

Forests and energy in OECD countries



FORESTS AND ENERGY WORKING PAPER 1

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Summary

The member countries of the Organisation for Economic Co-operation and Development (OECD) utilize about 5.9 million TJ (5.9 EJ) of *bioenergy* annually, while the rest of the world utilizes about 38 million TJ. These statistics reflect bioenergy derived from solid biomass sources, including *woodfuels* and *agrofuels*. Within the OECD countries, bioenergy is only one of many contributors to total primary energy supply (TPES). In most OECD member countries, bioenergy does not contribute significantly to TPES. The two main exceptions are Sweden and Finland, where it contributes 15 and 19 percent, respectively. The largest overall user of bioenergy within OECD is the United States, using more than 2 million TJ per year, but this equates to only 2.1 percent of the United States' TPES. Most OECD countries where bioenergy plays a significant role also have a large pulp and paper industry, with the combustion of black liquor during the Kraft pulping process contributing to overall bioenergy production values. During recent years a number of new technologies, such as gasification, pyrolysis and bioconversion of biomass, have been developed that will likely increase the industrial efficiency of bioenergy recovery and result in an expanded bioenergy industry.

The production of *liquid biofuels* for use in the transport sector is also significant in some OECD countries. The largest producers are the United States, producing about 18.4 billion litres of bioethanol annually, and Germany, producing 2 billion litres of biodiesel annually. Most of the liquid biofuels for use in transport across the OECD countries are categorized as *agrofuels*, being *food-based liquid biofuels* derived from agricultural products including sugar, starch and vegetable oil (as well as waste oil products). However, a number of new technologies are being pursued that should lead to the expanded use of both agricultural residues (*agrofuels*) and forest feedstocks (*woodfuels*) for the production of *cellulosic liquid biofuels* for transport. It is likely that several cellulosic liquid biofuel technologies will be commercialized over the next three to ten years. Several pilot-scale plants have already been in operation for several years (in Canada, Sweden, Japan, Spain, the United States and other countries); six industrial-scale demonstration plants have been approved for construction in the United States, with others being considered for construction in other OECD countries.

The vast majority of studies have shown that bioenergy technologies have a positive greenhouse gas (GHG) and energy balance. Although there are a few dissenting opinions, most studies underscore the ability of bioenergy, particularly cellulosic liquid biofuels for transport, to provide a positive net energy balance. Similarly, the GHG emissions associated with cellulosic liquid biofuel production and use are significantly lower than those obtained from fossil fuels and food-based liquid biofuels such as starch- or sugar-based bioethanol. The positive environmental performance of a range of bioenergy options is a strong incentive for expanding its use within OECD countries.

Canada and the United States have the largest reserves of commercial forest growing stock in OECD, followed by Australia, Sweden, France and Finland. Of these countries, the United States uses most *wood energy* (i.e., biomass for energy production), followed by France, Canada and Sweden. About 440 million m³ of forest biomass is utilized annually for wood energy production in OECD; about 129 million m³ is harvested directly from the forest, and about 296 million m³ recovered from processing residues and pulping liquors. In terms of heat and electricity generation, the majority of bioenergy applications in OECD countries utilize *woodfuels* from forestry or forest product residues; few *agrofuels* such as *energy crops* are specifically grown for this application. At present there is a lack of significant trade in the basic biomass feedstocks to support any significant bioenergy expansion within the OECD countries.

By 2010, policies currently in force across the OECD countries will call for an estimated additional 132 000 GWh of biomass-based electricity, as part of a larger goal to produce about 7.7 million TJ of bioenergy. These figures represent a 30 percent increase in bioenergy consumption for industrial and residential purposes, a relatively small adjustment. By 2017, about 3.7 million TJ of liquid biofuels for transport will be required across the OECD countries (with 2.8 million TJ of this demand coming from the United States). This represents a 514 percent increase over 2006 levels, and will likely have a very large impact on the amounts of *agrofuels* and *woodfuels* required for energy production.

For the foreseeable future, liquid biofuels for transport will be dominated by food-based liquid biofuels, catalysing the food-vs.-fuels debate. The increasing use of food-based liquid biofuels will likely have an impact on food and feed prices; costs for maize are projected to increase by up to 41 percent over 2005 prices, with similar increases anticipated for other agricultural commodities such as oilseed crops and soya. Increased food prices will have an impact on food security and human well-being in some nations, particularly where food is scarce owing to poor growing conditions or other environmental factors. Price increases for food commodities would also increase incomes in rural areas, however, potentially reducing poverty in these regions. Increasing the proportion of wood-based biofuels could help minimize the expected rise in food prices, and some models anticipate that real prices for food and agriculture will continue to decline over the longer term.

In Sweden and the United States, one result of increased bioenergy demand is the development of *energy plantations* on agricultural land to supply biomass feedstocks. As a result, the rate of afforestation – i.e., moving marginal agricultural land into willow or poplar plantations – has actually increased the amount of forested lands. In some other OECD countries, however, continued development of first-generation liquid biofuels derived from starch or sugar crops might lead to net deforestation as land is moved from forests to agriculture, although this has not yet occurred. More recent work on bioenergy crops such as switchgrass (*Panicum virgatum*) and various species of *Miscanthus* suggests that these crops can maximize biomass production per hectare compared with plantation trees, thus possibly competing for forested lands in the future. To date, there is very limited production of these types of crops within OECD.

The increasing use of bioenergy is also likely to increase forestry feedstock/timber/chip costs, which would have an impact on the ability of the traditional OECD-based forest products industries to compete in and ensure access to world markets. Forest product prices will also be affected by the increasing use of bioenergy within OECD countries. Even with the rising value of wood globally, the forest industry is experiencing lower returns on many commodities, compared with historic averages, for products such as lumber and pulp and paper. The present economic value of wood, which is low compared with historical data, may be aiding this commodity's use for relatively low-value applications such as bioenergy, particularly where a compelling environmental or social case can be made for this.

This paper concludes that short- to medium-term increases in forest biomass-to-energy in the major OECD countries, based on the short-term policy goals for renewable energy use, are likely to be significant but not huge. By 2010, OECD countries will likely require between 75 and 85 million m³ of additional woodfuels over 2004 levels, for bioenergy production. This is well within the predicted surplus forest biomass, or the difference between gross annual increment and annual removals. However, it is not known how much of the surplus forest biomass is economically viable for the bioenergy industry.

The increasing use of liquid biofuels for transport will likely have an impact on food and feed prices, but will not result in major increases in demand for forest biomass. The introduction of cellulosic liquid biofuels derived from woodfuels could help to reduce this impact significantly, but cost increases for agricultural crops are still anticipated for the immediate future. By 2017, meeting 10 percent of OECD's renewable fuel targets with wood-based cellulosic liquid biofuels would require an additional 63 to 73 million m³ of woodfuels. This would bring the total woodfuels required (including biomass for heat, power and renewable fuel production) to approximately 148 million m³ of additional biomass.

At present there is little competition for forest biomass between the energy sector and the traditional forest products sector, and it is unlikely that such competition will occur in the immediate future. However, recent price trends for wood have been increasing, and the increased use of wood energy – including increased demand for woodfuels such as wood pellets – may support this increase. Rises in wood prices may slow the development of wood energy opportunities over the medium to long terms, while catalysing energy plantation applications in various parts of the world. Increasing bioenergy demand within OECD could be covered by international trade, because sufficient wood fibre can be supplied globally to satisfy the OECD demand. It should be cautioned, however, that domestic development of bioenergy use around the world will affect the amount of surplus fibre available, and it might be more appropriate for OECD members to develop domestic sources of forest/agricultural biomass for bioenergy production.

Glossary of terms and units

B

Indicates one billion (B) units (1×10^9).

Bioenergy

Energy derived from all forms of biomass, including forest biomass: bioenergy may be derived in the form of heat, or transformed into electricity for distribution through a utility grid. Biomass may also be transformed into biofuels, which are portable feedstocks for use in the generation of bioenergy. Bioenergy is a form of renewable energy.

Biofuel

A feedstock that is intended for the production of bioenergy: biofuels may be solid (fuelwood, charcoal, wood pellets, briquettes, etc.) or liquid (bioethanol, biodiesel, bio-oil, etc.). Biofuels may be classified according to the source of the biomass, as follows:

- *Agrofuels*: feedstocks for the production of bioenergy, derived directly and indirectly from agricultural lands, and including sugar, starch, vegetable oils, palm-oil, straw, bagasse, etc.
- *Woodfuels*: feedstocks for the production of bioenergy, derived directly and indirectly from trees and shrubs grown on forest and non-forest lands, and including fuelwood, charcoal and *cellulosic liquid biofuels*, such as bioethanol and synthetic biodiesel.

CHP

Combined heat and power production: a CHP facility outputs electrical power, which can be sold via a utility grid, and heat, which can be used for industrial applications or in a district heating system.

European Commission

The executive branch of the European Union (EU – see below).

Energy crops

Agrofuels grown on farms and dedicated to energy production: energy crops are generally chosen for their ability to accumulate cellulosic biomass rapidly, and include switchgrass (*Panicum virgatum*) and elephant grass (*Miscanthus*).

Energy plantations

Woodfuels grown on forest and non-forest land and dedicated to energy production: the species planted in energy plantations are generally chosen for their ability to accumulate cellulosic biomass rapidly, and include poplar (*Populus* spp.) and willow (*Salix* spp.).

EU

European Union: a supranational political body made up of 27 European countries.

Fuel crops

Agrofuels grown on farms and dedicated to energy production, including sugar/starch, oil and other energy crops.

GHGs

Greenhouse gases: these include carbon dioxide (CO₂), methane (CH₄), ozone (O₃), nitrous oxide (N₂O) and many others. The impact of GHG emissions on global warming is often reported in CO₂ equivalents.

GJ

Gigajoule: unit of energy, $1 \text{ GJ} = 10^9$ joules.

GWh

Gigawatt hour: the amount of (usually electrical) energy expended by a 1 GW load over one hour: $1 \text{ GWh} = 1\,000 \text{ kWh} = 3.6 \text{ TJ}$.

LCA

Life cycle assessment: also known as life cycle analysis or life cycle inventory, it is a tool for measuring the environmental impact of a product throughout its life span.

Liquid biofuel

Bioenergy feedstocks in liquid form, used in industrial and transport applications: industrial liquid biofuels include black liquor, bio-oil and pyrolytic oil, used primarily for heat and power generation. Liquid biofuels for transport include bioethanol, biodiesel, and emerging biofuels such as biobutanol. In this report, two subsets of liquid biofuels for transport are considered:

- *Food-based liquid biofuels*: bioenergy feedstocks in liquid form, intended for use in the transport sector and derived from foodstuffs including *agrofuels* such as sugar, starch and vegetable oils. These are sometimes referred to as first-generation liquid biofuels.
- *Cellulosic liquid biofuels*: bioenergy feedstocks in liquid form, intended for use in the transport sector and derived from the cellulosic component of *agrofuels* and/or *woodfuels* (see biofuel above). Cellulosic liquid biofuels currently under investigation include bioethanol and synthetic biodiesel (or biosyn diesel). These are sometimes referred to as second-generation liquid biofuels.

M

Indicates 1 million (M) units (1×10^6).

MJ

Megajoule: unit of energy, $1 \text{ MJ} = 10^6$ joules.

OECD

Organisation for Economic Co-operation and Development: member countries are Austria, Australia, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, the Republic of Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States of America.

tonne

Metric tonne: equal to 1.102 imperial tons (2 000 pounds). In this report, a tonne is the exclusive measure of mass.

TJ

Terajoule: unit of energy, $1 \text{ TJ} = 10^{12}$ joules.

toe

Tonnes of oil equivalent: unit of energy, equal to approximately 42 to 45 GJ.

TPES

Total primary energy supply: indicates the primary source of energy from which applied energy sources (e.g., electricity generation) are derived.

UNECE

United Nations Economic Commission for Europe: established in 1947 to encourage economic cooperation among member states, it currently has 56 member countries.

Wood energy

Energy derived directly and indirectly from trees and shrubs grown on forest and non-forest lands (a subset of bioenergy, see above)

Acronyms

| | |
|-----------------|---|
| BP | British Petroleum |
| CDM | Clean Development Mechanism |
| CEM | Council of Energy Ministers (Canada) |
| CHP | combined heat and power |
| ETBE | ethyl-tert-butyl ether |
| ETS | Emissions Trading Scheme (EU) |
| EU | European Union |
| FAO | Food and Agriculture Organization of the United Nations |
| FT | Fischer-Tropsch |
| GDP | gross domestic product |
| GHG | greenhouse gas |
| IEA | International Energy Agency |
| IFPRI | International Food Policy Research Institute |
| IIASA | International Institute for Applied Systems Analysis |
| IMPACT | International Model for Policy Analysis of Agricultural Commodities and Trade |
| JI | Joint Implementation |
| JWEE | Joint Wood Energy Enquiry |
| LCA | life cycle assessment |
| MCPFE | Ministerial Conference on the Protection of Forests in Europe |
| MRET | mandatory renewable energy target |
| NGO | non-governmental organization |
| NRDC | National Resources Defence Council |
| OECD | Organisation for Economic Co-operation and Development |
| R&D | research and development |
| RD&D | research, development and deployment |
| RSPO | Roundtable on Sustainable Palm-Oil |
| SME | small- and medium-scale enterprise |
| TPES | total primary energy supply |
| UN | United Nations |
| UNECE | United Nations Economic Commission for Europe |
| UNEP | United Nations Environment Programme |
| USDA | United States Department of Agriculture |
| USDOE | United States Department of Energy |
| WTO | World Trade Organization |

1. Introduction

The combined factors of high energy prices, the need for secure energy supplies and concerns over climate change are renewing interest in advanced bioenergy technologies. This report focuses on policies and technologies for the production of bioenergy and liquid biofuels within Organisation for Economic Co-operation and Development (OECD) countries, complementing a second report focusing on non-OECD countries. The report was prepared for the Special Event on Forests and Energy, held at the Food and Agriculture Organization of the United Nations (FAO), Rome, on 20 November 2007.

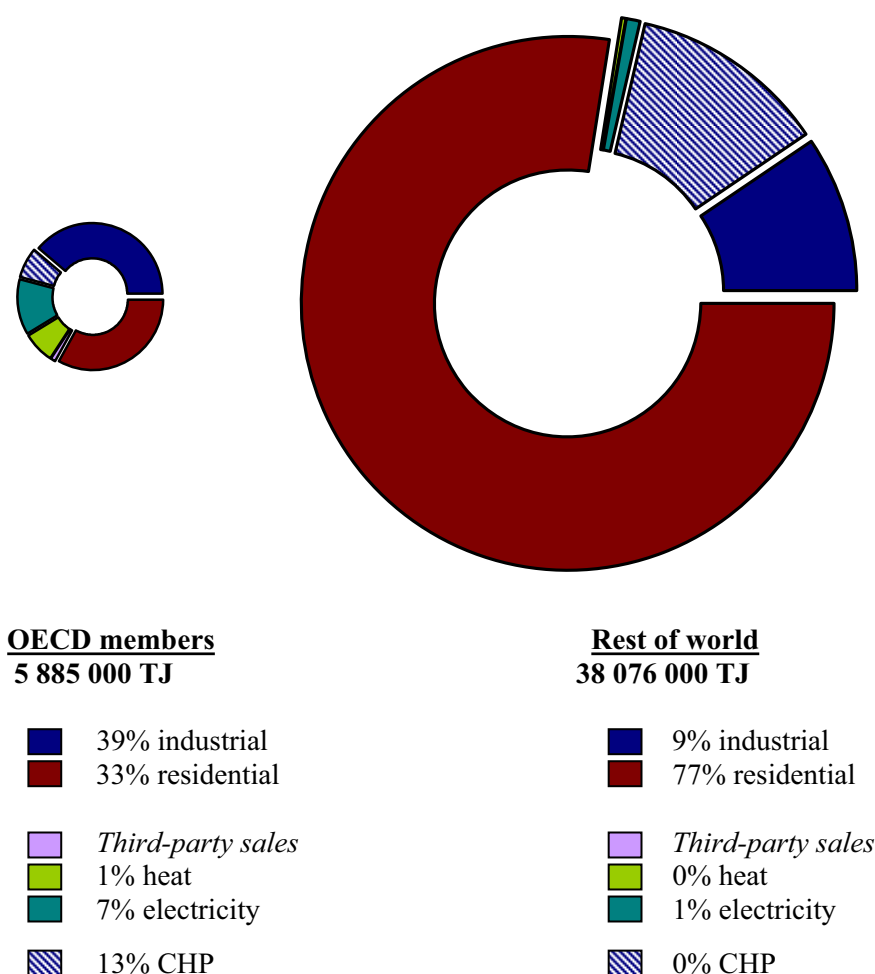
Bioenergy is defined as energy produced from biomass, including forests, farms, fisheries and municipal solid waste. Common technologies for bioenergy production include power boilers, in which biomass is combusted to generate heat and steam that can then be used to drive turbines and generate electrical power. In this type of facility, biomass can be the sole feedstock or be co-fired in combination with fossil feedstocks such as coal. Combined heat and power (CHP) facilities generate electricity and capture process heat, which can then be used in a district heating system or in other industrial, agricultural or services systems, thereby increasing efficiency. Biomass destined for bioenergy production may be processed into wood pellets, a high-density solid feedstock whose benefits include reduced transportation costs and improved handling characteristics. New technologies for bioenergy production that are being investigated have the potential to increase the efficiency of energy recovery from biomass. Figure 1 indicates that total bioenergy use within the 30 members of OECD was about 5.8 million TJ in 2004, compared with 38 million TJ in the rest of the world.

Figure 1 also gives the breakdown of bioenergy uses across OECD countries. Proportionally, the OECD countries use far more bioenergy for industrial purposes (an average of 39 percent of the total) than other countries. Production of heat, electricity and CHP are also much higher, accounting for 21 percent of total bioenergy use within OECD. Residential use constitutes 33 percent of bioenergy use, and other applications – such as non-industrial applications within agriculture, forestry, fisheries and commercial sectors – 7 percent. In contrast, residential use is the dominant application of bioenergy outside OECD. Bioenergy accounts for an average of only 2.6 percent of total primary energy supply (TPES) within the membership of OECD (IEA, 2006a; 2006b).

The term “biofuels” is used to describe modified feedstocks intended for the production of bioenergy. Biofuels may be solid feedstocks, such as wood pellets, charcoal briquettes and other similar high-density materials. Liquid biofuels include bio-oils or pyrolysis oils, which are similar to petroleum-based bunker oils and generally used in industrial applications. A wide selection of liquid biofuels, including bioethanol, biodiesel and emerging biofuels such as biobutanol, are produced primarily for use in the transport sector.

The most commonly used liquid biofuel for transport is bioethanol, which is food-based and derived from sugar- and starch-based processes. The second most commonly used for transport is biodiesel, another food-based liquid biofuel derived from vegetable oil or waste cooking oil. Many experts advocate liquid biofuels derived from sustainable biological sources as a potential substitute for petroleum-derived transport fuels such as gasoline or diesel (e.g., MacLean *et al.*, 2000; McMillan, 1997). At the end of 2006, worldwide production capacity for bioethanol fuel was about 45 million litres per year (Lichts, 2006), with Brazil and the United States accounting for about 80 percent. Global capacity for biodiesel is much lower, at about 4 million litres (EBB, 2007; NBB, 2007; Körbitz *et al.*, 2004), but some countries (notably Germany) are rapidly expanding their production capacities. The installed capacity for these liquid biofuels is rising dramatically in the face of high oil prices; biodiesel production rose by an average 50 percent a year between 2000 and 2005, while annual growth of about 15 percent was observed in bioethanol production over the same period. Although biodiesel is increasing in importance, it is clear that bioethanol will remain the dominant liquid biofuel for the transport sector for some years to come.

Figure 1. Consumption of bioenergy produced from solid biomass, OECD and rest of world, 2004



* Other bioenergy consumption includes non-industrial agriculture, forestry, fisheries, commercial applications and transport (not including liquid biofuels for transport).

Sources: IEA 2006a; 2006b.

Bioenergy options can be used to meet a number of policy goals. The use of liquid biofuels for transport is generally associated with lower greenhouse gas (GHG) emissions and improved energy balance compared with petroleum-based fuels (VIEWS, 2006), making them an attractive option for combating climate change and meeting national or international environmental performance targets. Similarly, bio-based electricity and heat may be generated with relatively low fossil inputs, resulting in a net reduction in GHG emissions over coal, oil or natural gas feedstocks (e.g., Gan and Smith, 2006; Gielen et al. 2001). Development of the bioenergy industry can also help diversify rural economies and increase employment, thereby supporting domestic development goals (Mabee et al. 2005; Hillring, 2002; Evans, 1997). The industry has long been promoted as a means of substituting renewable, sustainable biomass for fossil reserves of oil, which may increase the security of energy supplies and reduce dependence on foreign oil for OECD member countries. These attributes make bioenergy an attractive option to policy-makers, offering solutions to a number of domestic challenges. At the same time, policy is needed to increase the competitiveness of bioenergy (Jolly and Woods, 2004), and to assure sustainability in terms of socially equitable benefits and environmental impacts (FAO, 2007a; UN-Energy, 2007).

THE ROLE OF FORESTRY

The world's forests constitute a significant source of wood energy. According to the *State of the World's Forests 2007*, 52 percent of the estimated global forest harvest in 2006 was fuelwood, used

for heating, cooking and power production (FAO, 2007b). Major fuelwood-using regions include Africa (31 percent of global fuelwood consumption), Asia (44 percent) and South America (11 percent). Unlike industrial roundwood, fuelwood is generally removed for local use; international trade of this commodity is undeveloped and accounts for only 0.2 percent of total production (FAO, 2007a). New technologies can greatly increase the efficiency of wood energy recovery from forest biomass, however, and have the potential to develop new markets such as production of cellulosic liquid biofuels for use in the transport sector. Across the OECD membership, wood energy is the most important source of renewable energy.

This report discusses new technologies for wood energy production, including potential pathways for cellulosic liquid biofuel production. It reviews the supply of forest and agricultural biomass for bioenergy production (chapter 2); current policies that might increase the role of wood energy within OECD countries (chapter 3); and the implications that wood energy decisions might have for the global forest industry (chapter 4). Chapter 5 presents the authors' recommendations for future developments.

2. Production and supply of bioenergy

PRODUCTION AND PROCESSING ALTERNATIVES

Heat and power generation

Residential-scale power generation: The use of wood for cooking and heating is as old as civilization. Open fires make very inefficient use of the intrinsic energy of wood, however, recovering on average about 1 GJ per bone-dry tonne of wood – a conversion efficiency of approximately 5 percent. Traditional wood stoves can increase this efficiency to about 36 percent, and charcoal-based systems are between 44 and 80 percent efficient, depending on the furnace design and charcoal production methods. The most modern application for residential-scale power generation is the wood pellet stove, which delivers between 78 and 81 percent efficiency per tonne of feedstock (Mabee and Roy, 2001; Karlsson and Gustavsson, 2003).

Industrial-scale power generation: A number of technologies are currently in use or under development for industrial-scale bioenergy production. These include power boilers for heat recovery, CHP systems for the production of both heat and electrical power, and gasifier systems for advanced energy recovery.

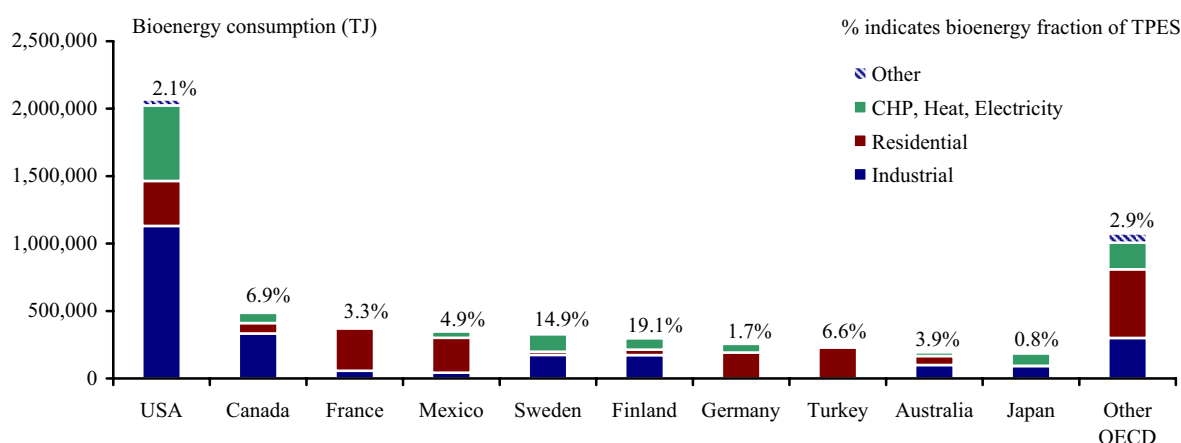
Steam-turbine power boilers, designed to work primarily with bark, can be added to sawmills to serve as an alternative to beehive burners and other forms of waste disposal. Heat from power boilers can be used to generate steam, which can be used in turn to meet process requirements or be directed to turbines for electricity generation. Recovery boilers are used in a similar way in pulp and paper mills, to recycle black liquor and recover pulping chemicals, as well as producing steam to drive the pulping process. Low energy costs over the long term in much of the developed world have not provided much incentive for installing electrical generation capacity within mills. The efficiency of a steam-turbine power boiler is generally about 40 percent (Karlsson and Gustavsson, 2003).

CHP facilities, when sited appropriately and sufficient for local needs, can use the steam to supply other industrial processes or support district heating grids for residential, institutional or industrial facilities. The recovery of both heat and power from the process is referred to as cogeneration, and can significantly increase the efficiency of operations. The efficiency of a CHP facility ranges between 30 and 44 percent (Karlsson and Gustavsson, 2003). When the most recent technological advances (see following paragraph) are used and flue-gas recovery and recycling incorporated, efficiency can rise to between 70 and 80 percent (Karlsson and Gustavsson, 2003).

New bioenergy technologies that use gasification (combustion in the absence of oxygen) have been reported to be much more efficient for energy recovery, in terms of electricity generation, than traditional combustion in a power boiler. An integrated gasification combined cycle may increase efficiencies to about 47 percent, theoretically reaching 70 to 80 percent with CHP. Significant technical hurdles remain, however, particularly regarding biomass-derived syngas clean-up requirements and associated char build-up problems.

The top ten users of bioenergy (in terms of absolute consumption) within OECD are identified in Figure 2. The figure shows that different nations have developed their bioenergy industries in different ways, with varying emphasis on industrial and residential uses and on heat and power production. Above each bar, Figure 2 indicates the consumption of bioenergy relative to TPES. Although the United States is the largest user of bioenergy among OECD countries, bioenergy is only a small component of its total energy supply, representing only 2.1 percent of TPES. By comparison, Finland and Sweden use the most bioenergy as percentages of TPES, at 19 and 15 percent, respectively. It should be noted that Figure 2 reflects the production of bioenergy from solid biomass, including woodfuels and agrofuels, but does not include municipal solid waste streams.

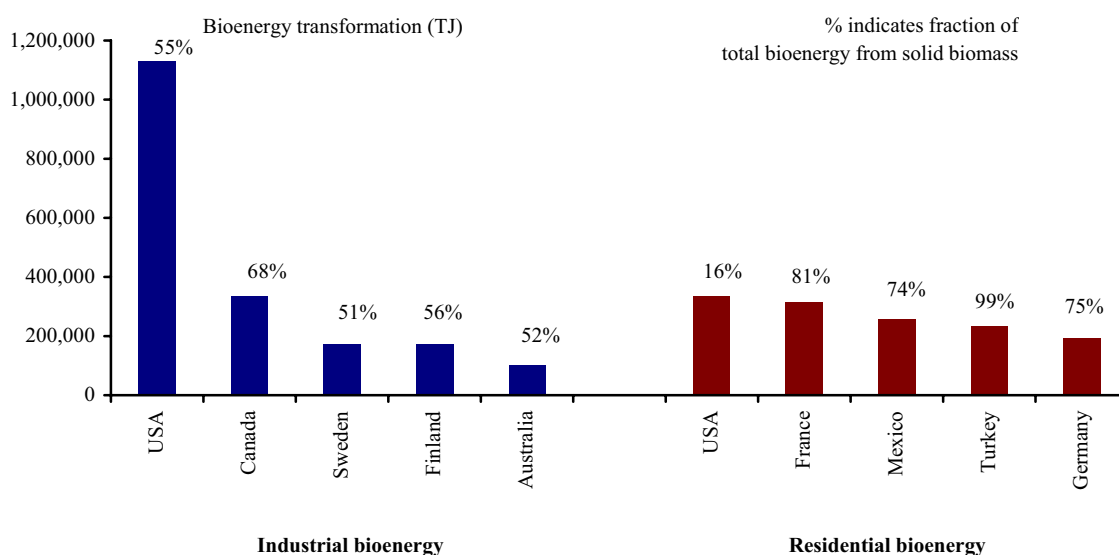
Figure 2. Top ten consumers of bioenergy from solid biomass, 2004



Sources: IEA 2006a; 2006b.

Figure 3 shows the top five users of industrial and residential bioenergy in OECD. The largest users of industrial bioenergy are in North America and Scandinavia, where the pulp and paper industry is a significant producer and user. These results are supported by the Joint Wood Energy Enquiry (JWEE),¹ which reported that the largest users of wood for industrial bioenergy by volume were the United States, Canada, Sweden and Finland, and that most forest biomass used for energy in these countries was recovered from indirect sources, including black liquor from Kraft pulping and other wood residues (Steierer *et al.*, 2007). Industrial applications accounted for just over 50 percent of total bioenergy use in each of these five countries. By comparison, in four of the five largest residential users of bioenergy, residential applications dominate total bioenergy use (accounting for more than 70 percent). The lone exception – the United States – uses only 20 percent of total wood-to-energy feedstocks in residential applications, compared with France’s 90 percent (Steierer *et al.*, 2007).

Figure 3. Top five users of industrial and residential bioenergy from solid biomass, 2004

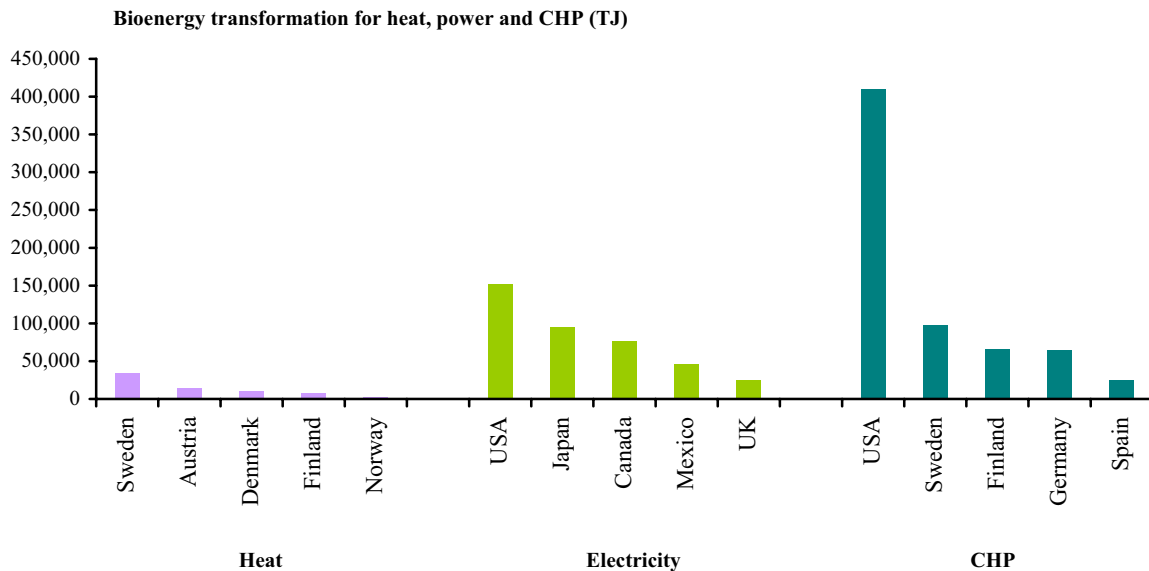


Sources: IEA 2006a; 2006b.

¹ A report by the United Nations Economic Commission for Europe (UNECE), FAO, the International Energy Agency (IEA) and the European Union (EU) examines the specific uses of wood for bioenergy in 12 European and two North American countries. Available at: <http://unece.org/trade/timber/docs/stats-sessions/stats-29/english/report-conclusions-2007-03.pdf>.

An average of 29 percent of wood energy in Europe is used for industrial purposes, compared with 43 percent in North America (Steierer *et al.*, 2007). More wood energy is used for residential applications in Europe than in North America. On average, residential applications account for 47 percent of wood-to-energy in Europe, compared with 18 percent in North America. There is uncertainty about the accuracy of household data, however, owing to the difficulty in collecting such information.

Figure 4. Top five users of heat, electricity and CHP derived from solid biomass, 2004



Sources: IEA 2006a; 2006b.

The most dominant use of bioenergy is for CHP production, of which the United States, Sweden, Finland and Germany are the main users; most electricity production in Europe results from expansion of CHP production in Germany and Spain. CHP is the principal technology for producing electricity from solid biomass, accounting for more than three-quarters of total production.

Additional data on bioenergy use throughout OECD is available in Tables A1, A2 and A3.

Wood pellet production and transport: Wood pellet production is an ideal method for transporting woodfuels from the forest to downstream processing facilities. Wood pellet furnaces, using the most advanced technologies for energy conservation and recovery, can deliver the most intrinsic bioenergy of all technology options. Wood pellets are generally produced from wood waste such as sawdust and shavings, rather than whole logs, and thus should be viewed as part of an integrated forest products manufacturing sector. The raw material is dried, mechanically fractioned to size and then extruded under intense pressure into pellets, a rapid process that is highly suited to medium- or large-scale production. During the process, the raw material is densified approximately 3.7 times. The wood pellets produced in western Canada have a bulk density of approximately 705 kg/m³ and a bulk stowage factor of approximately 1.5 m³/tonne (Melin, 2006). The efficiency of using wood pellets in small-scale furnaces ranges from 78 to 81 percent, making them the most effective tool for bioenergy production on the small scale (Karlsson and Gustavsson, 2003).

TABLE 1
Net energy efficiency of Canadian wood pellet exports

| Process stage | Energy input |
|--|----------------------|
| Harvest-to-mill | n.a. |
| Mill construction | 0.043 GJ/tonne |
| Mill operations (drying, milling, pressing, cooling, screening, bagging) | 0.244 GJ/tonne |
| Pellet transport: - 200 km truck | 0.230 GJ/tonne |
| - 1 000 km train | 0.630–0.700 GJ/tonne |
| - 10 000 km ship | 0.280–0.749 GJ/tonne |
| Total inputs | 1.47–1.97 GJ/tonne |
| Total outputs | 16 GJ/tonne |
| Net energy efficiency | 8.1–10.9 |

Source: Hoque *et al.*, 2006.

In Europe, particularly Scandinavia, the bulk of the pellets produced are used as fuel in central heating stations supplying heat for communities or cities.

There is interest in the energy efficiency of producing wood pellets in North America and shipping them overseas. As shown in Table 1, the energy used in transport can be kept to a minimum by maximizing the sea-borne component of travel. In this example, pellets are shipped by train from Prince George, British Columbia to Prince Rupert, loaded on a container ship, sailed to Stockholm via the Panama Canal, and unloaded and trucked to nearby power generators. Each transport component uses a significant amount of energy on a per tonne basis, with shipping being the most efficient option by far (Hoque *et al.*, 2006). Even incorporating the cost of construction and operation does not add significant amounts of energy to each tonne of delivered wood pellets.

The final net energy efficiency of wood pellets used in North America is estimated to range between 8 and 11 (energy out vs. energy in). It should be noted that in this example, the harvest and initial transport of forest biomass were assumed to be absorbed by the primary forest products industry.

Liquid biofuels for transport

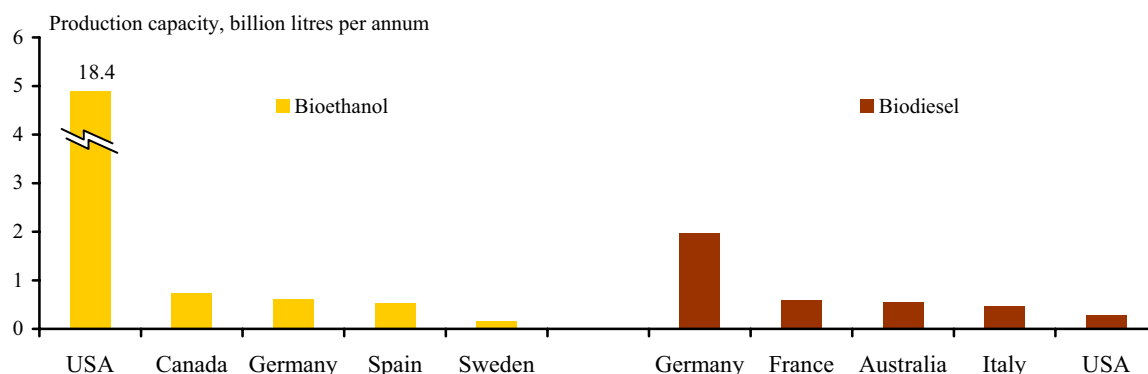
Production of liquid biofuels for transport: Liquid biofuels for the transport sector have been produced on a significant scale since the 1970s, using a variety of technologies. A first generation of food-based liquid biofuels is widely available today, primarily as sugar- and starch-based bioethanol, and oilseed- and waste oil-based biodiesel. The increased use of food-based liquid biofuels may have an impact on commodity food prices. A second generation of technologies under development may allow the use of cellulosic feedstocks, including agrofuels and woodfuels, to produce liquid biofuels for transport. The introduction of cellulosic liquid biofuels could reduce competition with food and would likely increase energy efficiency. These technologies will need another three to ten years to become economically competitive with fossil fuels or food-based liquid biofuels. Today, only a small proportion of liquid biofuels produced for transport are forest-based. Key producers of food-based liquid biofuels for transport in 2006 included Brazil, the United States and Germany, as well as China and India. The number of countries with significant food-based liquid biofuels production capacity is growing rapidly as technologies are adopted on an increasingly global scale.

Brazil is one of the world's largest bioethanol producers. Brazilian bioethanol is food-based, using sugar derived from sugar cane as feedstock. Brazil controls more than 75 percent of the world's export market for bioethanol, with primary exports going to OECD members, including the United States, countries in Europe, the Republic of Korea and Japan. Brazil's estimated total exports were

approximately 3.1 billion litres in 2006 (Lichts, 2006). Because many OECD members utilize these imports to help meet biofuel obligations, the potential impacts of increased demand for Brazilian bioethanol (including increased food prices and deforestation) should not be ignored.

The major food-based liquid biofuel producers among OECD countries are the United States, Canada, Germany, Spain and Sweden for bioethanol, and Germany, France, Australia, Italy and the United States for biodiesel. Bioethanol production worldwide is about 40 billion litres, and biodiesel capacity about 4 billion litres. The major OECD biofuel producers are shown in Figure 5.

Figure 5. OECD top five biofuel producers: bioethanol and biodiesel, 2006



Source: IEA 2007.

The development of an economically viable process for producing cellulosic liquid biofuels will allow the use of forest biomass in the transport sector. There are two distinct technological platforms that a woodfuels-based biorefinery might utilize to produce cellulosic liquid biofuels: thermochemical-based processes, and biological-based processes. These platforms could likely be combined to some extent in many pulp mills.

Thermochemical platforms: Thermochemical conversion platforms can liquefy or gasify woodfuels, collect the chemical components generated, and ultimately reassemble them into fuels and, possibly, industrial chemicals. These platforms combines process elements of pyrolysis, gasification and catalytic conversion. Pyrolysis and gasification may be used for bioenergy generation independently of catalysis, but the potential product range is greatly increased when the entire platform is implemented. If pyrolysis is carried out quickly (fast pyrolysis), a combination of vapours, condensable vapours and char is produced (Garcia *et al.*, 2000). Under slow pyrolysis, the gaseous products from pyrolysis and gasification are generally referred to as synthesis gases (or syngas) (Cetin *et al.*, 2005).

Cellulosic liquid biofuels for transport may be generated from the thermochemical platform by applying a catalysis stage to convert syngas into chemical building blocks and, eventually, end-products. There are proven catalytic processes for syngas conversion to fuels and chemicals, using syngas produced commercially from natural gas and coal. Fischer-Tropsch (FT) diesel (or biosyn diesel) is one potential cellulosic liquid biofuel product. Most current production of FT diesel is carried out in South Africa using coal as a feedstock; in part this arises from South Africa's many years of United Nations (UN) trade sanctions, which meant that there was no available source of petroleum for fuel production. Another potential catalytic conversion of biomass-based syngas is to higher alcohols, including bioethanol. The yield of FT fuels is estimated to range from 2.9 to 7.6 GJ/bdtonne biomass. Total energy efficiency is difficult to calculate, however, as significant heat and power recovery might also be achieved with this process. It is likely that the overall energy efficiency would rival the best small- and large-scale bioenergy processes described in the previous sections.

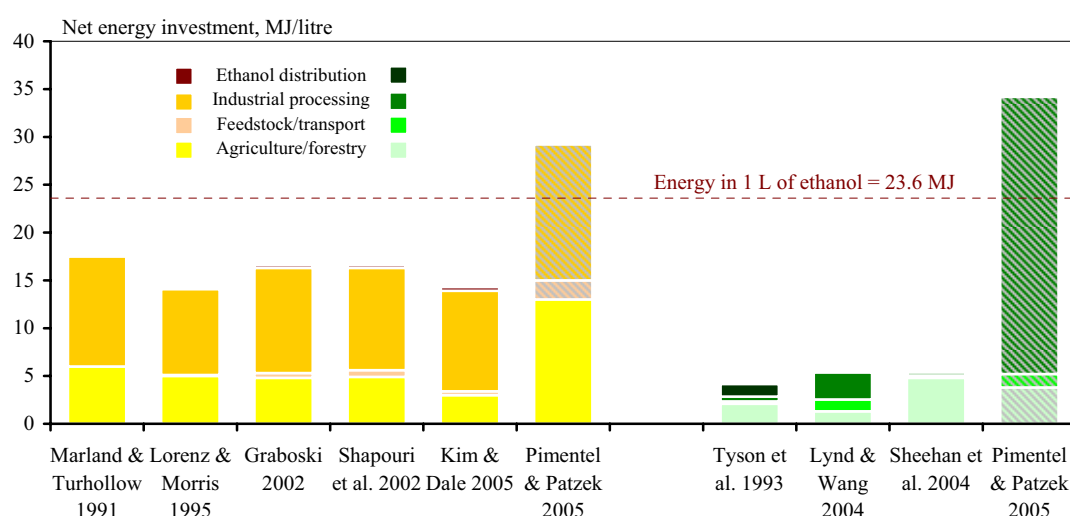
Biochemical platforms: Bioconversion platforms utilize biological agents – enzymes and microorganisms – to carry out structured deconstruction of the lignocellulose components of wood and agricultural residues. This platform combines process elements of pre-treatment with enzymatic hydrolysis to release

carbohydrates and lignin from the wood, followed by fermentation to create end-products. Essentially, this platform blends pulp and paper technology with the commercial biotechnology processes used in the agricultural products sector.

Using enzyme mixtures expressed from a variety of sources, the cellulose and hemicellulose components of wood can be hydrolyzed – in essence releasing their constituent sugars, including glucose, galactose, mannose, arabinose and xylose. These sugars are an intermediate chemical product that can be used as the basis for fermentation to bioethanol or a cellulosic liquid biofuel, or converted to a variety of other products. Fuel bioethanol, the primary output from the bioconversion platform, may be readily blended with gasoline or used on its own. Once hydrolyzed, six-carbon sugars can be fermented to bioethanol using age-old yeast processes. Although five-carbon sugars (xylose and arabinose) are more difficult to ferment, recently developed new yeast strains can ferment these sugars, but issues with the overall process efficiency still have to be resolved. Cellulosic liquid biofuels could be produced with estimated efficiencies of 2.6 to 6.4 GJ/bdtonne of wood, depending on the efficiency of five-carbon sugar conversion. As for the thermochemical platform, it is difficult to translate this to total energy efficiency, because the lignin component might be used to generate heat and power, or used in other ways to substitute fossil-based products. There is great potential for using the biochemical platform to produce cellulosic liquid biofuel from biomass, particularly given its suitability for co-product generation.

Energy efficiency of liquid biofuels for transport: Of all cellulosic liquid biofuels, the one currently closest to commercialization is bioethanol. A review of pertinent studies carried out by the National Resources Defence Council (NRDC, 2006) indicates that under current production methods, maize (starch-based) bioethanol represents only a slight improvement in energy efficiency over petroleum, while cellulosic (wood-based) bioethanol can improve this displacement by up to four times. In five of the six studies shown in Figure 6, starch-based bioethanol provided an energy return (energy out vs. energy in) of between 1.29 and 1.65. The dissenting study, by Pimentel and Patzek, used significantly higher energy inputs than are usually considered standard, thus generating far lower energy returns than were obtained by the majority of researchers in this field. Similarly, three out of four studies indicated that cellulose-based bioethanol provides energy returns ranging from 4.40 to 6.61. These are consistent with the potential for cellulose-to-bioethanol processes to be independent of significant fossil-based energy inputs. Again, the dissenting study by Pimentel and Patzek used energy input figures that were significantly out of line with the standards used by most researchers. These data indicate that development of cellulosic liquid biofuels utilizing forest feedstocks has the potential to improve energy efficiency and the overall energy balance.

Figure 6. Comparison of energy efficiency of bioethanol production, various studies

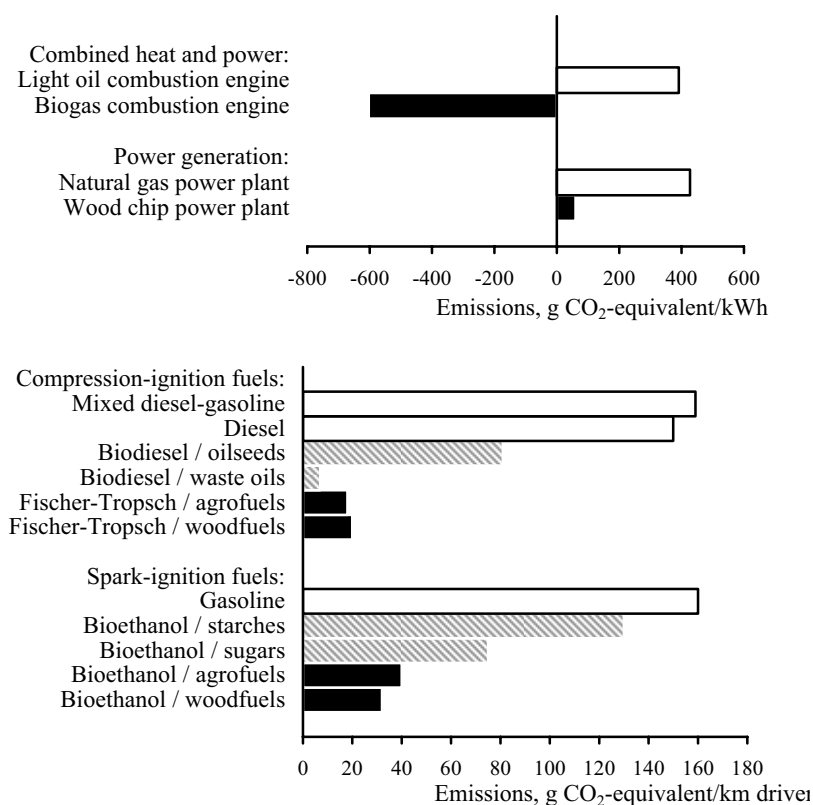


Source: NRDC, 2006.

Greenhouse gas emissions associated with bioenergy production

With small- and large-scale bioenergy options, the concern over GHG emissions is lessened because the emissions associated with combustion of these materials are “green” or closed-cycle emissions, as shown in Figure 7. Spitzer and Jungmeier (2006) analysed the emissions related to heat, electricity and CHP production following an LCA approach. Heat production from a combined cycle power plant operating on wood chips was found to produce about 60 g of CO₂-equivalent (CO₂-e) for each kilowatt of energy produced, compared with a similar plant using natural gas as a feedstock and producing about 427 g of CO₂-e/kWh. Emissions from a CHP facility operating on biogas were found to be -603 g of CO₂-e/kWh, assuming one-third electricity and two-thirds power generation. This indicates that the CHP plant not only has lowered emissions, but actually substitutes green carbon for fossil emissions. A conventional light oil combustion engine produces about 391 g of CO₂-e/kWh (again, assuming one-third electricity and two-thirds power generation). By substituting emissions, the fuel produces an overall negative emission (VIEWLS, 2005).

Figure 7. Comparison of GHG emissions of bioenergy (heat and CHP generation), biofuels and conventional fuels, using advanced (> 2010) technologies



Sources: Spitzer and Jungmeier, 2006; VIEWLS, 2005.

Although woodfuels from sustainably managed forests may be considered carbon neutral, there is concern about the possible increase in air pollution and its ecological and health impacts if wood combustion expands. In particular, wood combustion in installations with insufficient filters or incomplete combustion releases fine particulates that are an acknowledged health hazard. An increase in wood combustion without corresponding upgrades of technology – particularly in households, where inefficient fireplaces and stoves are common – would increase particle emissions in Europe, with consequential health risks, including reduced life expectancies. Combustion efficiency as a way of reducing particulate emissions should be considered during the evolution of wood energy policy. As increased biomass combustion has major consequences, a holistic approach is necessary when setting targets and policies to combat climate change.

When cellulosic liquid biofuel production is compared with food-based liquid biofuel production and conventional petroleum use, a significant reduction in GHG emissions can be seen, as shown in Figure 7. Two integrative reports brought together the major LCAs conducted in a number of OECD countries in Europe and North America. One, the VIEWLS project, first reported in November of 2005 (VIEWLS, 2005) and corroborates data released in the other, earlier report by the Institute for Energy and Environmental Research in Heidelberg, which provides some additional LCA reviews (Quirin *et al.*, 2004). In general, both reports show that biofuels made from both agrofuels and woodfuels (i.e., lignocellulosic materials, shown in black in Figure 7) are characterized by reduced CO₂ emissions compared with similar food-based and petroleum products (shown by striped and white bars, respectively), and can play a role in meeting Kyoto Protocol obligations.

These findings indicate that wood energy can offer significant improvements over fossil fuel options when heat and power generation are considered, while cellulosic liquid biofuel technologies show improved performance over food-based liquid biofuels or petroleum alternatives for the transport sector.

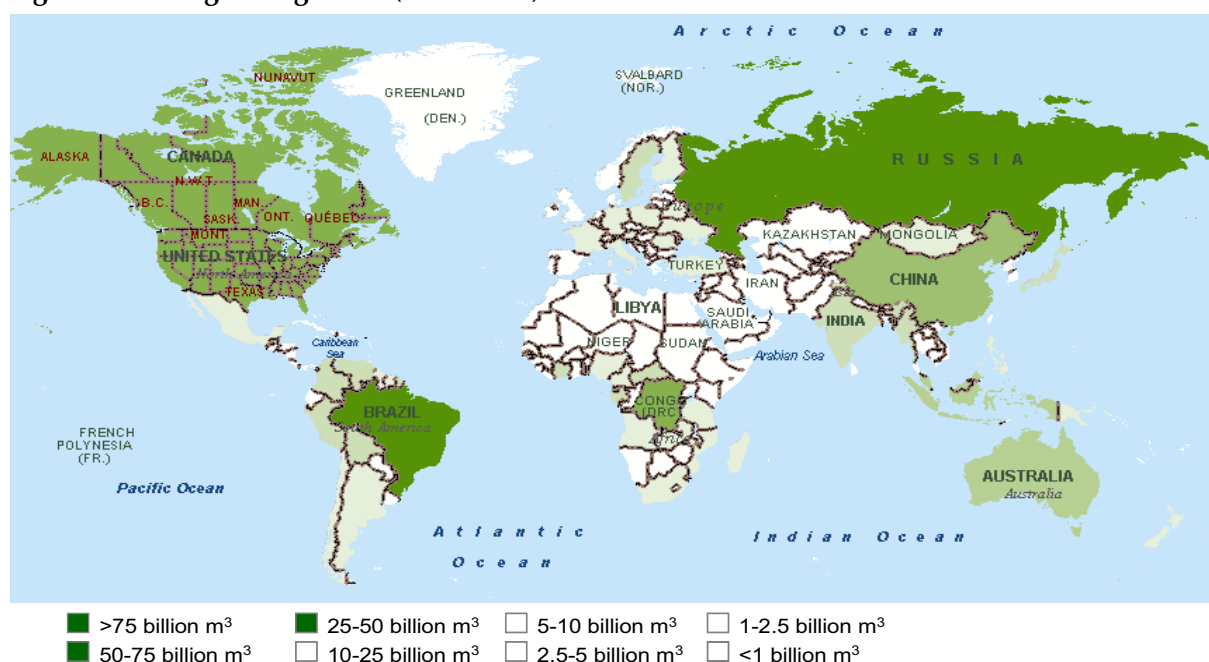
FOREST FIBRE SUPPLY

Total growing stock

The latest global forest resources assessment (FAO, 2006a) indicates that total forest growing stock worldwide was just over 416 billion m³ in 2005, of which approximately 171 billion m³ could be considered commercial growing stock. The distribution of total growing stock is shown in Figure 8. The OECD countries with the largest commercial total growing stocks include the United States (35 billion m³) and Canada (33 billion m³), followed by Australia, Sweden, France and Finland.

The United States is the dominant producer of industrial roundwood from forests, and imports the most industrial forest products. Canada is the second largest producer of roundwood, and the largest net exporter of industrial forest products to the world market. Australia, Sweden, Germany and Finland are also major forested nations within OECD.

Figure 8. Total growing stock (billion m³)

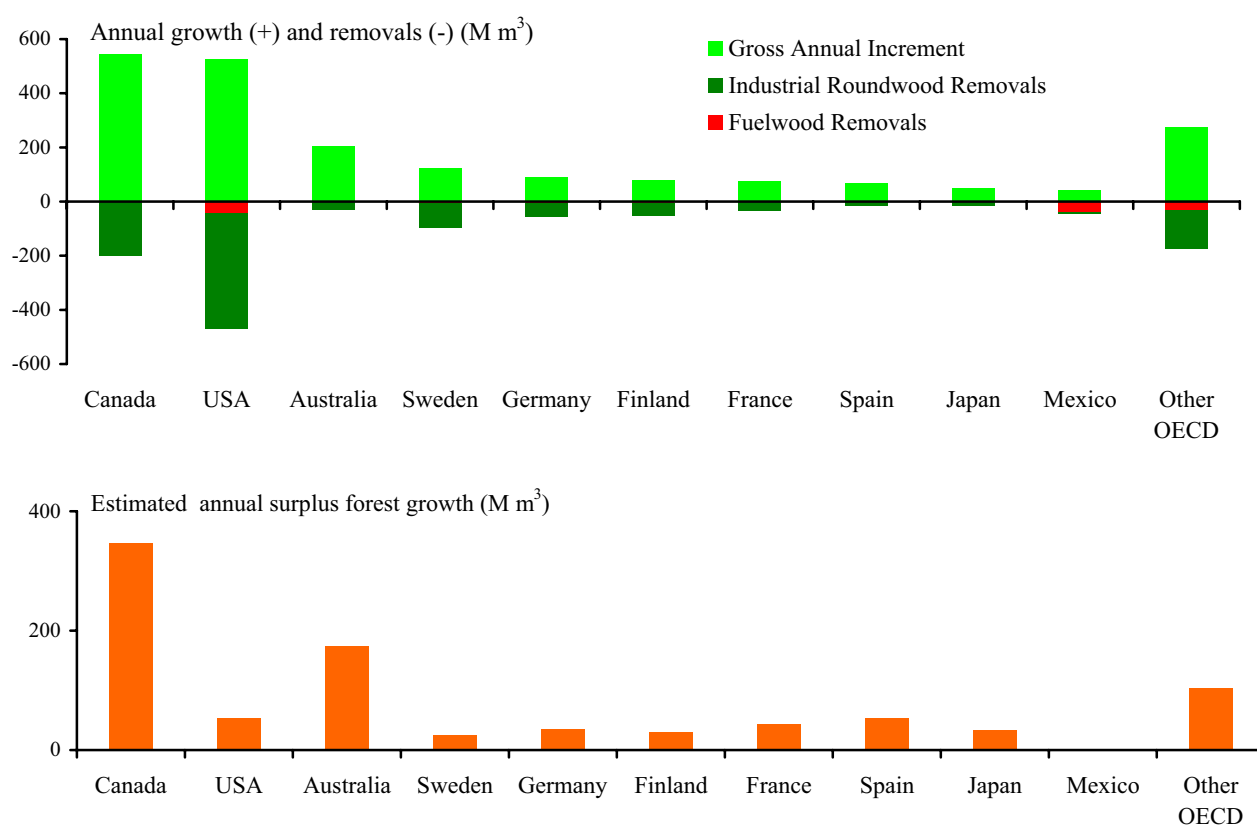


Source: FAO, 2006a.

Global industrial roundwood production was about 1.7 billion m³ in 2005, compared with fuelwood production of approximately 1.8 billion m³ (FAOStat, 2007a). About 65 percent of global industrial roundwood was produced within OECD member countries, compared with only about 13 percent of fuelwood. The largest producers of fuelwood were India (306 million m³), China (191 million m³) and Brazil (138 million m³). Production of fuelwood is significant in only a few OECD countries, primarily the United States and Mexico.

Imports and exports of industrial roundwood reached about 130 million m³ globally in 2005, compared with fuelwood at 3.6 million m³ (FAOStat, 2007a). Trade in fuelwood has increased slowly since 1961, when 1.9 million m³ was imported and 1.6 million m³ exported worldwide. These figures indicate that the vast majority of fuelwood is still produced and consumed locally. The fact that significant fuelwood use occurs in private households acts as a barrier to the collection of good country-level data.

Figure 9. Forest growth and removals, OECD countries (million m³)



Sources: FAOStat, 2007a; FAO, 2006a; 1998.

Comparing annual forest growth (or increment) with annual removal of industrial roundwood and fuelwood gives some idea of the amount of forest biomass that may be available for bioenergy purposes, as shown in Figure 9. The annual growths shown in the figure were estimated by combining reported average increments for all species (from FAO, 1998) with current estimates of commercial forest areas (from FAO, 2006a). The resulting estimate is the gross annual increment, which does not include natural incidence of tree mortality. Removals of industrial roundwood and fuelwood were obtained from FAOStat (2007a). Estimates of surplus forest growth are calculated by subtracting removals from the gross annual increment.

The estimates shown in Figure 9 are subject to a number of issues. First, as already stated, the gross annual increment does not include tree mortality from insects, disease, fire or other non-anthropogenic causes. These impacts can be significant; for example, at the time of writing, an ongoing outbreak of mountain pine beetle in Canada was killing an estimated 100 million m³ of

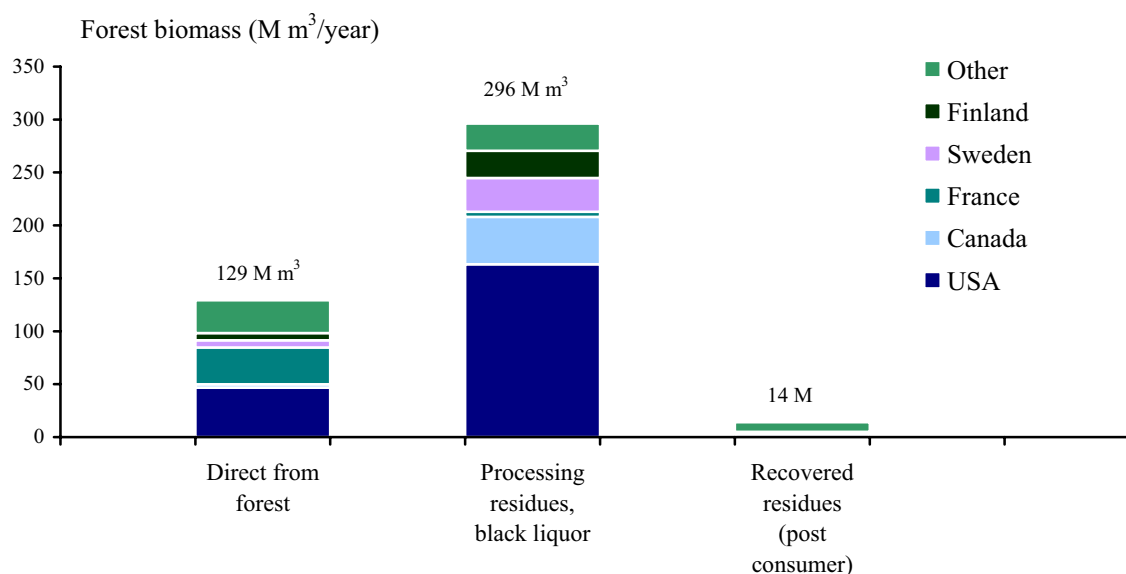
lodgepole pine per year (Eng *et al.*, 2005). Another issue is that actual annual increment can vary significantly over the geographical range of a forest, or between forests of different ages. Thus, the estimates of annual surplus forest growth should not be viewed as definitive, but rather as indicative of general trends. Finally, the estimate is based on the reported commercial forest area, but this does not necessarily reflect the economically viable forest region. A large proportion of the surplus reported may not be accessible, owing to difficult terrain, remote locations or environmental concerns.

Overall, these figures indicate that there may be an annual surplus of forest growth, which would represent a sustainable source of biomass for bioenergy production. The countries with the largest estimated surpluses are Canada and Australia. The estimated surpluses in biomass are significant when taken as a proportion of total gross annual increment, ranging from a low of 10 percent in the United States to a high of 77 percent in Spain.

Forest biomass for wood energy in OECD

The current international statistics (kept by IEA and FAO) for energy and forests do not specify the amount of wood utilized for industrial energy purposes. Some idea of how much forest biomass is used in all energy applications may be discerned from JWEE (Steierer *et al.*, 2007), which was commissioned jointly by UNECE, FAO, IEA and the EU, and examines the specific use of wood for bioenergy in 12 OECD member countries: the United States, Canada, France, Sweden, Finland, Germany, Austria, the Czech Republic, Norway, Switzerland, the Netherlands and the United Kingdom. Within these countries, about 440 million m³ of forest biomass was used for bioenergy purposes. Direct harvesting for energy purposes was found to total about 129 million m³, which was significantly higher than expected (Steierer *et al.*, 2007). The primary source of wood for bioenergy purposes was the recovery of processing residues, including black liquor, which accounted for 296 million m³.

Figure 10. Forest biomass for wood energy by source, OECD countries



Source: Steierer *et al.*, 2007.

The breakdown of forest biomass sources for wood energy purposes is shown in Figure 10. The United States is the largest single user of wood energy, using about 212 million m³ annually from different sources. France obtains 84.3 percent of its total wood energy feedstock from direct harvest, the highest proportion found in the JWEE study (Steierer *et al.*, 2007). In Europe, an average of 45 percent of wood energy comes from direct harvests, 49 percent from residual waste streams, and 6 percent from recovered material. By comparison, in North America, only 19 percent of wood-to-energy comes from direct harvest, 80 percent from residue recovery and 1 percent from post-consumer waste recovery.

Trade of wood energy feedstocks from forests

The forest-based commodities most likely to be directed towards wood energy applications include woodfuels – fuelwood and charcoal – wood chips and particles, and wood residues (as tracked by FAO). Trade in these items was summarized by Hillring (2006) and is presented in Figure 11. Wood chips and particles are commonly used as feedstock for panel products, including medium-density fibreboard and particleboard, as well as for pulp and paper products; wood residues can be used to produce particleboard and wood pellets. The trade in each of these commodities is relatively low compared with that in forest products shown in Figure 10. The most dominant importers of these types of materials in OECD are Japan, followed by Italy, Germany and the Republic of Korea. The most dominant exporters in OECD include France, Germany, Austria, Canada, Australia and the United States (Hillring, 2006).

The lack of significant trade in basic feedstocks to support wood energy applications must be addressed as the demand for wood energy begins to grow throughout OECD. Although countries may be able to source feedstocks domestically, it is clear from the section on Total growing stock that some OECD countries (notably Canada and Australia) may have much greater sustainable supplies of biomass than others, and some may have limited biomass surpluses in excess of current demand. A potential solution is to develop woodfuel commodities such as wood pellets that can be shipped at lower costs (owing to increased density) and handled more readily in industrial processes, as described in the section on Heat and power generation.

OTHER FEEDSTOCK FOR BIOENERGY

Woodfuels: forest plantations

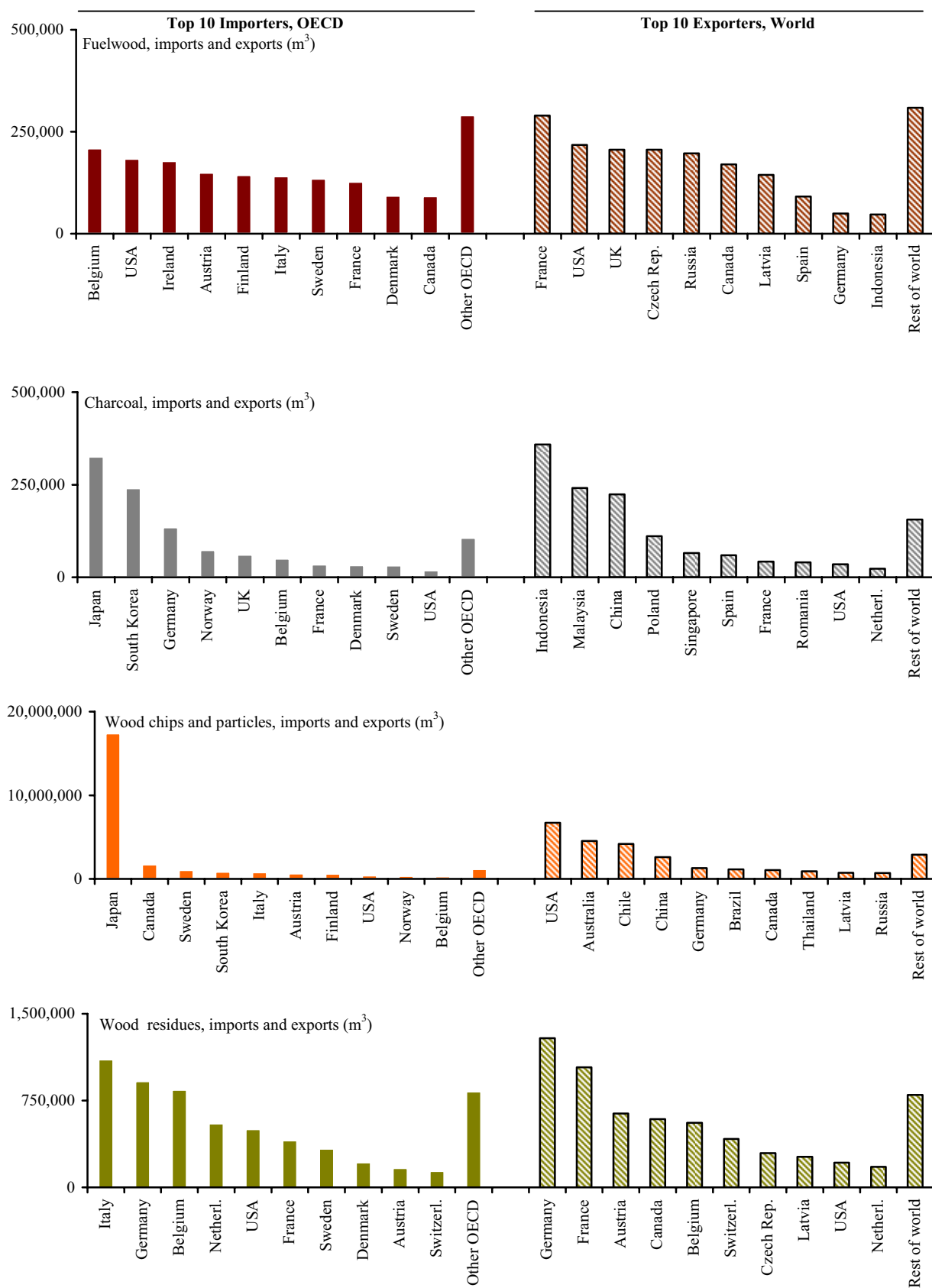
The total area of forest plantations in 2005 was approximately 140 million ha (FAO, 2006a). Plantation forestry is not yet widely adopted in OECD; only the United States (with 17 million ha) and Japan (10 million ha) report forest plantations of any size (FAO, 2006a). Other countries with significant plantation areas include China (31 million ha), Romania (17 million ha), the Sudan (5 million ha) and Brazil (5 million ha). In each of these countries, the primary purpose of planted forests is either ecological (anti-desertification, etc.) or industrial fibre supply. In most of the latter cases, the fibres are destined for the pulp and paper industry; energy plantations for the wood energy sector have not yet been established.

Agrofuels: sugars and oilseed crops

Two primary crops can easily be diverted to the production of liquid biofuels: sugar cane and other sugar crops are agrofuels that can be processed to bioethanol very cost-effectively; and oilseed crops can be diverted to biodiesel production. Sugar cane is not a widespread crop within OECD, where only Australia (38 million tonnes) and the United States (25 million tonnes) rank as major producers, but sugar beet is grown in many OECD countries. OECD sugar production tends to be devoted to food products, although recent developments, such as the construction of British Sugar's first bioethanol facility based on sugar beet in the United Kingdom, indicate that this trend may change in the future. The world's primary producer of sugar cane is Brazil, with an annual 422 million tonnes (as of 2005). About half of Brazilian sugar cane production goes to the bioethanol industry. Other major sugar producers include India (232 million tonnes), China (87 million tonnes), Pakistan (47 million tonnes), Mexico (45 million tonnes) and Thailand (44 million tonnes). An advantage of sugar cane use is the potential contribution of bagasse, the lignocellulosic component of the sugar cane stalk, which can be used as a feedstock to generate bioenergy in sugar cane-based bioethanol facilities.

Throughout the world, oilseed crop production is more widespread than sugar crops. Primary producers within OECD are the United States (16 million tonnes), Canada (2.2 million tonnes), France (1.9 million tonnes) and Germany (1.5 million tonnes). Other major international producers are China (15.4 million tonnes), Malaysia (13.5 million tonnes), Indonesia (12.1 million tonnes), Brazil (8.4 million tonnes), Argentina (7.2 million tonnes) and India (7.2 million tonnes). Production of oilseed crops is more limited, as many of these plants require optimal soil and growing conditions, and not every site is suitable. It may be supposed that increases in oilseed crop production will be limited by this factor. Other oilseed plants, such as *Jatropha*, are being explored as a feedstock for biodiesel production.

Figure 11. Trade in potential feedstocks for wood energy



Source: Hillring, 2006.

3. Current policies, targets and measures to promote bioenergy

Policies to support bioenergy can provide incentives or set mandates to increase bioenergy use, including wood energy use. These incentives or mandates may be targeted to producers, distributors and/or consumers.

Incentives in use today include infrastructure grants, loan guarantees and public–private partnerships to create bioenergy capacity, as well as broader measures such as tax exemptions or fixed-price mechanisms. The United States is the leader in making funds available for the development of pilot and demonstration facilities, primarily in the biofuels area. Tax incentives commonly applied include reductions or exemptions on excise, fuel or sales taxes, and can be observed across the OECD membership. Fixed-price mechanisms set a premium or bonus that is paid above the normal rate for energy (usually electricity), directly to the energy producers or distributors; these types of mechanisms exist in Denmark and Spain.

Several different policies can set mandates for renewable energy. For example, feed-in tariffs set a specific price that electrical utilities must pay to the domestic producers of green electricity. The additional costs of these schemes are paid by utilities and passed through to the power consumers. Another option is a renewable energy obligation, which essentially mandates the amount of renewable energy that must be used within the total energy portfolio, either as a percentage of total energy use or as a percentage of energy purchased by various user groups. Renewable fuel standards or obligations can be applied to biofuels in a similar fashion. These policy tools are often linked to tax incentives that can be applied to the renewable energy portion.

Green certificates are currently issued in five OECD member countries, with a number of other countries considering adoption of this mechanism. Under this scheme, renewable electricity is sold at conventional prices; to cover the additional cost of producing green electricity, all consumers must purchase a certain number of green certificates from renewable electricity producers to cover a quota or percentage of their total electricity consumption. This is a market-based mandate, where renewable electricity producers can compete with one another to sell green certificates to distributors or consumers.

BIOENERGY AS A COMPONENT OF RENEWABLE ENERGY

North America

In the United States, renewable energy represented 4.4 percent of TPES in 2003, of which bioenergy accounted for 3.0 percent, using feedstocks from combustible renewables and wastes (2.1 percent from solid biomass). Growth in renewable energy since 2000 has been accounted for by increased use of combustible renewables and wastes; hydro and geothermal capacity and production have stagnated or regressed since 1990. At present, 16 United States states have renewable portfolio standards, which require electricity providers to have a minimum amount of renewables in their generation mix. Public benefit funds (also known as system benefits charges) serve as a tax on electricity consumption; the revenue from these funds is used to support various energy-related public goals, including increased use of renewables. Efforts are under way at the federal level to expand the existing US cent 0.9/kWh tax credit for biomass energy to include forest-derived biomass; current subsidies apply only to closed-loop systems or dedicated energy plantations (UNECE/FAO, 2006). Additional subsidies will likely be needed to support open-loop systems, such as forest thinnings-to-energy proposals in the western United States, where forests have to be thinned to reduce catastrophic fire risks. The United States Government provides loan guarantees to biomass energy projects under the Biomass Energy and Alcohol Fuels Act of 1980. A production tax credit will direct US\$10 billion towards renewable energy options by 2013; a portion of these funds will be used for bioenergy projects.

The primary government goals in the bioenergy sector are improving the efficiency of biomass-driven gasification projects, by allowing about 22 percent of the cost of cleaned and reformed synthesis gas, from approximately US\$9.2/MJ in 2003 to US\$7.2/MJ in 2010. This is combined with a drive to reduce harvesting and storage costs of biomass, and to identify new sources of cellulosic biomass supply. The availability of cellulosic feedstock has been the subject of numerous reports, including the recent “Billion Ton Report” prepared by the United States Department of Agriculture (USDA) (Perlack *et al.*, 2005).

In Canada, wood energy forms a significant portion of TPES, mostly through the combustion of black liquor in the pulp and paper industry. A Renewable Energy Working Group has been assembled by the Canadian Council of Energy Ministers (CEM) with the task of providing a framework to enable all Canadian jurisdictions, individually and/or collectively, to maximize renewable energy potential. No national-level targets have been set for renewable energy, although some provincial governments have set goals for their own jurisdictions.

In December 2005, the Mexican Government passed legislation setting the goal of reaching 8 percent renewable energy use by 2012, a 3 percent rise from 2005 levels. The law establishes a federally supported fund for the implementation of renewable energy projects.

The goals for renewable electricity and energy use across North America are summarized in Table 2.

Europe

Among the Member States of the EU, responsible energy use is promoted by three policy tools: (1) energy efficiency in buildings and end-use applications are supported by Directives 2002/91/EC and 2006/32/EC, respectively (EC, 2006; 2002); (2) the trade of GHG emissions throughout the EU is enabled by Directive 2003/87/EC, which created the largest multi-country and multi-sector emissions trading bloc in the world (EC, 2003c); and (3) the production of electricity from renewable energy sources in the internal energy market is set out in Directive 2001/77/EC (EC, 2001). Each of these policy tools recognizes renewable energy, including bioenergy, as an important component of future energy supply. Of the three tools, renewable energy legislation (particularly feed-in tariffs and green certificates) has the most important impact on bioenergy use in the EU. An additional directive (2004/8/EC) sets targets for the generation of CHP, as a means of increasing efficiency of energy recovery. This directive is not applied specifically to renewables and does not supersede the renewable energy target laid out in Directive 2001/77/EC (EC, 2004). The EU has introduced new renewable energy targets for 2020, including a specific Bioenergy Action Plan, discussed below (EC, 2005).

The EU’s Directive 2001/77/EC promotes the production of electricity from renewable energy sources in the internal energy market. The 2010 target for production is 22 percent across the EU, with indicative targets for each Member State. There is no harmonized EU support scheme, and promotion of renewables is thus a national priority without transferability. A number of schemes support renewables in different EU Member States. As a result, a number of mechanisms have been utilized, with most EU countries choosing feed-in tariffs, some opting for obligations, a few choosing fiscal incentives, and no country (at time of writing) utilizing tenders.

Given the nature of renewable energy policy in Europe, it is difficult to consider bioenergy on its own; in almost all current policy, there are no specific goals for bioenergy, which policies refer to simply as one tool within a suite of technology options. The EU does have longer-term targets for renewable energy, however, including the most recent target of 20 percent renewable energy by 2020. As part of these more ambitious targets, a Biomass Action Plan has been developed, which introduces measures designed to increase biomass use to about 150 mtoe (approximately 6.3 billion TJ) (EC, 2005).

The following paragraphs consider the impacts and development of renewable energy policy as an umbrella incorporating bioenergy.

Feed-in tariffs: The most widely utilized policy measure to ensure renewable energy use in EU Member States is the feed-in tariff. In many jurisdictions, however, the long-term cost-effectiveness of using this mechanism is being questioned. In some countries, including Austria, the Czech Republic, Germany and Italy, green certificates are being considered as an alternative, providing each country with a flexible mechanism that closely matches the EU's Emissions Trading Scheme (ETS) in structure and adaptability.

Feed-in tariffs in Austria force energy producers to allocate green power (including bioenergy) to electricity traders, in proportion to the latter's annual sales volume. The tariffs were originally fixed on a regional basis, but were switched to the national level to increase cost-effectiveness. Concerns about the cost of the feed-in system have prompted government officials to discuss the need for caps on the total amounts spent to support renewable energy. It has been suggested that feed-in tariffs be limited to ten years, and that they be lowered by 5 percent a year. According to the Austrian Government, the feed-in tariff represents an expensive means of cutting GHG emissions: approximately €200/tonne for biomass, €100/tonne for wind power and €900/tonne for photovoltaic power.

In the Czech Republic, renewable energy does not play a major role at present, accounting for 2.5 percent of primary energy supply and 4.2 percent of electricity generation in 2002. In the past, government policy focused on feed-in tariffs, but although these tariffs proved effective in delivering installed capacity, they should be reduced regularly to motivate greater efficiency. The Government of the Czech Republic is considering green certificates as a tool for promoting a more effective trading system while accommodating regional certificate trading.

Germany is also on track to meet its domestic goal of producing 12.5 percent of electricity from renewable sources by 2010. The country's feed-in tariff for renewables has resulted in rapid deployment of new electricity capacity, but at a high cost. Estimates show that between 2000 and 2012, the feed-in tariff will cost €68 billion in total. It has been suggested that the government focus on creating sustainable market pressure to bring down the costs of operating and developing its renewable energy resources. As renewables are well established in the market – they are set to increase to 20 percent of generation by 2020 – the government should consider moving towards a more flexible policy that meshes renewable resources with the overall electricity market, providing additional research and development (R&D) subsidies to the particular technologies that require it.

In Hungary, renewable energy potential is limited and remains to be developed. There is significant short-term potential in bioenergy resources and renewable municipal wastes for electricity and heat production. There is concern that the use of a single feed-in tariff for electricity generated from renewable sources may end up supporting relatively high-cost renewable energy options while generating rents for lower-cost options. In Hungary, energy from biomass is principally derived from wood processing, and bioenergy use will increase with investments in modern wood-fired boilers and small power plants. Wood waste combustion complements coal in power plants, partly to increase the lifetime of old coal-fuelled power plants and to reduce their fuel costs. Hungary is experimenting with fuel switching projects.

Italy is moving from using fixed feed-in tariffs for renewable energy to a more market-oriented minimum quota obligation scheme with tradable green certificates. This should increase the amount of renewable energy in a country where, despite its significant potential, renewable energy represented only 5.4 percent of TPES in 2000. In 2002, the government introduced a renewable energy obligation associated with green certificates, to increase the cost-effectiveness of public support for renewable energy development and stimulate further investments in electricity production from renewable energy sources (Decree 79/1999). Transitional arrangements were made for projects presented since 1999 and applying feed-in tariffs, so that they may be eligible for the green certificate scheme from 2002. Electricity generated from renewable energy sources has priority access to the transmission grid. The renewable energy obligation does not distinguish between various renewable energy sources; the choice of source is left to operators, based on market principles.

In Luxembourg, the current buy-back tariff scheme does not have a time limit or a degression element. This means that investors lack incentives to increase productivity, and could be very costly to the economy.

Spain has fixed feed-in tariffs for renewable energy, differentiated by technology. This has been the primary tool for promoting renewable electricity in the past, and has delivered impressive growth rates for wind generation, putting Spain in third place worldwide for wind generating capacity. In an attempt to increase cost-efficiency, the government introduced a new regime for selling renewable electricity in 2004, whereby renewable energy producers can sell their power directly to the market, receiving the average market price plus differentiated premiums based on that price.

In Turkey, a renewable energy law has been submitted to Parliament for approval; it includes fixed feed-in tariffs and a purchase obligation for electricity distributors. Turkey's use of hydropower, geothermal and solar thermal energy has increased since 1990. The total share of renewables in TPES has declined, however, owing to the decreasing use of non-commercial biomass and the growing role of natural gas in the system.

Renewable energy obligations: The best example of renewable energy obligations in effect is in Denmark. Renewable energy supply – primarily from wind – more than doubled between 1992 and 2003, when it accounted for 13.4 percent of TPES. Electricity generation rose sixfold to pass 25 percent in 2005. The obligation system in Denmark requires that market payments for electricity generated from renewable sources be recovered from electricity consumers through a levy on every kilowatt-hour of electricity sold. In 2005, this amounted to approximately 3 percent of the household consumer's final bill, when all taxes and grid charges were included, and approximately 9 percent of the electricity bill for businesses. Danish customers directly paid a total of kroner (DKr) 2 088 billion in 2004 to support renewable energy, equal to about 0.2 percent of the country's gross domestic product (GDP). This is a substantial proportion of the total wholesale price paid for electricity in Denmark, at approximately 20 percent.

Although the Danish example is a success story, estimates from the Danish Economic Council and the Danish Energy Agency show that the cost of reducing each tonne of CO₂ emissions has historically been substantially higher through renewables than it could have been through other programmes, such as energy efficiency or international mechanisms. As market prices for electricity rise, however, comparative prices for renewables should be less costly for Danish consumers.

The Netherlands provides another example of matching obligations with subsidies. Subsidy allocations are changing, however, possibly towards a tender system. For some renewable energy options, tendering could be a more cost-effective method of allocating financing than the first-come, first-served method; both methods are currently under review. Annually, the government sets the budget maximum and determines how subsidies are to be allocated. Allocations vary among the renewable options available and depend on the market structure. The budget maximum is set high enough to ensure that the target of 9 percent renewable electricity in 2010 is met. The subsidy per kilowatt-hour remains the same for the whole subsidy period, which is crucial for investor confidence. The size of the subsidy per kilowatt-hour still depends on the costs and benefits of renewable electricity compared with non-renewable options. The size of the subsidy for new investors is calculated annually. As soon as the positive and negative externalities of renewables and other energy forms have been internalized – which is currently not the case – the size of the subsidy per kilowatt-hour will be set taking this into account. When this is the case, longer-term subsidies can be phased out.

Green certificates: In Norway, a green certificate scheme has been adopted in conjunction with Sweden. Construction of new renewables capacity that started after 1 January 2004 is eligible for green certificates, but since the size of the target has not yet been decided, it is difficult to predict how much this support will be worth. Recipients of government investment support for new renewable capacity will be allowed to participate in the certificates market if they pay back the investment support received. The efficiency and effectiveness of a green certificates system could be improved through international trading, because this would increase the market size of the certificates and

enhance the efficient introduction of more competitive renewable energy sources throughout the market.

A number of factors restrict bioenergy uptake in Norway. The dispersed nature of Norwegian settlements means that the density required for heat networks based on biomass can be achieved in only a few locations, although residential bioenergy use can certainly be achieved. Norway has a good biomass resource from agriculture and forests, but use of this for energy production has been restrained by the availability of cheap hydro-generated electricity. Lack of secure access to biomass fuel of the right quality and price is a major constraint to future development.

In Sweden, the renewable energy goal focuses on biomass power. The government hopes to raise annual generation from renewable plants by 10 TWh between 2002 and 2010. The primary means of meeting this goal is the electricity certificate scheme, which obliges electricity suppliers to acquire electricity certificates from renewable plants equal to a certain percentage of the electricity they supply; this percentage will rise to 16.9 percent by 2010. This scheme has a strong market component that will promote generation from the lowest-cost renewable energy technology and foster competition, thus increasing production efficiencies. The costs of such a system must be monitored closely, however, as the ambitious targets may lead to excessive prices for the certificates, which would ultimately lead to very high bills for consumers.

Other policy approaches: In Portugal, to promote the development of wood energy a tender for 15 thermal forestry biomass power stations with a total installed capacity of 100 MW was issued in 2006.

In Switzerland, most wood energy use currently takes place in the residential sector. SwissEnergy has established two objectives for renewables for 2010: to generate 0.5 TWh of additional electricity, and 3 TWh of additional heat compared with 2000 levels. These represent a 60 percent increase in electricity generation and a 40 percent increase in heat production from renewables. There are no fixed targets for individual renewable energy sources. Many cantons subsidize wood energy at the regional level. At the national level, Switzerland continues to debate the policy approach to supporting renewable energy, and has examined labelling systems that might be applicable to green certificates.

Finland has adopted a national action plan for renewable energy sources, as part of the National Climate Strategy of 2001. The goal of this programme is to increase the use of renewable energy by 30 percent over 2001 levels by 2010. Approximately €120 million has been allocated to annual subsidies and grants (2003 to 2010) through this programme. Approximately 90 percent of the proposed increase will be bioenergy (IEA, 2007). Finland also offers capital grants, and supports a strong R&D programme. Tax subsidies for power production based on renewable energy sources (including biomass) are also available. This combination of grants and tax incentives has proved very successful.

Greece suffers from a high level of local resistance and administrative barriers to new energy infrastructure, and has not determined the mechanism that it will utilize to promote renewable energy systems.

The goals for renewable electricity and energy use across Europe are summarized in Table 2.

Other OECD countries

The use of renewable energy in Australia is currently low. A mandatory renewable energy target (MRET) commenced on 1 April 2001, requiring the generation of 9 500 GWh of renewable electricity per year by 2010 (likely to be about 3.5 percent of total electricity sales). The MRET was reconfirmed in June 2004 by the Australian Government. It has resulted in new capacity in some technologies (wind, solar and hydro), but has not yet led to significant investment in bioenergy. One area of specialization for the MRET might be in areas where renewables could be more cost-effective, including for remote area power generation. This focus could increase demand for biomass energy in regions where biomass is readily available and electrical grid access limited. The MRET allows the trade of green certificates among renewable electricity producers (AGO, 2007).

In Japan, the supply of new and renewable energy sources is expected to grow threefold as a result of maximum efforts by both the public and private sectors. The main policy tools utilized to reduce CO₂ emissions from fossil fuels are energy conservation, promotion of renewable energy and fuel switching. The government aims at a rapid development of renewable energy by 2010, although Japan's starting point is relatively low. Indicative targets include an increase from 900 MW to 4.2 GW for biomass and combustible wastes by 2010. These targets are supported by a renewables portfolio standard introduced in June 2002, which states that utilities must use new renewable sources for 1.35 percent of their total output by 2010. Retailers will have three options for fulfilling this obligation: (1) production from their own generation; (2) buying green electricity from other companies that generate electricity from renewables; and (3) buying part of the obligations fulfilled by other retailers. The third option resembles the tradable green certificate system introduced by other countries.

New Zealand has not taken mandatory measures for renewable energy, owing to its existing favourable and competitive renewable energy sources, particularly for wind. The government continues to remove barriers to the growth of renewable energy supply, including revising the Resource Management Act.

The Republic of Korea has one of the lowest shares of renewable energy sources in OECD, with about 2.1 percent of TPES supplied by renewable sources in 2004. The country's target, to raise this to 5 percent by the end of 2010, will require supportive policies that are not yet in place.

The goals for renewable electricity and energy use across these OECD countries are summarized in Table 2.

LIQUID BIOFUELS FOR TRANSPORT

Policy measures to promote the use of liquid biofuels for transport include renewable fuel mandates, tax incentives and direct funding for capital projects or fleet upgrades. Successful policy interventions take many forms, but success depends on external factors, including biomass availability, an active industry, and relatively high prices for oil and other fossil feedstocks.

North America

In the United States, among the drivers for the liquid biofuel for transport industry have been the rapid surges in global oil prices experienced in the 1970s and 1980s, which led to rising prices for transportation fuel. There was, and still is, a strong agricultural lobby interested in creating additional revenue streams for farmers. The United States bioethanol industry is food-based, using maize and – to a lesser extent – wheat as feedstock for wet- and dry-milling processes. Different policy options have been employed to help build the industry. Both federal and state governments have offered the industry direct funding in the form of public–private partnerships and research funds, as well as tax incentives and state-level renewable fuel mandates, i.e., legislated amounts of renewable fuels contained in the fuel sales within a state, defined in terms of blending level or renewable fuels (DSIRE, 2006; USDOE, 2006). United States production of liquid biofuels for transport is significant, with capacity of more than 19 billion litres in 2006, but comprises only about 2.6 percent of all liquid fuel consumption (on an energy basis). As part of the 2006 Energy Plan, the government announced a renewable fuel standard under which liquid biofuels would account for about 5 percent of transportation fuel demand by 2012. In order to become a more significant component of the transportation fuel sector, biofuel production must grow tremendously, which will require access to cellulosic biomass. To support this, the Advanced Energy Initiative includes the Biorefinery Initiative, which aims to make cellulosic bioethanol cost-competitive by 2012, providing significant funding to achieve this goal (US\$91 million in 2006, \$150 million in 2007; Government of the United States, 2006). Recently, the United States Department of Energy (USDOE) announced significant funding of up to US\$385 million for six cellulosic bioethanol plants across the country, as well as US\$200 million for ten smaller demonstration plants and US\$375 million for three research centres. In February 2007, British Petroleum (BP) announced that the BP Energy Biosciences Institute, a US\$500 million investment over ten years, would be headquartered in the United States at the University of California at Berkeley.

TABLE 2
Renewable electricity and energy targets, OECD membership

| OECD country | Renewable energy target | Target year | Source |
|--------------------|--|--------------|----------------------------|
| Australia | 9 500 GWh above 2001 rates | 2010 | AGO, 2007 |
| Austria | 78.1% of gross electricity consumption: approx. 56 200 GWh | 2010 | EEA, 2007 |
| Belgium | 6.0% of gross electricity consumption: approx. 10 400 GWh | 2010 | EEA, 2007 |
| Canada | No national target | | IEA, 2007 |
| Czech Republic | 8.0% of gross electricity consumption: approx. 6 600 GWh (5-6% renewable share of total energy) | 2010 | EEA, 2007; REN21, 2006 |
| Denmark | 29.0% of gross electricity consumption: approx. 10 900 GWh | 2010 | EEA, 2007 |
| Finland | 31.5% of gross electricity consumption: approx. 28 800 GWh | 2010 | EEA, 2007 |
| France | 21.0% of gross electricity consumption: approx. 115 600 GWh (7% renewable share of total energy) | 2010 | EEA, 2007 |
| Germany | 12.5% of gross electricity consumption: approx. 90 500 GWh (4% renewable share of total energy) | 2010 | EEA, 2007 |
| Greece | 20.1% of gross electricity consumption: approx. 13 900 GWh | 2010 | EEA, 2007 |
| Hungary | 3.6% of gross electricity consumption: approx. 1 500 GWh | 2010 | EEA, 2007 |
| Iceland | 100% of gross electricity consumption (no change from 2004) | 2010 | EEA, 2007 |
| Ireland | 13.2% of gross electricity consumption: approx. 4 500 GWh | 2010 | EEA, 2007 |
| Italy | 25.0% of gross electricity consumption: approx. 117 600 GWh | 2010 | EEA, 2007 |
| Japan | 3% of new energy forms: approx. 733 000 TJ Biomass thermal use target: 118 000 TJ Waste biomass (including black liquor recovery): 185 000 TJ | 2010 | IEA, 2007 |
| Korea, Republic of | 5% renewable energy in total primary energy supply | 2010 | MOCIE, 2007 |
| Luxembourg | 5.7% of gross electricity consumption: approx. 1 800 GWh | 2010 | EEA, 2007 |
| Mexico | 8% renewable energy use | 2012 | Bremauntz, 2006 |
| Netherlands | 9.0% of gross electricity consumption: approx. 10 500 GWh | 2010 | EEA, 2007 |
| New Zealand | 30 000 TJ renewable energy | 2012 | IEA, 2007 |
| Norway | 89.8% of gross electricity consumption (no change from 2004) | 2010 | EEA, 2007 |
| Poland | 7.5% of gross electricity consumption: approx. 17 700 GWh (7.5% renewable share of total energy) | 2010 | EEA, 2007 |
| Portugal | 39.0% of gross electricity consumption: approx. 20 600 GWh | 2010 | EEA, 2007 |
| Slovakia | 31.0% of gross electricity consumption: approx. 9 200 GWh | 2010 | EEA, 2007 |
| Spain | 29.4% of gross electricity consumption: approx. 92 000 GWh (12.1% renewable share of total energy) | 2010 | EEA, 2007 |
| Sweden | 60.0% of gross electricity consumption: approx. 90 000 GWh | 2010 | EEA, 2007 |
| Switzerland | Increase renewable electricity by 10% over current consumption: approx. 5 400 GWh electricity | 2030 | SFOE, 2007 |
| Turkey | 30.9% of gross electricity consumption (no change from 2004) | 2010 | EEA, 2007 |
| United Kingdom | 10% of gross electricity consumption: approx. 47 600 GWh | 2010 | BERR, 2007; EEA, 2007 |
| United States | Triple bioenergy and bioproducts use Identify 1 billion tonnes of cellulosic feedstock for energy and fuel production: 368 million tonnes forest biomass; 933 million tonnes agricultural biomass | 2010 2030 | IEA, 2007; Himmel, 2007 |

Canada is also poised to become a major biofuel producer, and currently produces about 700 million litres of liquid biofuels for transport annually, with another 700 million litres of capacity under construction (CRFA, 2006). Much of the funding for R&D in biofuels depends on the Canadian Federal Government's environment strategy, which evolved significantly with the ascension of a Conservative minority federal government in 2005. In 2006, Canadian biofuel targets were announced: 5 percent bioethanol by 2010; and 2

percent biodiesel by 2012 (fuel consumption on an energy basis). About Can\$500 million has been set aside to help develop renewable energy technologies, including liquid biofuels.

Mexico does not have a national target for liquid biofuel production, but passed a Biofuels Promotion and Development Law on 26 April 2007 (Chavez and Nawn, 2007). In February 2006, the Mexican Government passed a measure supporting a 10 percent bioethanol blend for the country's main urban centres; this measure also grants the Inter-Sector Commission for Rural Development the authority to establish regional programmes for both bioethanol and biodiesel (Garten Rothkopf, 2007). Mexico remains concerned about the potential impact that biofuel production may have on food production and prices, and intends to proceed slowly towards realizing production potential.

Europe

In the EU, the primary policy tool for development of a liquid biofuel industry is the directive on promotion of the use of biofuels for transport (Directive 2003/30/EC; EC, 2003a). The motivations behind this directive include improving the security of energy supply, and reducing the environmental impact of the transport sector. To meet these priorities, the directive sets reference values for an increasing share of biofuels, from 2 percent of total fuel supply in 2005 to 5.75 percent in 2010 (based on energy content). The European Commission is considering a revised directive that would set a binding target of 10 percent biofuels by 2020. Owing to relatively slow growth in the industry, it is anticipated that renewable fuels will occupy about 4.2 percent of the market by 2010 – significantly less than the existing policy target (EC, 2007). Many EU Member States have passed the biofuels directive into national law, including Belgium (Anon., 2006a), the Czech Republic (Anon., 2006b), France (Anon., 2006b), Germany (Neumann, 2006), Greece (Anon., 2004), Latvia (Anon., 2006c), Lithuania (Anon., 2006d), Sweden (Guldbrand, 2006) and the Netherlands (Anon., 2006e). A parallel directive was created to restructure the community framework for the taxation of energy products and electricity (Directive 2003/96/EC), allowing excise tax exemptions for biofuels produced or blended within European countries (EC, 2003b). Today, most EU Member States, including Austria, Belgium, Cyprus, Denmark, Estonia, France, Germany, Hungary, Italy, Latvia, Lithuania, Luxembourg, Malta, Poland, Slovakia, Slovenia, Spain, Sweden and the United Kingdom, have introduced exemptions at levels up to 100 percent, using the precepts laid down in Directive 2003/93/EC.

As of late 2005, only one country exceeded the goals set out in the directive. German biofuel use (primarily biodiesel) accounted for 3.75 percent of total fuel consumption in 2005. The German biodiesel industry expanded largely as a result of the removal of excise taxes on this fuel type; German excise taxes are in the range of 200 percent of petroleum-based fuel production costs, so this exemption created an economic incentive sufficient to increase capacity rapidly, from 500 million litres in 2000 to 2 billion litres in 2006. In 2006, however, the German Government decided to act on overcompensation issues and introduced a schedule to tax biodiesel at increasing rates, starting at 9 percent in 2006/2007 and rising to 45 percent from 2012 onwards. This has had an immediate effect on the domestic German biodiesel industry, with about 10 percent of plants halting production and a number of producers investigating a change of operations (Munack and Krahl, 2007).

Swedish biofuel use (primarily bioethanol) accounted for 2.2 percent of total fuel use in the same year, coming closest to achieving the goal. As most cars in Sweden now run on E5 bioethanol blends, however, the country has encountered a constraint in the form of the EU directive on fuel quality, which limits renewable fuel blends to a maximum of 5 percent (on an energy basis). Other countries, including the United Kingdom, have identified this directive as a barrier to achieving the goals of the directive on biofuel use. As an additional measure to promote wider use of biofuels, the European Commission submitted a revised draft of the fuel quality directive in January 2007. The proposed adaptations should enable a higher volume (up to 10 percent) of biofuels to be used in petrol, but these amendments are yet to be approved by the Council (made up of EU Member State governments).

In France, about 1.2 percent of fuel sales consisted of renewable fuels in 2005, mostly in the form of bio-ETBE or bioethanol. In Austria, biodiesel production reached almost 100 million litres, or approximately 1.1 percent of national fuel consumption (Salchenegger, 2005). Spain used significant amounts of both bioethanol (1.49 percent of total petrol) and biodiesel (0.10 percent of total diesel) (Anon., 2006f). Most EU members have not yet reached their biofuel use goals under the biofuel directive, although the situation is changing rapidly as new capacity comes on-line.

Other OECD countries

Japan aims to introduce a renewable component to its national fuel supply, using ethyl-tert-butyl ether (ETBE) at 7 percent blends to achieve the equivalent of a 3 percent bioethanol blend (Saka, 2007). This will require approximately 840 million litres of ETBE to be blended with gasoline across Japan by 2012. Australia aims to achieve 350 million litres of renewable fuel production by 2010; it is estimated that this goal may be achieved by 2007, given the amount of capacity currently under construction (Schuck, 2007). New Zealand is discussing the introduction of a renewable fuels obligation, but has not passed a law to support this (NZ MOT, 2007).

Iceland has not yet developed goals or standards for liquid biofuel use, owing to lack of domestic feedstocks. The goals and targets of all OECD members for renewable fuel use are summarized in Table 3.

TABLE 3
Renewable fuel targets, OECD membership

| OECD country | Renewable fuel target* | Target year | Source |
|--------------------|--|-------------|-------------------------|
| Australia | 350 million litres renewable fuels | 2010 | Schuck, 2007 |
| Austria | 5.75% | 2010 | EC, 2007 |
| Belgium | 5.75% | 2010 | EC, 2007 |
| Canada | 5% bioethanol, 2% biodiesel | 2010 | CRFA, 2006; Mabee, 2007 |
| Czech Republic | 3.27% | 2010 | EC, 2007 |
| Denmark | No national target (5.75% EU) | 2010 | EC, 2007 |
| Finland | No national target (5.75% EU) | 2010 | EC, 2007 |
| France | 7.00% (5.75% by 2008) | 2010 | EC, 2007 |
| Germany | 5.75% | 2010 | EC, 2007 |
| Greece | 5.75% | 2010 | EC, 2007 |
| Hungary | 5.75% | 2010 | EC, 2007 |
| Iceland | No national target | | IEA, 2007 |
| Ireland | No national target (5.75% EU) | 2010 | EC, 2007 |
| Italy | 5.00% | 2010 | EC, 2007 |
| Japan | 840 million litres bio-ETBE | 2012 | Saka, 2007 |
| Korea, Republic of | No national target | | MOCIE, 2007 |
| Luxembourg | 5.75% | 2010 | EC, 2007 |
| Mexico | No national target | | IEA, 2007 |
| Netherlands | 5.75% | 2010 | EC, 2007 |
| New Zealand | Target under discussion | | NZ MOT, 2007 |
| Norway | No mandatory goal | | IEA, 2007 |
| Poland | 5.75% | 2010 | EC, 2007 |
| Portugal | 5.75% | 2010 | EC, 2007 |
| Slovakia | 5.75% | 2010 | EC, 2007 |
| Spain | No national target (5.75% EU) | 2010 | EC, 2007 |
| Sweden | 5.75% | 2010 | EC, 2007 |
| Switzerland | No national mandate but some local targets | | IEA, 2007 |
| Turkey | No national targets | | IEA, 2007 |
| United Kingdom | 3.50% (5% volume) | 2010 | EC, 2007 |
| United States | 133 billion litres renewable fuels | 2017 | Himmel, 2007 |
| | 30% bioethanol in gasoline | 2030 | |

* Renewable fuel targets may be absolute (i.e., measured by litres) or expressed as a percentage of total transport fuel consumption. Unless otherwise noted, percentage targets are calculated on an energy, not a volume, basis.

Liquid biofuels for transport policies

From this review, it is clear that successful policy options to support liquid biofuels for transport may take several forms, including targets and mandates, exemption of biofuels from national excise taxation schemes, direct government funding of capital projects to increase capacity or upgrade distribution networks, and consumption mandates for government or corporate vehicle fleets. These policies can be differentiated by their relative emphasis on government, industry or consumer actions. In most biofuel producing countries examined here, a number of policies have been enacted to develop industrial capacity and encourage consumption. It is very difficult to measure the individual successes of these policies because of the synergistic effects that multiple policies may have.

In the United States, incentives including infrastructure grants, loan guarantees and public-private partnerships may play a much more positive role in the national biofuel implementation agenda. Strong funding to establish facilities, including all aspects of research, development and deployment (RD&D), is present in each of the states where bioethanol production is significant. For other governments creating policy to support biofuel implementation agendas, the United States experience offers some valuable lessons. The bioethanol industry has been successful in meeting social criteria such as rural employment, but its ability to increase energy security has been limited by the relatively small capacity of production facilities at present. This should serve as a cautionary measure for governments in both Canada and the EU, whose biofuel-related policy puts more emphasis on the environment and energy security than on social or economic concerns. Biofuel production can only improve energy security when enough capacity is brought on-line. Thus, security-related policy geared to the short term cannot succeed to any great extent. Policy-makers must realize that measurable success over the short term will most likely be achieved using policies with clear economic goals. Although environmental goals are an important driver in many OECD countries, they are difficult to quantify owing to the relatively low contribution that biofuels make to overall transportation fuel supply. The implication is that security-related policy, such as mandated renewable fuel use, is likely to take the form of long-term programmes with very few immediate rewards.

The experiences gained from developing bioethanol capacity using both sugar- and starch-based processes contain many lessons for other biofuels, including biodiesel and the lignocellulose-based bioethanol industry. Use of these fuels can respond to a variety of domestic issues, including the need to diversify local economies, increasing concerns over environmental damage associated with fossil fuel use, and a growing security rationale for shifting to domestic fuel sources. The emerging industry, including the lignocellulosic-based sector, may find opportunities for strategic linkages and partnerships that capitalize on these political issues.

These findings indicate that successful implementation agendas can take many forms, but success measured as biofuel production capacity is equally dependent on external factors, including feedstock availability, an active industry and competitive energy prices. It is important that policies reflect realistic use scenarios for bioethanol and other biofuels in the future.

EMISSIONS TRADING

Emission trading is made available through cap-and-trade principles, complemented with Kyoto Protocol mechanisms such as Joint Implementation (JI) and the Clean Development Mechanism (CDM). The EU's ETS facilitates emissions trading through accounts in electronic registries set up by Member States. Through the cap-and-trade mechanism, emitters receive a yearly decreasing emissions budget, and emissions that exceed this budget must be covered by certificates purchased from the EU-wide market. All of the registries are overseen by a central administrator at the EU level, who checks each transaction for irregularities. The system thus keeps track of the ownership of credits in the same way that banks keep track of money. ETS covers about 46 percent of CO₂ emissions in the EU, including industrial furnaces (> 20 MW), power plants, refineries, and major industries such as coke, steel, paper, pulp and chemical production. Small furnaces (< 20 MW) and transport-related emissions are not included in ETS. Biomass and waste incineration is also exempted from ETS, and may only play a part in JI/CDM projects undertaken by Member States. This is owing to perceived problems with CO₂-related renewable energy projects, including relatively low CO₂ reductions, high avoidance

costs and competition with compulsory avoidance (i.e., landfill gas usage). Furthermore, feed-in tariffs have been found to be more profitable.

Another option for including biomass energy projects within ETS is to utilize Kyoto Protocol mechanisms such as JI and CDM. JI projects within the EU are not viewed favourably, because there is a strong potential for double-counting credits. Thus, CDM or JI with partners outside the EU are the only viable options for including biomass-derived energy within the EU credit system. Reforestation and afforestation projects are eligible to receive credits under this mechanism, and increased trade for bioenergy feedstocks may be facilitated through such application.

SUSTAINABILITY ISSUES

Environmental sustainability

To be successful, bioenergy options (including wood energy) should be both environmentally and socially sustainable. Policy is beginning to address the environmental dimension of bioenergy. The new EU directive on biofuels and bioenergy has a strong sustainability component. In order to ensure that forests are not cut down to produce wood energy and that woodfuels are produced in ways that have solid environmental benefits, the European Commission is working on a system to discourage production practices that create more GHG emissions than they save, and to discourage the conversion of land with high biodiversity value to the growth of feedstocks for woodfuels. A public consultation on woodfuel sustainability issues, aiming to gather the views of public authorities, businesses, NGOs and other parties interested in these issues, had a closing date of 18 June 2007. The aim of the commission is to develop a sustainability scheme that works; that imposes only a limited administrative burden; and that is compatible with World Trade Organization (WTO) rules. The scheme will be proposed as part of the new comprehensive directive on renewable energy sources to be adopted later in 2007.

With a view to reducing the cost of bioenergy applications and promoting research, the European Commission is also working on a European Strategic Energy Technology Plan, which will set clear objectives and targets for European energy research and technology. Among other issues, this plan – to be tabled at the end of 2007 – will address the development of second-generation biofuels to make them fully competitive alternatives to hydrocarbons. Development will be speeded through support to new projects for European demonstration plants.

The development of sustainability criteria for bioenergy use (particularly of wood energy) is similar to the processes to create guidelines for sustainable forest management. All OECD members participate in either the Montréal Process² or the Helsinki Process³, which define internationally agreed criteria and indicators for the conservation and sustainable management of temperate and boreal forests. Among these guidelines are criteria for the conservation of biological diversity, as well as forest ecosystem health and vitality. The criteria defined for sustainable forest management may act as a barrier to the development of energy crops, which are generally fast-rotation monocultures that may not be native or representative species of the natural forest type. Development of energy crops within the confines of sustainable forest management will require the balancing of ecosystem function, biological diversity and global energy needs. Many of the agencies involved in creating guidelines for sustainable forest management (e.g., the United Nations Environment Programme [UNEP]) could be involved in developing guidelines for the sustainable and renewable use of bioenergy from all the world's forests. The various forest certification schemes could be updated to include bioenergy use.

² Participating OECD countries are Australia, Canada, Japan, Mexico, New Zealand, the Republic of Korea and the United States. See www.mpci.org for more information.

³ Also known as the Ministerial Conference on the Protection of Forests in Europe. Participating OECD countries are Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Spain, Sweden, Switzerland, Turkey and the United Kingdom. See www.mcpfe.org for more information.

Social sustainability

Regarding social sustainability, it is difficult to make accurate assumptions about the role that bioenergy, specifically wood energy, may play in employment. However, most European and North American governments have taken the position that development of a bioenergy industry could be a positive force in improving rural economies. The *Renewables 2005 global status report* estimated that 1.7 million direct jobs had been created from renewable energy manufacturing, operation and maintenance as of 2004 (REN21, 2005). Some analysts in the forest industry take issue with these figures, however, stating that far fewer new jobs have been created than would be created by expansions in the traditional forest sectors, such as solid wood, pulp and paper, and wood panel manufacture. A recent comparison of total employment effects (Pöyry, 2007) found that the pulp and paper industry provided employment opportunities that were almost 13 times greater than similar-scale ventures in the bioenergy industry.

Somewhat in contrast to these findings, other studies have shown that bioenergy development may have the potential to deliver jobs and improve economies where higher-value product opportunities do not exist. The following are some specific examples of employment estimates:

- In the United States, USDA predicts that 4 500 jobs will be created per every million litres of bioethanol produced. These figures reflect direct employment within the mill; employment would also increase on the farm and through the creation of secondary jobs to provide equipment and services for the operations (www.eere.energy.gov/biomass).
- USDOE predicts that advanced technologies currently under development will help the biomass power industry install more than 13 000 MW of biomass power by 2010, with more than 40 percent of the fuel supplied from 4 million acres (1.62 million ha) of energy crops and the remainder from biomass residues, creating an additional 100 000 jobs. This would help rural economies significantly (www.greenjobs.com)
- In Europe, predictions estimate that the increase in energy provided from biomass fuel production could result in the creation of more than 515 000 jobs by 2020. This prediction takes account of the direct, indirect and subsidy effects on employment, as well as jobs displaced in conventional energy technologies (www.greenjobs.com).

The development of some bioenergy options, particularly food-based liquid biofuels, may have an impact on food supplies. To date, liquid biofuel production has largely relied on agricultural feedstocks including sugar, grain and oilseeds. There has been rising concern that liquid biofuel production will lead to higher food prices, which could have devastating effects on the developing world, where disposable incomes are lower. The “Mexican tortilla crisis” of January 2007 saw prices for this staple rising three- or fourfold over those of summer 2006, to a high of approximately US\$1.81/kg from only US\$0.63/kg the previous year (Roig-Franzia, 2007). The cause of this crisis was reputedly high maize prices and a shortage of Mexican maize, resulting in increased imports from the United States, where maize is in high demand for bioethanol production. Some commentators questioned this analysis, however, citing the fact that most biofuel production is based on “yellow” or livestock maize, while tortilla production uses “white” or human-grade maize, the price of which had not risen nearly as quickly (Philpott, 2007). Whether this fluctuation in food prices was owing to increasing biofuel demand or simply to a normal supply shortfall has yet to be determined. More discussion on the impact of bioenergy on food supplies is found in the section on Threats to the food supply in chapter 4.

4. Potential impacts on forests of increasing demand for wood energy

IMPLICATIONS OF POLICY TARGETS FOR BIOENERGY PRODUCTION

Many countries across the OECD have set targets for future renewable energy use, as described in the previous chapter. In order to understand the impacts of increased renewable energy use (particularly bioenergy), the policy goals for renewable electricity, renewable energy and renewable fuel use have been translated into corresponding units of energy, and estimates made of the bioenergy proportion of these targets. The estimated future requirements for bioenergy are shown in Table 4.

TABLE 4

Estimated impacts of policy targets for bioenergy in OECD countries

| | 2004 | | | 2010 | | |
|-------------------------|------------------------------|------------------|-----------------------------|------------------------------|------------------------|------------------------|
| | Biomass-to-electricity (GWh) | Bioenergy (TJ) | Renewable fuels (2006) (TJ) | Biomass-to-electricity (GWh) | Bioenergy (TJ) | Renewable fuels (TJ) |
| Australia | 790 | 193 698 | 17 863 | 1 192 | 221 846 ^b | 17 863 ^c |
| Austria | 1 745 | 134 128 | 3 325 | 2 319 | 148 404 ^b | 21 285 |
| Belgium | 512 | 24 801 | 39 | 1 445 | 17 312 ^b | 21 478 |
| Canada | 7 938 | 486 444 | 18 413 | 9 461 ^a | 546 362 ^b | 85 629 ^d |
| Czech Republic | 593 | 50 318 | 5 203 | 1 176 | 89 972 | 11 563 |
| Denmark | 1 834 | 57 506 | 2 777 | 1 969 | 47 684 ^b | 10 743 |
| Finland | 10 183 | 306 799 | - | 11 318 | 54 483 ^b | 10 174 |
| France | 1 371 | 387 483 | 22 201 | 2 226 | 711 112 | 131 905 |
| Germany | 3 900 | 256 636 | 77 945 | 5 044 | 372 915 | 124 198 |
| Greece | - | 38 381 | 117 | - | 47 773 ^b | 17 625 |
| Hungary | 678 | 34 356 | - | 1 051 | 36 732 ^b | 11 839 |
| Iceland | - | - | - | - | - | - |
| Ireland | 8 | 7 704 | - | 21 | 8 849 ^b | 14 458 |
| Italy | 352 | 70 622 | 15 491 | 555 | 48 776 ^b | 87 950 |
| Japan | 11 592 | 189 005 | - | 13 951 ^a | 332 499 | 22 680 ^e |
| Korea, Republic of | 21 | 6 963 | 4 205 | 38 ^a | 8 980 ^b | - |
| Luxembourg | - | 643 | - | - | 671 ^b | 7 518 |
| Mexico | 2 494 | 347 410 | - | 3 495 ^a | 443 636 ^b | - |
| Netherlands | 1 836 | 30 326 | 2 661 | 2 897 | 32 944 ^b | 30 053 |
| New Zealand | 421 | 35 118 | - | 504 ^a | 41 380 ^b | - |
| Norway | 300 | 46 884 | - | 300 | 51 657 ^b | - |
| Poland | 768 | 170 056 | 7 076 | 2 714 | 263 493 | 34 424 |
| Portugal | 1 264 | 112 331 | 39 | 2 022 | 145 528 ^b | 18 114 |
| Slovakia | 3 | 14 517 | 3 051 | 7 | 15 483 ^b | 4 863 |
| Spain | 4 250 | 168 572 | 13 845 | 6 881 | 783 931 | 94 002 |
| Sweden | 6 614 | 343 249 | 3 203 | 8 616 | 367 674 ^b | 19 065 |
| Switzerland | 27 | 24 574 | - | 31 ^a | 26 698 ^b | - |
| Turkey | 46 | 232 041 | - | 46 | 300 451 ^b | - |
| United Kingdom | 1 867 | 46 972 | 1 995 | 5 106 | 39 537 ^b | 60 738 |
| United States | 40 331 | 2 067 645 | 397 051 | 47 238 ^a | 2 213 194 ^b | 2 805 369 ^f |
| Total | 101 738 | 5 885 182 | 596 501 | 131 621 | 7 719 977 | 3 663 537 |
| Increase over 2004/2006 | | | | 29% | 31% | 514% |

^a No formal targets: proportion of biomass-to-electricity/renewable electricity in gross electricity generation remains same as in 2004.

^b No formal targets: proportion of bioenergy in TPES remains same as in 2004.

^c Australia's target of 350 million litres of biofuel is likely to be exceeded as of 2006; the target is thus lower than actual production.

^d Canada's renewable fuel target includes specific goals for bioethanol (5 percent) and biodiesel (2 percent).

^e Japan's targets for renewable fuels (ETBE) are for 2012, not 2010. The figure shown is not adjusted.

^f United States targets for renewable fuels (bioethanol) are for 2017. The figure shown is not adjusted.

Table 4 makes several assumptions. In countries where renewable energy targets are set as a percentage of energy supply, renewable energy requirements were based on forecasts of future electricity use, TPES and energy use, which were calculated based on historic increases in these categories. Where bioenergy targets were not specifically set, the proportion of bioenergy within renewable energy supply was assumed to remain constant in each forecast.

It can be seen from Table 4 that the estimated impact of renewable energy and green electricity targets in terms of bioenergy use are relatively modest. Electricity from biomass sources is anticipated to increase by 29 percent over six years, and overall bioenergy production (of which bioelectricity is a subset) by 31 percent across the entire OECD membership. By contrast, targets for renewable biofuel use in OECD have the potential to make a much greater impact. The total increase over 2006 use, in terms of energy content, is estimated to be as much as 514 percent by 2017 (United States target years).

The implications of increased bioenergy use at the relatively modest rates proposed are likely to be manageable. Multiple sources of biomass (including agricultural, forest and municipal solid waste) could and should be applied to meet this goal. However, the incredible rise in renewable fuels for transport, if met by liquid biofuels, could have a much stronger impact. In absolute terms, the goals for renewable fuel use for transport will likely increase total OECD bioenergy outputs by 3.6 million TJ per year, a 50 percent increase over current (2004) bioenergy use in these nations. The dominant form of biomass that will be required for renewable fuel production in 2017 will likely still be agrofuels that are part of the food chain, creating the likelihood of large impacts on food prices around the world.

The potential implications on woodfuel demand that all bioenergy targets may have in OECD are discussed in the following section. The implications that bioenergy growth might have on food commodities and other forest product commodities are considered in the third section, along with the impacts on forest product prices and employment. A global outlook for potential bioenergy production is provided in the last section.

IMPLICATIONS OF BIOENERGY TARGETS ON WOODFUEL USE IN OECD COUNTRIES

It is very difficult to apply commonly available statistics on energy and forests (provided by IEA and FAO, respectively) to the specific role of forests for bioenergy. This section discusses the potential expansion of woodfuels use based on the goals and targets described in the previous section for the 12 OECD countries that were examined by JWEE, as described in the section on Forest biomass for wood energy in OECD in chapter 2. As reported, the largest users of wood for forest bioenergy, by volume, were the United States, Canada, France, Sweden and Finland (Steierer *et al.*, 2007).

Three arbitrary scenarios for future wood energy use are considered. All these scenarios are based on the premise that fossil fuel prices remain high. They consider current trends (scenario A), the impact of policies designed to select forest-based bioenergy options over other renewable energy (scenario B) and the addition of policies to mandate a proportion of forest-based biofuels in renewable transport fuel supply (scenario C). Specific assumptions include the following:

- *Scenario A (to 2010)*: Wood energy use rises proportionally to expected increases in renewable energy consumption, according to current trends and/or renewable energy policy goals. No changes in efficiency of energy recovery are considered; an average conversion efficiency of approximately 60 percent of the intrinsic energy in wood (i.e., older technologies) is applied. Policies that would support this scenario focus on renewable energy, but do not attempt to increase the efficiency of energy recovery, or specify wood as an energy source.
- *Scenario B (to 2010)*: Wood energy is selected to cover the increases in renewable energy consumption that are dictated by current trends and/or renewable energy policy goals. New technologies are applied to improve the efficiency of wood energy recovery to approximately 80 percent of the intrinsic energy in wood. Expected increases in green electricity consumption are met by bioelectricity generated through CHP facilities, to maximize wood energy recovery.

• *Scenario C (to 2017)*: Scenario B is continued, with the addition of a cellulosic liquid biofuel component. By 2017, it is assumed that 10 percent of all liquid biofuels for transport produced over 2006 levels will be sourced from woodfuels. The use of 2017 as a threshold date stems from the United States biofuel targets for this date. It should be noted that although additional increases in bioenergy targets will likely apply to the members of OECD before this date, they are not anticipated here.

Figure 12. Scenarios of additional woodfuel requirements to meet projections of future wood energy use

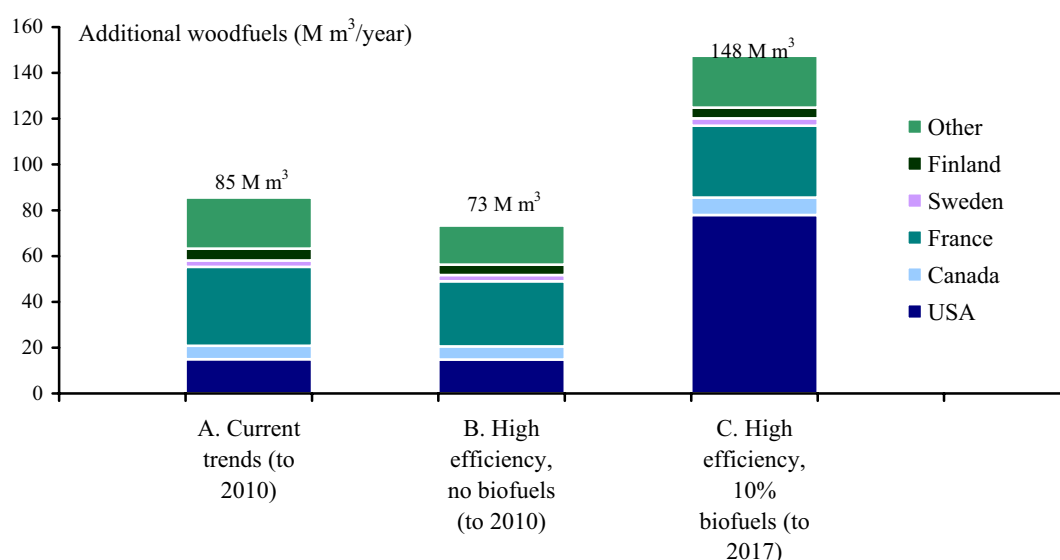


Figure 12 illustrates the scenarios of future wood energy use in terms of the additional woodfuels that would be required above 2004/2005 levels across the 12 OECD members described in the JWEE report. According to this document, about 440 million m³ of woodfuels go into bioenergy applications at present (Steierer *et al.*, 2007). By 2010 (in scenarios A and B), an additional 73 to 85 million m³ of woodfuels will be required to meet the policy targets described in the previous section of this chapter. In a business-as-usual case (scenario A), it is assumed that the proportion of wood energy in the renewable energy supply remains the same, although it is possible that other, cheaper lignocellulosic feedstocks may be selected instead (i.e., switchgrass or *Miscanthus*). The amounts of wood required to generate additional bioenergy to meet targets are described in scenario B, which reflects a future in which the use of wood-based bioenergy is mandated through policy. By 2017 (in scenario C), these estimates could rise to as much as 148 million m³ in additional woodfuels, if policy mandates that 10 percent of new liquid biofuel production for transport is derived from forest biomass. As illustrated in Figure 12, most of the new biomass will be required by five OECD countries: the United States, Canada, France, Sweden and Finland. All the data used to create Figure 12 are found in Annex Table A4.

Several important messages may be taken from Figure 12. The first is that short- to medium-term increases in total wood energy use in the major OECD countries are likely to be significant, but not overwhelming. In scenario A, an extension of current trends in bioenergy use would result in an increase in demand for woodfuels of approximately 20 percent. Increased efficiency of wood energy conversion, as in scenario B, would result in an increase in demand for woodfuels of only 17 percent over 2004/2005 levels, while increasing the energy output by 24 percent over the same period. If this forecast is extended and woodfuels begin to be used in the production of cellulosic liquid biofuels, as in scenario C, demand for woodfuels could grow by as much as 34 percent by 2017.

From these scenarios, it can be seen that over the medium term the demand for additional forest biomass for wood energy production in the form of heat and electrical power may be matched by a demand for feedstocks to generate cellulosic liquid biofuels, driven primarily by the United States. It might be assumed that countries with a large amount of forest biomass, including Canada, Sweden

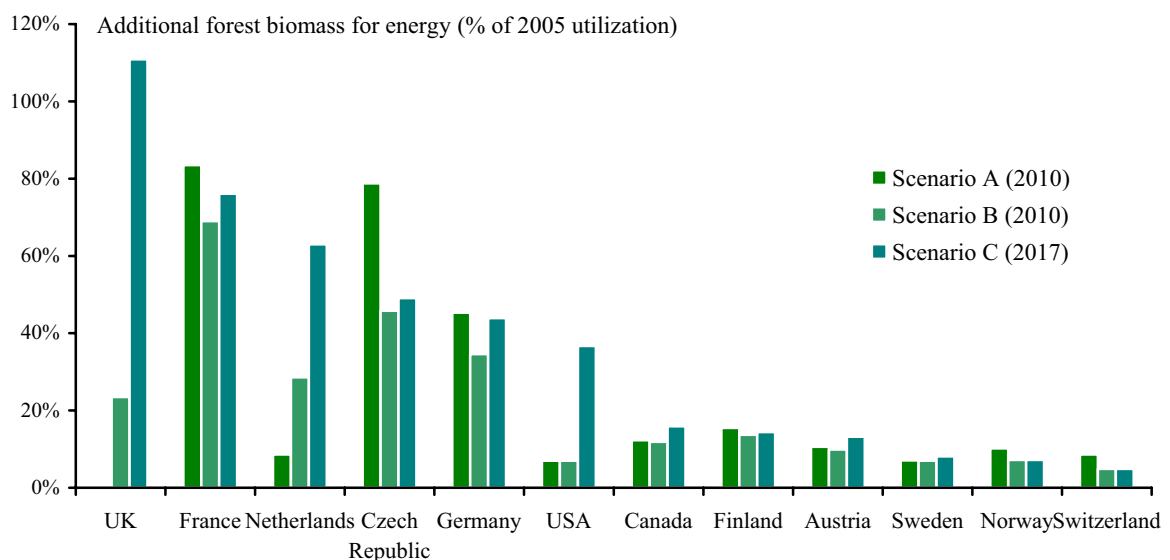
and Finland, might follow more aggressive trends towards woodfuels for cellulosic liquid biofuel production than current policy dictates, which would increase the demand. Sweden has already indicated a desire to be “fossil-free” by 2020, which would entail more effective conversion of forest biomass to wood energy products than current targets incorporate.

The JWEE report identifies three sources of woodfuels for energy: direct harvesting, indirect recovery of processing residues, and recovery of post-consumer waste. Figure 12 does not attempt to break future demand for woodfuels into these categories, but it is often mentioned that processing residues collected at the mill, which are readily available for further application, are usually the first source of woodfuels to be exploited (McCloy, 2003). As a significant amount of the existing wood-to-energy feedstock already comes from processing residues, it might be anticipated that the additional demand shown in Figure 12 is more likely to be sourced through direct forest harvesting and, possibly, post-consumer recovery of waste.

One last message from Figure 12 is that countries with an aggressive renewable energy target (such as France in this example) have the potential to become major consumers of woodfuels. In fact, several OECD countries would have to increase utilization of woodfuels dramatically under the scenarios proposed here.

Figure 13 shows the percentage increases in woodfuels utilization. In one or more of the scenarios posited, France, the United Kingdom, the Netherlands, the Czech Republic and Germany would all require additional woodfuels equivalent to more than 50 percent of current levels of usage. This is partly because the total demand for forest biomass in these countries is low to begin with, so minor increases in demand result in major percentage increases (see Annex Table A4 for more information). The major producers of industrial roundwood and forest products, particularly the United States, Canada, Finland and Sweden, are expected to have much lower increases in flows of forest biomass to wood energy applications.

Figure 13. Additional woodfuel requirements as percentages of current wood-to-energy utilization



COMPETITION FOR LAND AND RESOURCES

Threats to the food supply

The Mexican tortilla crisis of January 2007, described at the end of chapter 3 is an example of the impacts that bioenergy development may have on food prices and food security.

Rosegrant *et al.* (2005; 2006) have examined the potential impact of the growing demand for energy on real world food prices using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) developed by the International Food Policy Research Institute

(IFPRI) in Washington, DC. This model works at the national level to analyse baseline and alternative scenarios for food demand, supply, trade, income and population. It uses commodity price and consumer price indices to assess “real” changes in prices for crops, and takes both producer and consumer subsidies into account. National figures are then agglomerated into regional and global assessments. IMPACT was used to examine the interaction between crop demand for biofuel feedstock and the demand and production of crops for both food and feed, to see how scenarios for projected growth in biofuel production could affect global food availability, prices and consumption until 2020. An aggressive biofuel growth scenario assumed that total biofuel consumption would rise between two- and tenfold in specific countries or regions around the world, including China, India, Brazil, the United States and the EU. The scenario of aggressive biofuel growth is thus very similar to the anticipated development of biofuel use across OECD, as shown in Table 4. This scenario also presumed that oil prices would stay high in real terms.

Three cases were examined: a business-as-usual case, in which the focus remains on food-based liquid biofuels; a cellulosic liquid biofuel case, in which new development focuses on using energy crops or wood; and an agricultural productivity improvement case, in which cellulosic development is combined with improvements in agricultural practices. Scenarios of biofuel growth are compared with baseline scenarios of food availability, prices and consumption between 2005 and 2020 from IMPACT (Rosegrant *et al.*, 2005). It should be noted that these scenarios do not reflect the potential impacts of climate change on food productivity. In the business-as-usual case, real food prices were estimated to rise significantly by 2020, as shown in Table 5. However, offsetting new development with cellulosic biofuel could reduce these increases somewhat. The third column in Table 5 (headed “Shift to wood-based biofuels”) illustrates the likely impact of increased wood-to-biofuel use. The final column illustrates that combining cellulosic biomass with agricultural improvements could result in the lowest possible price increases. Each of these cases suggests higher real crop prices in the future, however (Rosegrant *et al.*, 2006).

TABLE 5
Expected rises in food commodity prices over 2005 (percentages)

| | Scenario of aggressive biofuel growth to 2020 | | |
|------------|---|------------------------------|---|
| | Focus remains on food-based biofuels | Shift to wood-based biofuels | Wood-based biofuels + agricultural improvements |
| Cassava | 135% | 89% | 54% |
| Sugar beet | 25% | 14% | 10% |
| Sugar cane | 66% | 49% | 43% |
| Oilseeds | 76% | 45% | 43% |
| Maize | 41% | 29% | 23% |
| Wheat | 30% | 21% | 16% |

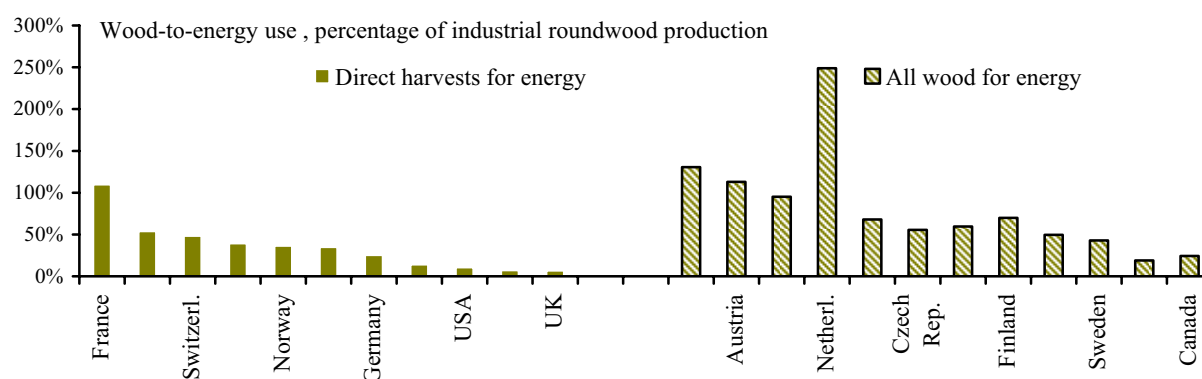
(Rosegrant *et al.*, 2006)

It is clear that each of the three cases presented in Table 5 would entail higher average prices in the global food marketplace, although national-level changes would vary. These results are confirmed by other models, notably the FAO analysis by Schmidhuber (FAO, 2006c), which found that the extra demand for biofuel feedstocks has resulted in increased global agricultural commodity prices. An increase in food prices would have an impact on food security in some nations, particularly where food is scarce owing to poor growing conditions or other environmental factors. A price increase for food commodities would also increase incomes in rural areas, however, potentially reducing poverty in these regions. Increasing the proportion of wood-based biofuels could help minimize the expected rise in food prices (as per Rosegrant’s analysis), but some cost increases must be expected. It should be noted that, historically, real prices for food and agriculture have been declining, and a departure from this trend to meet biofuel demand may not be permanent (FAO, 2006c).

Threats to wood fibre supply and forest ecosystems

There is a perception that increases in forest-based bioenergy will have an impact on traditional processing industries. This is likely to occur; already, in some OECD countries, removals of wood from the forest for bioenergy applications (Steierer *et al.*, 2007) account for half or more of industrial roundwood production (FAO, 2007b). In other OECD countries, the amount of wood being used for bioenergy purposes is still small compared with industrial roundwood harvest. When residue recovery and post-consumer waste are factored in, however, the wood use for energy exceeds industrial roundwood production in several OECD countries (Figure 14). The potential impacts of increasing biomass recovery from these forests include nutrient scarcity, loss of biodiversity, changes to ecosystem function and differences in forest regeneration.

Figure 14. Wood-for-energy as percentages of industrial roundwood



Sources: Steierer *et al.*, 2007; FAO, 2007b.

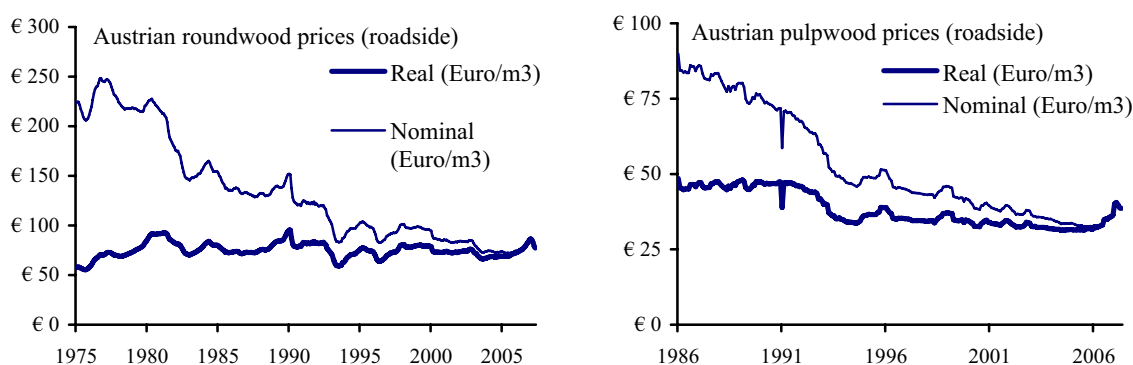
It is interesting to note that the major forest product producing nations within OECD, including the United States, Canada, Sweden, Finland and Germany, do not yet utilize large amounts of wood for energy compared with industrial roundwood removals. Of these nations, the primary exporters of forest products are Canada, Sweden and Finland (FAO, 2007b). An increase in domestic bioenergy use within these exporting nations could increase feedstock costs, which would have an impact on the ability of traditional forest product industries to compete on world markets. An increase in wood for bioenergy use in the United States and Germany could also increase feedstock costs, with the same effect. In all cases, the cost of domestically produced traditional forest products could be expected to rise if wood-to-bioenergy use increases. However, as it is likely that non-renewable prices would also rise (particularly given strong petroleum prices), these increases in cost might not have as great an impact as might otherwise be expected. Ultimately, a move towards increased trade with non-OECD members might be expected, for raw material feedstocks, traditional forest products and bioenergy products.

Increased bioenergy use within OECD could have widespread effects around the world. Nations with large forest resources, including the Russian Federation and Brazil, might be expected to supply increased demand for bioenergy feedstocks, which could result in increased deforestation and forest loss. For example, the greatest deforestation occurs in Brazil, where about 3.1 million ha of forest is currently removed every year (FAOStat, 2007a). Most of the deforested area is being used for non-sugar cane agriculture, such as the raising and feeding of cattle. Although in Brazil approximately 190 000 ha of sugar cane plantations are established every year, largely for bioethanol production in southern parts of the country (FAOStat, 2007b), this is equivalent to only about 6 percent of Brazil's deforestation rate. The second highest deforestation rate globally is in Indonesia, where 1.8 million ha (or 2 percent of the forest cover) is disappearing annually. There is some evidence that bioenergy products destined for export are the culprit for this high rate of deforestation. The world's most significant oil-palm plantations are in Indonesia and Malaysia. In Indonesia, between 3.6 and 6.8 million ha of land are under oil-palm plantations, which are increasing by 15.7 percent per year. There

are reports that the outputs from these plantations are being used for biodiesel production, primarily for use in Europe (Carrere, 2001; Colchester *et al.*, 2006).⁴ If true, this is a clear example of increasing bioenergy demand within OECD affecting forests outside OECD. The Roundtable on Sustainable Palm-Oil (RSPO) was established to monitor the impact of increasing palm-oil use, and has set an objective to develop criteria that define sustainable palm-oil production. RSPO principles and criteria were adopted in November 2005 for an initial period of two years, and will be reviewed through public consultation in November 2007 (RSPO, 2007).

Figure 15. Trends in Austrian wood prices (roundwood, pulpwood)

Potential impacts on forest products prices



Source: UNECE, 2007.

The long-term trend in forest product prices has been declining. Figure 15 illustrates two examples of long-term pricing, using nominal (reported) prices for Austrian roundwood and Austrian pulpwood delivered to roadside (UNECE, 2007).⁵ Real prices are reported in euros; nominal prices, in 2006 figures, were calculated using consumer price indices.

As shown on the left side of Figure 15, roundwood prices in Austria have remained fairly flat in nominal terms since 1975. With some fluctuations, prices at the roadside have remained at about €50/m³. Real prices, which take into account inflationary pressures, show that the value of wood has actually been declining on a per cubic metre basis, however. The right side of Figure 15 shows that there is also a long-term decline in nominal pulp prices, which is exacerbated by inflationary pressures. The real value of these goods is less than half that of 1986.

Similar price trends have been reported in other European nations (for Sweden, see Hillring, 1997). It is difficult to determine the long-term global trend, owing to factors that include currency conversions, the impacts of national inflation rates, national tax regimes and data availability. The long-term trend in timber commodities markets has shown both positive and negative trends (Kellard and Wohar, 2006), which indicates that declining trends may break in favour of a more positive incline.

The long-term declining trends observed here are supported by global estimates of the future forest products market (FAO, 1997b), which predict that the real prices of industrial roundwood, sawnwood and wood-based panels will change little until 2010, with those of newsprint, printing and writing paper decreasing slightly (FAO, 1997b; Trømborg, Buongiorno and Solberg, 2000). Over the past five years, however, real prices of forest products have been seen to rise around the world. These increases are evident in Austria, as Figure 15 shows. The latest forest products annual market review noted that

⁴ The claims in the Colchester *et al.* report should be read with caution given the lack of corroborating evidence from other sources, including FAO and the Oilworld.biz website; these sources indicate that between 300 000 and 500 000 ha of land is being converted to oil-palm cover annually. Approximately 17 to 27 percent of Indonesian deforestation (and 80 percent in Malaysia) may be explained by the establishment of oil-palm plantations.

⁵ Austria was chosen as an example because it has the longest price trends on file in the UNECE Price Database, as seen at <http://www.unece.org/trade/timber/mis/price-stats.htm>

prices for softwood sawlogs increased in most regions of North America and Europe in 2005/2006 (UNECE/FAO, 2006; 2007). Higher transportation costs were cited as a major reason for these increases. Pulpwood prices have also increased in these regions, again probably owing to increasing transportation costs and an improved pulp market. Prices for sawnwood and pulpwood are predicted to continue to rise over the next few years (UNECE/FAO, 2006).

Given these trends in wood prices, three observations can be made. First, even with rising wood value, the forest industry is experiencing lower returns today than in previous years. This will act as a barrier to reinvestment or to new companies entering the area. Second, the present value for wood, which is low compared with historical data, may be a factor in the decision to use wood in relatively low-value applications such as bioenergy, although compelling environmental or social arguments can also be made for this use. Third, increased competition for wood fibre as bioenergy opportunities are explored should support the recent trend towards higher wood prices. As wood prices rise, this trend may act to slow development of bioenergy opportunities over the medium to long term.

Potential development of energy crops

One potential outcome of bioenergy development may be increases in the use of energy crops, including perennial crops such as miscanthus and switchgrass and fast-growing tree species such as coppice willow and poplar. The most desirable characteristics of these energy crops are their ability to generate raw biomass with minimal agricultural or silvicultural intervention. Bioenergy goals differentiate energy crops from existing forest plantations, which have largely been created for the pulp and paper industry and which are characterized by higher fibre quality (but perhaps lower growth rates) (FAO, 2006a). Today, energy crops are being pursued as an option for bioenergy feedstocks in at least two OECD countries.

In the United States, the so-called Billion Ton Report indicated that more than 1.3 billion dry tonnes of biomass potential could be retrieved from agricultural and forest lands – feedstock with the potential to generate more than one-third of the current demand for transport fuels. To achieve this goal, significant areas of land (22.3 million ha) would be set aside for energy crops, generating an average of about 20 dry tonnes of biomass per hectare (Perlack *et al.*, 2005). Interestingly, the Perlack *et al.* report does not anticipate conversion of forest land to energy plantations, but instead focuses on idle cropland.

Sweden has already seen extensive development of energy crop plantations. By 1995, about 15 000 ha of coppice willow (*Salix*) plantations had been established to supply biomass to various energy applications (primarily district heating). Between 1995 and 2005, however, about 30 percent of these plantations were reduced in size or taken out of service completely, predominantly because of crop management issues. Helby, Rosenqvist and Roos (2006) report that the plantations did not necessarily fail for economic reasons, but rather because of unsound agricultural decisions. The availability of subsidies for biomass production encouraged farmers to convert unsuitable, low-productivity sites to *Salix* plantations. This incentive was at one point as high as Swedish kroner (SKr) 14 000/ha (approximately €1 500/ha) for planting and fencing; although reduced, the current incentive remains significant, at SKr 5 000/ha (approximately €540) for new planting (Helby, Rosenqvist and Roos, 2006)

In both Sweden and the United States, the development of energy plantations has focused on agricultural land. This allows the net benefits of financial incentives to be delivered directly to farmers, rather than forest companies. As pointed out in the section on Sustainability issues and bioenergy in chapter 3, the members of OECD also participate in the Montréal Process or the Helsinki Process, and development of energy crops on forest land may contravene some of the criteria for sustainable forest management laid out by these processes. Each country should assess the impacts of increased demand for bioenergy in terms of overall environmental goals. In some OECD countries, the development of bioenergy might require the conversion of a percentage of forest land to other land-use types to allow energy crops, which would effectively increase deforestation rates and reduce the range of natural forests. The Ministerial Conference on the Protection of Forests in Europe (MCPFE) is developing a series of guidelines for afforestation to guide the creation of energy plantations (MCPFE, 2007), but it is unclear how these guidelines might be applied to land that has been deemed agricultural instead of forest area.

POTENTIAL GLOBAL SUPPLIES OF FOREST BIOMASS FOR WOOD ENERGY PRODUCTION

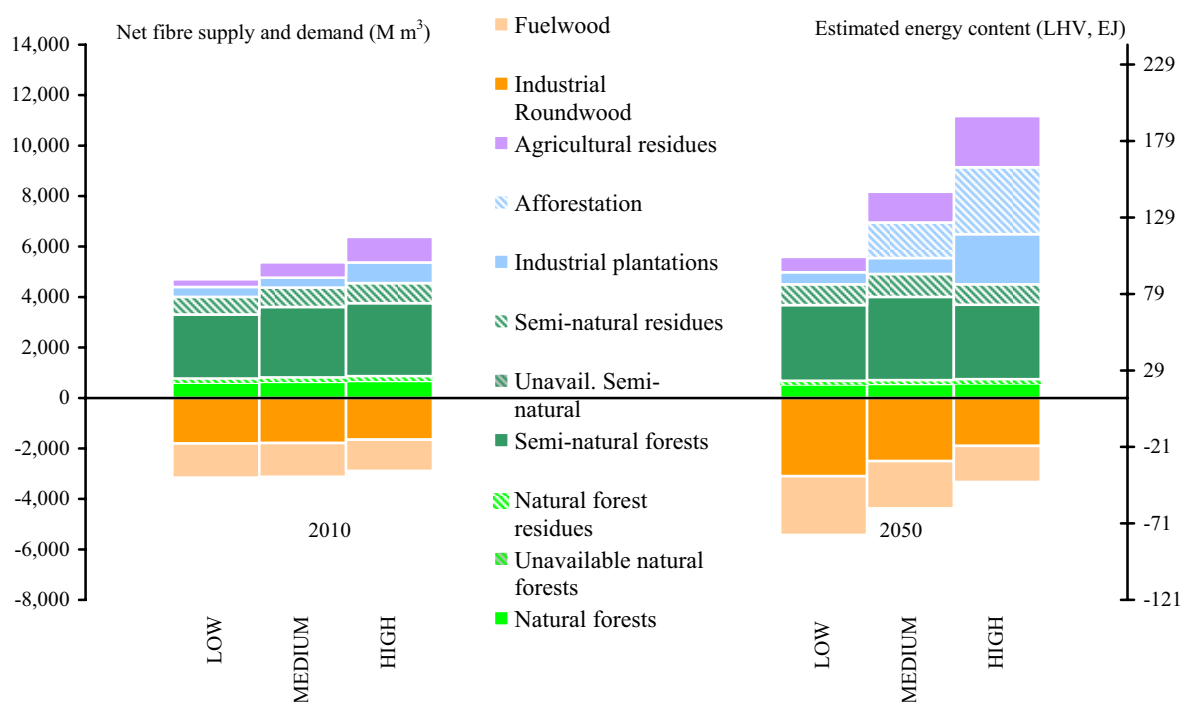
A number of regional and global outlook studies on forest fibre availability were reviewed to determine the renewable global supply of forest biomass for wood energy production in terms of both volume and energy content. These included a range of FAO studies, such as the *Provisional outlook for global forest products consumption* (FAO, 1997d), the *Global fibre supply model* (FAO, 1998), the *Asia-Pacific forestry sector outlook study* (FAO, 1997e), the *Forestry outlook study for Africa* (FAO, 2003) and *Socio-economic trends and outlook in Latin America* (FAO, 2004). The International Institute for Applied Systems Analysis's (IIASA) *Global supply of biomass for energy and carbon sequestration from afforestation/reforestation activities* study was also considered (Obersteiner *et al.*, 2006), as were the *Forests in flux* study carried out by UNEP (Malhi, Meir and Grace, 1999) and the Smeets, Faaij and Lewandowski (2004), *A quick scan of global bio-energy potentials to 2050*. Data from these studies was used to create a range of global scenarios describing industrial wood fibre supply and demand. By comparing supply and demand outlooks, it was also possible to estimate the "surplus fibre" available for non-traditional purposes, including woodfuels.

A wide review of agricultural outlook studies to guide estimates of agrofuel availability was not completed for this report. Instead, FAO statistics (FAOStat, 2007b) were utilized, in conjunction with expert assessments of residue availability from different crop types, to create low, medium and high estimates of agricultural residue production for cereal crops. The methodology and references used are described in the section on Other feedstock for bioenergy in chapter 2. For 2010, arbitrary scenarios of 15, 30 and 50 percent residue recovery for bioenergy production were applied. For 2050, each of these figures was doubled, to reflect the potential increases in energy crop development.

Using these studies, the following three composite scenarios of sustainable biomass availability were assembled:

- *The low scenario* reflects increased economic competitiveness, with increased demand for forest products and a corresponding decrease in investment in long-term forestry. This results in increased deforestation rates and decreasing investment in silviculture, which is evident in lower yields and lower plantation establishment. A minimal recovery of cereal crop residues or establishment of agricultural energy crops is anticipated. Technology is assumed to remain at current efficiency levels.
- *The medium scenario* describes a business-as-usual case in which plantation establishment, deforestation and silvicultural yields continue as currently seen; forest products demand is also assumed to follow current trends. A medium recovery of cereal crop residues and/or establishment of agricultural energy crops is incorporated. Technology efficiency is assumed to advance to best practice levels.
- *The high scenario* reflects an environmental future in which green requirements drive more commercial forestry to industrial plantations, and an accelerating amount of natural forests are put under legal protection. Demand for forest products is expected to grow very little, as additional demand is offset by conservation and recycling strategies. Recovery of cereal crop residues and/or establishment of agricultural energy crops is incorporated at a high level. Technology efficiency is assumed to advance to best practice levels.

Potential additional biomass from afforestation activities is included in the medium and high scenarios for 2050. The potential new biomass from the collection of forest residues is incorporated in all scenarios. These scenarios are illustrated in Figure 16.

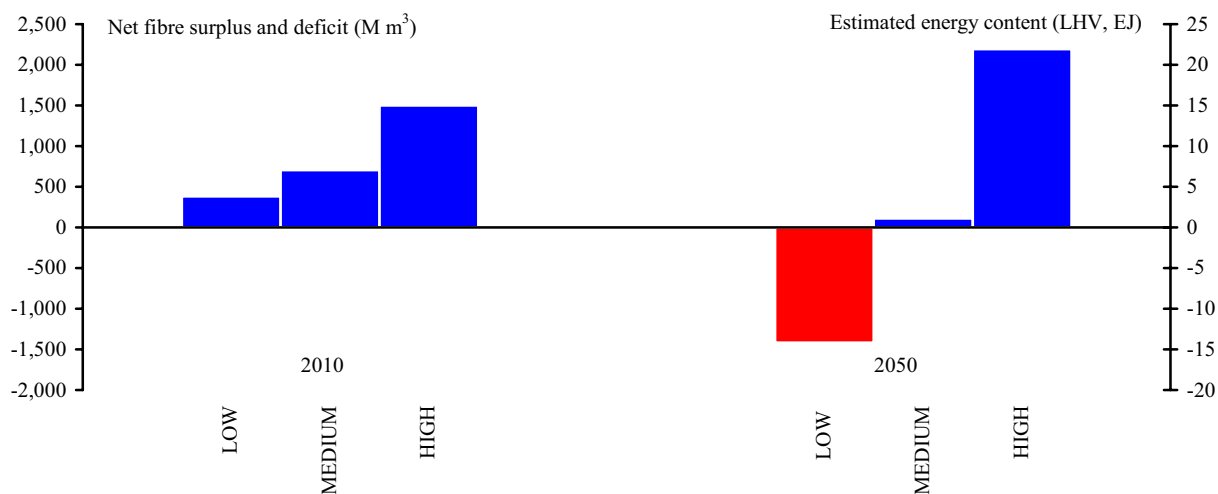
Figure 16. Scenarios of global forest biomass supply and demand, 2010 and 2050 (million m³, EJ)

For the purpose of this figure, 1 bone-dry tonne of agricultural residue is assumed to be 1 m³. In practice, volumes range dramatically for agricultural residues.

Based on current forest land and trends in its use, the annual sustainable supply of forest biomass is estimated to range between 4.4 and 5.4 billion m³ (47.5 to 58.0 EJ) in 2010, and 5.0 to 6.5 billion m³ in 2050 (or 53.8 to 70.1 EJ based on a best practices approach achieving approximately 80 percent energy recovery). Estimates of the contribution of natural (undisturbed) forests are relatively low, while semi-natural forests become most important in the business-as-usual case (the medium scenario). In the strongly economic case and the green future (the low and high scenarios, respectively), semi-natural forests contribute less, because the forested land base available for wood supply is reduced as land is taken out of production and placed under protection. In a green future, the contribution of industrial plantations is significantly higher than in any other scenario. Estimated full recovery of forest residues could provide between 0.6 and 1.7 billion m³ of additional fibre annually by 2010, equivalent to between 6.6 and 17.8 EJ of energy; this could rise to between 0.6 and 2.2 billion m³ (6.5 to 23.2 EJ) by 2050. Additional afforestation of plantation species on previously non-forested land could provide between 1.4 and 2.7 billion m³ (15.2 to 28.6 EJ) annually by 2050. Finally, between 0.302 and 1.02 billion tonnes of cereal crop residues may be available in 2010 for bioenergy; this is equivalent to approximately 4.7 to 15.8 EJ of energy, using best practices. By 2050, depending on the rate of energy crop establishment, this might rise to between 604 million and 2.04 billion tonnes of biomass, or 9.4 to 31.6 EJ of energy.

The potential surplus (or deficit) of forest biomass and the associated energy content based on best practices are shown in Figure 17.

Figure 17. Net global fibre surplus/deficit and associated energy content, 2010 and 2050 (million m³, EJ)



The global surplus forest biomass in 2010 is estimated to be between 0.3 and 1.4 billion m³, compared with estimated additional demand for forest biomass in OECD countries of between 73 and 148 million m³ per year (Figure 12). In the short term, therefore, more than enough forest biomass in excess of demand is likely to be available globally to meet OECD country requirements for woodfuels. The impact of increased demand for wood energy in OECD countries will have a significant impact on the amount of excess forest biomass that is available, however, taking between 10 and 25 percent of the estimated global surplus. In addition, there may be increases in demand from wood processing industries that are not considered in these scenarios. Finally, the global availability of fibre does not necessarily cover the demand in some regions.

The use of fuelwood becomes key in analysing the future availability of forest biomass for bioenergy purposes. Because so much of the roundwood harvested annually belongs to the fuelwood category, improvements in the efficiency of utilizing types of woodfuel could provide significant amounts of wood energy worldwide. By instituting a best practices approach to energy recovery (i.e., using CHP with flue gas recovery, or wood pellet stoves with approximately 80 percent efficient energy recovery per bone-dry tonne of biomass), the amount of energy available through fuelwood recovery increases dramatically, and the resource may be extended significantly.

5. Recommendations

Some key recommendations for policy-makers developing wood energy applications in OECD member countries include the following:

1. *Development of better data describing wood energy feedstocks, including biomass recovery from forests and trade of forest biomass for this purpose.* JWEE is an excellent example of this type of investment. Although FAO has done much to improve fuelwood statistics, more resources need to be made available to assess the impacts on the landscape of wood removals for bioenergy production. In particular, this should include:

- quantifying the potential of forest biomass to contribute to bioenergy generation, in terms of desired wood energy output (heat, bioelectricity, cellulosic liquid biofuel, etc.);
- evaluating the individual contributions that natural forests, woody biomass outside forests, energy plantations, residues and post-consumer material make towards wood energy production;
- determining trade-offs among different land-use decisions (agricultural vs. forest lands), in terms of ecological, economic and social impacts, and using this analysis to inform decisions about woodfuels;
- aligning data collection efforts to current reporting processes such as the Forest Resource Assessment.

2. *Development of clear national-level policy goals for forests and energy that reflect the principles of sustainable forest management, keeping relevant environmental, social and economic constraints in mind.* These goals should differentiate between imported and domestic woodfuels in terms of regulatory, technical and other requirements, and consider trade-offs between woodfuels and agrofuels for the biomass-based energy market. National goals may differ among and within OECD members; country-specific issues should be examined and country-specific solutions sought. The following five-component approach could be considered for developing wood energy policy at the national level:

- Based on forest potentials, evaluate policy incentives for the production or consumption of wood energy that reflect possible impacts on other sectors of the economy. In particular, consider the opportunities and threats for the existing forest sector if wood is used for bioenergy purposes.
- Consider policy actions that facilitate access to and utilization of forest resources. Such actions may include improving or securing transport and handling infrastructures, and developing economic incentives that ensure the viability of forest biomass recovery for bioenergy production.
- Ensure that policy incentives for wood energy work in synergy with policy in other sectors, such as rural employment, environment protection and land-use management.
- Address regulatory issues pertaining to the use of wood energy at all appropriate planning levels (local, sub-national, national and regional) to ensure that policy incentives for wood energy do not have undesired outcomes.
- Establish sustainability criteria for the wood energy production, conversion and end-use chain, including LCAs to be applied to domestically produced or imported biofuels. These criteria should take ecological sustainability, environmental conditions, social requirements and economic contributions into account, and should make reference to existing national forest programmes.

3. *Continuation of strong research, development and deployment programmes for wood energy applications.* Government funding for all aspects of RD&D related to wood energy technologies should be separate from that for other renewable energy technologies. Key points that might be addressed within national RD&D programmes include:

- ensuring flexibility to encourage innovation: for example, particular technological platforms should not be specified by policy, but be guided by industry's assessment of technical capabilities, potential co-products and total economic returns;
- supporting research and development throughout the value chain, including developing new value-added products and promoting the best available technologies and practices;
- promoting efficient use of energy and resource inputs and process technologies: all systems for either wood energy or wood products processing should satisfy high standards for energy and resource efficiency, cost-effectiveness and environmental performance.

4. *Ensuring the participation of all stakeholders when developing and adopting wood energy policies.* Focus should be on providing information and educational programming to: (i) forest landowners and tenure holders, so that they can make informed decisions about management of forest resources; and (b) the general public, as potential consumers of wood energy. Stakeholders to be considered include, but are not limited to:

- small- to medium-scale forest enterprises (SMEs) and forest owners;
- national and international industrial forest products companies, particularly those with forest-based operations;
- local, regional and national governments, particularly ministries responsible for forests, environment and energy issues;
- non-governmental organizations (NGOs) that are concerned with sustainability and environmental performance;
- aboriginal peoples and forest-dependent communities living within the forest resource or having ownership over the resource.

5. *Development of a network to transfer wood energy technologies from OECD countries to the developing world.* Within OECD, the IEA Bioenergy Implementing Agreement is such a network; this approach could be used as a template for developing a participatory network of developing countries interested in technology transfer and bioenergy development. Most advances in bioenergy technologies have been made in OECD regions, as is evident from the distribution of bioelectricity generation and industrial bioenergy use. A network is needed to transfer technologies to developing partners to ensure effective utilization of global forest resources for wood energy production. In developing such a network, the following issues should be considered:

- The network should build on existing organizations, such as the FAO Programme on Wood Energy, the FAO International Bioenergy Platform and IEA Bioenergy, which have similar goals and complementary spheres of activity.
- The network should focus on best practices in wood mobilization, wood energy production and wood energy application.
- Key network activities might include facilitating meetings among member countries, organizing seminars and presentations, commissioning reports on timely topics, catalysing cooperative research among partners and engendering policy discussions to identify the most effective policies for developing wood energy in these regions.
- The network should include a focus on education and training issues, which should play a central role in mobilizing wood resources around the world. Governments, academic institutions and professional bodies should address education, training and the need for sensitization of forest owners, the forest workforce, SMEs involved in forest operations and energy consumers, with regard to skills and entrepreneurship. Wood energy issues should be introduced into national forestry training curricula.

References

- AFTA.** 2000. *Brazilian alcohol: A review of production, subsidies and incentives*. Brussels, Association for Fair Trade in Alcohol (AFTA).
- AGO.** 2007. Mandatory renewable energy target. Australian Greenhouse Office (AGO), Department of the Environment and Water Resources, Government of Australia. Available at: www.greenhouse.gov.au/markets/mret/.
- Anon.** 2004. *1st national report regarding promotion of the use of biofuels or other renewable fuels for transport in Greece*. Athens, Ministry of Development.
- Anon.** 2006a. *Progress report on the promotion of biofuels in Belgium in 2006*. Brussels, Federal Public Service of Finance.
- Anon.** 2006b. *Report for 2005 by the Czech Republic for the European Commission on the implementation of Directive 2003/30/EC*. Memorandum SN 3231/06. Prague.
- Anon.** 2006c. *Report pursuant to Article 4(1) of Directive 2003/30/EC*. Riga.
- Anon.** 2006d. *Report on measures encouraging the use of biofuels and other renewable resources*. Vilnius.
- Anon.** 2006e. *Besluit biobrandstoffen wegverkeer 2007*. *Staatsblad van het Koninkrijk der Nederlanden, 2006*, p. 542. Available at: <http://www.mvo.nl/biobrandstoffen/download/Besluit%20Biobrandstoffen%202007.pdf>
- Anon.** 2006f. *Report by the Directorate-General for Energy Policy and Mines regarding Article 4(1) of Directive 2003/30/EC*. Madrid, Ministry of Industry, Tourism and Trade of Spain.
- BERR.** 2007. Renewables web site. Department for Business, Enterprise and Regulatory Reform (BERR), Government of the United Kingdom. Available at: www.dti.gov.uk/energy/sources/renewables/index.html.
- Bowyer, J.L. & Stockmann, V.E.** 2001. Agricultural residues: An exciting bio-based raw material for the global panels industry. *Forest Products Journal*, 51(1): 10–21.
- Bremauntz, A.F.** 2006. *Relevancia de la discusión sobre el tema de bioenergía*. BioenergyWorkshop, Monterrey, 3 August 2006.
- Carrere, R.** 2001. Oil palm: the expansion of another destructive monoculture. In *The bitter fruit of oil palm: dispossession and deforestation*, pp. 9–10. London, World Rainforest Movement.
- Cetin, E., Moghtaderi, B., Gupta, R. & Wall, T.F.** 2005. Biomass gasification kinetics: influences of pressure and char structure. *Combustion Science and Technology*, 177(4): 765–791.
- Chavez, L. & Nawn, J.** 2007. *Mexico Bio-Fuels Annual Report 2007*. Global Agriculture Information Network (GAIN) Report No. MX7042, 12 June 2007. Available at: <http://www.fas.usda.gov/gainfiles/200706/146291366.pdf>
- Colchester, M., Jiwan, N., Andiko, Sirait, M., Firdaus, A.Y., Surambo, A. & Pane, H.** 2006. *Promised land: palm oil and land acquisition in Indonesia – implications for local communities and indigenous peoples*. Forest Peoples Programme, Sawit Watch, HuMA and the World Agroforestry Centre. Available at: www.forestpeoples.org/documents/prv_sector/oil_palm/promised_land_eng.pdf.
- CRFA.** 2006. *Canadian renewable fuel statistics*. Ottawa, Ontario, Canadian Renewable Fuels Association (CRFA). Available at: www.greenfuels.org.
- de Montalembert, M.R. & Clément, J.** 1983. Fuelwood supplies in the developing countries. Forestry Paper No. 42. Rome, FAO.

- DSIRE.** 2006. Database of state incentives for renewables and efficiency (DSIRE). North Carolina State University, Raleigh, USA.
- EBB.** 2007. *Statistics – the EU biodiesel industry*. Brussels, European Biodiesel Board (EBB). Available at: www.ebb-eu.org/stats.php.
- EC.** 2001. *Promotion of electricity produced from renewable energy sources in the internal electricity market*. Directive 2001/77/EC. OJEC L 283/33, 27 September 2001. Brussels.
- EC.** 2002. *Energy performance of buildings*. Directive 2002/91/EC. OJEC L 1/65, 16 December 2002. Brussels.
- EC.** 2003a. *Promotion of the use of biofuels and other renewable fuels for transport*. Directive 2003/30/EC. OJEU L 123/42, 17 May 2003. Brussels.
- EC.** 2003b. *Restructuring the Community framework for the taxation of energy products and electricity*. Directive 2003/96/EC. OJEU L 283/51, 31 October 2003. Brussels.
- EC.** 2003c. *Establishing a scheme for greenhouse gas emission allowance trading within the Community*. Directive 2003/87/EC. OJEU L 275/32, 13 October 2003. Brussels.
- EC.** 2004. *Promotion of cogeneration based on a useful heat demand in the internal energy market*. Directive 2004/8/EC. OJEU L 52/50, 21 February 2004. Brussels.
- EC.** 2005. *Biomass action plan*. Communication from the Commission to the Council and the European Parliament. COM (2005) 628 Final. Brussels, 7 December 2005.
- EC.** 2006. *Energy end-use efficiency and energy services*. Directive 2006/32/EC. OJEU L 114/64, 5 April 2006. Brussels.
- EC.** 2007. *Biofuels progress report: Report on the progress made in the use of biofuels and other renewable fuels in the Member States of the European Union*. Communication from the Commission to the Council and the European Parliament. COM(2006) 845 Final. Brussels, 10 January 2007.
- EEA.** 2007. *Share of renewable electricity in gross electricity consumption (%) 1990 –2004 and 2010 indicative targets*. European Environment Agency (EEA) and Eurostat. Available at: <http://dataservice.eea.europa.eu/atlas/viewdata/viewpub.asp?id=2631>
- Eng, M., Fall, A., Hughes, J., Shore, T., Riel, B., Hall, P. & Walton, A.** 2005. *Provincial level projection of the current mountain pine beetle outbreak: An overview of the model (BCMPB v2) and results of year 2 of the project*. Victoria, British Columbia, Canadian Forest Service Mountain Pine Beetle Initiative, BC Forest Service. pp. 51.
- Europa.** 2007. Eurostat transportation statistics. Available at: <http://epp.eurostat.ec.europa.eu/portal/>.
- Evans, M.K.** 1997. The economic impact of the demand for ethanol. Lombard, Illinois, USA, Midwestern Governors' Conference.
- FAO.** 1987. *Simple technologies for charcoal making*. Forestry Paper No. 41. Rome.
- FAO.** 1997a. *Decade of wood energy activities within the Nairobi Programme of Action (A)*. Forestry Paper No. 108. Rome.
- FAO.** 1997b. *FAO provisional outlook for global forest products consumption, production and trade to 2010*. Rome, Forestry Policy and Planning Division.
- FAO.** 1997c. *The State of the world's forests 1997*. Rome, Forestry Policy and Planning Division.
- FAO.** 1997d. *Provisional outlook for global forest products consumption*. Rome. 390 pp.
- FAO.** 1997e. *Asia-Pacific forestry sector outlook study. Forest resources and roundwood supply in the Asia Pacific countries: situation and outlook to the year 2010*. Rome. 153 pp.
- FAO.** 1998. *Global fibre supply model*. Rome. 141 pp.

- FAO.** 2002. *Economic analysis of wood energy systems*. Rome.
- FAO.** 2003. *Forestry outlook study for Africa: African forests: a view to 2020*. Rome. 98 pp.
- FAO.** 2004. *Socio-economic trends and outlook in Latin America: Implications for the forestry sector to 2020*. Rome. 43 pp.
- FAO.** 2006a. *Global forest resources assessment 2005, main report. Progress towards sustainable forest management*. Forestry Paper No. 147. Rome.
- FAO.** 2006b. *State of the world's forests 2005, main report*. Rome.
- FAO.** 2006c. Impact of an increased biomass use on agricultural markets, prices and food security: a longer-term perspective. Prepared by J. Schmidhuber for the International Symposium of Notre Europe, Paris, 27–29 November 2006.
- FAO.** 2007a. Bioenergy homepage. Rome, Natural Resources Management and Environment Department. Available at www.fao.org/nr/ben/ben.en.htm.
- FAO.** 2007b. *State of the world's forests 2007*. Rome.
- FAOStat.** 2007a. *FAO forestry statistics*. Rome.
- FAOStat.** 2007b. *FAO agricultural statistics*. Rome.
- Gan, J.B. & Smith, C.T.** 2006. A comparative analysis of woody biomass and coal for electricity generation under various CO₂ emission reductions and taxes. *Biomass Bioenergy*, 30(4): 296–303.
- Garcia, L., French, R., Czernik, S. & Chornet, E.** 2000. Catalytic steam reforming of bio-oils for the production of hydrogen: effects of catalyst composition. *Applied Catalysis a-General*, 201(2): 225–239.
- Garten Rothkopf.** 2007. *A blueprint for green energy in the Americas: strategic analysis of opportunities for Brazil and the hemisphere, featuring the global biofuels outlook 2007*. Prepared for the Inter-American Development Bank. Available at www.gartenrothkopf.com.
- Gielen, D.J., de Feber, M., Bos, A.J.M. & Gerlagh, T.** 2001. Biomass for energy or materials? A Western European systems engineering perspective. *Energy Policy*, 29(4): 291–302.
- Government of the United States.** 2006. *Advanced Energy Initiative*. Washington, DC, National Economic Council.
- Guldbrand, L.** 2006. *Report pursuant to Directive 2003/30/EC*. Memorandum M2006/2879/E. Stockholm.
- Helby, P., Rosenqvist, H. & Roos, A.** 2006. Retreat from *Salix* – Swedish experience with energy crops in the 1990s. *Biomass Bioenergy*, 30(5): 422–427.
- Heruela, C.S.** 2003. *Wood energy information analysis in Asia*. Rome, FAO, April 2003.
- Hillring, B.** 1997. Price trends in the Swedish wood-fuel market. *Biomass Bioenergy*, 12(1): 41–51.
- Hillring, B.** 2002. Rural development and bioenergy - experiences from 20 years of development in Sweden. *Biomass Bioenergy*, 23(6): 443–451.
- Hillring, B.** 2006. World trade in forest products and wood fuel. *Biomass Bioenergy*, 30(10): 815–825.
- Himmel, M.** 2007. *US biofuel update*. IEA Bioenergy Task 39 Business Meeting, Denver, Colorado, USA, 28 April 2007. Available at: www.task39.org.
- Hoque, M., Sokhansanj, S., Bi, T., Mani, S., Jafari, L., Lim, J. & Zaini.** 2006. *Economics of torrefied pellet production for export market*. Canadian Society for Bioengineering Paper No. 06-103, 2006 CSBE-SCGAB Annual Meeting, Edmonton, AB, Canada.

- IEA.** 2007. Global renewable energy policies and measures Database. Available at: www.iea.org/Textbase/pamsdb/grresult.aspx?mode=gr.
- IEA Statistics.** 2006a. *Renewables information*. Paris.
- IEA Statistics.** 2006b. *World energy statistics*. Paris.
- Jolly, L. & Woods, J.** 2004. *Int. Sugar J.*, 106: 118.
- Karlsson, Å. & Gustavsson, L.** 2003. External costs and taxes in heat supply systems. *Energy Policy*, 31: 1541–1560.
- Kellard, N. & Wohar, M.E.** 2006. On the prevalence of trends in primary commodity prices. *Journal of Development Economics*, 79(1): 146–167.
- Körbitz, W., Berger, C., Waginger, E. & Wörgetter, M.** 2004. *Best case studies on biodiesel production plants in Europe*. Vienna, IEA Bioenergy Task 39.
- Lichts, F.O.** 2006. *World Ethanol & Biofuels Report*, 5:48.
- Lindstrom, M., Skidmore, E., Gupta, S. & Onstad, C.** 1979. Soil conservation limitations on removal of crop residues for energy production. *Journal of Environmental Quality*, 8(4): 533–537.
- Mabee, W.E.** 2007. *Canadian biofuel update*. IEA Bioenergy Task 39 Business Meeting, Denver, Colorado, USA. 28 April 2007. Available at: www.task39.org.
- Mabee, W.E., Gregg, D.J. & Saddler, J.N.** 2005. *Appl. Biochem. Biotech.*, 121: 765.
- Mabee, W.E. & Roy, D.N.** 2001. *Fuelwood – an overview. A compendium of plant and animal life-cycle and their impact on the environment*, Vol. 2, pp. 310–317. Calcutta, India, Srebhumi Publishing Company.
- MacLean, H.L., Lave, L.B., Lankey, R. & Joshi, S.** 2000. *J. Air Waste Manage. Assoc.*, 50: 1769.
- Malhi, Y., Meir, P. & Grace, J.** 1999. *Forests in flux. Climate change: the threats to world forests*. Edinburgh, UK, World Conservation Monitoring Centre and UNEP. 64 pp.
- Masera, O.R., Drigo, R. & Trossero, M.A.** 2003. *Woodfuels integrated supply/demand overview mapping (WISDOM)*. Rome, FAO.
- McCloy, B.W.** 2003. Estimated Production, Consumption and Surplus Mill Residues in British Columbia - A 2003 Update. Natural Resources Canada, Ottawa, Ontario. 11 pp.
- McMillan, J.D.** 1997. *Renew. Energ.*, 10: 295.
- MCPFE.** 2007. *Pan-European guidelines for afforestation and reforestation: with a special focus on mitigation and adaptation to climate change*. Draft, 9 May 2007. DOC. NO ELM -1/4/2007. Available at: <http://www.mcpfe.org/documents/meetings/2007/elm2>
- Melin, S.** 2006. *Export vs. domestic market opportunities*. Canadian Bioenergy Association Workshop: Export markets vs. domestic business opportunities. Holiday Inn Vancouver Centre, Vancouver, BC, Canada. 31 August 2006.
- MOCIE.** 2007. *Outlook for energy consumption in 2010*. Ministry of Commerce, Industry and Mining, Republic of Korea. Available at: <http://english.mocie.go.kr/language/eng/toward/energy02.html>.
- Munack, A. & Krahl, J.** 2007. *Biofuels in Germany: Research Projects and Political Framework*. IEA Bioenergy Task 39 Business Meeting, Denver, Colorado, USA. 28 April 2007. Available at: www.task39.org.
- NBB.** 2007. *Biodiesel production capacity*. Washington, DC, National Biodiesel Board, (NBB). Available at: www.biodiesel.org.
- Neumann, L.** 2006. *Third national report on the implementation of Directive 2003/30/EC*. Berlin, Federal Ministry of Food, Agriculture and Consumer Protection, Germany.

- NRDC.** 2006. Ethanol: energy well spent – a survey of studies published since 1990. New York, Natural Resources Defence Council (NRDC) and *Climate Solutions*, 8.
- NZ MOT.** 2007. *Biofuels sales obligation final policy questions and answers*. New Zealand Ministry of Transport (NZ MOT). Available at: www.transport.govt.nz/.
- Obersteiner, M., Alexandrov, G., Benítez, P.C., McCallum, I., Kraxner, F., Riahi, K., Rokityanskiy, D. & Yamagata, Y.** 2006. *Global supply of biomass for energy and carbon sequestration from afforestation/reforestation activities*. Mitigation and Adaptation Strategies for Global Change Springer, Netherlands ISSN:1381-2386 (Paper) 1573-1596.
- OECD.** 2007. *OECD in figures 2005*. Table on energy consumption and electricity generation. Available at: www.oecd.org/topicstatsportal/0,3398,en_2825_495616_1_1_1_1_1,00.html.
- Panshin, A.J. & de Zeeuw, C.** 1980. *Textbook of wood technology*, 4th ed. Toronto, Ontario, Canada, McGraw-Hill. 218 pp.
- Perlack, R.D., Wright, L.L., Turhollow, A.F. & Graham, R.L.** 2005. *Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply*. Oak Ridge, Tennessee, USA, ORNL. 79 pp.
- Philpott, T.** 2007. Bad wrap – how Archer Daniels Midland cashes in on Mexico’s tortilla woes. *Grist*, 22 February 2007. Available at: www.grist.org/comments/food/2007/02/22/tortillas/.
- Pöyry.** 2007. *The Pöyry bioenergy perspective*. IVA “The Future of Bioenergy”, 7 February 2007. Available at: www.iva.se/upload/seminarier/ivabioene%20p%C3%B6yry%20summary%20vasara.pdf.
- Quirin, M., Gartner, S.O., Pehnt, M. & Reinhardt, G.A.** 2004. *CO2 mitigation through biofuels in the transport sector: status and perspectives – main report*. Heidelberg, Germany, Institute for Energy and Environmental Research. 66 pp.
- REN21.** 2005. *Renewables 2005 global status report*. Washington, DC, Worldwatch Institute, Renewable Energy Policy Network.
- REN21.** 2006. *Renewables 2006 global status report*. Washington, DC, Worldwatch Institute, Renewable Energy Policy Network.
- Roig-Franzia, M.** 2007. A culinary and cultural staple in crisis. *Washington Post*, 22 January 2007, p. A01.
- Rosegrant, M.W., Ringler, C., Msangi, S., Cline, S.A. & Sulser, T.B.** 2005. *International model for policy analysis of agricultural commodities and trade (IMPACT-WATER): Model description*. Washington, DC, IFPRI.
- Rosegrant, M.W., Msangi, S., Sulser, T. & Valmonte-Santos, R.** 2006. Biofuels and the global food balance. In *Bioenergy and agriculture: promises and challenges*. Hazell, P. & Pachauri, R.K. (eds.). 2020 Focus No. 14, November 2006. Washington, DC, IFPRI.
- RSPO.** 2007. Roundtable for Sustainable Palm Oil website. Available at: www.rspo.org.
- Russell, C.** 1996. The straw resource: a new fiber basket? In M. Wolcott and L. Leonhardy, eds. *Proceedings of the International Particleboard/ Composite Materials Symposium*. Pullman, Washington, USA, Washington State University.
- Saka, S.** 2007. *Japan biofuel update*. IEA Bioenergy Task 39 Business Meeting, Denver, Colorado, USA, 28 April 2007. Available at: www.task39.org.
- Salchenegger, S.** 2005. *Biofuels in the transport sector in Austria: 2005*. Vienna, Federal Environment Agency.
- Schuck, S.** 2007. *Australia biofuel policy*. IEA Bioenergy Task 39 Business Meeting, Denver, Colorado, USA, 28 April 2007. Available at: www.task39.org.

- SFOE.** 2007. Renewable Energy homepage. Swiss Federal Office of Energy (SFOE). Available at: www.bfe.admin.ch/themen/00490/index.html?lang=en.
- Shanahan, J., Smith, D., Stanton, T. & Horn, B.** 1999. *Crop residues for livestock feed*. Colorado State University Cooperative Extension. Available at: www.ext.colostate.edu/pubs/livestk/00551.html.
- Smeets, E., Faaij, A.P.C. & Lewandowski, I.** 2004. *A quickscan of global bio-energy potentials to 2050: an analysis of the regional availability of biomass resources for export in relation to the underlying factors*. Utrecht, Netherlands, Copernicus Institute, University of Utrecht. 122 pp.
- Spitzer, J. & Jungmeier, G.** 2006. *Greenhouse gas emissions of bioenergy systems*. European Conference on Bioenergy Research, Helsinki, 19–20 October 2006. Available at: http://ec.europa.eu/research/energy/pdf/gp/gp_events/biorefinery/bs4_03_spitzer_en.pdf.
- Steierer, F., Fischer-Ankern, A., Francoeur, M., Wall, J. & Prins, K.** 2007. *Wood energy in Europe and North America: a new estimate of volumes and flows*. Geneva, JWEE, UNECE/FAO, 6 February 2007.
- Trømborg, E., Buongiorno, J. & Solberg, B.** 2000. The global timber market: implications of changes in economic growth, timber supply, and technological trends. *For. Pol. Econ.*, 1(1): 53–69.
- UNECE.** 2007. Timber Committee price database. Available at: www.unece.org/trade/timber/mis/fp-stats.htm.
- UNECE/FAO.** 2006. *Forest products annual market review 2006*. Available at: www.unece.org/trade/timber/docs/fpama/2006/fpamr2006.pdf.
- UNECE/FAO.** 2007. *Forest products annual market review 2007*. Available at: www.unece.org/trade/timber/docs/fpama/2007/fpamr2007.pdf.
- UN-Energy.** 2007. *Sustainable bioenergy: a framework for decision makers*. Available at: www.fao.org/docrep/010/a1094e/a1094e00.htm.
- USDA.** 2005. *Biomass as feedstock for a bioenergy and bioproducts industry*. Washington, DC, Agricultural Research Service, USDA.
- USDOE.** 2006. *State & federal incentives and laws*. Rockville, Maryland, USA, Alternative Fuels Data Centre, Office of Energy Efficiency and Renewable Energy.
- VIEWLS.** 2005. *Shift gear to biofuels*. Utrecht, Netherlands, SenterNovem. 60 pp.

Annex: data tables

TABLE A1
Bioenergy production and consumption in OECD countries, 2004

| OECD country | Production | Bioenergy (TJ) | | Consumption | Bioenergy (% TPES) |
|-------------------|------------|----------------|---------|-------------|-----------------------|
| | | Imports | Exports | | |
| United States | 2 067 645 | | | 2 067 645 | 2.1% |
| Canada | 786 444 | | | 786 444 | 6.9% |
| France | 387 483 | | | 387 483 | 3.3% |
| Mexico | 347 410 | | | 347 410 | 4.9% |
| Sweden | 343 249 | | | 343 249 | 14.9% |
| Finland | 309 452 | | 2 653 | 306 799 | 19.1% |
| Germany | 256 636 | | | 256 636 | 1.7% |
| Turkey | 232 041 | | | 232 041 | 6.6% |
| Australia | 193 698 | | | 193 698 | 3.9% |
| Japan | 189 005 | | | 189 005 | 0.8% |
| Poland | 170 056 | | | 170 056 | 4.3% |
| Spain | 168 572 | | | 168 572 | 2.8% |
| Austria | 134 231 | 7 683 | 7 786 | 134 128 | 9.5% |
| Portugal | 112 331 | | | 112 331 | 9.8% |
| Czech Republic | 54 318 | 500 | 4 500 | 50 318 | 2.8% |
| Denmark | 47 241 | 10 265 | | 57 506 | 5.5% |
| Norway | 45 540 | 1 357 | 13 | 46 884 | 3.8% |
| Italy | 44 922 | 25 700 | | 70 622 | 0.6% |
| United Kingdom | 38 933 | 8 039 | | 46 972 | 0.4% |
| Greece | 38 381 | | | 38 381 | 3.0% |
| New Zealand | 35 118 | | | 35 118 | 4.6% |
| Hungary | 34 356 | | | 34 356 | 3.1% |
| Netherlands | 30 326 | | | 30 326 | 0.9% |
| Switzerland | 24 674 | 350 | 450 | 24 574 | 2.1% |
| Belgium | 16 181 | 8 620 | | 24 801 | 0.7% |
| Slovakia | 14 753 | | 236 | 14 517 | 1.9% |
| Ireland | 7 704 | | | 7 704 | 1.2% |
| Republic of Korea | 5 893 | 1 070 | | 6 963 | 0.1% |
| Luxembourg | 643 | | | 643 | 0.3% |
| Iceland | - | | | - | - |

Sources: IEA 2006a; 2006b.

TABLE A2
Industrial-scale bioenergy transformation in OECD countries, 2004

| OECD country | Industrial use (TJ) | Bioenergy transformation | | | |
|-------------------|------------------------|-----------------------------------|----------------------------------|--------------|-------------|
| | | Electricity ^a (GWh) | Electricity ^b (TJ) | Heat (TJ) | CHP (TJ) |
| United States | 1 130 893 | 40 331 | 151 241 | - | 409 577 |
| Canada | 332 900 | 7 938 | 76 208 | - | - |
| Sweden | 173 926 | 6 614 | - | 33 152 | 97 216 |
| Finland | 172 888 | 10 183 | 12 703 | 6 974 | 65 754 |
| Australia | 100 259 | 790 | 4 561 | - | 22 000 |
| Japan | 92 716 | 11 592 | 94 274 | - | - |
| France | 56 565 | 1 371 | - | - | 14 952 |
| Spain | 56 162 | 4 250 | - | - | 25 060 |
| Portugal | 55 319 | 1 264 | 1 033 | - | 7 479 |
| Mexico | 42 817 | 2 494 | 46 182 | - | - |
| Poland | 31 881 | 768 | - | 1 470 | 7 435 |
| New Zealand | 26 577 | 421 | - | - | 6 002 |
| Austria | 25 214 | 1 745 | 10 308 | 13 394 | 9 928 |
| Norway | 15 386 | 300 | 1 307 | 1 564 | - |
| Belgium | 12 052 | 512 | 2 782 | - | 2 050 |
| Slovakia | 11 482 | 3 | - | 1 261 | 283 |
| United Kingdom | 11 137 | 1 867 | 24 196 | - | - |
| Czech Republic | 10 713 | 593 | 2 288 | 691 | 15 899 |
| Greece | 8 643 | - | - | - | - |
| Italy | 8 500 | 352 | 2 671 | - | 1 301 |
| Switzerland | 7 724 | 27 | - | - | 1 844 |
| Ireland | 5 784 | 8 | - | - | 102 |
| Netherlands | 3 793 | 1 836 | - | - | 17 217 |
| Denmark | 3 531 | 1 834 | - | 10 151 | 20 770 |
| Republic of Korea | 3 503 | 21 | 195 | - | - |
| Hungary | 2 361 | 678 | 8 210 | 165 | 45 |
| Germany | - | 46 | 249 | - | 64 636 |
| Turkey | - | 3 900 | - | - | 229 |
| Luxembourg | - | - | - | - | - |
| Iceland | - | - | - | - | - |

^a Gross biomass-to-electricity production, includes self-generation for industrial use as well as third-party sales.

^b Transformation to electricity for third-party sale, not including self-generation for industrial use.

Sources: IEA 2006a; 2006b.

TABLE A3
Residential bioenergy transformation in OECD countries, 2004

| OECD country | Bioenergy transformation | | |
|-------------------|--------------------------|--|--|
| | Residential use (TJ) | Residential wood-to-energy ^a (000 m ³) | Residential wood-to-energy* (% of total wood-to-energy) |
| United States | 332 779 | 43 244 | 20.4% |
| France | 314 292 | 36 927 | 89.5% |
| Mexico | 258 411 | n/a | n/a |
| Turkey | 231 563 | n/a | n/a |
| Germany | 192 000 | 13 211 | 43.6% |
| Poland | 103 360 | n/a | n/a |
| Spain | 84 539 | n/a | n/a |
| Canada | 77 336 | 3 230 | 6.8% |
| Australia | 66 440 | n/a | n/a |
| Austria | 64 841 | 8 538 | 59.1% |
| Portugal | 48 500 | n/a | n/a |
| Italy | 45 800 | n/a | n/a |
| Finland | 41 000 | 5 724 | 17.4% |
| Greece | 29 393 | n/a | n/a |
| Norway | 28 284 | 3 167 | 54.9% |
| Sweden | 23 936 | 8 923 | 22.7% |
| Hungary | 20 781 | n/a | n/a |
| Denmark | 20 311 | n/a | n/a |
| Czech Republic | 19 500 | 5 131 | 64.6% |
| Switzerland | 10 059 | 1 293 | 34.2% |
| Netherlands | 9 316 | 412 | 21.0% |
| United Kingdom | 8 541 | 620 | 39.7% |
| Belgium | 7 874 | n/a | n/a |
| New Zealand | 2 539 | n/a | n/a |
| Republic of Korea | 1 842 | n/a | n/a |
| Ireland | 1 817 | n/a | n/a |
| Slovakia | 1 297 | n/a | n/a |
| Japan | 678 | n/a | n/a |
| Luxembourg | 643 | n/a | n/a |
| Iceland | - | n/a | n/a |

^a Taken from JWEE (Steierer *et al.*, 2007).

Sources: IEA 2006a; 2006b; Steierer *et al.*, 2007.

TABLE A4
Scenarios of increased wood bioenergy use

| | Wood energy (TJ) | Wood energy (000 m ³) | Scenario A (2010) | | Scenario B (2010) | | Scenario C (2017) | |
|--------------------|------------------|-----------------------------------|-------------------|-----------------------------------|--------------------|-----------------------------------|--------------------|-----------------------------------|
| | | | Wood energy (TJ) | Wood energy (000 m ³) | Wood energy (TJ) | Wood energy (000 m ³) | Wood energy (TJ) | Wood energy (000 m ³) |
| United States | 1 982 757 | 212 475 | 2 122 331 7.0% | 227 432 7.0% | 2 202 837 11.1% | 227 318 7.0% | 2,483,374 25.2% | 290,381 36.7% |
| France | 375 070 | 41 266 | 688 332 83.5% | 75 732 83.5% | 707 924 88.7% | 69 725 69.0% | 721,115 92.3% | 72,690 76.1% |
| Canada | 435 678 | 47 810 | 489 343 12.3% | 53 699 12.3% | 512 027 17.5% | 53 506 11.9% | 520,590 19.5% | 55,431 15.9% |
| Germany | 281 814 | 30 271 | 409 501 45.3% | 43 986 45.3% | 410 439 45.6% | 40 758 34.6% | 422,859 50.0% | 43,550 43.9% |
| Sweden | 359 044 | 39 377 | 384 593 7.1% | 42 179 7.1% | 405 071 12.8% | 42 132 7.0% | 406,977 13.4% | 42,560 8.1% |
| Finland | 299 630 | 32 914 | 346 200 15.5% | 38 030 15.5% | 359 565 20.0% | 37 423 13.7% | 360,583 20.3% | 37,652 14.4% |
| Austria | 130 806 | 14 442 | 144 728 10.6% | 15 979 10.6% | 151 273 15.6% | 15 865 9.9% | 153,402 17.3% | 16,344 13.2% |
| Czech Republic | 72 542 | 7 939 | 129 710 78.8% | 14 195 78.8% | 118 490 63.3% | 11 576 45.8% | 119,646 64.9% | 11,836 49.1% |
| Norway | 53 703 | 5 773 | 59 170 10.2% | 6 361 10.2% | 58 476 8.9% | 6 189 7.2% | 58,476 8.9% | 6,189 7.2% |
| Switzerland | 34 523 | 3 785 | 37 508 8.6% | 4 112 8.6% | 36 690 6.3% | 3 971 4.9% | 36,690 6.3% | 3,971 4.9% |
| Netherlands | 17 475 | 1 963 | 18 984 8.6% | 2 132 8.6% | 31 542 80.5% | 2 524 28.6% | 34,547 97.7% | 3,199 63.0% |
| United Kingdom | 9 973 | 1 562 | 9 973 0.0% | 1 562 0.0% | 37 489 275.9% | 1 929 23.5% | 43,562 336.8% | 3,295 110.9% |
| Total | 4 053 016 | 439 577 | 4 840 371 | 525 400 | 5 031 823 | 512 916 | 5,361,821 | 587,098 |
| Increase over 2004 | | | 19.4% | 19.5% | 24.2% | 16.7% | 32.3% | 33.6% |