rich blends, plus the cooling effect from ethanol's high latent heat of vaporisation, allows a higher compression ratio in engines designed for ethanol-rich blends. This is especially the case for vehicles using direct-injection systems. These characteristics at least partially offset the lower energy content of ethanol vis-à-vis gasoline.

Biodiesel

The most well-established technology for biodiesel production is the *transesterification* of vegetable oil or animal fats. The process involves filtering the feedstock to remove water and contaminants, and then mixing it with an alcohol (usually methanol) and a catalyst (usually sodium hydroxide or potassium hydroxide). This causes the oil molecules (triglycerides) to break apart and reform into esters (biodiesel) and glycerol, which are then separated from each other and purified. The process also produces glycerine, which is used in many types of cosmetics, medicines and foods.[3]

Total production of biodiesel worldwide is small compared to that of ethanol, amounting to about 2.9 Mtoe (64 kb/d) in 2004. More than 90% is produced and consumed in Europe. Germany and France are the biggest producers, followed by Italy, Austria, Belgium, the Czech Republic and Denmark. Production has risen sharply in recent years, surging in 2005 (Figure 3). Outside Europe, the largest producers are the United States, Brazil and Australia. Brazil opened its first biodiesel plant, using a mixture of vegetable oil and sewage, in March 2005. International trade in biodiesel is minimal as yet.

Figure 1.4 : **World Biodiesel Production**



As with ethanol, most biodiesel is blended with conventional fuel, usually in proportions of up to 20% biodiesel (B20) for use in conventional vehicles, but it is also marketed in some countries in a pure form (B100) that some diesel vehicles can handle. In Germany, B100 is available at more than 700 service stations. The solvent and lubricant properties of biodiesel, which improves the performance of diesel engines and the life of engine parts, make it an attractive blending component. Biodiesel contains only about 90% as much energy as conventional diesel, but its high cetane number and lubricity mean that fuel economy is almost the same.

Biofuels production and use have been primarily driven by farm policy. Under the EU Common Agricultural Policy and a trade agreement with the United States, set-aside land – farm land left fallow for which farmers are paid a per-hectare subsidy under a scheme to reduce surplus output – can be used to grow crops for biofuels up to a limit of 1 million tonnes of soybean equivalent per year. In addition, biodiesel enjoys a minimum tax exemption of 90% of that on conventional diesel. Some countries, including Germany, levy no excise tax at all on biodiesel. Several countries also provide financial incentives for investment in bio-refineries. In 2003, the European Union adopted a directive requiring all member states to set non-binding national targets for a minimum share of biofuels in the overall transport-

[3] The co-production of glycerine improves the economics of making biodiesel, but the market value of glycerine is falling as biodiesel production rises because the commercial demand for non-energy uses is limited: it may increasingly be used as an energy input to the production process itself.

fuel market. The target was 2% for end-2005, rising to 5.75% by end-2010. In fact, the share reached only about 1.4% in 2005, though it was well up on the level of 0.6% in 2003.

The recent proliferation of biofuel programs around the world can be attributed to a combination of factors. Countries that wish seek to bolster their agricultural industries (long the main driver of biofuel programs) have been joined by an increasing number of nations that are concerned about such factors as high oil prices, political instability in oil-exporting countries, climate-altering greenhouse gas emissions, and urban air pollution. Continuing developments in biorefining technology have also brought greater attention to biofuels as a potentially large-scale and environmentally sustainable fuel.
A diverse range of countries around the world has recently sought new ways to promote use of biofuels. For example:

- In *Japan*, the government has permitted low-level ethanol blends in preparation for a possible blending mandate, with the long-term intention of replacing 20 percent of the nation's oil demand with biofuels or gas-to-liquid (GTL) fuels by 2030.

- In *Canada*, the government wants 45 percent of the country's gasoline consumption to contain 10 percent ethanol by 2010. Ontario will be the center of the ethanol program, where the government expects all fuel to be a 5 percent blend of ethanol by 2007.

- A *European Union* directive, prompted largely by the requirements of the Kyoto Protocol, has set the goal of obtaining 5.75 percent of transportation fuel needs from biofuels by 2010 in all member states. In February 2006, the EU adopted an ambitious Strategy for Biofuels with a range of potential market-based, legislative, and research measures to increase the production and use of biofuels. *France*, in particular, has announced plans to rapidly expand both ethanol and biodiesel production, with the aim of reaching the EU targets before the deadline.

- In the *United States*, high oil prices and agricultural lobbying prompted the recently enacted Renewable Fuels Standard (RFS), which will require the use of 28.4 billion liters (7.5 billion gallons) of biofuels for transportation in the country by 2012. Many U.S. government fleet vehicles that run on diesel fuel are now required to use B20 blends under new guidelines implementing the Energy Policy Act of 1992. Many in the industry believe that these targets represent a floor, rather than a limit, to biofuel production.

- In *Brazil*, the government hopes to build on the success of the Proalcool ethanol program by expanding the production of biodiesel. All diesel fuel must contain 2 percent biodiesel by 2008, increasing to 5 percent by 2013, and the government hopes to ensure that poor farmers in the north and northeast receive much of the economic benefits of biodiesel production

- Elsewhere in Latin America, as of 2006, *Columbia* will be mandating the use of 10 percent ethanol in all gasoline sold in cities with populations over 500,000. In *Venezuela*, the state oil company is supporting the construction of 15 sugar cane distilleries over the next five years, as the government phases in a national E10 blending mandate. In *Bolivia*, 15 distilleries are being constructed, and the government is considering authorizing blends of E25. *Costa Rica* and *Guatemal*a are also in the trial stages for expanding production of sugar cane fuel ethanol. *Argentina*, *Mexico*, *Paraguay*, and *Peru* are all considering new biofuel programs as well. As the world's leader in fuel ethanol, Brazil has helped many of these countries learn from its example.

- In Southeast Asia, *Thailand*, eager to reduce the cost of oil imports while supporting domestic sugar and cassava growers, has mandated an ambitious 10 percent ethanol mix in gasoline starting in 2007. For similar reasons, the *Philippines* will soon mandate 2 percent biodiesel to support coconut growers, and 5 percent ethanol, likely beginning in 2007. In *Malaysia* and *Indonesia*, the palm oil industries plan to supply an increasing proportion of the countries' diesel.

- Chinese and Indian planners have also sought to expand the national supply of ethanol and biodiesel. In *India*, a rejuvenated sugar ethanol program calls for E5 blends throughout most of the country, a level the government plans eventually to raise to E10 and then E20. In *China*, the government is making E10 blends mandatory in five provinces that account for 16 percent of the nation's passenger cars.

- In Africa, efforts to expand biofuels production and use are being initiated or are underway in numerous countries, including Kenya, Malawi, Zimbabwe, Ghana, Ethiopia, Benin, Mozambique, Senegal, Guinea Bissau, Ethiopia, Nigeria, and South Africa.

- **The Netherlands** to date has accepted to objectives of the Biofuels Directive of the European Commission and agreed to replace 5.75% of road transport fuels by biofuels by 2010. Bioethanol at present is produced by Bio-ethanol in Rotterdam (100 kton/yr). Bue Ocean Associates (Amsterdam 110 kton/yr) and Nedalco (140-180 kton/yr) are expected to start production in 2007-2008. Biodiesel is now produced by Sunoil in Emmen (65 kton/yr). Another 1300 kton production capacity is in planning stage, although it is uncertain to what extent this will be realized (source: ECOFYS data). The Platform Groene Grondstoffen, part of the Energy Transition of the Netherlands proposed to replace 60% the road transport fuels by biofuels after 2030 [PGG, 2006]. This should in particular be realized by imported biomass and biofuels.

Biofuels promise new and dynamic export flows of both raw materials and finished products. Today global trade in biofuels, however, remains fairly small relative to both biofuel demand and traditional fossil fuels trade. In 2004, international trade of ethanol was around 3 billion litres, as opposed to around 920 billion litres of international trade in crude oil.
As illustrated, international trade in ethanol underwent a strong expansion, from very limited exports in 2000 led by the United States and the EU, to a dynamic market in 2004 largely dominated by Brazil. Brazil has about 50 percent market share of global ethanol exports, with India and the United States as main export markets.
The cane sugar exports pattern does not show any trade increase over the period 2000- 2004. As trade in cane sugar does not seem to be affected by the surge in ethanol production, one can assume that sugar is not traded for the purpose of ethanol production. Several factors may contribute to this situation: ethanol production from sugar is a rather widely known and cheap process that can be easily replicated; the cost of transport of raw sugar, as compared to that of equivalent ethanol, makes it disadvantageous. The other main feedstock used to produce ethanol is maize. As it is the case for sugar cane, the surge of ethanol production does not seem to have had any relevant impact on world trade of maize. This may also be due to the fact that the top maize world producer - the United States - is also a large ethanol consumer and this limits the scope for maize exports. As international trade in feedstocks does not seem to evolve along the path of growing ethanol demand, it can be assumed that producing countries are for the time being relying on domestically produced feedstocks for ethanol manufacturing.

Biodiesel
The international market of biodiesel is in its infancy, therefore no reliable trade statistics are available. Biodiesel has recently been re-classified by the World Customs Organization under the HS code 3824 90 – an industrial code which includes a large spectrum of chemical products and preparations of the chemical or allied industries (including those consisting of mixtures of natural products) not elsewhere specified or included. It is, therefore difficult to identify trade flows, trends and opportunities specific to biodiesel. Trade in biodiesel feedstocks, however, has experienced significant growth that may be partly attributed to the rising demand for biodiesel.

Exports of palm oil and soybean oil have registered a sharp increase since 2000. Main importers of soybean include several Asian developing countries that use it for food purposes. Therefore, the surge in soybean exports does not seem to be linked to biodiesel production.
The pattern is different for international trade in palm oil, which is the second most traded oil worldwide. The diet of developing countries, but not developed countries, includes palm oil. There are flows of palm oil from Indonesia and Malaysia to developing countries like India, Bangladesh, Kenya and Mexico on the one hand, and to developed countries like Germany, the Netherlands and the United Kingdom on the other hand. While it is hard to assess which percentage of palm oil is used as food and which percentage is used

as energy feedstock, it can be assumed that part of the recent palm oil import surge into the EU has been used for biodiesel production.

Trade flows seem to indicate that feedstocks are traded internationally and that oil processing into biodiesel takes place in countries different from those which produce the feedstocks, as opposed to bioethanol which is manufactured where its feedstocks are cultivated. One possible explanation is that biodiesel until now has been produced almost exclusively in the EU which owns the technology and know-how related to biodiesel processing. Additional considerations related to logistics may also play a role. Trade of edible oils concerns crude oil, while the process of refining is usually carried out in the importing countries. A limited number of large firms control the refining process. The transport, storage and other facilities which are used for trading crude edible oils may then be used for trading biodiesel feedstocks.

2. Technical options (biomass-biofuel combinations).

Three main routes can be distinguished to produce transportation fuels from biomass: gasification can be used to produce syngas that can be converted to methanol, Fischer-Tropsch liquids, DiMethylEther (DME) and hydrogen. Production of ethanol can take place via direct fermentation of sugar and starch rich biomass, the most utilized route for production of biofuels to date, or this can be preceded by hydrolysis processes to convert ligno-cellulosic biomass to sugars first. Finally, biofuels can be produced via extraction from oil seeds (vegetal oil from e.g. rapeseed or palmoil), which can be esterified to produce biodiesel.

The characteristics of those fuels differ widely: hydrogen, being a very light gas, requires very extensive infrastructure. All other fuels considered, except DME, are liquids and can be stored and distributed with relatively conventional infrastructure. Ethanol and especially methanol have a lower energy density than gasoline, so for the same amount of energy in a vehicle more weight has to be taken on board. Other aspects concern the toxicity and environmental impacts of the fuels due to leakages or calamities. Gasoline and diesel partly contain aromates, with carcinogenic properties. Methanol is not carcinogenic but is a more dangerous liquid than gasoline when it comes into contact with human skin. Measures need to be taken to reduce exposure risks compared to gasoline and diesel, such as closed filling systems (e.g. as applied for LPG). This will result in (somewhat) higher (investment) costs. Fischer-Tropsch liquids and ethanol are barely toxic and the sulphur and aromate content of those fuels are zero, which are advantages compared to gasoline and diesel. In addition, the existing infrastructure for gasoline and diesel can be used [IEA, 2004].

Methanol, hydrogen and hydrocarbons via gasification: Methanol, hydrogen and Fischer-Tropsch diesel can be produced from biomass via gasification. All routes need very clean syngas before the secondary energy carrier is produced via relatively conventional gas processing methods. Besides MeOH, hydrogen and FT-liquids, DME (DiMethylEther) and SNG (Synthetic Natural Gas) can also be produced from syngas. Several routes involving conventional, commercial, or advanced technologies under development, are possible. A train of processes to convert biomass to required gas specifications precedes the methanol or FT reactor, or hydrogen separation. The gasifier produces syngas, a mixture of CO and H_2, and a few other compounds. The syngas then undergoes a series of chemical reactions. The equipment downstream of the gasifier for conversion to H_2, methanol or FT diesel is the same as that used to make these products from natural gas, except for the gas cleaning train. A gas turbine or boiler, and a steam turbine optionally employ the unconverted gas fractions for electricity co-production [Hamelinck, 2004].

So far, commercial biofuels production via gasification does not take place, but interest is on the rise and development efforts have been made over the past decades. Also noteworthy is the installed gasification capacity (entrained flow) at Schwarze Pumpe (former East Germany) for producing methanol from waste streams, which is a major industrial experience with this technology. Renewed attention for using gasification technology for production of transport fuels concerns in particular Fischer-Tropsch diesel and hydrogen. In Freiburg - Germany, the company Choren demonstrates FT-diesel production via biomass gasification. Once clean syngas is available, known process technology for producing methanol, FT-liquids, DME and hydrogen can be applied. The main development challenges are gas cleaning, scale-up of processes and process integration. More recent technological concepts, such as liquid phase methanol production and once-through Fischer-Tropsch synthesis (combined with electricity generation) and new gas cleaning and separation technology offer potentially lower production costs and higher overall efficiencies on the longer term. More research, demonstration and development activities over a prolonged period of time are however needed to reach such a situation. In countries like Germany, the Netherlands and Sweden interest to develop advanced gasification for syngas production is on the rise again and plays an important role in long-term RD&D strategies.

Overall energetic efficiencies of relatively 'conventional' production facilities, could reach around 60% (on a scale of about 400 MW_{th} input). Deployment on large scale (e.g over 1000 MW_{th}) is required to benefit maximally from economies of scale, which are inherent to this type of installations. In total however, this (set of) option(s) has a strong position from both efficiency and economic perspective [Tijmensen et al, 2002], [Hamelinck and Faaij, 2002], [Williams et al., 1995], [Hamelinck et al., 2004]. Generic performance ranges resulting from detailed pre-engineering studies are reported in table 2.1.

Such gasification units could also be co-fed with coal. When equipped with CO2 capture facilities, the input share of fossil fuel can still become ''carbon neutral''(see e.g. [Celik et al., 2004], who have analysed that about 50% of the carbon in gasified coal can be captured when producing FT-liquids via gasification). When more biomass would be utilized, negative emissions could be obtained. Also, existing large-scale gasification technology (entrained flow) can be used, because such gasification processes are developed and deployed for coal and heavy oil residues. Biomass feedstock could be supplied as crude bio-oils obtained via pyrolysis in the biomass production areas or treated via torrefaction, which basically means 'roasting' of the biomass reducing the moisture content and facilitating grinding and further pelletisation. Such densification steps reduce long distance transport costs and facilitate feeding to pressurized gasification systems [see e.g. Hamelinck et al., 2004 and Calis et al., 2003].

Fermentation; production of ethanol

Ethanol from sugar and starch: Production of ethanol via fermentation of sugars is a classic conversion route, which is applied for sugar cane, maize and cereals on a large scale, especially in Brazil, the United States and France. Sweden and Spain have more modest production levels of ethanol. Ethanol is generally mixed with gasoline, which, at low percentages, can be done without adaptations to the current vehicle fleet. Ethanol production from food crops like maize and cereals is not competitive when compared to gasoline and diesel prices and needs subsidies, although some improvements are still possible. Ethanol production from sugar cane, however has established a strong position in Brazil and increasingly in other countries in tropical regions (such as India, China and various countries in Sub-Saharan Africa). Production costs of ethanol in Brazil have steadily declined over the past few decades and have reached a point where ethanol is competitive with production costs of gasoline [Rosillo-Calle and Cortez, 1998]. As a result, bio-ethanol is no longer financially supported in Brazil and competes openly with gasoline [Goldemberg et al., 2004]. Large scale production facilities, better use of bagasse and trash residues from sugar cane production e.g. with advanced (gasification based) power generation or hydrolysis techniques (see below) and further improvements in cropping systems, offer further very good perspectives for sugar cane based ethanol production.

Ethanol from (ligno)-cellulosic biomass: hydrolysis of cellulosic (e.g. straw) and ligno-cellulosic (woody) biomass can open the way towards low cost and efficient production of ethanol from these abundant types of biomass. The conversion is more difficult than for sugar and starch because from ligno-cellulosic materials, first sugars need to be produced via hydrolysis. Lignocellulosic biomass requires pretreatment by mechanical and physical actions (e.g. steam) to clean and size the biomass, and destroy its cell structure to make it more accessible to further chemical or biological treatment. Also, the lignin part of the biomass is removed, and the hemicellulose is hydrolysed (saccharified) to monomeric and oligomeric sugars. The cellulose can then be hydrolysed to glucose. The sugars are fermented to ethanol, which is to be purified and dehydrated. As only the cellulose and hemicellulose can be used in the process, the lignin is used for power production. To date, acid treatment is an available process, but still too expensive to be fully competitive. Enzymatic treatment is commercially unproven but various pilot/demonstration plants are operated in North America and Sweden. Assuming, that mentioned issues are resolved and ethanol production is combined with efficient electricity production from unconverted wood fractions (lignine in particular), ethanol costs could fall below current gasoline prices, as low as 12 Euroct/litre assuming biomass costs of about 2 Euro/GJ. Overall system efficiencies (fuel + power and heat output) could go up to about 70% (LHV). For the agricultural sector and agro-food industry this technology is very important to boost the competitiveness of existing production facilities (e.g. by converting available crop and process residues), which provides drivers for both industry and agriculture to support this technology [Hamelinck et al., 2006]. [Lynd et al., 2006]

3. Performance and impacts

The Energy Balance and Environmental Impact of Biofuels
The net impact of replacing conventional fuels with biofuels on airborne gaseous emissions depends on several factors. These include the type of crop; the amount and type of energy embedded in the fertilizer used to grow the crop and in the water used; the resulting crop yield; the energy used in gathering and transporting the feedstock to the bio-refinery; and the energy intensity of the conversion process. Calculating the energy and emissions balance of biofuel production requires estimates of or assumptions about all these variables, as well as the energy or emissions credit that should be attributed to the various by-products. Carbon-dioxide emissions at the point of use are assumed to be zero, on the grounds that the biomass feedstock is a renewable resource (the carbon emitted is exactly equal to the carbon absorbed by the biomass).
In practice, the amount and type of primary energy consumed in producing biofuels and, therefore, the related emissions of greenhouse gases, varies enormously.

A recent study compares several reports published on corn-based ethanol production in the United States in order to compile estimates of primary fossil-energy input/output ratios and net greenhouse-gas emissions using consistent parameters (Farrel et al., 2006). It concludes that the "best point estimate" indicates that the primary energy input (excluding the biomass feedstock) is equal to about 80% of the energy contained in the ethanol output.[4] About 20% of the primary energy is petroleum, and the rest coal and natural gas. On this basis, greenhouse-gas emissions are only 13% lower compared with petroleum. The emission savings from ethanol production in Brazil are considerably higher, because crop yields are much higher, process energy needs are lower than for corn-based ethanol as the sugar is fermented directly and the crushed stalk of the plant (known as bagasse) rather than fossil-energy is used in the production process. For each unit of ethanol produced, only about 12% of a unit of fossil energy is required (IEA, 2004). As a result, CO_2 emissions calculated on a well-to-wheels basis are also very low, at about 10% of those of conventional gasoline. Studies also indicate that the conversion of sugar beet into ethanol in Europe can yield reductions in well-to-wheels emissions of up to 60% compared with gasoline.
Estimates for the net reduction in greenhouse-gas emissions that are obtained from rapeseed-derived biodiesel in Europe range from about 40% to 60% compared to conventional automotive diesel. As with ethanol, however, these results are sensitive to several factors, including the use of the by-products and yields. If more of the glycerine produced with the bio-diesel is used for energy purposes, the net emission savings would be higher. Biodiesel yields vary widely according to the conversion process, the scale of production and region, as well as the type of crop used.

Biofuels production and use involves environmental effects other than greenhouse-gas emissions. Reliable data on local pollutant emissions is hard to come by, but various studies that have been carried out suggest that tailpipe emissions of nitrogen oxides, sulphur dioxide, carbon monoxide (CO) and particulates are generally low compared with conventional gasoline and diesel, but may be offset to some degree by higher emissions from fossil fuel and fertilizer use in the production of biomass.. In the case of ethanol, part of the emission savings comes from the better fuel economy of ethanol compared with gasoline. In addition, a molecule of ethanol contains oxygen, which contributes to more complete combustion of the carbon and reduces emissions of CO – a contributor to urban smog. Studies have shown that E10 can achieve a reduction of at least 25% reduction in CO emissions. On the other hand, NOx emissions from ethanol are little different to those from gasoline, while emissions of volatile organic compounds can be higher because of higher vapour pressure.
In addition, major changes in agricultural land-use could profoundly affect local and regional eco-systems, with both positive and negative implications for flora and fauna. Much will depend on how and what land is used and what crops are considered. Different categories can be distinguished (see table 3.1 for a summary on cropping systems):

[4] Previous studies suggest a range of 0.6 to 0.8 units of primary energy for each unit of ethanol produced (IEA, 2004).

Table 2.1: Global overview of current and projected performance data for the main conversion routes of biomass to fuels (e.g. based on: [Faaij and Hamelinck, 2002], [Hamelinck and Faaij, 2002], [Tijmensen et al., 2001], [de Jager et al., 1998], [Ogden et al, 1999], [Wyman et al., 1993], [IEA, 1994], [IEA, 2004], [Damen, 2001], [Williams et al. 1995], etc.). Due to the variability of data in the various references and conditions assumed, all cost figures are indicative. Footnotes summarize assumptions, generally reflecting EU conditions.

	Energy efficiency (HHV) + energy inputs		**Investment costs (Euro/kWth input capacity)**		**O&M (% of inv.)**	**Estimated production costs (Euro/GJ fuel)**	
Concept	**Short term**	**Long term**	**Short term**	**Long term**		**Shorter term**	**Longer term**
Hydrogen: via biomass gasification and subsequent syngas processing. Combined fuel and power production possible; for production of liquid hydrogen additional electricity use should be taken into account.	60% (fuel only) (+ 0.19 GJe/GJ H2 for liquid hydrogen)	55% (fuel) 6% (power) (+ 0.19 GJe/GJ H2 for liquid hydrogen)	480 (+ 48 for liquefying)	360 (+ 33 for liquefying)	4	9-12	4-8
Methanol: via biomass gasification and subsequent syngas processing. Combined fuel and power production possible	55% (fuel only)	48% (fuel) 12% (power)	690	530	4	10-15	6-8
Fischer-Tropsch liquids: via biomass gasification and subsequent syngas processing. Combined fuel and power production possible	45% (fuel only)	45% (fuel) 10% (power	720	540	4	12-17	7-9
Ethanol from wood: production takes place via hydrolysis techniques and subsequent fermentation and includes integrated electricity production of unprocessed components.	46% (fuel) 4% (power)	53% (fuel) 8% (power)	350	180	6	12-17	5-7
Ethanol from beet sugar: production via fermentation; some additional energy inputs are needed for distillation.	43% (fuel only) 0.065 GJe + 0.24 GJth/GJ EtOH	43% (fuel only) 0.035 GJe + 0.18 GJth/GJ EtOH	290	170	5	25-35	20-30
Ethanol from sugar cane: production via cane crushing and fermentation and power generation from the bagasse. Mill size, advanced power generation and optimised energy efficiency and distillation can reduce costs further on longer term.	85 litre EtOH per tonne of wet cane, generally energy neutral with respect to power and heat	95 litre EtOH per tonne of wet cane. Electricity surpluses depend on plant lay-out and power generation technology.	100 (wide range applied depending on scale and technology applied)	230 (higher costs due to more advanced equipment)	2	8-12	7-8
Biodiesel RME: takes places via extraction (pressing) and subsequent esterification. Methanol is an energy input. For the total system it is assumed that surpluses of straw are used for power production.	88%; 0.01 GJe + 0.04 GJ MeOH per GJ output Efficiency power generation on shorter term: 45%, on longer term: 55%		150 (+ 450 for power generation from straw)	110 (+ 250 for power generation from straw)	5 4	25-40	20-30

- Assumed biomass price of clean wood: 2 Euro/GJ. RME cost figures varied from 20 Euro/GJ (short term) to 12 Euro/GJ (longer term), for sugar beet a range of 12 to 8 Euro/GJ is assumed. All figures exclude distribution of the fuels to fueling stations.
- For equipment costs, an interest rate of 10%, economic lifetime of 15 years is assumed. Capacities of conversion unit are normalized on 400 MWth input on shorter term and 1000 MWth input on longer term.
- Diesel and gasoline production costs vary strongly depending on the oil prices, but for indication: recent cost ranges (end 90-ies till 2006 are between 4-9 Euro/GJ. Longer term projections give estimates of roughly 6-10 Euro/GJ. Note that the transportation fuel retail prices are usually dominated by taxation and can vary between 50 - 130 Euroct./litre depending on the country in question.

Annual crops

Typical 1st generation biofuels are produced from conventional agricultural crops, being annual crops as rapeseed, maize and cereals. Although suchs crops can be manaed in different ways (from very intensive to ecological farming principles), they require better quality farmland, fertilizer inputs and crop protection with agrochemicals. Overall ecological impacts are therefore not better or worse than conventional farming. More demand for agricultural crops will however also put pressure on land resources and prices of (other) commodity products. Competition for land, food and fodder may therefore results in induced land-use elsewhere (e.g. by removing forest cover), higher food and fodder prices. The latter is already observed connected to expanding biofuel production in India (sugar) and the US (maize).

Perennial crops.

Perennial crops are planted for more than one year. Tree species such as Eucalyptus, Poplar or Willow are typically established for periods of 15-25 years. Such trees form a root system from which multiple harvests can take place, e.g. once every 3-7 years. Grasses, such as Miscanthus or Switchgrass have similar characteristics, but can be harvested each year. As a result, management is far less intensive compared to annual crops and fossil energy inputs are generally low with typical energy input/output ratio's of 1:10 – 1:20. The permanent leaf cover reduces the need for weed control substantially. Most nutrients remain on the land because harvest takes places after the nutrient rich leaves have dropped and generally soil carbon and quality increase over time, especially when compared to conventional farming. Another advantage is that perennial crops can, though with lower productivity, grow on lower quality lands, including degraded and marginal lands. In those cases, competition with food production is far less or absent and over a longer period of time, soil restoration and increased carbon storage in soil carbon can be achieved.

Sugar cane and palmoil

Sugarcane cultivation in Brazil is based on a ratoon-system, which means that after the first cut the same plant is cut several times on a yearly bases. This can continue for several years, but the productivity will gradually decline over time, so removal of the planting and new crop establishment takes place after periods of 3-5 years. Sugar cane is therefore a bit in between an annual and perennial crop in terms of intensity and enviromental impacts. Generally, soil productivity and quality has been maintained over decades of sugar cane production. Current management practices also recycle large parts of the nutrients from the sugar mill and distillery back to the fields. Most sugar cane production in Brazil and other countries is rainfed and does not use irrigation.

Palmoil is produced on plantations with in general a lifetime similar to other perennial crops. It is a fairly productive crop in terms of (net) energy yields per hectare and the most efficient oil seed crop. Palm oil palms can be grown on relatively poor soils and overal ecological impact can be similar to other perennial crops. However, especially in SE Asia, expansion of palm oil production is associated with loss of (rain)forest cover.

Overall evaluation of biomass feedstock – biofuel combinations

Table 2.1 gave a compact summary of estimates for costs of various fuels that can be produced from biomass. A distinction is made between performance levels on the short and on the longer term. Generally spoken, the economy of 'traditional' fuels like Rapeseed MethylEsther and ethanol from starch and sugar crops in moderate climate zones is poor and unlikely to reach competitive price levels even in the longer term. Also, the environmental impacts of growing annual crops are not as good as perennials because per unit of product considerable higher inputs of fertilizers and agrochemicals are needed. In addition, annual crops on average need better quality land than perennials to achieve good productivities. Perennial crops can also be grown on marginal lands, thereby achieving potential other key benefits such as soil quality improvement.

A key exception under 'conventional' biofuels is production of ethanol from sugar cane in tropical regions where good soils are available, which proves currently a competitive system in the Brazilian context and some other countries. For countries where sugar cane production is feasible, commercially available technology allows for production of relatively low cost ethanol. Brazilian experience shows that ethanol production competitive with gasoline is possible at current oil prices [Rosillo-Calle, 1998], [Goldemberg et al., 2004]. Ethanol production capacity based on sugar cane is increasing in some African, several Latin American and Asian (most notably India and China) countries. Furthermore, better use of cane residues (e.g. for power generation or use via hydrolysis processes) can further improve the performance of cane based ethanol production.

But it is production of methanol (and DME), hydrogen, Fischer-Tropsch liquids and ethanol produced from ligno-cellulosic biomass that offer much better perspectives and competitive fuel prices in the longer term (e.g. around 2015). Partly, this is because of the inherent lower feedstock prices and versatility of producing ligno-cellulosic biomass under varying circumstances. In the section on biomass resources it is argued that biomass residues and perennial cropping systems could supply a few hundred EJ by mid-century in a competitive cost range between 1 – 2 Euro/GJ. Furthermore, as discussed, the (advanced) gasification and hydrolysis technologies under development have the inherent improvement potential for efficient and competitive production of fuels (sometimes combined with co-production of electricity).
An important point is also that when the use of such 'advanced' biofuels (especially hydrogen and methanol) in advanced hybrid or Fuel Cell Vehicles (FCV's) is considered, the overall chain ('tree - to – tyre') efficiency can drastically improve compared to current bio-diesel or maize or cereal derived ethanol powered Internal Combustion Engine Vehicles; the effective number of kilometres that can be driven per hectare of energy crops could go up with a factor of 5 (from a typical current 20.000 km/ha for a middle class vehicle run with RME up to over 100.000 km/ha for advanced ethanol in an advanced hybrid or FCV [Faaij and Hamelinck, 2002]). Note though, that the exception to this performance is sugar cane based ethanol production; in Brazil the better plantations yield some 8000 litre ethanol/ha*yr, or some 70.000 km/yr for a middle class vehicle. In the future, those figures can improve further due to better cane varieties, crop management and efficiency improvement in the ethanol production facilities [Damen, 2001]. Furthermore, FCV's (and to a somewhat lesser extent advanced hybrids) offer the additional and important benefits of zero or near zero emission of compounds like NO_x, CO, hydrocarbons and small dust particulates, which are to a large extent responsible for poor air quality in most urban zones in the world.

Table 3.1: Performance characteristics of some (potential) energy crops considered on short and long term in Europe and current status (sources used include: [Broek, 2000], [Biewinga, et al., 1996], [Dornburg et al., 2003], [Borjesson, 1999], [Hall et al., 1993].)

Crop		**Typical yield ranges (odt/ha*yr)**	**Energy inputs (GJprim/ha*yr**	**Typical net energy yield (GJ/ha*yr)**	**Production cost ranges European context (Euro/GJ)**	**Status in Europe and other remarks.**
Rape	Short term	2.9 (rapeseed) 2.6 (straw)	11	110 (total)	20	Widely deployed in Germany and France, to lesser extent in Austria and Italy. Requires better quality land. Annual crop fitting rotation schemes. Depends on considerable subsidies to compete, also on longer term
	Longer term	4 (rapeseed) 4.5 (straw)	12	180 (total)	12	
Sugar Beet	Short term	14	13	250	12	Annual crop, requires good quality land. High productivity but also higher emission levels of agrichemicals. Deployment in Europe for energy production is (only surpluses are used for ethanol).
	Longer term	20	10	370	8	
SRC-Willow	Shorter term	10	5	180	3-6	Perennial crop with typical rotation of some 3-4 years. Suited for colder and wetter climates. Commercial experience gained in Sweden and to a lesser extent in the UK and some other countries. Major interest from Eastern Europe, where conditions are well suited. On somewhat longer term in CEEC low cost levels can be achieved.
	Longer term	15	5	280	<2	
Poplar	Shorter term	9	4	150	3-4	Perennical crop, currently especially planted for pulpwood production in various countries. Current typical rotation times 8-10 years. Poplar is well suited to deliver both biomaterial and energy fractions as a typical multi-product system. Economy depends on production region as well as market prices for main material produced
	Longer term	13	4	250	<2	
Miscant hus	Shorter term	10	13-14	180	3-6	Perennial C4-crop that is harvested each year. So far, only limited commercial experience in Europe. Breeding potential hardly explored. Suited for warmer climates, where principally high yields are possible.
	Longer term	20	13-14	350	~2	

- Biomass logistics: For woody crops, transport, handling and storage costs add about 10% to the fuel costs in case of road transport in the vicinity of the plant. Energy inputs are about 1-2% of the heating value of the biomass (somewhat higher for sugar beet). When long distance transport (intercontinental) transport is considered, the logistics can add between 0.5-1 Euro/GJ. Energy inputs can vary between 6-10% of the heating value of the biomass.
- HHV per dry tonne is used for calculating energy yields; wood: 19 GJ/tonne, rapeseed: 28 GJ/tonne, straw: 16 GJ/tonne, sugar beet: 19 GJ/tonne)

4. Biomass supply potentials; availability of resources and land.

Introduction

Various biomass resource categories can be considered: residues from forestry and agriculture, various organic waste streams and, most important, the possibilities for active biomass production on various land categories (e.g grass production on pasture land, wood plantations and sugar cane on arable land and low productivity forestation schemes for marginal and degraded lands.

Biomass is considered the most important renewable energy source for the coming decades, worldwide, in Europe and in the Netherlands. Targets and projections for the contribution of biomass to the energy supply reach over 30% of the global energy demand during this century; a similar role as mineral oil plays today.

Biomass resources in the Netherlands

The recently formulated long term energy transition vision for the Netherlands suggests that 30% of the national energy supply could be covered by biomass after 2030, including 60% of the demand for transport fuels, a quarter of the demand for electricity production and another quarter of the demand for feedstocks (especially in the chemical industry) [PGG, 2006]. This also implies that biomass is the single largest energy supply option for reducing GHG emissions and reduce dependency on mineral oil for the Netherlands. It is the key route to 'green' the transport sector and chemical industry through biofuels and biomass feedstocks. Total demand for biomass in the Netherlands could add up to around 1000 PJ after 2030 (assuming energy efficiency increases keep the total primary energy demand at around 3000 PJ, biomass covers 1/3 of the national energy supplies).

Available biomass resources in the Netherlands are not insignificant but clearly limited. Various reviews on availability of residues from forestry and agriculture, verge grass, organic wastes such as sludges, organic domestic waste ('GFT'), manure, demolition wood and the organic fraction of Municipal Solid Waste (MSW) add up to maximally 200 PJ (of which MSW covers about 50%). Production of energy crops in the Netherlands (be it agricultural or perennial crops) is expensive (see section 3). Nevertheless, assuming economics are not considered important, energy cropping on e.g. set-aside land in the Netherlands and areas on to which management restrictions apply (such as buffer zones around nature areas) may contribute an additional 10-60 PJ. (for more details see: [Faaij et al., 1997], [Faaij et al., 1998], [Dornburg et al., 2006] en [Dornburg and Faaij, 2006]). It should be noted that a significant part of the mentioned biomass sources is fairly unsuited for production of biofuels because of their high moisture content (sludges, GFT) or because they are difficult or expensive to transport to larger scale facilities (e.g. manure). Nevertheless, more biomass resources may be mobilized in the Netherlands via production of algue, more intensive management of grasslands and more intensive use of agricultural residues (see [Sanders et al., 2006]). However, most of these options are still in early Research and Development stage and for example production costs and sustainability implications are so far poorly understood.

As a consequence, meeting a target of 1000 PJ primary energy supply will require large scale import of biomass or energy carriers derived from biomass (such as transport fuels produced elsewhere). This may add up to 60-80% of total biomass supplies. This is equivalent to 25-40 Mton biomass per year (dry matter basis). Assuming such amounts are produced via active cropping systems, this requires, depending on the land quality and production system assumed, between 1 – 4 Million hectares of land outside the Netherlands (considering biomass yields between 10 – 25 ton dry matter/ha*yr; 10 tonnes is feasible at present in NW and central European conditions, 25 ton is possible on plantations on good quality land in tropical regions). This can be compared to a total national land surface of 3.5 million hectares of which 2 million hectares of arable land.

Given that national biomass resources and potentials are limited, the bulk of the demand is to be covered by imported biomass (or biofuels). Imported biomass already accounts for the bulk of the growth of biomass use in the Netherlands, especially by means of co-firing wood pellets in existing coal fired power stations [Junginger and Faaij, 2006]. The use of palm oil for co-firing has been strongly reduced already after the strong societal debate on the (percieved) unsustainable production practices. Other countries show similar trends, enhanced by the growing use of biofuels for transport.

However, large scale biomass imports are currently scrutinized and criticized and there is strong debate about the ecological and socio-economic impacts in exporting regions. At the same time, recent studies demonstrate that global biomass production potentials are large enough to cover a major part of the future world's energy demand (see below). While residues can play a role on the short term, the key to developing those production *potentials* lays in combining the introduction of biomass production systems with improvements in agricultural management and the use of marginal lands in a sustainable way. Further, ecological as well as socio-economic advantages for exporting regions could be achieved simultaneously, especially with woody crops and grasses and provided proper criteria are followed, based on regional priorities. However, both the scientifc knowledge base, as market experience with such biomass production schemes, related certification and trading is still limited. Therefore, early demonstration of sustainable biomass production and supply is vital for the learning process to realize large-scale biomass supplies on medium to longer term on a sustainable basis.

<u>The potential for bio-energy on longer term</u>

This section focuses on the potential availability of biomass resources for energy and materials. It briefly discusses the various resource categories: residues from forestry and agriculture, various organic waste streams and, most important, the possibilities for active biomass production on various land categories (e.g. for wood plantations or energy crops as sugar cane).

Biomass residues potential may be divided into:

- *Primary residues:* residues generated pre- and at harvest of main product, e.g. tops and leaves of sugar cane.
- *Secondary residues:* residues generated in processing to make products, e.g. bagasse, rice husks, black liquor.
- *Tertiary residues:* residues generated during- and post end use (+ non-used products), e.g. demolition wood, municipal solid waste.

In general, biomass residues (and wastes) are intertwined with a complex of markets. Many residues have useful applications such as fodder, fertilizer and soil conditioner, raw material for, e.g., particle board, Medium Density Fibre board (MDF) and recycled paper, etc. Net availability as well as (market) prices of biomass residues and wastes therefore generally depend on market demand, local as well as international markets for various raw material and on the type of waste treatment technology deployed for remaining material. The latter is particularly relevant when tipping fees are deployed, giving some organic waste streams a (theoretical) negative value. Typically, the net availability of organic wastes and residues can fluctuate and is influenced by market developments, but also on climate (high and low production years in agriculture) and other factors.

<u>Biomass residues and organic wastes</u>

Residues from agriculture: Estimates are available from various studies. Potential depends on yield/product ratios and the total agricultural land area as well as type of production system. Less intensive management systems require re-use of residues for maintaining soil fertility. Intensively managed systems allow for higher utilisation rates of residues but also usually deploy crops with lower crop to residue ratios.
Estimates vary between some 15 up to 70 EJ per year. The latter figure is based on the regional *production* of food (in 2003) multiplied by harvesting or processing factors and the assumed recoverability factors [Smeets et al., 2004]. These figures do not subtract the potential alternative use for agricultural residues. As indicated by [Junginger et al., 2001], competing applications can reduce the net availability of agricultural residues for energy or materials significantly.

Dung: this category especially concerns the use of dried dung. Total estimated contribution could be 5-55 EJ worldwide. The low estimate based on global current use, the high estimate is the technical potential. Utilisation (collection) on longer term is uncertain because this is particularly considered a poor man's fuel [Faaij et al., 2000].

Organic Wastes: This category includes the organic fraction of Municipal Solid Waste and waste wood (e.g., demolition wood). Estimates on the basis of literature values strongly dependent on assumptions on economic development, consumption and the use of biomaterials; the ranges projected for MSW on longer term (e.g., beyond 2040) amount to 5-50 EJ. Higher values are possible when more intensive use is made of biomaterials [Fischer and Schrattenholzer, 2003].

Forest residues: The (sustainable) energy potential of the world's forests is partly uncertain. A recent evaluation of forest reserves and development of demand for wood products concluded that: even in the case of the highest wood demand projections found in literature, the demand can (in theory) be met without further deforestation. The bioenergy potential from forestry can contribute 1 to 98 EJ/y of surplus natural forest growth and 32 to 52 EJ/y harvesting and processing residues in 2050. The most promising regions are the Caribbean and Latin America, the former Soviet Union and partially North America. Key variables are the demand for industrial round wood and fuel wood, plantation establishment rates, natural forest growth and the impact of technology and recycling [Smeets et al., 2005].

<u>The potential for energy crops</u>

Clearly, active biomass production requires land. The potential for energy crops therefore largely depends on land availability considering that worldwide a growing demand for food has to be met, combined with nature protection, sustainable management of soils and water reserves and a variety of other sustainability criteria. Given that a major part of the future biomass resource availability for energy and materials depend on these (intertwined, uncertain and partially policy dependent) factors, it is impossible to present the future biomass potential in one simple figure. A review of available studies of future biomass availability carried out in 2002 (17 in total) revealed that no complete integrated assessment and scenario studies were available by than [Berndes et al., 2003]. These studies were amongst others carried out for and by: IPCC, US EPA, World Energy Council, Shell, Stockholm Environmental Institute a.o.

LAND USE FOR ENERGY PRODUCTION

Biomass production requires land. Relatively conservatively, the productivity for a perennial crop (like Willow, Eucalyptus or Switchgrass) lies between 8 - 12 tonnes dry matter per hectare per year. The heating value of dry clean wood amounts about 18 GJ/tonne (LHV). One hectare can therefore produce about 140 - 220 GJ/ha*yr. (gross energy yield, energy inputs for cultivation, fertiliser, harvest, etc amount about 5%).
1 PJ would require 4,500 - 7,000 ha. 1,500 MWth (the amount of fuel needed to fire a base load power plant with 40% efficiency of 600 MWe) would require 140,000 - 230,000 ha, and 100 EJ (about one quarter of the world's current energy use) would ask 450 - 700 Mha. Yields on longer term and on better quality land in tropical regions can raise over 25 ton/ha*yr, thus reducing land demand for producing 100 EJ to some 200 Mha.
For comparison: current arable land in the world amounts about 1.5 Gha (1.500 Mha). Pastures account for about 3.5 Gha (adding up to some 5 Gha used for food production worldwide). Forests (ranging from tropical rainforest up to plantations) amount some 4 Gha and another 4.2 Gha is qualified as 'inproductive' (including marginal and degraded lands, nature reserves, mountains and deserts).

Figure 4.1 summarizes the main findings. It is concluded that: the studies arrived at widely different conclusions about the possible contribution of biomass in the future global energy supply (e.g., from below 100 EJ yr^{-1} to above 400 EJ yr^{-1} in 2050). The major reason for the differences is that the two most crucial parameters—land availability and yield levels in energy crop production—are very uncertain, and subject to widely different opinions (e.g., the assessed 2050 plantation supply ranges from below 50 EJ yr^{-1} to almost 240 EJ yr^{-1}). However, also the expectations about future availability of forest wood and of residues from agriculture and forestry vary substantially among the studies.

The question how an expanding bioenergy sector would interact with other land uses, such as food production, biodiversity, soil and nature conservation, and carbon sequestration has been insufficiently analyzed in the studies. A refined modeling of interactions between different uses and bioenergy, food and materials production—i.e., of competition for resources, and of synergies between different uses—would facilitate an improved understanding of the prospects for large-scale bioenergy and of future land-use and biomass management in general

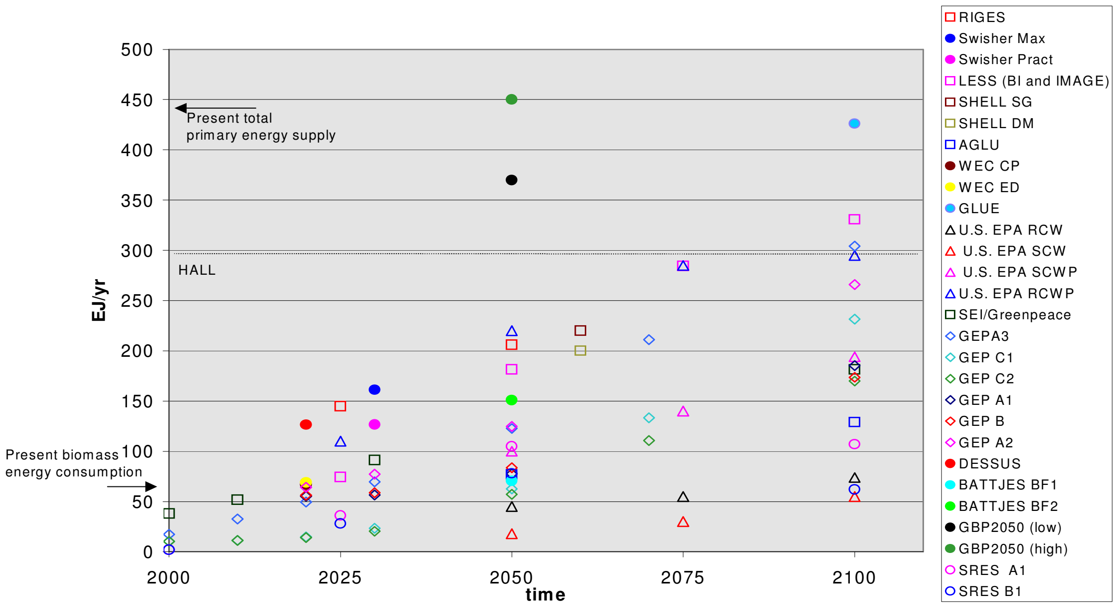


Figure 4.1: Results of a review of 17 studies [Berndes et al., 2003] projecting biomass potentials up to the year 2100, expressed in EJ.

<u>State-of-the-art insights</u>

Recently, these issues were addressed in several studies. One approach is reported in [Smeets et al., 2006] where bottom-up information was used on land-use, agricultural management systems on a country-by-country basis, projections for demand for food and information on possible improvements in agricultural management (both for crops and production of meat and diary products).

In this study a methodology and results of a *bottom-up analysis* of the *global technical bioenergy production potential* (aggregated in regions) in 2050 is developed and presented. Included in this study are:

- The *best available knowledge* from extensive study of existing databases, scenarios and studies.
- The impact on gaps and weak spots in the *knowledge base*. Existing studies frequently ignore or only partially identify weak spots in the knowledge base, data from existing studies and the interaction between existing studies.
- The impact of (most important) *underlying factors* that determine the bioenergy production potential.
- The impact of *sustainability criteria* such as avoidance of deforestation and competition for land between bioenergy production and food production and protection of biodiversity and nature conservation.

Three bioenergy sources are included in this study: residues from the agricultural sector and forestry industry, surplus wood production from forestry and bioenergy from specialised energy crops. Previous studies indicate that the highest potential comes from specialised bioenergy crops produced on degraded land and surplus agricultural land (0-998 EJy^{-1}). Therefore, the core focus of this study is on assessing land use patterns and how these are influenced. The production of bioenergy from specialised bioenergy crops is limited to *surplus land or land not suitable for agriculture*.

The key elements that determine the bioenergy production potential and their correlations are identified and shown in figure 4.2. Future trends are analysed by means of *scenario analysis*, which allows an analysis of the impact that various parameters have on the bioenergy potential. The methodology is applied here at the regional level, but can also be used at a country level.

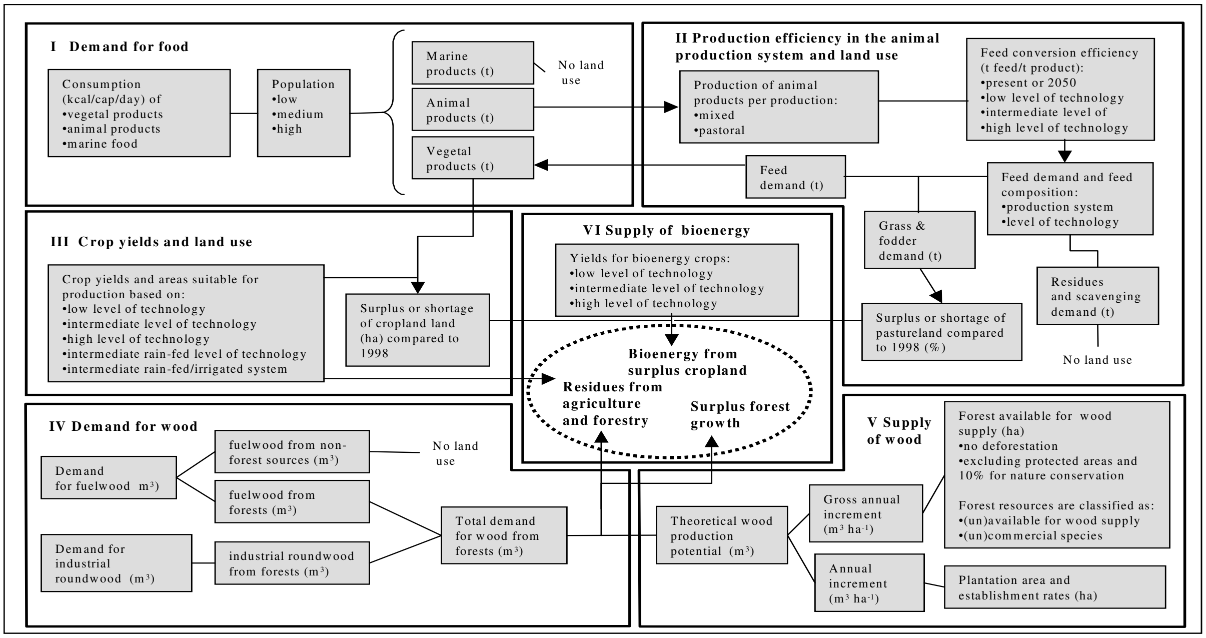


Figure 4.2. Overview of key elements and correlations included in the assessment of [Smeets et al., 2006].

In one recent analyses, so-called integrated assessment based modelling was deployed. These complex modelling techniques, that interlink demographic, economic, land-use and climate and technological information enable the exploration of the geographic (technical) and economic potential for active biomass production under the different scenario assumptions.
Scenario's were taken from IPCC terminology, to describe different future worlds in terms of economic development, trade, technological progress, climate changes, etc. The four scenarios are based on storylines published by the Intergovernmental Panel on Climate Change (IPCC) in the Special Report on Emissions Scenarios (SRES) (Nakicenovic, 2000) as implemented with the IMAGE 2.2 model (IMAGEteam, 2001). The storylines describe different social, economic, technological, environmental and policy developments. Basically the four scenarios ('stories') are constructed along two dimensions, i.e. the degree of globalisation versus regionalisation, and the degree of orientation on material versus social and ecological values. The four scenarios do not have a particular order and are listed alphabetically and numerically, i.e. A1; A2; B1; B2. These scenario's hold the most important assumptions regarding food demand and supply [Hoogwijk et al., 2005].

Synthesis of findings on long term global biomass potentials:
Summarizing, both the technical and economic potential of biomass resources for energy and material use can be very large, up to over 2 times the current global energy demand, without competing with food production, protection of forests and nature. Besides residues from agriculture and forestry (which are significant, but also limited due to competing applications) and organic waste, especially active production (e.g. energy crops) of biomass is responsible for these potentials. Key however, to the development of competitive energy cropping systems is the rationalization of agriculture, especially in developing countries, which can result in considerably higher land-use efficiencies for agriculture and, thus, a surplus of productive land. Perennial crops (such as Eucalyptus, poplar, grasses as Miscanthus and sugar cane) provide the most favourable economics and environmental characteristics for biomass production. Table 4.1 (based on Faaij et al., 2000, Smeets et al., 2004 and Hoogwijk et al., 2005) provides a summary of the biomass categories discussed in this section.

In theory, energy farming on current agricultural land could, with projected technological progress, contribute over 800 EJ, without jeopardising the world's food supply. Organic wastes and residues could possibly supply another 40-170 EJ, with uncertain contributions from forest residues and potentially a very significant role for organic waste, especially when bio-materials are used on a larger scale. In total, the upper limit the of bio-energy potential could be over 1000 EJ (per year) [Hoogwijk et al., 2003], [Smeets et al., 2004]. This is considerably more than the current global energy use of about 430 EJ.

Table 4.1: Overview of the global potential bio-energy supply on the long term for a number of categories and the main pre-conditions and assumptions that determine these potentials.

Biomass category	**Main assumptions and remarks**	**Potential bio-energy supply up to 2050.**
Energy farming on current agricultural land	Potential land surplus: 0-4 Gha (more average: 1-2 Gha). A large surplus requires structural adaptation of intensive agricultural production systems. When this is not feasible, the bio-energy potential could be reduced to zero as well On average higher yields are likely because of better soil quality: 8-12 dry tonne/ha*yr is assumed. (*)	0 – 700 EJ (more average development: 100 – 300 EJ)
Biomass production on marginal lands.	On a global scale a maximum land surface of 1.7 Gha could be involved. Low productivity of 2-5 dry tonne/ha*yr. (*) The supply could be low or zero due to poor economics or competition with food production.	(0) 60 – 150 EJ
Bio-materials	Range of the land area required to meet the additional global demand for bio-materials: 0.2-0.8 Gha. (average productivity: 5 dry tonnes/ha*yr). This demand should be come from category I and II in case the world's forests are unable to meet the additional demand. If they are however, the claim on (agricultural) land could be zero.	**Minus** (0) 40 –150 EJ
Residues from agriculture	Estimates from various studies. Potential depends on yield/product ratio's 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.	Approx. 15 – 70 EJ
Forest residues	The (sustainable) energy potential of the world's forests is unclear. Part is natural forest (reserves). Range is based on literature data. Low value: figure for sustainable forest management. High value: technical potential. Figures include processing residues.	(0) 30 - 150 EJ
Dung	Use of dried dung. Low estimate based on global current use. High estimate: technical potential. Utilisation (collection) on longer term is uncertain.	(0) 5 – 55 EJ
Organic wastes	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 and waste wood. Higher values possible by more intensive use of bio-materials.	5 – 50 (+) EJ (**)
Total	Most pessimistic scenario: no land available for energy farming; only utilisation of residues. Most optimistic scenario: intensive agriculture concentrated on the better quality soils. (between brackets: more average potential in a world aiming for large scale utilisation of bio-energy)	**40 – 1100 EJ (250 - 500 EJ)**

(*) Heating value: 19 GJ/tonne dry matter.

(**) The energy supply of bio-materials ending up as waste can vary between 20-55 EJ (or 1100-2900 Mtonne dry matter per year (see table 4; biomass lost during conversion, such as charcoal is logically excluded from this range). This range excludes cascading and does not take into account the time delay between production of the material and 'release' as (organic) waste.

Latin America, Sub-Saharan Africa and Eastern Europe clearly are promising regions, also Oceania and East and NE Asia jump out as potential biomass production areas on the longer term. The latter can in particular be explained by the projected demographic developments (possibly declining population in China after 2030) and fast technological progress in agriculture, leading to substantial productivity increases.

These analyses also show that a large part of the technical potential for biomass production may be developed at low production costs in the range of 2 U$/GJ [Hoogwijk et al., 2004], [Smeets et al., 2005].

Major transitions are however required to exploit this bio-energy potential. Especially improving agricultural efficiency in developing countries (i.e. increasing crop yields per hectare) is a key factor. It is still uncertain to what extent and how fast such transitions can be realized in different regions. Under less favourable conditions, the (regional) bio-energy potential(s) could be quite low.

A recent asesment effort (Sims *et al.*, 2006), used lower per-area yield assumptions and bio-energy crop areas projected by the IMAGE 2.2 model, suggested modest potentials for energy crops (22 EJ yr^{-1}) by 2025. Differences among studies are largely attributable to uncertainty in land availability and yield; those with the largest projected potential assume that not only degraded / suplus land are used, but also land currently used for food production.

Also, it should be noted that technological developments (in conversion, as well as long distance biomass supply chains (i.e. comprising intercontinental transport of biomass derived energy carriers) can dramatically improve competitiveness and efficiency of bio-energy. Increased competitiveness is logically a driver to develop the production potentials of bio-energy. Such effects are to date not well analysed and incorporated into integrated assessment or macro-economic models.

Critical Issues:

The message from recent analyses dealing with global biomass potentials on the long term is a complex one: technical and even economic potentials can be very large and could make biomass a fundamental alternative for oil during this century. However, those potentials need to be developed to a large extent. Available residues and organic wastes from agriculture, forerstry and the waste treatment sector are substantial, but also limited. The (sustainable) use of different types of land (marginal and degraded, as well as good quality agricultural and pasture land) depends on the succes of accelerating the improvements in current agricultural management and integrating biomass production in a sustainable way in current land-use patterns. Our understanding of how this can be achieved from region to region is often limited. Current experiences with energy crops as Willow (in Sweden) and Sugar cane (in Brazil) give leads on how biomass production can gradually be introduced in agriculture and forestry. In developing countries (e.g. sub-saharan Africa) very large improvements can be made in agricultural productivity given the current agricultural methods deployed (often subsistence farming), but better and more efficient agricultural methods will not be implemented without investments and proper capacity building and infrastructure improvements. Much more experience is needed with such schemes, in which the introduction of bio-energy can play a pivotal role to create more income for rural regions by additional bio-energy production. Financial resources generated could than accelerate investments in conventional agriculture and infrastructure and also lead to improved management of agricultural land.

Critical issues that require further research and especially more regional demonstrations and experience with biomass production are:

Competition for water resources

Water is logically a critical resource for both food and biomass production and a constrained resource in many world regions. Water scarcity in relation to additional biomass production has been addressed to a limited extent (see e.g. Berndes, 2002 who concludes that:

There are major expectations that bioenergy will supply large amounts of CO_2 neutral energy for the future. A large-scale expansion of energy crop production would lead to a large increase in evapotranspiration appropriation for human uses, potentially as large as the present evapotranspiration from global cropland. In some countries this could lead to further enhancement of an already stressed water situation. But there are also countries where such impacts are less likely to occur. One major conclusion for future research is that assessments of bio-energy potentials need to consider restrictions from competing demand for water resources.

availability of fertilizers and pest control

Increases in agricultural productivity, in particular in DC's, can only be achieved when better management and higher productivities are achieved. This implies availability of fertilisers and pest control methods. It's use needs to be within sound limits. 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. Such practices must however be secured by sufficient knowledge, funds and human capacity & knowledge.

land-use planning taking biodiversity and soil quality into account

Criticism is raised by various new analyses (MNP, European Environment Agency) that further intensification of agriculture and large scale production of biomass energy crops may result in a losses of biodiversity compared to current land-use, even when international standards for nature protection (10-20%

of land reserved for nature) are respected. Biodiversity standards are to be interconnected with biomass production still when changes in land-use are considered. Fact is that perennial crops (which are the preferred category of crops for energy production) have a (much) better ecological profile than annual crops and benefits with respect to biodiversity can be achieved when perennial crops are displaced. However, insights in how biodiversity effects can be optimised (and improved compared to current land-use) when sound landscape planning is introduced are limited. Some indications are given by experiences in Sweden and the UK with integration of Willow production on landscape level with overall positive effects. Sao Paulo State has strict standards for sugar cane production areas and standards for original vegetation that do not necessarily lead to a loss in biodiversity. Also here, more regional efforts, experience and specific solutions are needed.

The use and conversion of pasture land connected to more intensive methods of cattle raising.

A key land category in making more efficient use of land used for food production are the worlds's grasslands used now for grazing. The analyses that were discussed here show that much land can be released when production of meat and diary products is done in more intensive (partly land-less in closed stables) schemes. Grasslands could than be used for production of energy grasses or partly converted to woodlands. Such changes in land-use functions are so far poorly studied, allthough similar conversion take place in for example Brazil. The impacs of such changes should be closely evaluated.

socio-economic impacts, in particular in rural regions.

Large scale production of modern biofuels, partly for the export market, could provide a major opportunity of many rural regions around the world to generate major ecomic activity, income and employment. Given the size of the global market for transport fuels, the benefits that can be achieved by reducing oil imports and possibly net exports of bio-energy are vast. Nevertheless, it is not a given that those benefits end up with the rural population and farmers that need those benefits most. Also the net impacts for a region as whole, including possible changes & improvements in agricultural production methods should be kept in mind when developing biomass and biofuel production capacity. Although various experiences around the globe (Africa-WB, Brazil, India biofuels) show that major socio-economic benefits can be achieved, new biofuel production schemes should ensure the involvement of the regional stakeholders, in particular the farmers. Experience with such schemes needs to be built around the globe.

Macro-economic impacts of changes in land-use patterns

Although the analyses discussed indicate that both worlds' food demand and additional biomass production *can* (under relevant pre-conditions) be achieved, more intensive land-use and additional land-use for biomass production may lead to macro-economic effects on land and food prices. Although this is not necessarily a bad mechanism (it could be vital for farmers to enable investment in current production methods), the possible implications on macro-economic level are poorly understood. More analyses are needed that can highlight with what speed of implementation and change undesired economic effects can be avoided.

5. Supply, demand and competition for biomass resources
(largely based on IPCC 4th Assessment report, forthcoming, 2007)

Introduction
The mitigation potentials of biomass use over time are a complex area. Biomass supplies originate in agriculture (residues and cropping), forestry, waste supplies, as well as in biomass processing industries (e.g. paper & pulp and sugar industry). Key applications for biomass are conversion to heat, power, transportation fuels and biomaterials.

Biomass demand for biomass from different sectors:

Demand of biomass for transport fuels:
Transport biomass demand covers production of biofuels of both agricultural crops as sugar cane, rapeseed, corn, etc, as well as so-called second generation biofuels produced from lignocellulosic biomass. The first category dominates on the shorter term. Penetration of second generation biofuels depends on the speed of technological development and market penetration of gasification technology for synfuels and hydrolysis technology for production of ethanol from woody biomass. Demand projections for biofuels are largely based on WEO-IEA (2006) projections; with relatively wide range between 3 scenario's (reference with low, 1st generation biofuel usages, alternative scenario with increased 1st generation biofuel usage and alternative ++ that assumes introduction of 2nd generation biofuels based on lignocellulose before 2020. The estimated production volume according to WEO amount 8-25 EJ of fuel worldwide, or an estimated demand for primary biomass of about 14 – 40 EJ primary. However, also higher estimates exist ranging between 45-85 EJ demand for primary biomass in 2030 (or roughly 30-50 EJ of fuel).

Demand for biomass for electricity production
In the energy supply chapter, biomass demand for production of power and heat is considered. The demand projections included there are based on estimates indirectly linked to WEO-IEA (2006) projections. The exact information basis for this is relatively unclear and largely relies on expert estimates. Demand for biomass for heat and power will also be strongly influenced by (availability and introduction of) competing technologies such as CCS, nuclear power, wind energy, solar heating, etc. The projected demand in 2030 for biomass would be around 9-13 EJ in OECD, 1-3 EJ in EIT (Economies in Transtion), and 18-27 EJ in non-OECD (total range: 28-43 EJ). These estimates focus on electricity generation. Heat is not explicitly modelled or estimated in the WEO, therefore underestimating total demand for biomass. In practice, power generation from biomass takes place in CHP (Combined Heat and Power) mode, so the net avoided emissions per unit of biomass are higher.

Industry
Industry is an important user of biomass for energy, most notable the paper en pulp industry and sugar industry that both utilise residues for generating process energy (steam and electricity). Possible mprovements in energy production from such residues are significant, most notably deployment of efficient gasification/combined cycle technology that could stronlgy increase net power output of pulp mills as well as sugar mills using sugar cane as feedstock. Additional mitigation potentials depend on projections for the demand for such commodities, recycling rate for paper. This will however not result in *additional* biomass demand. Biomass can also be used for the production of chemicals, plastics, as well as reducing agent for steel production (charcoal) and for construction purposes (replacing for example metals or concrete). Projections for such production routes and subsequent demand for biomass feedstocks are scarce and their deployment is expected to be limited up to 2030.

Built environment
In the built environment biomass is especially used for heating. This includes both non-commercial use of biomass (also as cooking fuel), as well as use of biomass in modern stoves. Use of biomass for domestic heating could represent a significant mitigation potential. However, no quantitative estimates are available on future biomass demand for the built environment (e.g. heating with pellets or cooking fuels).

Biomass Supplies

Biomass production on agricultural and degraded lands

Table 5.1 summarizes the biomass supply potentials as discussed in section 4 of this report. Those potentials come with considerable uncertainties. In addition, the estimates given represent scenario results for the year 2050. The biggest contribution can come from energy crops on arable land, under the condition that efficiency improvements in agriculture are fast enough to outpace food demand, to avoid increased pressure on forests and nature areas (see e.g. [Smeets et al., 2007], [Hoogwijk et al., 2005]. Technically, the potential for such efficiency increases are very large, but the extent to which such potentials can be exploited over time is still poorly studied. Hoogwijk et al., 2005, provided projections for biomass supplies for different SRES scenario's up to 2100, showing considerable ranges, but also highlighting the potential to develop 100-250 EJ biomass production potential in a cost range of 1-2 U$/GJ around 2050. Altogether, based on expert opinion and the data provided, up to 2050 a contribution of some 200 EJ is possible under the condition that biomass production is successfully introduced in key regions as Latin America, Sub-Saharan Africa, Eastern Europe and Oceania, combined with gradual improvements in agricultural practice and management (including livestock). Potential beyond 2050 may be even larger. Such development schemes, that could also generate substantial additional income for rural regions that could export bio-energy and biofuels, are however uncertain and implementation depends on many factors such as trade policies, agricultural policies, establishment of sustainability frameworks such as certification and investments in infrastructure and conventional agriculture (see also [Faaij & Domac, 2006]).
In addition, the use of degraded lands for biomass production (e.g. in reforestation schemes: 8-110 EJ) can contribute significantly. Although such low yielding biomass production generally result in more expensive biomass supplies, competition with food production is almost absent and various co-benefits, such as regeneration of soils (and carbon storage), improved water retention, protection from (further) erosion may also off-set part of the establishment costs. An interesting actual example of such biomass production schemes is establishment of Jathropa crops (oilseeds) on marginal lands.

Biomass residues and wastes:

Table 5.1 also depicts the energy potentials in residues from forestry (12-74 EJ) and agriculture (15-70) as well as waste (10-15). Those biomass resource categories are largely available before 2030, but also partly uncertain. Key explanatory factors are possible competing uses (e.g. increased use of biomaterials such as MDF production from forest residues and use of agro-residues for fodder and fertilizer) and differing assumptions on sustainability criteria deployed with respect to forest management and intensity of agriculture. The current energy potential of waste (mainly MSW) is approximately 8 EJ/yr, which could increase to 13 EJ in 2030. The biogas fuels from waste—landfill gas and digester gas, is much smaller.

Synthesis of biomass supply & demand:

Overall, the lower end of the biomass supply estimate (estimated at about 100 EJ) lays above the lower estimate of biomass demand (estimated to be 73 EJ). The latter however does not include estimates of domestic biomass use (e.g. cooking fuel, although that use may diminish over time depending on development pathways of developing countries), no explicit estimate for increased biomass for production of heat (although additional demand for that may be limited) and low estimates of biomass use in industry (excluding the possible demand of biomass for new biomaterials). It seems such a demand can be met by biomass residues from forestry, agriculture, waste and dung and a limited contribution from energy crops. Such a 'low biomass demand' pathway may especially develop when biofuels remain to be produced from agricultural crops that have more limited potentials, lower GHG mitigation impact and less attractive economic prospects, in particular in temperate climate regions. The major exception here is sugar cane based ethanol production.

The estimated high biomass demand consists of an estimated maximum use of biomass for power production and constrained growth of production of biofuels when the WEO projections are considered (25 EJ biofuels and about 40 EJ primary biomass demand). Total combined demand for biomass for power and fuels adds up to about 130 EJ. Clearly, a more substantial contribution from energy crops (perhaps partly from degraded lands, e.g. producing jathropa oil seeds) is required to cover such a total demand, but this still seems feasible, also for 2030; the low end estimate for energy crops for agricultural land amounts 50 EJ, which is in line with the 40 EJ primary projected demand for biofuels.

However, as also acknowledged in the WEO, the demand of biomass for biofuels around 2030 will especially depend on the commercialization of second generation biofuel technologies (i.e. large scale gasification of biomass for production of synfuels as Fischer-Tropsch diesel, methanol or DME and hydrolysis of lignocellulosic biomass for production of ethanol). Such technologies offer competitive biofuel production compared to oil prices between 40-50 U$/barrel (assuming biomass prices around 2 U$/GJ) (see e.g. [Hamelinck and Faaij, 2006]. Another key option is the wider deployment of sugar cane for ethanol production, especially on larger scale using state-of-the art mills, possibly combined with hydrolysis technology additional ethanol production from bagasse (as argued by [Moreira, 2006] and other authors). Availability of such technologies before 2020 may lead to an acceleration of biofuel production and use already before 2030. Biofuels may therefore become the most important demand factor for biomass, especially on longer term (i.e. beyond 2030).

A more problematic situation can develop when the high demand scenario's develop and biomass resource development (both for residues as cultivated biomass) fails to keep up with demand. Although the higher end of biomass supply estimates (2050) reach much further than the maximum projected biomass demand for 2030, the net availability of biomass in 2030 will be considerably lower than the 2050 estimates. If biomass suppllies fall short, this is likely to lead to significant price increases of raw material, thereby directly affecting the economic feasibility of various biomass applications. Generally, biomass feedstock costs can cover 30-50% of the production costs of secondary energy carriers, so increasing feedstock prices will quickly slow down growth of biomass demand (but simultaneously stimulate investments in biomass production). To date, very limited research on such interactions, especially on global scale, is available.

Given the relatively small number of relevant scenario studies available to date, it is fair to characterize the role of biomass role in long-term stabilization (beyond 2030) as very significant but with relatively large uncertainties. Further research is required to better characterize the potential. A number of (obvious) key factors influence biomass' GHG mitigation potential is worth noting: baseline (economic growth, energy supply alternatives (e.g., available technology, marginal production costs), biomass technological change assumptions (e.g., rate of development of cellulosic ethanol conversion technology, timing of BECS technology availability) land use competition, emissions), mitigation alternatives (overall and land related).

Nevertheless, biomass as a whole with its' combined applications has a very large mitigation potential. Estimates for 2030 are discussed in the next subsection.

Mitigation potential
Generally avoided GHG emissions, assuming sustainable biomass production for power and heat production amount 80 – 110%. The high-end figure includes possible positive carbon storage effects in soils and benefits of clean up of organic wastes and subsequent avoided CH4 emissions. Second generation biofuels can achieve similar performance figures. However net avoided GHG emissions (including e.g. N2O emissions of fertilizer use) of biofuel production from crops as corn, rapeseed or sugar beet amount around 50% with best practice methods and sometimes less.
Direct replacement of coal (e.g. for power generation) is currently one the most effective uses of biomass use from GHG mitigation perspective. But over time, avoided GHG emissions per ton of biomass or hectare planted with biomass crops is expected to gradually move to fuels. This is because the carbon intensity of power (and heat) will decrease due to increasing shares of other renewables, CCS, fuel shifting and nuclear power. For fuels, the fossil reference is oil and increasingly CTL, GTL and tar sands, that result in higher CO2 emissions per unit of transport fuel compared to mineral oil based gasoline and diesel.

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Table 5.1: Biomass supply potentials and biomass demand in EJ as based on relevant chapters in the 4th assessment report of the IPCC on mitigation ([IPCC, 2007]; forthcoming). No specific estimates for biomass supplies for 2030 were available in literature, so comparisons between supply potentials and demand projections should be interpreted with caution.

From	**Biomass supplies until 2050 (EJ)**		**Energy supply biomass demand 2030 (EJ)**	**Transport biomass demand 2030 (EJ)**	**Built environment**	**Industry**
Agriculture Residues Dung Energy crops on arable land & pastures Crops on degraded lands	15 – 70 5 – 55 50 - 300 8 - 110		OECD: 12-18 EIT: 1 (*) Non OECD: 23-60	OECD: 5-10 EIT: 1 Non OECD: 3-14	Relevant, in particular in developing countries as cooking fuel.	Sugar industry significant. Food & beverage industry No quantitative estimate on use for new biomaterials (e.g. bio-plastics) not significant for 2030
Forestry	12 - 74		Key application	Relevant for 2nd generation biofuels.	relevant	
Waste	10 - 15		Power and heat production	Possibly via gasification	minimal	Cement industry
Industry	Process residues					Relevant; paper & pulp industry
Total supply primary biomass	100 - 640					
Total demand primary biomass	73 – 128		28-43 (electricity) Heat excluded, but implicitly partly covered by CHP.	45-85	Relevant (currently several dozens of EJ; additional demand may be limited.	Significant demand; paper & pulp and sugar industry run on own process residues; additional demand expected to be limited.

(*) EIT: Economies in Transition

Overall, biomass, with the diverse range of applications, is potentially a major GHG mitigation option, already for 2030, and with substantial growth potential beyond that time frame. Key preconditions for such contributions are development of biomass production capacity (energy crops) in balance with improvements in agricultural practice, investments in logistic capacity, development of sustainable international biomass & biofuels markets and trade and commercialization of second generation biofuel production capacity.
Essential is that lignocellulosic biomass resources from perennial cropping systems (trees and grasses) provide a much better ecological and economic performance than food crops. Furthermore, such crops do not exclusively have to be produced on agricultural land and competition with food production is reduced.

This also implies that a range of policies covering those issues is needed to develop the biomass option. A vital element is that sustainability of biomass production and use needs to be secured, especially in relation to competition for land and food, water resources, biodiversity and socio-economic impacts. Current biofuel production for example is dominated by use of food crops with increasing prices of food commodities as a result. Perennial crops and lignocelllulosic resources offer an important alternative to food crops though. Safeguards could be implemented, e.g. via internationally supported certification schemes for biomass production and international trade, which are now argued by a wide range of governments, market parties, international bodies and NGO's [Fritsche et al., 2006], [IEA Task 40], [van Dam et al., 2006].

Given that there is a lack of studies on how biomass resources may be distributed over various demand sectors, no allocation of the different biomass supplies for various applications is suggested here. Furthermore, the net avoidance costs per ton of CO2 of biomass usage depends on a large variety of factors, including the biomass resource and supply (logistics) costs, conversion costs (which in turn depends on availability of improved or advanced technologies) and reference fossil fuel prices, most notably of oil. Although for specific resources and markets avoidence costs are available or projected, it is not attempted to estimate this here in detail for bio-energy or for biomass supplies separately. Nevertheless, in both energy supply (electricity production from biomass) and transport (biofuels) mitigation potentials for 2030 are estimated to amount 1.2 Gton CO2 and 0.4 – 1.2 Gton respectively (totalling 1.6 – 2.4 Gton). For alone transport, this may increase to 1.8 – 2.3 Gton for 2050, implying a further doubling of biomass use for transport fuels beyond 2030. It is also indicated that the bulk of this potential (for both electricity and fuels) is likely lay below 25 U$/ton CO2 avoided.
Mitigation potentials of biomass resource potentials projected in chapters 8 (agriculture) and 9 (forestry) could reach much further even: biomass from agriculture (residues and crop production) may avoid up to 6-26 Gton and biomass resources from forestry 0.8 - 5 Gton towards 2050 (assuming average avoidance factors per ton of biomass used for energy). It is expected that biomass-technology combinations that could be available beyond 2030, would result in cost figures below 100 U$/ton CO2 avoided and a large fraction of that below 25 U$/ton CO2.
Therefore, despite uncertainties, in particular on sustainable development of biomass resource potentials in balance with food production, water resources, etc., biomass use and development can make a major contribution in the first of half of this century to mitigating greenhouse gas emissions. In particular perennial cropping systems and production of second generation biofuels could play a vital role in harnessing this potential in a sustainable way.

6. Sustainability criteria for biomass and biofuels

Setting standards and establishing certification schemes are possible strategies that can help ensure that biofuels are produced in a sustainable manner (WWI 2006). Recently, policy makers, scientists and others have recognized these aspects.

Last years, various efforts have been undertaken as steps towards certification for traded biomass (and biofuels). Key documents have been published by [Lewandowski *et al.*, 2005), [Fritsche *et al.* (2006a)], [WWI (2006)] and [Zarrilli, (2006)]. These studies focus on specifics aspects in the discussion of biomass certification and include in their discussion relevant initiatives related to their studies. A comprehensive study providing an overview of recent developments in sustainable biomass certification is considered highly relevant for all actors involved, given the rapid developments in the field.

The last years, **The Netherlands** has been importing wood pellets, agricultural residues and bio-oil for electricity production [Junginger *et al.* 2006)]. The Dutch government has expressed its intention to incorporate sustainability criteria for biomass in relevant policy instruments. In the short term this may include the feed-in tariff 'Environmental Quality Electricity Production' (MEP) and the obligation for biofuels for road transport. However, this will also largely depend on the new Dutch government, which (after the elections of November 2006) was not installed at the time of writing. On the longer term a broader application of these sustainability criteria is envisaged. A project group "Sustainable Production of Biomass" was established in 2006 by the Interdepartmental Program Management Energy Transition to develop a system for biomass sustainability criteria for the Netherlands for the production and conversion of biomass for energy, fuels and chemistry.

A set of generic sustainability criteria and corresponding sustainability indicators is formulated. They follow the 'people, planet, and profit' approach and aim at keeping in line, as much as possible, with existing conventions and certification systems. No distinction was made between imported biomass and biomass that is produced in the Netherlands. However, the criteria only apply for biomass destined for end-use in the Netherlands, not for possible transit. The criteria were developed based on a set of key starting points from the project group, consultation with Dutch stakeholders and scientific support. Biomass sustainability criteria and indicators/procedures were developed for the short-term (2007) and medium term (2011) (Cramer *et al.* 2006) see also table 6.1. The work of the group is ongoing, and an updated report is expected in the early spring of 2007, which will be considered by the Dutch government for consideration.

A pilot study, initiated by Control Union Certifications within the framework of the project group, evaluated the possibilities of implementing the sustainability criteria in the field. The study also looked at the compatibility of the sustainability criteria to the Green Gold Label, the RSPO standard and the 'Utz Kapeh Code of Conduct' 2006[5]. Findings show that the principles are, to varying degree, already included in existing standards. The sustainability criteria from Cramer *et al.* (2006) require greater attention to carbon dioxide emissions, competition (principle 2) and certain environmental matters. Most verifiers are achievable and only some of them, e.g. for GHG balance, are difficult to achieve (Control-Union 2006).

[5] This is an internationally recognized set of economic, social and environmental criteria for responsible coffee production

Table 6.1: Summary of sustainability criteria, indicators, procedures and suggested levels for 2007 and 2011 (Cramer *et al.* 2006):

Criterion and level	Indicator/procedure 2007	2011
1. GHG balance, net emission reduction by >=30% in 2007 and >= 50% in 2011	Testing with the aid of calculation methods, Use of standard values for different steps in standard chains	As 2007
2. Competition with food, local energy supply, medicines and building materials Insight in the availability of biomass for above in 2007, Supply is not allowed to decrease in 2011	Footnote [6]	Footnote [7]
3. Biodiversity, no deterioration of protected areas or valuable ecosystems; in 2011 also insight into active protection of local eco-systems	No plantations near gazetted protected areas or High Conservation Value areas maximum 5% conversion of forest to plantations within 5 years, Footnote 4	Footnote 5. As 2007 Additional obligatory management plan for active protection of local ecosystems
4. Economic prosperity, insight into possible negative effects on the regional and national economy in 2007, insight into active contribution to the increase of prosperity in 2011	Footnote 4, based on Economic Performance indicators as expressed in the Global Reporting Initiative	Footnote 5
5. Well-being, including		
5.a Working conditions of workers No tightening in 2011	Compliance with Social Accountability 8000 and other treaties	As 2007
5.b Human rights No tightening in 2011	Compliance with universal declaration of Human Rights	As 2007
5.c Property rights and rights of use No tightening in 2011	Three criteria from existing systems (RSPO 2.3, FSC 2, FSC 3)	As 2007
5.d *Insight in social conditions of local population* In 2011, insight into active contribution to improvement of social circumstances local population	Footnote 4	Footnote 5
5.e *Integrity* No tightening in 2011	Compliance with Business principles of countering bribery	As 2007
6. Environment, No negative effects on the environment including:		
6.a Waste management No tightening in 2011	Compliance with local & national legislation and regulation, GAP principles	As 2007
6.b use of agro-chemicals (incl. Fertilizers)	Compliance with local & national legislation and regulation	Comply with strictest EU, local, national rules and legislation
6.c Insight into the prevention of erosion and soil exhaustion, and conservation of the fertility level	Footnote 4. Reporting includes following aspects: Erosion management plan; Prevention of extensive cultivation on steep slopes, marginal or vulnerable soil; Monitoring of the condition of the soil and management plan; Nutrient balance	Footnote 5
6.d Insight into conservation of quality and quantity of surface and groundwater	Footnote 4, special attention for water use and treatment	Footnote 5
6.e Emissions to air	Comply with local and national legislation and regulations	Comply with EU regulations

For criteria 2-6 a dialog with national and local stakeholders is required.

A few national governments (Netherlands, UK, Belgium, with Germany coming up in 2007) and EC on supra-national level have taken the initiative to start developing a policy framework to guarantee sustainable biomass. The systems in Belgium and UK have as main criteria reduction of GHG emissions

[6] For this criterion a reporting obligation applies. A protocol for reporting will be developed.
[7] New performance indicators will be developed for this criterion between 2007-2011.

for sustainable biomass feedstock, as most probably Germany will include as well. For UK this is possibly later extended with other criteria. Only the Netherlands has developed a wider set of principles including environmental, social and economic criteria. A framework for implementation is still in process. Belgium has coupled the criteria with the granting of green certificates. The UK aims to develop carbon certification schemes for environmental assurance. The EC intends to develop a system of certificates so that only biofuels whose cultivation complies with minimum sustainability standards will count towards the targets.

Also various companies are actively involved in various parts of the biomass chain and formulation criteria. Their interest in biomass certification depends on their role in the biomass chain. Energy companies have to justify the sustainability of their end product to the consumer, stimulating companies as Essent and Electrabel to develop a biomass certification system. Companies as DaimlerChrysler or Shell, also active on the end side of the chain, are involved in research and pilot projects related to new technologies and sustainability of their products. Companies on the production and transport side of biomass play a role in how to guarantee sustainable biomass production. For companies as Unilever or Cargill, trading products for food and/or energy production, the discussion on food security and change of economics for their products is highly relevant.

In addition various NGOs and international bodies (such as UNCTAD) are actively involved in the development of a biomass certification system. Initiatives are taken to develop proposals on principles and criteria for sustainable biomass certification, including environmental, social and economic criteria. NGOs are mainly active on the production side of the biomass chain and have a strong concern about the environment and well being of the poor in rural areas. Some NGOs have provided suggestions on the implementation for a biomass certification system. NGOs play an active role in forums and have started pilot studies.

The need to secure the sustainability of biomass production and trade in a fast growing market is widely acknowledged by various stakeholder groups and setting standards and establishing certification schemes are recognized as possible strategies that help ensure sustainable biomass production and trade.
Recently, various stakeholder groups have undertaken a wide range of initiatives as steps towards the development of sustainability standards and biomass certification systems. Sustainability standards and criteria are developed by various organizations. Between them, there seems to be a general agreement that it is important to include economic, social and environmental criteria in the development of a biomass certification system. However, mutual differences are also visible in the strictness, extent and level of detail of these criteria, due to various interests and priorities.
Concrete initiatives to translate these standards into operational criteria and indicators and to monitor and verify them through an established biomass certification system are more limited. At this moment, there are two certification systems for biomass in operation, initiated by energy companies, and some pilot studies are in implementation or under development.

The development of a (biomass) certification system is impeded by a number of issues. Many uncertainties on the feasibility, implementation, costs and compliance with international trade law of international biomass certification systems remain. Also, the possible risk of proliferation of individual standards and systems causes loss of efficiency and credibility. Therefore, it is worthwhile to consider in this preliminary phase which ways can be followed if the strategy to be taken is the development of a reliable, efficient biomass certification system. Various approaches are possible, all with its own strengths and limitations. However, for all apply that some urgent actions can be identified, needed for further development:

1. **Better international coordination between initiatives is required to improve coherence and efficiency in the development of biomass certification systems**. Various international organizations can take the lead in this as EC (for European region), UNEP/FAO/UNCTAD or others. This does not only prevent proliferation of biomass certification systems, but also provides a clearer direction in the approach to be taken (e.g. national or international oriented, mandatory or voluntary) for national and local initiatives.

2. Existing WTO agreements already provide some support about the role of WTO within the development of a biomass certification system. However, no precedent within WTO exists for biomass certification. **A negotiation process on this topic between WTO members to reach further agreements and more insight in the topic is needed**.

3. Certification is not a goal on itself, but means to an end. It can be one of the policy tools that can be used to secure the sustainability of biomass. Setting up good practice codes and integrating sustainability safeguards in global business models may be also effective ways to ensure this. Thus, **an open vision for (a combination with) alternative policy tools should be maintained to look for the best suitable options to secure sustainable biomass production and trade**.

4. At this moment, experience is limited to make some criteria operational and more experience and time is required. Issues such as the design of specific criteria and indicators according to the requirements of a region, how to include avoidance of leakage effects and the influence of land use dynamics require the development of new methodologies and integrated approaches. On the other hand, there is a need to secure the sustainability of biomass in a fast growing market on the short term. **A gradual development of certification systems with learning (through pilot studies and research) and expansion over time, linked to the development of advanced methodologies can provide valuable experience, and further improve the feasibility and reliability of biomass certification systems**. This stepwise approach gives the possibility for coherence of activities, monitoring and adjustment if needed.

7. Policy developments

Policy instruments are vital to the development of strong biofuel industries. If governments and others wish to significantly expand production and use of these fuels at the domestic and global levels, they will need to have an effective "toolbox" of wide-ranging policy strategies. The most common policies supporting biofuels today are blending mandates and exemptions from fuel taxes. Other policy instruments have included loan guarantees; tax incentives for agriculture and forestry, consumers and manufacturers; preferential government purchasing policies; and research, development and demonstration funding for current and next-generation biofuels and technologies.

Although governments adopt biofuel policies for a variety of reasons, the main driver to date has been to advance economic development in rural areas and create jobs. Subsidies for these fuels have been justified as indirect aid to domestic agriculture, and farmers increasingly recognize the market potential of energy crops as added sources of income. In parallel, governments have been motivated by a desire to reduce dependence on foreign oil and minimize the associated security and economic costs. Governments that have ratified the Kyoto Protocol are also promoting biofuels as a way to meet national or regional greenhouse-gas (GHG) emissions reductions targets, as the transportation sector accounts for a growing share of emissions related to global climate change (approximately 25 percent today).

As awareness of the potential of advanced biofuels grows, new policy instruments are emerging to facilitate their market development. Research investments sponsored by the U.S. Department of Energy, for example, recently led to a 30-fold reduction in the cost of producing enzymes used in cellulosic ethanol production, a major advance toward commercializing this technology. Researchers in several countries are also working on "co-product" development, using bio-based resources to produce biofuels as well as additional marketable products. And many countries are moving toward more-sustainable approaches in their biomass planning processes, including Brazil's gradual phase-out of burning in sugar cane harvesting and Malaysia's development of "Sustainable Palm Oil Principles" in response to environmental concerns about palm oil production.

It is clear from existing experience that the policies governments adopt, and the specific ways these policies are designed and implemented, will be critical to how the biofuel industry develops and what impacts (positive or negative) it will have. This chapter describes the range of policies that have been used to date to promote biofuels at the national and international levels. The emphasis of the chapter is on market creation, with a brief analysis of which policies have been most effective thus far. Further discussion of specific types of policies, including quality and sustainability standards and certification systems, are found in other chapters and in the final recommendations of this report.

Regional, National, and Local Policies
Several regions and countries have implemented targets, policies, standards, and action plans that aim to boost biofuel production and consumption substantially in the coming decade. Table 7.1 highlights selected national, regional, and state fuel-blending targets and mandates for ethanol and biodiesel.

Table 7.1: Selected Regional, National, and State Biofuel Mandates or Targets

Country or Region	Fuel	Mandates or Targets
Australia	Biofuel	350 million liters by 2010
Brazil	Biodiesel	2% of diesel by 2008; 5% by 2013
	Ethanol	20–25% of all gasoline (current)
Canada		
Ontario	Ethanol	5% of gasoline by 2007

Saskatchewan	Ethanol	7% of gasoline as of April 2005
China		
National	Ethanol (corn)	2.5% of gasoline by end of 2005[b]
Jilin	Ethanol (corn)	10% of gasoline from October 2005
Colombia	Ethanol	10% in all cities of more than 500,000 people
European Union	**Biofuels**	**2% of motor fuel by 2005[c]; 5.75% by 2010 (targets)**
Netherlands	**biofuels**	**Adopted the EC objectives** **For the long term (beyond 2030) the vision of the Platform Groene Grondstoffen of the Energy Transition proposes 60% of all road transport fuels to be replaced by biofuels, partly based on imports.**
Austria	Biofuels	2.5% of all motor fuel by October 2005; 5.75% by October 2008
France	Biofuels	7% of motor fuel by 2010; 10% by 2015
Sweden	Biofuels	Eliminate use of fossil fuels 100% by 2020
India	Ethanol	10% ethanol blending (E10) in 9 of 28 states and 4 of 7 federal territories (all sugar cane-producing areas) starting in 2003[d]
	Biodiesel	5% of diesel fuels, no set date
Japan	Biofuels (or gas-to-liquid fuels)	20% by 2030 (target)
Malaysia	Biodiesel (palm oil)	5% of diesel by 2008
Philippines	Biodiesel (coconut methyl ester-CME)	1% CME for all government vehicles (began in 2004); 1–5% of diesel from CME biodiesel blends 2006–2014
Thailand	Ethanol	10% gasoline blend to replace conventional gasoline by 2007
	Biofuels	10% of all motor fuel by 2012
United States		
National	Ethanol	28 billion liters (7.5 gallons) of ethanol to be produced by 2012
Hawaii	Ethanol	At least 85% of gasoline must contain 10% ethanol by April 2006
Minnesota	Ethanol	20% of gasoline by 2013 (up from current 10%)
	Biodiesel	2% of diesel as of October 2005
Montana	Ethanol	10% of gasoline

Notes: (a) here, ethanol feedstock is sugar cane unless otherwise noted; (b) Chinese provinces have had to suspend blending mandates due to ethanol shortages; (c) This target applies to all member states of the European Union. However, member states may choose targets that go further than the European target. The actual share achieved as of February 2006 is approximately 1.4 percent; (d) due to poor cane crop yields during 2003–2004, India had to import ethanol in order to meet state blending targets, and has had to postpone broader targets until sufficient supplies of domestic ethanol reappear on the market.

European Union

The European Union (EU) has had a regulatory framework in place to promote biofuels since the early 1990s. For example, the Common Agricultural Policy (CAP) included production quotas for oilseed food crops (the so-called Blair House Agreement) for EU member states, as well as exemptions from certain taxes, and explicitly granted permission to grow non-food crops on set-aside lands. In 2003, the EU issued a directive stating that all member states should set national targets for the use of biofuels in the transport sector of 2 percent by 2005, and 5.75 percent by 2010. As a result, most member states have developed national biofuel plans, and several are providing substantial tax relief to promote biofuel production, as a result of the Transportation Fuels Fiscal Directive of 2003.

This Directive provides certain fuel tax exemptions for biofuels to enhance their market competitiveness. For example, Sweden and Spain grant 100-percent tax relief for biofuels. However, this varies greatly in other EU countries, creating the need for greater harmonization of energy tax laws within the EU to facilitate the development of alternative fuels.

Despite these efforts, it has appeared unlikely that the EU targets for 2010 would be met under the 2003 policy framework—the EU market share for biofuels was expected to reach only 1.4 percent by the end of 2005, unless international trade is facilitated.

In December 2005, the European Commission (EC) issued a Biomass Action Plan that sets out measures to promote biomass for transportation, heating, and electricity through cross-cutting policies that address supply, financing, and research. The plan concentrates on balancing domestic production and imports, using ethanol to lower fuel demand, and reducing technical barriers. It states the EC's intention to propose a strategy with an integrated approach to reducing carbon dioxide (CO_2) emissions associated with the transport sector, including the use of biofuels, fiscal incentives, congestion avoidance, consumer information, and improvements in vehicle technology.[i] It also proposes to amend EU standard EN 14214 to facilitate the use of a wider range of vegetable oils as biodiesel feedstock, and to ensure that only biofuels "whose cultivation complies with minimum sustainability standards count towards [EU biofuels] targets." In addition, the plan discusses the need to maintain current preferential market access for developing nations, acknowledges sugar reforms and the need to help developing countries to advance their biofuel markets, and mentions the need to keep these objectives at the forefront of considerations during bilateral and multilateral trade negotiations.

In February 2006, the Commission adopted a new and ambitious "EU Strategy for Biofuels," which builds on the Biomass Action Plan, to boost production and use of biofuels. It sets out three primary goals: "to promote biofuels in both the EU and developing countries; to prepare for large-scale use of biofuels by improving their cost-competitiveness and increasing research into 'second generation' fuels; [and] to support developing countries where biofuel production could stimulate sustainable economic growth." Key policy tools will include stimulating demand, possibly through biofuel obligations, examining how biofuels can best contribute to greenhouse gas emissions targets, and directing research money toward developing the biorefinery concept and next-generation biofuels.

In addition to regional level policies, several European countries have national programs to promote biofuels. Austria has established mandatory targets for these fuels combined with tax exemptions, while France has enacted a tendering process that sets a maximum amount of biofuels for the market, with tax reductions for this amount of fuel. Slovenia, the Czech Republic, and the Netherlands reportedly have plans to introduce obligations in the 2006–2007 timeframe, as does Germany (which started taxing biodiesel at a rate of 15 percent in early 2006, up from zero previously). And the United Kingdom is considering a trading system for biofuel certificates, as well as a blending obligation and certification system.

Latin America
Latin America is experiencing tremendous biofuels growth, following the leadership of Brazil in this area. Brazil's success stems from a combination of policies enacted over the years, beginning with the Proalcool program launched in 1975 to reduce dependence on imported oil. A combination of tax breaks and blending mandates drove investment in ethanol production and use and brought about rapid progress in the nation's ethanol industry. Subsidies to increase sugar production and distillery construction, along with government promotion of all-ethanol cars and development of a distribution infrastructure, also helped fuel development.

In recent years, Brazil has begun to focus on biodiesel production and use as well. The government has mandated the use of 2 percent biodiesel by 2008, and 5 percent by 2013. In 2004, Brazil issued an Executive Order and law encouraging biodiesel producers to buy feedstock from family farmers; the following year, it passed a law that, among other things, exempts from taxes any biodiesel produced by family farms. The oil company Petrobras has begun tendering for biodiesel, facilitating development of the market.

Brazil has a National Agri-Energy Plan that addresses fuel ethanol, biodiesel, agri-forestry residues, and cultivated energy forests. In addition, to facilitate the development of a diverse international biofuels trade, Brazil recently signed multiple memoranda of understanding (MOUs) with the governments of Nigeria, Japan, Venezuela, China, and India—as well as with private entities in these nations. These MOUs are intended to create frameworks for countries to share technology and to help the latter countries develop, market, and trade ethanol-related technologies and expertise. Brazil's aims are twofold: to increase demand for Brazilian biofuels around the world, and to help guarantee reliability of supply in the global marketplace, enhancing private sector development. For instance, if a drought resulted in lower production levels in Brazil, other countries such as South Africa and India could still supply the market, and vice versa.

Other countries in Latin America have begun to enact biofuel incentives as well. An ethanol-blending mandate is now in force in some regions of Venezuela, and the government is considering enacting a 10-percent national blending requirement. Colombia currently requires a 10 percent ethanol blend in cities with more than 500,000 people. Several other countries in the region also have biofuel initiatives, including Argentina, Mexico, Paraguay, and Peru.

North America
Like Brazil, the United States first began to seriously promote ethanol in response to the oil crises in the 1970s, primarily through tax policies. More recently, the Farm Security and Rural Investment Act of 2002 (the "Farm Bill") contains an energy title designed to promote energy efficiency and the development of clean energy from alternative resources that can be produced by the agricultural sector, including biofuels. The title authorizes support for biofuels through a variety of programs, including biorefinery development grants, biomass R&D, and federal procurement requirements for bio-based products. However, funding for these programs has been inconsistent, and several programs have received reduced funding or none at all. Planning is now under way for a new five-year Farm Bill for 2007, and it remains to be seen whether the government will support such programs with concrete funding commitments.

Most U.S. federal biofuel incentives to date have focused on ethanol. However, the nation's first federal biodiesel tax incentive was enacted as part of the American Jobs Creation Act (Jobs Bill) of 2004, to help reduce the price of biodiesel for consumers. (The 2004 Jobs Bill also applies to ethanol, extending federal tax credits through 2010 and expanding the flexibility of these credits so they apply to any ethanol blend fraction up to 10 percent.) Biodiesel use is also being promoted in the military: as of June 2005, the U.S. Navy and Marine Corps were required to operate non-tactical diesel vehicles on a 20 percent (B20) biodiesel blend.

In 2005, the U.S. government enacted a new Energy Policy Act (EPAct), the first major energy law adopted in 13 years. It includes several incentives to spur expansion of a biofuel market, including a Renewable Fuels Standard (RFS) that requires the production of 28 billion liters of ethanol by 2012, tax incentives for E85 fueling stations, biofuels tax and performance incentives, and authorizations for loan guarantees, a bioenergy R&D program, and biorefinery demonstration projects.

In addition to these national provisions, a growing number of U.S. states are enacting policies to encourage market expansion of biofuels, including RFS laws and tax incentives. North Dakota, for example, committed in 2005 to providing up to $4.6 million (€3.8 million) over two years to facilitate ethanol production, creating a tax incentive for consumers who purchase E85 gasoline, establishing an investment tax credit for ethanol and biodiesel production facilities, and offering income tax credits and other benefits for biodiesel. In the fall of 2005, New York state launched a Strategic Energy Action Plan that includes tax credits up to $10,000 (€ 8,265) for alternatively fueled vehicles, depending on vehicle weight. And in early 2006, New York Governor George Pataki announced an initiative to make renewable fuels tax-free and available at service stations throughout the state. Minnesota has enacted the most ambitious mandates in the United States thus far, calling for ethanol to represent 20 percent of gasoline by 2013; it also requires a 2 percent biodiesel blend. As of early 2006, new initiatives were under way in several other states and at the federal level as well.

Several provinces in Canada are also promoting the production and use of ethanol through subsidies, tax breaks and blending mandates. Ontario, for example, has enacted a renewable fuels standard of 5 percent ethanol beginning in January 2007. Manitoba and Saskatchewan have also mandated the blending of ethanol into gasoline. At the national level, Canada aims to replace 35 percent of its gasoline with E10 blends by 2010 in order to meet commitments under the Kyoto Protocol; this would require the production of 1.2 billion liters (350 million gallons) of ethanol.

Policy Lessons to Date and Remaining Barriers

The modern biofuel industry is still relatively young, with little long-term policy experience. Brazil, the United States and Malawi have the longest record of support for biofuels, and the experiences in these countries and elsewhere provide valuable lessons on ways to support the nascent industry. It is also important to address remaining barriers—whether policy or institutional—that slow the advancement of biofuels.

Research and development are critical to the success of biofuels, but, as with other renewable fuels and technologies, market creation is the most important force for driving their production and use. There is no example in the world of a country that has established a biofuel market without the use of mandates and/or subsidies, and the combination of these two policy tools has been most effective. But a comprehensive approach to market development is essential. Thus, it is also important to enact policies that develop the necessary infrastructure for production and distribution.

Some key barriers that remain are:

- Development of a sustainble biomass resource base and supplies. This is in particular the case for large scale supply of (cultivated) perennial crops under various conditions (including marginal lands as well as integrated into agricultural land use)
- Development and implementation of credible and effective sustainability frameworks for biomass production and supplies in the interntional market.
- Development of well working and stable international markets for biomass and biofuels.
- Cost reduction of biofuel production up to levels competitive with 40-55 U$ barrel of oil. This is particular the case for second generation conversion technology. This requires consistent policy support for a prolonged period of time, and a policy mix that enforces technological learning.
- Incentives for biofuels should be harmonized, in particular in the European Union between member states and minimize disturbance of other markets (food and forestry).The current short term objectives enforce strong expansion of 1st generation biofuel production, which has a significant effect on agricultural markets already. A more balanced approach, targeting larger scale deployment of 2nd generation biofuels on medium term (e.g. around 2015) is preferable.

8. Implementation and strategy

From a regional or national focus in the eighties and nineties, biomass and bio-energy and biofuels have increasingly become an international matter. Biomass and biofuel markets are developing into international markets and international trade of biomass and biomass derived energy carriers is on the rise [IEA Task 40, 2005]. Furthermore, certificate and emission trading as well as projects realized as under the Clean Development Mechanism or as Joint Implementation activity make it more and more difficult to maintain very specific national policies. The recent EC biofuel directive is a prime example of a pan-European target that has important consequences for a European bio-energy market, both for production of biomass feedstock and transport fuels. Similar arguments hold for technology developments and the RDD&D trajectories needed to commercialize more advanced, competitive and efficiency conversion capacity in particular for production of electricity and fuels [Faaij, 2004].

Large-scale demonstration, e.g. of Fischer-Tropsch liquid (or other synfuels such as DME or methanol) production via gasification of biomass, is likely in the foreseeable future (e.g. before 2010). Various European countries have shown interest in moving in this direction and serious demonstration activities are being undertaken in Germany and Sweden. Crucial for the economic feasibility of such schemes is their application on large-scale (i.e. over 1000 MWth). Related development and investment risks (also concerning a secure supply of biomass) are therefore considerable. Ethanol production from ligno-cellulosic biomass offers similar perspectives as well as technological and development challenges. RD&D efforts in developing advanced ethanol production technology (including hydrolysis techniques) are significant and various demonstration projects are being carried out (Sweden, US) that may pave the way to large scale commercial use of this technology before 2015 or so.
As discussed, inherent to the advanced conversion concepts, it is relatively easy to capture (and subsequently store) a significant part of the CO2 produced during conversion at relatively low additional costs. This is possible for ethanol production (where partially pure CO2 is produced) and in particular for gasification concepts. Production of syngas (both for power generation and for fuels) in general allows for CO2 removal prior to further conversion. For FT production about half of the carbon in the original feedstock (coal, biomass) can be captured prior to the conversion of syngas to FT-fuels. This possibility allows for carbon neutral fuel production when mixtures of fossil fuels and biomass are used and negative emissions when biomass is the dominant or sole feedstock. Flexible new conversion capacity will allow for multiple feedstock and multiple output facilities, which can simultaneously achieve low, zero or even negative carbon emissions. Such flexibility may prove to be essential in a complex transition phase of shifting from large scale fossil fuel use to a major share of renewables and in particular biomass. The possibility of achieving negative carbon emissions may prove a crucial ''back-stop'' technology when climate change develops at a more rapid pace than so far considered and very rapid emission reductions are strived for.

Biomass derived transportation fuels currently (early 2006) represent somewhat more than 1 EJ (or slightly over 2% of total bio-energy use worldwide) largely covered by ethanol production from sugar and starch crops. But it is especially in this field that global interest is growing, in Europe, Brazil, North America and Asia (most notably Japan, China and India). Four main drivers explain this growing interest:

1. The transport sector is particularly difficult to tackle in terms of GHG emission reductions; biomass is the only option for supplying (liquid) carbon neutral hydrocarbons.
2. The strategic importance of reducing the dependency on oil, imported from a declining number of exporting countries that experience political instability, is growing as is the concern that global oil production may peak sooner than previously expected; transport fuels are by far the most important product produced from mineral oil.
3. Technological developments offer clear perspectives of *competitive* and efficient production of biofuels from biomass, most notably ethanol via hydrolysis and fermentation techniques and fuels such as Fischer-Tropsch, methanol, DME and hydrogen via gasification. Sugar cane based ethanol production in tropical regions already provides a competitive alternative and ethanol production from this source is growing rapidly.

4. In addition, in the medium term (e.g. after 2020), biomass use for transport fuels may prove to become a more effective way to reduce GHG emissions using biomass than power generation. This can be explained by the partly observed and partly expected reduction in carbon intensity of power generation due to large scale penetration of wind energy, increased use of highly efficient natural gas fired Combined Cycles and deployment of CO2 capture and storage (in particular at coal fired power stations) and possibly nuclear energy.

Development of global bio-energy and biofuel markets provides major opportunities and links international bioenergy trade with rural development on a global scale. If indeed the global bio-energy market is to develop to a size of 400 EJ over this century (which is well possible given the findings of recent global potential assessments) the value of that market at 4 - 8 U$/GJ (considering pre-treated biomass such as pellets up to liquid fuels as ethanol or synfyels) amounts some 1,6 – 3.2 Trillion U$ per year. Not all biomass will be traded on the international markets logically, but such an indicative estimate makes clear what the economic importance of this market can become for rural regions worldwide, as are the employment implications. Considering that about one quarter of the mentioned 400 EJ could be covered by residues and wastes, one quarter by regeneration of degraded and marginal lands and the remaining half from current agricultural and pasture lands, over 1,000 Million hectares worldwide may be involved in biomass production, divided over some 500 million hectares of arable and pasture land and a larger surface of marginal/degraded land. This is some 8% of the global land surface and one fifth of the land currently in use for agricultural production.

Recommendations and strategy

A growing number of governments are actively supporting the development of the biofuels sector in recognition of the external energy-security and environmental benefits from substituting imported petroleum-based fuels. Although national circumstances vary markedly, in every country that has managed to develop a sizable biofuels industry, strong government support has been required to kick-start the industry and bridge the gap between the market value of the fuel and its production cost. Government support has taken various forms, including direct financial assistance to bio-refiners and retailers in the form of grants, tax credits or cheap loans, subsidies to farmers, tax exemptions for flex-fuel vehicles and tax exemptions or rebates for biofuels. A number of countries have also set targets for the percentage and quantity of biofuels to be used in pure form or blended with conventional fuels. In some countries, fuel retailers are obliged to market particular blends, such as E25 in Brazil. A 2% biodiesel blend, which is currently voluntary, will become mandatory in that country from 2008. Mandatory targets for oil companies are applied in 11 countries.

A large expansion of biofuel production in most countries would require even stronger support than is currently. It will also depend on opportunities to trade, in view of the substantial differences in production costs across regions. Trade barriers for agricultural products would need to be lifted in many cases. Trade barriers are restricting access in many industrialised countries to imported biofuels, which is holding back the growth of the industry in countries with the lowest production costs.

Some main findings from this review are:

1. There are rapid developments in biofuel markets; increasing production capacity, increasing international trade flows, increased competition with conventional agriculture (rising prices observed for e.g. sugar and maize) and strong international debate about the sustainability of biofuels production. Biofuels are at this stage exclusively produced from agricultural crops.
2. Biomass and biofuels is developing into a globalized energy source with advantages (opportunities for exporters, more stability on the market; increased availability of biomass and more secure investments in conversion capacity and biofuel supplies) and concerns (competing land claims, involvement of farmers).
3. 1st generation biofuels, especially in temperate regions (EU, North America) do not offer a sustainable perspective on longer term: they remain expensive compared to gasoline and diesel (even at high oil prices), are often ineffient in terms of net energy and GHG gains and have a less desirable environmental impact. Furthermore, they can only be produced on higher quality

farmland in direct competition with food production. Sugar cane based ethanol production and to a certain extent palmoil and jathropa oilseeds are notable exceptions to this given their high production efficiencies and low(er) costs.

4. 2nd generation biofuels produced from lignocellulosic feedstocks (residues from forestry, agriculture, organic wastes and cultivated trees and grasses on both marginal lands and potential surplus farmland offer a promising future though. Both hydrolysis based ethanol production and production of synfuels via advanced gasification from biomass of around 2 Euro/GJ can deliver high quality fuels in a competitive with oil prices down to 40 U$/barrel. Net energy yields for unit of land surface are high and GHG emission reductions can be achieved over 90%. This requires a development and commercialization pathway of 10-20 years though, depending very much on targeted and stable policy support and frameworks. The two key technological concepts have specific shorter term opportunities (that could be seen as niches) for commericalization:
    a. Ethanol: 2nd generation can build on the 1st generation infrastructure by being built as 'add-ons' to existing factories for utilisation of crop residues. One of the best examples is the use of bagasse and trash at sugar mills that could strongly increase the ethanol output from sugar cane.
    b. Synfuels via gasification of biomass: can be combined with coal gasification as currently deployed for producing synfuels (such as DME, Fischer-Tropsch and Methanol) to obtain economies of scale and fuel flexibility. Carbon capture and storage can easily be deployed with minimal additional costs and energy penalties as an add on technology.
5. The biomass resource base can become large enough to supply 1/3 of the total world's energy needs during this century. Although the actual role of bio-energy will depend on its competitiveness with fossil fuels and on agricultural policies worldwide, it seems realistic to expect that the current contribution of bio-energy of 40-55 EJ per year will increase considerably. A range from 200 to 400 EJ may be observed looking well into this century, making biomass a more important energy supply option than mineral oil today. Considering lignocellulosic biomass, about half of the supplies could originate from residues and biomass production from marginal/degrade lands. The other half can be produced on good quality agricultural and pasture lands without jeopardizing the worlds food supply, forests and biodiversity. The key pre-condition to achieve that is that agricultural land-use efficiency, including livestock production, is increased, especially in developing regions. Improvement potentials of agriculture and livestock are substantial, but expoiting such potentials is a challenge.
6. Biomass trading and the potential revenues for biomass produces could provide a key lever for rural development and enhanced agricultural production methods given the market size for biomass and biofuels. However, safeguards (for example well established certification schemes) need to be installed internationally to secure sustainable production of biomass and biofuels. In the period before 2020 substantial experience should be obtained with both sustainable biomass production under different conditions as well as deploying effective and credible certification procedures.

Key elements for a strategy on biofuels for the Netherlands:
Considering the various aspects addressed in this overview document the Netherlands should strive for:

- to choose a very modest approach on further expansion of 1st generation biofuels. Given the Netherlands is lagging behind with implementing those fuels, the emphasis in all key long term policy strategies on biofuels (EC, Germany, Sweden, as well as the Energy transition strategy of the Netherlands) and the outlook that 2nd generation biofuels can become competitve, have much better ecological performance and far larger potentials than 1st generation biofuels, investments and market support should be fully targeted at development of 2nd generation production capacity.
- Invest considerably in 2nd generation biofuel technology in collaboration with leading countries and companies. Secure an investment climate for early demonstration, most notably for flexible gasification capacity. Such technology development could be linked to demonstration at the Buggenum plant, the scheduled Magnum Plant, in the Rijnmond areas or other large seaports (Delfzijl, Amsterdam, Vlissingen), possibly linked to gasification capacity in existing refineries.

Combining such technology with carbon capture and storage capabilities results in a very flexible concept with respect to fuel input (coal, biomass), carbon balance (up to negative when biomass use is combined with capture of CO2 released during the conversion) and output (different synfuels, hydrogen en power can be generated). Such capabilities are very important in the coming decades when changes in the energy infrastructure are both dynamic and uncertain. Also, such capacity can respond according to biomass availability and prices; an important uncertain factor on the shorter term.

- Policy targets for 2010 could be met especially by importing well performing biofuels from elsewhere. Such fuels could especially be ethanol from sugar cane (not exclusively from Brazil), but also oil crops from tropical regions, provided these are produced meeting sustainability criteria as formulated by the committee Cramer on sustainable biomass production.
- Play a leading role in the international debate and processes to establish accepted sustainability frameworks for internationally traded biomass and biofuels. In particular support and pull European initiatives on this, in collaboration with other leading nations and international bodies.
- Stronly support the builing of (commercial) experience with biomass production, certification and trading from other parts of the world, focused on supplying ligno-cellulosic resources and high quality intermediate energy carrriers such as pellets, bio-crudes and torrefied biomass.
- Build up this market on short term in conjunction with expanding production of electricity from imported biomass. The supply infrastructure is than developed before 2nd generation biofuel capacity becomes commercial (which could be expected between 2010 and 2015, provided that active policies are pursued), solving an important 'chicken – egg' problem
- Merge policy efforts of especially the Minsitry of Economic Affairs and Foreign Affairs (international collaboration) to work with partner countries to set up biomass production and logistic capacity. Also CDM/JI can be deployed as a tool. Part of the funds for international collaboration and poverty alleviation can be combined with efforts to implement sustainable biomass production capacity. Such schemes should be set-up on short term, supported by a substantial R&D programme involving research institutes and market parties in both inside and outside the Netherlands. (This is also recommended by the Platform Groene Grondstoffen of the Energy transition, [PGG, 2006]).
- Implement clear financing strategies for imported biomass with clearly decreasing support over time. Such stable and long term oriented policy strategies should in particular enforce technological learning of the whole chain from biomass production, supply and conversion to biofuels.
- Distribution and use of biofuels: the introduction of synthetic diesel and ethanol is not to result in major problems with infrastructure or the vehicle fleet, since both fuels are well suited for blending. Considering synfuels for gasification, also DME and methanol should be considered because these can be produced and used with somewhat higher efficiency and somewhat lower costs. Those fuels do require modifications on distribution infrastructure and vehicles although these are rather similar to the current LPG infrastructure.

Final remark: This report focused on production of biomass and biofuels. It should be noted though that efficiency increases in vehicles remain an essential part of any strategy to reduce Greenhouse gas emissions of road transport. At present, a hectare of good quality land delivers a very modest 20.000 km/ha per year for biodiesel from rapeseed used in a middle class car equiped with a conventional internal combustion engine. The net energy service per hectare can triple considering production of wood or grass and subsequent production of ethanol or methanol, to some 60.000-70.000 km/ha per year using the same vehicle. When advanced hybrid drive chain technology is considered (assuming the same vehicle performance and comfort), the net energy service per hectare can raise to 120.000-140.000 km/ha per year. This implies that moving from current 1st generation biofuels to second generation biofuels, combined with improved vehicle efficiency by deploying different, but known, drive chain technology, can reduce the land demand by a factor of 5 or more.
In addition, the high quality fuels produced via 2nd generation technology generally enable higher engine efficiencies and have the additional benefit of reduced emissions to air such as small particulates and soot, SO2 and NOx. Important benefits to consider when devising supportive policies for biofuels!

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