IEA Bioenergy
Task 39
Commercializing 1st- and 2nd- Generation
Liquid Biofuels from Biomass

Potential impacts of bioenergy policy

Suggestions for north-south linkages in biofuel development

A REPORT TO IEA BIOENERGY TASK 39

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Executive Summary

In Latin America, Africa and parts of Asia, woodfuels (including fuelwood and charcoal) are the main forest products being removed from forests and from trees outside forests. Key FAO Forestry Papers in this area extend over almost thirty years, and include #108 'Decade of wood energy activities within the Nairobi Programme of Action' (FAO 1997a), #41 'Simple technologies for charcoal making' (FAO 1987), and #42 'Fuelwood supplies in the developing countries' (FAO 1983). Recent monographs of interest include 'Economic analysis of wood energy systems' (FAO 2002), authored by the Wood Energy Programme, and 'Wood energy information analysis in Asia' (FAO 2003), published jointly under the EC-FAO Partnership Programme. FAO has also applied state-of-the-art tools to the analysis of woodfuels, illustrated most recently by the WISDOM model (Woodfuels integrated supply/demand overview mapping) (Masera et al. 2003). FAO's Programme on Wood Energy is designed to promote sustainable wood energy systems, focusing on strengthening institutional capacity and developing innovative initiatives that allow stakeholder engagement in creating wood energy systems. The goal of the Programme is to offer accessible, affordable, and clean-burning woodfuels that can contribute positively to both environmental and social goals.

The Bioenergy Program of the International Energy Agency (IEA) was set up in 1978 with the aim of improving cooperation and information exchange between countries that have national programmes in bioenergy research, development and deployment. Most members of IEA Bioenergy are members of the Organization for Economic Cooperation and Development, representing the developed countries of Europe, North America and Asia. Activities are directed towards collective energy policy objectives of energy security, economic and social development, and environmental protection. One important activity undertaken in pursuit of these goals is a programme to facilitate co-operation to develop new and improved energy technologies.

This study finds that wood fuel, currently harvested on a global scale but used in an inefficient manner, represents a large, potentially significant energy resource for the world. Bioenergy technology has the ability to greatly increase both small- and large-scale energy recoveries, transforming wood fuel from a small-scale application to a large-scale, efficient energy source. In many developing countries, the potential for wood fuel meets or exceeds the current demand for fossil energy, including oil, gas, and coal. These countries could form the basis of a network designed for technology transfer and bioenergy facilitation.

Development of a bioenergy industry in these countries could have both economic and environmental benefits. We show that biofuels have a positive greenhouse gas (GHG) and energy balance. While there are dissenting opinions in the scientific community, the vast majority of studies have underscored the ability of bioenergy and particularly wood-based biofuels to provide a positive net energy balance. The GHG emissions associated with biofuel production are significantly lower than fossil fuels, and the emission associated with wood-based biofuels are lower than agricultural-based biofuel such as starch- or sugar-based ethanol.

There are still questions to be answered about the sustainability of fuelwood removals and plantations designed for biofuel production. This is particularly true regarding oil palm plantations in countries like Indonesia and Malaysia. While the FAO has done a very good job of improving fuelwood statistics, more resources need to be made available to assess the impacts of fuelwood removals on the landscape. One area of note is Africa, where trees outside forests make up a large portion of the total growing stock; removals of this type of biomass could be costly, and may have ecological impacts that are more severe than fuelwood removals in closed forests.

The FAO Programme on Wood Energy and IEA Bioenergy have similar goals and complementary spheres of activity. The IEA Bioenergy Implementing Agreement could be used as a template to develop a participatory network of developing countries interested in technology transfer and development of bioenergy. This type of network could facilitate meetings between member countries, organize seminars and presentations, commission reports on timely topics, and catalyze cooperative research between partners. This type of approach has been highly successful within the IEA Bioenergy Implementing Agreement, and the authors feel that this approach has significant merit and could be applied in this case.

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1 Global forests - Current conditions and trends

1.1 Total growing stock

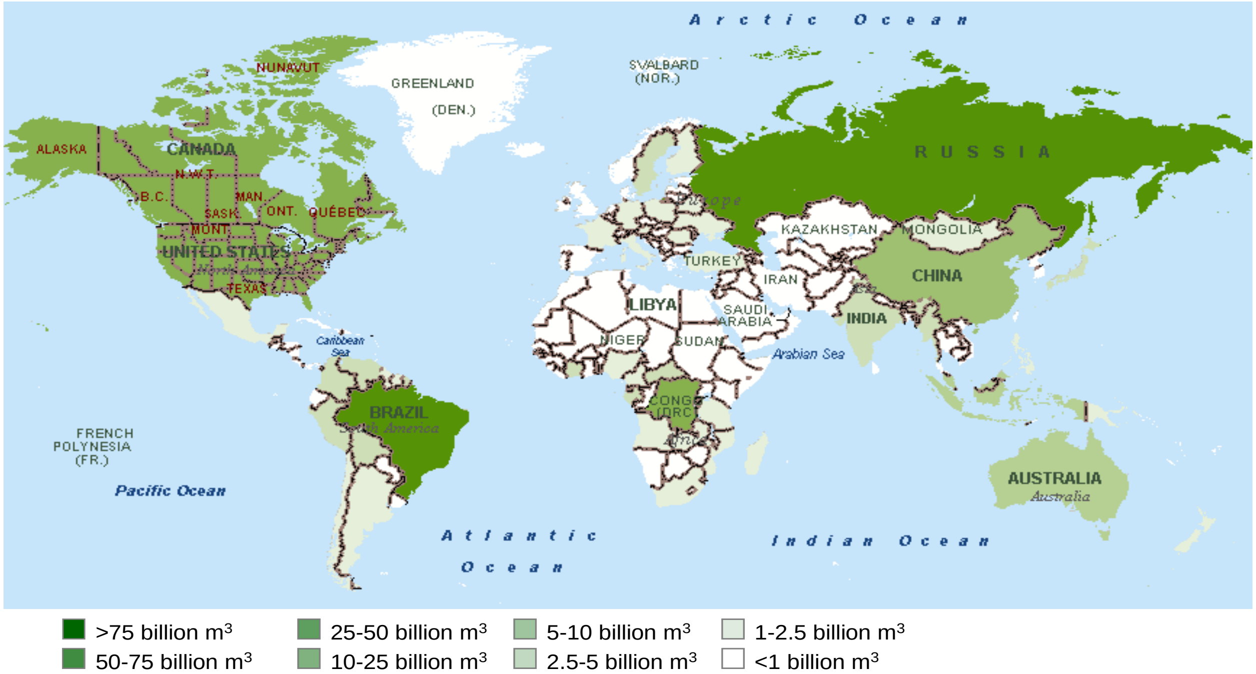

Figure 1: Total growing stock (billion m^3) (FAO 2006a)

According to the latest Global Forest Resources Assessment (FAO 2006a), total forest growing stock was just over 416 billion m^3, of which approximately 171 billion m^3 could be considered commercial growing stock. The distribution of total growing stock is shown in Figure 1. The figure includes both forested areas (lands more than 0.5 ha with tree canopy cover of more than 10%) as well as other wooded land (land with a canopy cover of 5-10%) (FAO 2006). The countries with the largest total growing stock include the Russian Federation (82 billion m^3), Brazil (81 billion m^3), the Unite States of America (35 billion m^3), Canada (33 billion m^3), and the Democratic Republic of Congo (31 billion m^3). The countries with the largest forest area include the Russian Federation (809 million ha), Brazil (478 million ha), Canada (310 million ha), the USA (303 million ha), China (197 million ha), and Australia (164 million ha). The lowest reported forest areas were found in North Africa and the Middle East, as expected.

The countries with the largest amounts of growing stock found in other wooded land include the Russian Federation (1.6 billion m^3), China (1 billion m^3), Mozambique (0.7 billion m^3), Botswana (0.6 billion m^3) and the Congo (0.5 billion m^3). The countries with the greatest percentage of total growing stock found in other wooded land include Mozambique (71% of 1.24 billion m^3), South Africa (40% of 1.1 billion m^3), Botswana (75% of 770 million m^3), Mali (57% of 443 million m^3), and Saudi Arabia (88% of 194 million m^3). The distribution of growing stock on other wooded land, as a percentage of total growing stock, is largely centred in the tropical region of the globe. In countries where a large percentage of the total growing stock is found in other wooded land, one may expect increased difficulties in both industrial wood collections as well as in reforestation of these areas. These difficulties are due to the low wood densities per ha and corresponding increases in recovery costs.

1.2 Fuelwood consumption

According to the latest FAOStat Forestry Data (FAOStat 2007a), fuelwood production worldwide in 2005 was approximately 1.8 billion m^3, with the largest producers being India (306 million m^3), China (191 million m^3), Brazil (138 million m^3), Ethiopia (95 million m^3), Indonesia (74 million m^3), and the Democratic Republic of Congo (71 million m^3). The countries that have shown the greatest absolute increase in fuelwood production since 1961 include India (+151 million m^3 over 1961 levels), China (+85 million m^3), Ethiopia (+57 million m^3), the Democratic Republic of the Congo (+53 million m^3) and Brazil (+50 million m^3). The countries that have shown the greatest % increase in fuelwood production since 1961 include South Africa (1552% over 1961 levels), French Guiana (627%), Chile (589%), the Netherlands (580%), Madagascar (508%), Somalia (410%), Jordan (408%), and Niger (408%). The countries that have shown the greatest % decrease in fuelwood production since 1961 include Japan (1% of 1961 levels), Iran (6%), Morocco (7%), Mauritius (12%), and Portugal (20%).

There has been some reported trade in fuelwood, with global totals of 3.2 million m^3 in imports and 4.3 million m^3 in exports for 2005. Some wood fuel is being consumed in countries without domestic production, which accounts for the difference in these figures. Trade has increased slowly since 1961, when 1.9 million m^3 of fuelwood was imported and 1.6 million m^3 exported worldwide. These figures indicate that the vast majority of fuelwood is still produced and consumed locally.

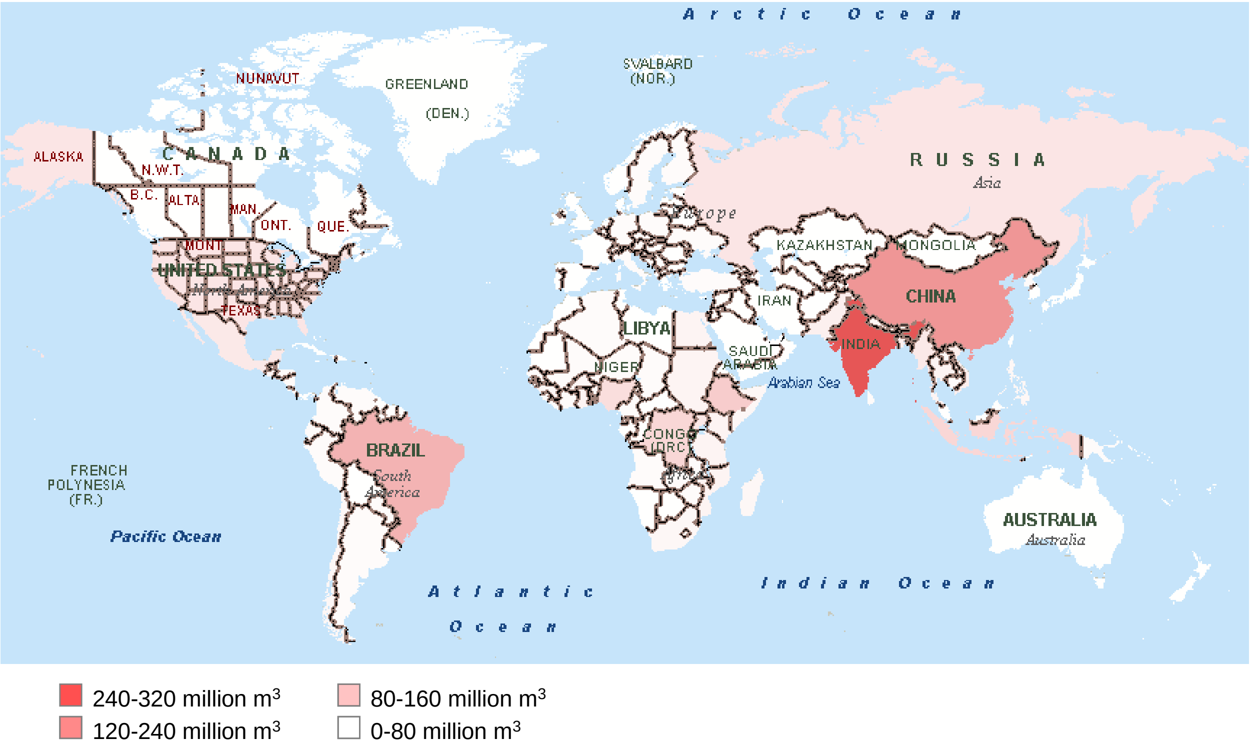

Figure 2: Estimates of global fuelwood consumption (million m^3) (FAOStat 2007a)

By combining production, imports and exports from FAOStat Forestry Data, estimates of worldwide consumption of fuelwood were created as shown above in Figure 2. Some expected patterns of consumption are present - there is significant consumption of wood fuel in the developing countries of Asia, Africa and Latin America. Countries where strong population pressures exist (India and China) lead in global consumption. However, some developed countries, including the Russian Federation, Sweden, Finland, and the United States, utilize a significant amount of fuelwood on an annual basis.

1.3 Trends in forest products prices

The long-term trend in forest products prices has been declining. Figures 3 and 4 illustrate two examples of long-term pricing, using nominal (reported) prices for Austrian roundwood and Austrian pulpwood (respectively) delivered to roadside (UNECE 2007). Nominal prices reported in Euros by UNECE. Real prices, in 2006 figures, were calculated using Consumer Price Indices.

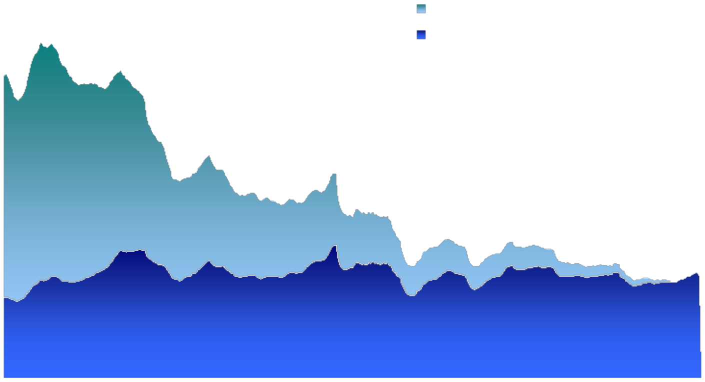

Figure 3 Trends in Austrian roundwood prices (1975-2006) (UNECE 2007)

It can be seen from Figure 3 that 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 per cubic metre. However, real prices which take into account inflationary pressures show that the value of wood has actually been declining on a per cubic metre basis. Similarly, Figure 4 shows that there is a long-term decline in nominal pulp prices which is exacerbated by inflationary pressures. The real value of these goods is less than half of their 1986 value.

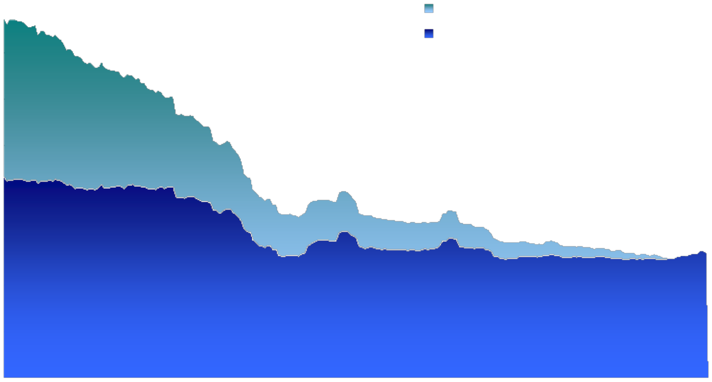

Figure 4: Trends in Austrian pulpwood prices (1986-2006) (UNECE 2007)

Similar price trends have been reported in other European nations (i.e. Sweden, Hillring 1997). It is difficult to determine the long-term trend on a global basis, due to various factors including currency conversions, the impacts of national inflation rates, national tax regimes, and availability of data. However, the long-term trend in timber commodities markets have been observed to show both positive and negative trends (Kellard and Wohar 2006), which indicates that these declining trends may break at some point in favour of a more positive incline.

The declining trends observed here are supported by global estimates of the future forest products market (FAO 1997b), which predicted that the real prices of industrial roundwood, sawnwood and wood-based panels would change little until the year 2010, and that the real prices of newsprint, printing and writing paper would decrease slightly (FAO 1997b, Trømborg et al. 2000). Given the long-term declines observed here, two observations can be made. The first is that the lower returns experienced by the forest industry today compared to previous years will act as a barrier to reinvestment or to new companies entering the area. The second is that the declining value for wood will enable its use for relatively low-value applications like bioenergy, particularly where a compelling environmental or social case can be made for its use.

2 Introduction to bioenergy

2.1 Basic definitions

Bioenergy

- Refers to heat and/or electrical power generated from the combustion of biomass
- Examples include direct firing, cogeneration, district heating, etc.

Lignocellulose-based biorefinery

- Single facility or group of facilities
- May produce material bioproducts (including traditional fibre-based products) or biochemicals (bulk polymers, platform chemicals, bioplastics)
- Must produce bioenergy and/or 2nd-generation biofuel outputs
- Analogous to a petroleum refinery in combining high-value, low-volume and high-volume, low-value products

1st-generation biofuels

- Commercial technologies with almost 50 billion litres annual production
- Based on food or foodstuff waste (sugar, starch, vegetable oil, waste animal and vegetable oils)
- Includes sugarcane ethanol, starch-based or ‘corn’ ethanol, biodiesel, straight vegetable oil (SVO), etc.

2nd-generation biofuels

- Non-commercial at this time although pilot and demonstration facilities progressing
- Based on non-food feedstocks including agricultural and forest biomass (primarily lignocellulosic)
- Can be distributed and used in conventional infrastructure (cars, tanks, filling stations, etc.)
- Can be blended with petroleum-based fuels
- Includes forest-based biofuels such as ‘cellulosic’ ethanol, biosyndiesel (biomass-to-liquid or BTL), Fischer-Tropschs, etc.

3rd-generation biofuels

- Non-commercial at this time although laboratory-scale work progressing
- Cannot be distributed or used in conventional infrastructure
- Cannot be blended with petroleum-based fuels
- Requires major development of new propulsion systems (i.e. fuel-cell vehicles)
- Includes hydrogen (or bio-hydrogen)

2.2 Residential bioenergy use

IEA Statistics includes bioenergy as a component of Combustible Renewables and Waste. This category is made up of a number of data series including biomass, animal products, gas/liquids from biomass, industrial waste and municipal waste. Biomass is defined as any plant matter used directly as fuel or converted into fuels or electricity and/or heat, including wood, wood waste, energy crops such as switchgrass, ethanol, and black liquor from the pulp and paper industry. Data collected by the IEA under this heading are often based on small sample surveys or other incomplete information, and so the data presented here should not be used for more than illustrative purposes.

Residential bioenergy use is defined as household level application of bioenergy in any of the forms listed above. Typical household use of bioenergy is in the form of fires for cooking and heating; wood stoves and charcoal technology may be applied, as may wood pellet furnaces. In some regions, this may also include district heating for residential areas.

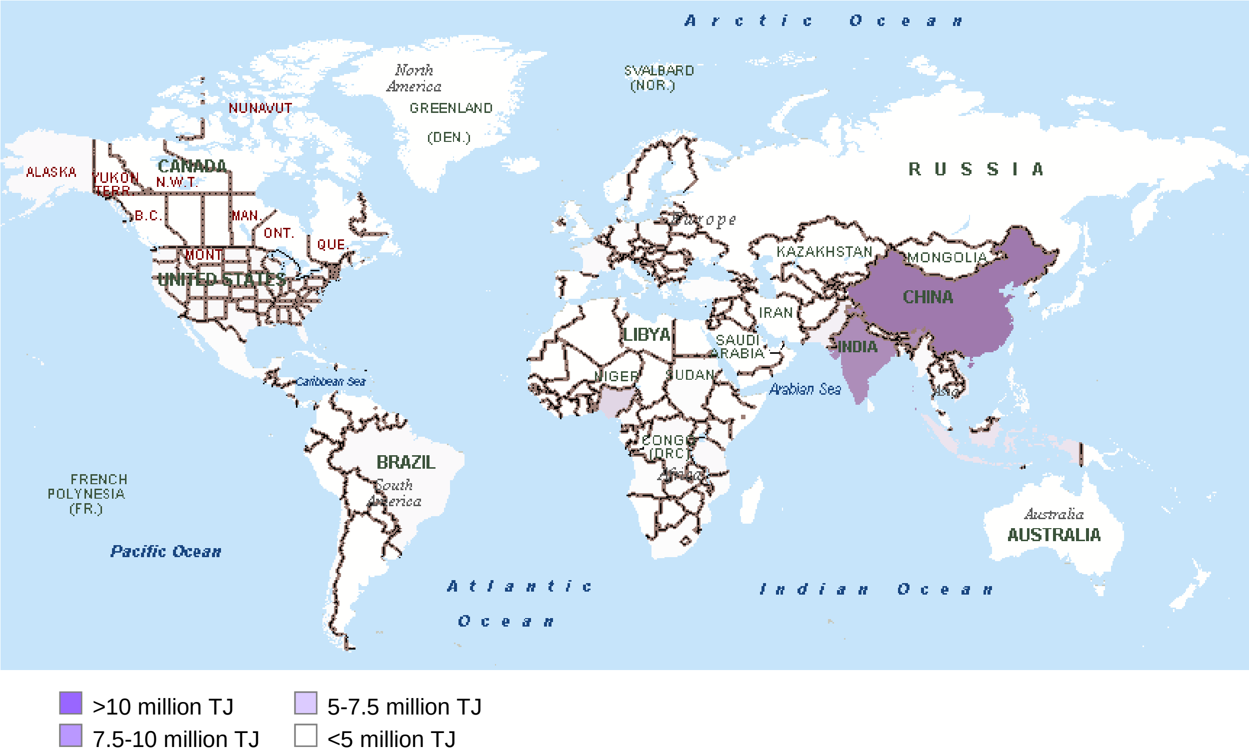

Figure 5: Residential bioenergy use (million TJ, 2004) (IEA Statistics 2006a, IEA Statistics 2006b)

IEA Statistics on the residential use of bioenergy is reported in Figure 5 above. As expected, the primary users of residential bioenergy (using 2004 data) are found in the developing world, with the largest users including China (9.1 million TJ), India (7.9 million TJ), Nigeria (2.9 million TJ) and Indonesia (1.8 million TJ). Thirteen countries were reported as diverting all bioenergy to residential uses, including Bangladesh, Serbia, Namibia, Bosnia, Libya, Algeria, Luxembourg, Israel, Jordan, Qatar, Saudi Arabia, Botswana and Turkey.

It should be noted that, while fuelwood is not the only supply of biomass for residential bioenergy, the largest users of fuelwood (China and India) are also the largest consumers of residential bioenergy. It may be assumed that a significant portion of the feedstock used in residential application in these countries is biomass from forests or from other wooded lands.

2.3 Industrial bioenergy use

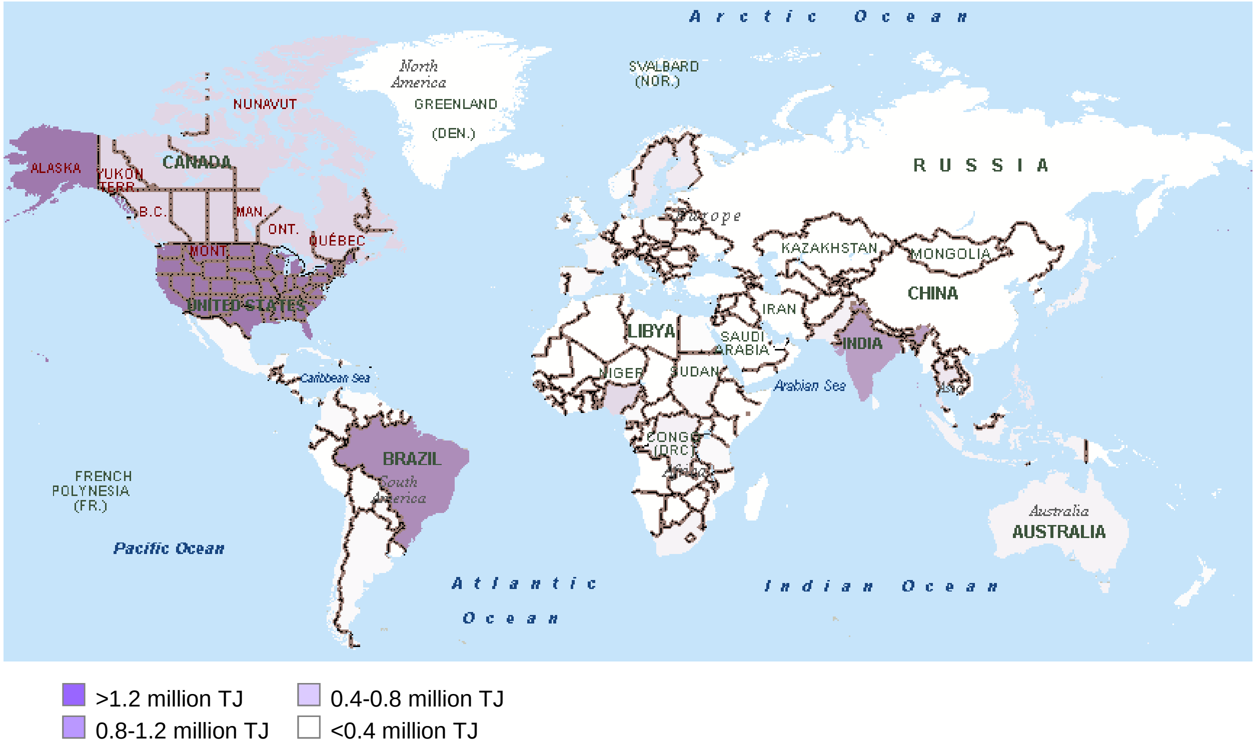

Figure 6: Industrial bioenergy use (million TJ, 2004) (IEA Statistics 2006a, IEA Statistics 2006b)

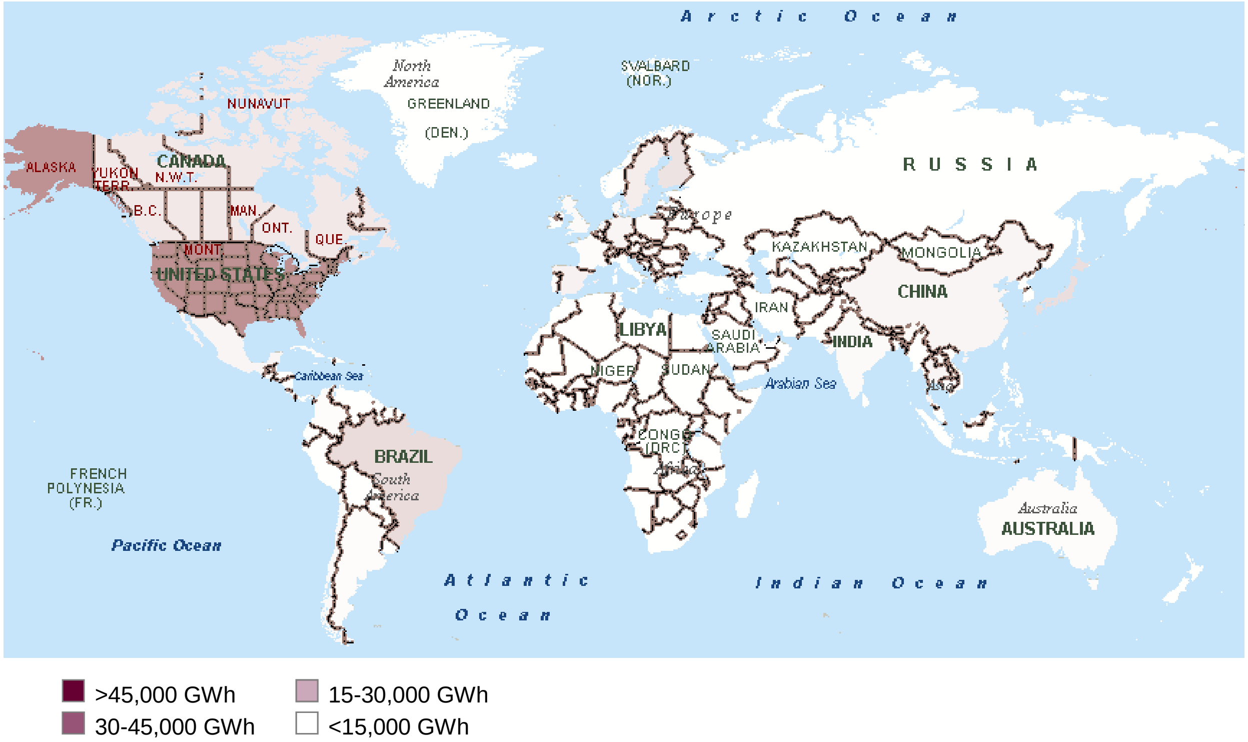

Figure 7: Industrial bioelectricity use (GWh, 2004)

In Figure 6, IEA Statistics on industrial bioenergy use are presented. The largest users of industrial bioenergy are the United States (1.1 million TJ), Brazil (0.9 million TJ), India (8.0 million TJ), and Canada (0.3 million TJ). In North America and Scandinavia, most of this energy is generated by the pulp and paper industry through black liquor recovery and gasification. In India and Brazil as well as in other areas of Africa and Asia, a number of small-scale power generators use a variety of biomass feedstocks, both agricultural and forest-based. For example, in Brazil a large part of the bioenergy produced is derived from sugarcane bagasse and is used by the ethanol industry. The greatest users of industrial bioenergy as a percentage of bioenergy use included Slovakia (79%), New Zealand (76%), and Ireland (75%)

The industrial recovery of bioenergy represents the application of advanced technology, and it is not surprising that a large portion of this capacity is found in the developed world. The use of advanced technology is made even clearer when biomass-derived electricity is examined, as shown in Figure 7. The primary producers of bioelectricity are the United States (40 TWh), Brazil (13 TWh), Japan (12 TWh), Finland (10 TWh), Canada (8 TWh), and Sweden (6 TWh).

3 Platforms for bioenergy production

3.1 Platforms and efficiency of energy recovery

Regardless of the technology employed, a certain amount of heat is produced when any given amount of wood is combusted. This is known as the heat value or calorific value of the wood. Heat values for widely used tree species are highly variable, with average values of 20.55 MJ/tonne for *Pinus* spp., 20.1 MJ/tonne for *Poplar* spp. and *Eucalyptus* spp., and 16.75 MJ/tonne for *Acacia* spp. (Panshin, de Zeeuw 1980). The intrinsic factor that most influences heat value is the moisture content within the wood. The presence of more water within the material means that more energy must be used to remove this water. This is an important consideration, as moisture content can be controlled through proper preparation before burning. Other important factors to consider are the chemical composition of the wood species, and the density of the wood being considered. Finally, the technology employed has significant impacts on energy recovery. A range of typical energy recovery values (η_e) are provided in Table 1 below.

Table 1: Efficiency of bioenergy recovery

	Combustion efficiency η_e	Heat recovery GJ/bdt
Small-scale bioenergy		
Open fire	0.05	1
Traditional wood stove	0.36	7.2
Charcoal	0.44-0.79	8.8-15.7
Wood pellet stove	0.78-0.81	15.6-16.2
Large-scale bioenergy		
Steam-turbine power boiler	0.40	8
Combined Heat & Power (CHP)	0.30 - 0.44	6 - 8.8
Gasifier/power generator	0.47	9.4
CHP with Flue Gas recovery	0.70 - 0.80	14 - 16
Biofuels[*]		
Fischer-Tropsch fuels		2.9 - 7.6
Syngas-to-ethanol		3.1
Wood-to-ethanol		2.6 - 6.4

Sources: Mabee (2001); Karlsson, Gustavsson (2003)

[*] Note: Combustion efficiency not calculated as no heat/energy recovery is included in biofuel production processes

3.1.1 *Small-scale bioenergy*

One way in which we can improve the use of wood as a fuel is to increase the efficiency with which we burn the material. Certain technologies have particular application at the small (household) scale.

Open fire provides about **5%** efficiency in the conversion of woody biomass into heat; the rest of the energy produced escapes into the open atmosphere. This can be somewhat improved by proper use of heat reflectors or masonry, but this remains the lowest energy recovery option for bioenergy production.

Wood stoves can increase this efficiency to over **35%** (Preston 1982). A wood stove works by controlling the air input into the fire. By limiting the oxygen present within the stove, pyrolysis is induced along with aerobic burning. Pyrolysis (or heating in the absence of oxygen) takes place at temperatures ranging from 450° - 600° C.

Charcoal is one of the best ways in which the energy potential of wood can be exploited; about 8% of the wood used for energy around the world goes to charcoal production. Brazil, India, Kenya, Nigeria and Sudan are the primary producers of charcoal, Worldwide charcoal production was estimated to be about 21,600,000 tonnes in 1997 (FAO 1997c). Charcoal production reduces the mass of oven-dry wood significantly, yielding only between 16-32% of original ovendry mass, but delivering similar energy recovery factors to wood pellets under ideal combustion conditions. The greatest drawback to charcoal production is the time required to achieve a high-quality product; even brick or cement kilns require 8-14 days for charcoal production, which means industrial application is limited (FAO 1987). The efficiency of using charcoal can range between **44-79%**, based on the technology used to combust the charcoal product and the efficiency of charcoal production (Mabee 2001).

3.1.2 *Wood pellets*

Wood pellet production is another ideal method of increasing intrinsic heat recovery, and one that can work at both small and large scale. Wood pellet furnaces, operating with the most advanced technologies for energy conservation and recovery, can deliver the greatest amount of intrinsic bioenergy of all technology options. Wood pellets are generally produced out of wood waste such as saw dust and shavings. The raw material is dried, mechanically fractioned to size and thereafter extruded under intense pressure into pellets, a rapid production process that is highly suited to mid-scale or large-scale production. During the process, the raw material is densified approximately 3.7 times. The product produced in Western Canada has a bulk density of approximately 705 kg/m^3 and a bulk stowage factor of approximately 1.5 m^3/tonne (Melin 2006). The efficiency of using wood pellets in small-scale wood pellet furnaces can range between **78-81%**, making wood pellets the most effective tool for bioenergy production on the small scale (Karlsson, Gustavsson 2003).

Table 2: Net energy efficiency of Canadian wood pellet exports

Process Stage	Energy input
Harvest-to-mill	n.a.
Mill construction	0.043 GJ/tonne
Mill operation (Drying-Milling-Pressing-Cooling-Screening-Bagging)	0.244 GJ/tonne
Pellet transport:	
• 200 km truck	0.230 GJ/tonne
• 1000 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 entire communities or even entire cities.

There have been questions about the energy efficiency of producing wood pellets in North America and shipping them overseas. As shown in Table 2, 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 and sailed to Stockholm via the Panama Canal, and then unloaded and trucked to nearby power generators. It is clear from the table that each component of the transport uses about the same amount of energy on a per tonne basis (Hoque et al. 2006). Even incorporating the cost of construction and operation do 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 **8-11** (energy out vs. energy in). Please note that in this example, the harvest and initial transport of forest biomass is assumed to be absorbed by the primary forest products industry.

3.1.3 *Large-scale bioenergy*

A number of existing technologies are currently in use for large-scale bioenergy production. These technologies include power boilers for heat recovery, combined heat and power (Cogen or 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 and serve as an alternative to beehive burners and other forms of waste disposal. Heat from power boilers can be used to generate steam, which in turn can be used to meet process requirements or directed to turbines for electricity generation. Power boilers have improved significantly with the introduction of fluidized bed technology.

In a similar fashion, recovery boilers are used in pulp and paper mills to recycle black liquor and recover pulping chemicals, as well as to produce steam which drives the pulping process. The steam can also be used to power turbines in order to generate electricity, although long-term low energy costs in much of the developed world has not provided much incentive for this type of capacity until lately. The design of recovery boilers has improved significantly over the latter half of the 20th century and particularly since the 1980's; breakthroughs include the ability to concentrate black liquors to higher solids contents and better systems control that help reduce char buildup and plugging in the system.

The largest example of a biomass power facility in Canada is the plant in Williams Lake, BC, a 66 MW electricity generating plant that has been operational since 1993. This facility consumes about 600,000 tonnes of wood residues including bark, chips and sawdust annually. The wood waste fuel is provided by five surrounding sawmill operations; the electricity generated at the facility is sold under a 25-year electricity purchase agreement to BC Hydro. This facility uses standard boilers and a high pressure steam turbine for electricity production. The efficiency of a steam-turbine power boiler is generally about **40%** (Karlsson, Gustavsson 2003).

Combined heat and power facilities, given appropriate siting and sufficient local need, can make use of the process steam to supply other industrial processes, or to support district heating grids for heating residential, institutional, or industrial facilities. The recovery of both heat and power from the process is referred to as cogeneration, and can significantly raise the efficiency of these operations. The efficiency of a combined heat and power (CHP) facility can range between **30-44%** (Karlsson, Gustavsson 2003). Using the most recent technological advances (see below) and incorporating flue-gas recovery and recycling, this efficiency can rise to between **70-80%** (Karlsson, Gustavsson 2003).

Gasifier/power generators have been reported to be much more efficient for energy recovery, in terms of electricity generation, than traditional combustion in a power boiler. Electrical generation from typical biomass power generation plants have efficiencies up to the **30%** range. An integrated gasification combined cycle may be used to increase efficiencies, by using the waste heat from the turbine to make steam that then can be used to generate additional electricity, to about **47%** (Karlsson, Gustavsson 2003). In conjunction with a district heating system, this type of system can give theoretical efficiencies that reach **70-80%**. Efficiencies have been noted for both co-firing systems (where biomass is gasified, and then the gaseous products are combusted with a fossil fuel such as coal or natural gas) and in dedicated biomass gasification processes (Gielen, de Feber 2001). Because the potential for energy recovery is so much higher, gasification systems without any downstream catalysis stage might be applied in some situations to increase bioenergy production, without impacting on existing product streams in sawmilling or pulping operations. This type of 'evolutionary' technology application is a logical step on the path towards greater process efficiencies and increased energy self-generation. Significant technical hurdles remain, however, particularly regarding biomass-derived syngas clean-up requirements and associated char buildup problems.

3.1.4 Biofuels

There are essentially two distinct technological platforms that a lignocellulose-based biorefinery might utilize to produce biofuels from forest biomass. These platforms are grouped into thermochemical-based processes and biological-based processes. These platforms are described separately in this document, but likely would be combined to some extent in working mills.

Thermochemical conversion platforms can liquefy or gasify wood, collect the chemical components which are generated, and ultimately reassemble these components into fuels and possibly industrial chemicals. This platform combines process elements of pyrolysis, gasification, and catalytic conversion. Pyrolysis and gasification may be used for bioenergy generation independently of catalysis; however, 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, French et al. 2000). If pyrolysis is carried out at a slower rate (slow pyrolysis), the gaseous products from pyrolysis and gasification are generally referred to as synthesis gases (or syngas) (Cetin, Moghtaderi et al. 2005).

Biofuels may be generated from the thermochemical platform by applying a catalysis stage to convert syngas into chemical building blocks and eventually end products. Proven catalytic processes for syngas conversion to fuels and chemicals exist using syngas produced commercially from natural gas and coal. These proven conversion technologies can be applied to biomass-derived syngas. Fischer-Tropsch diesel (or biosyn diesel) is one potential biofuel product; this fuel was first discovered in 1923 and was commercially based on syngas made from coal, although the process could be applied to natural gas- or biomass-derived syngas. The process of converting CO and H2 mixtures to liquid hydrocarbons over a transition metal catalyst has become known as the Fischer-Tropsch (FT) synthesis. Most existing production of FT-diesel was carried out in South Africa, in part because that country was under UN trade sanctions for many years and had no available source of petroleum for fuel production. Another potential catalytic conversion of biomass-based syngas is to higher alcohols, including ethanol. Ethanol and other higher alcohols form as byproducts of both Fischer-Tropsch and methanol synthesis, and modified catalysts have been shown to provide better yields. It is estimated that the yield of Fischer-Tropsch fuels would range between **2.9-7.6** GJ/bdtonne; however, the total energy efficiency is difficult to calculate, as significant heat and power recovery might also be achieved with this process. It is likely that the overall energy efficiency of this process would rival the best small- and large-scale bioenergy processes described in the sections above.

Bioconversion platforms utilize biological agents, in the form of enzymes and microorganisms, to carry out a structured deconstruction of lignocellulose components. This platform combines process elements of pretreatment with enzymatic hydrolysis to release carbohydrates and lignin from the wood, followed by fermentation to create end products. Essentially, this platform represents a blend of pulp and paper technology with commercial biotechnology processes being used today by 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 ethanol, a renewable transportation fuel, or converted to a variety of other products. Fuel ethanol, 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 ethanol using age-old yeasts and processes. Five-carbon sugars, however, are more difficult to ferment; new yeast strains are being developed that can process these sugars, but issues remain with process efficiency and the length of fermentation. Based on a review of the literature, it is estimated that ethanol yields from lignocellulosics will range between **2.6-6.4** GJ/bdtonne of wood, depending upon the efficiency of five-carbon sugar conversion. As with 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 products that would substitute for fossil-based products. There is great potential for biofuel production from biomass using the bioconversion platform, particularly given its suitability for coproduct generation.

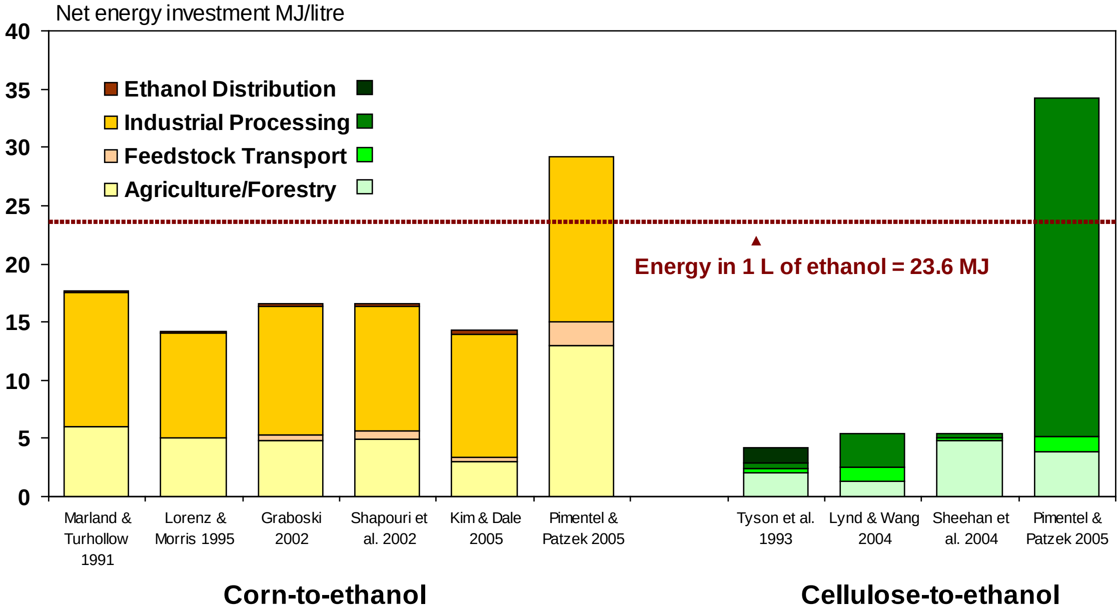

Figure 8: Comparing energy efficiency of ethanol production, various studies (NRDC 2006)

3.1.5 *Energy efficiency of biofuels*

Of all wood-based biofuels, the one currently closest to commercialization is ethanol. This biofuel has the advantage of building on a very vibrant sugarcane- and starch-based ethanol industry, particularly active in countries such as Brazil and the USA. A review of pertinent studies carried out by the NRDC (2006) indicates that, given current production methods, corn (starch-based) ethanol displaces petroleum use substantially, and cellulose (wood-based) ethanol can improve this displacement by up to four times (as shown in Figure 8 above). In five out of six studies, starch-based ethanol provided an energy return (energy out vs. energy in) of between **1.29-1.65**. The dissenting study, by Pimentel & Patzek, used significantly higher energy inputs than considered standard today, returning much higher figures than the majority of researchers in this field. Similarly, three out of fours studies indicated that cellulose-based ethanol provides energy return of between **4.40-6.61,** which is consistent with the potential of cellulose-to-ethanol processes to be independent of significant fossil-based energy inputs. Again, the dissenting study by Pimentel & Patzek used energy input figures that were significantly out of line with the standards used by most researchers.

3.2 Greenhouse gas emissions

With small- and large-scale bioenergy options, the concern over greenhouse gas (GHG) emissions is lower because the emissions associated with combustion of these materials represent 'green' or closed-cycle emissions. However, the generation of biofuels, which embody a significant amount of up-stream processing and potential fossil inputs, is more problematic. This section summarizes the status of our understanding of biofuel GHG outputs.

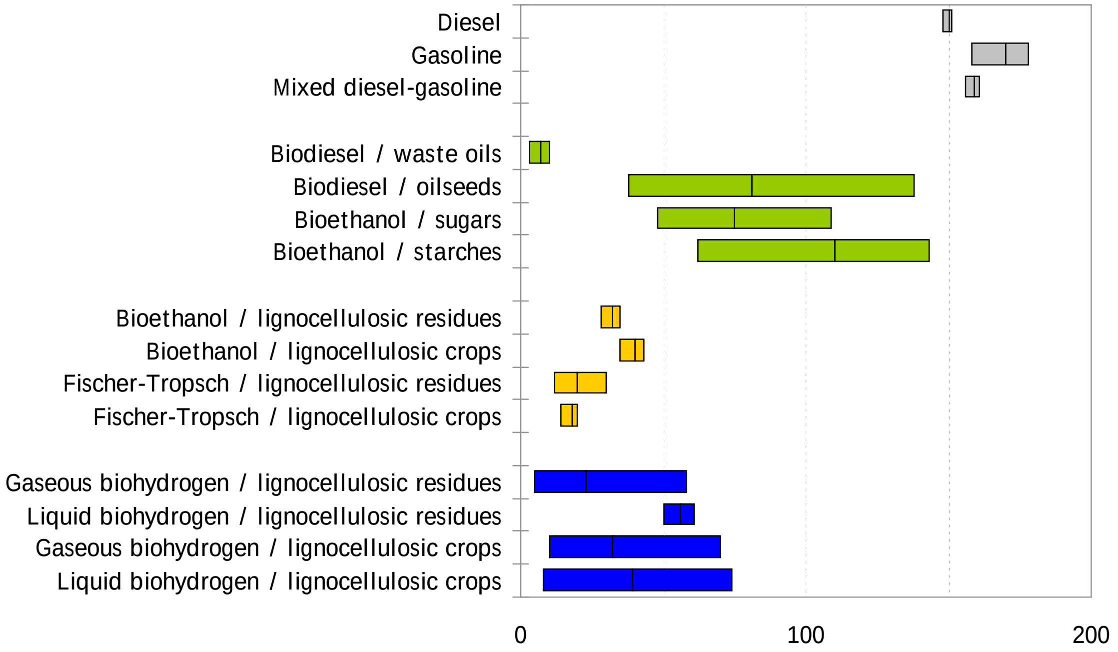

Figure 9: Comparing greenhouse gas emissions (grams CO_2-equivalent per kilometer driven) of biofuels, using advanced (>2010) technologies (VIEWLS 2005)

Greenhouse gas production associated with lignocellulosic-based feedstocks is anticipated to be much lower than with conventional fuels or widely used biofuels such as biodiesel or sugar- or starch-based ethanol, as shown in Figure 9 The environmental performance depends very much on the specific life cycle of the fuel, including the country in which the life cycle assessment (LCA) was conducted, the feedstock on which the fuel is based, the vehicle used, the propulsion system, and the overall state of technology. Two major integrative reports have been carried out that have brought together the major LCA's conducted in a number of OECD countries in Europe and North America. One, the VIEWLS project, released their first report in November of 2005 (VIEWLS 2005). The VIEWLS project corroborates data released in an 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 lignocellulosic materials (shown in brown in Figure 9) are characterized by reduced carbon dioxide emissions when compared to similar products derived from petroleum (shown in grey), and thus can play a role in meeting Kyoto Protocol obligations or reduced pollution guidelines. In the studies considered by the VIEWLs project, vehicles built with conventional (2000) technology and utilizing diesel fuel had emissions ranging between 162 to 203 g CO_2-equivalent per kilometer. Similarly, gasoline-powered conventional vehicles had emissions ranging between 182-280 g CO_2-e per km. In other studies considered by the VIELWS project (and as shown in grey in Figure 10 above), it was anticipated that internal-combustion engines built with advanced technology (estimated to be available by 2010) may have slightly reduced GHG emissions, ranging between 147-152 g CO_2-e per km for diesel and 160-190 g CO_2-e per km for gasoline. The studies considered in the VIEWLS project indicated that lignocellulosic-based biofuels (shown in orange) offer significant savings over starch- or sugar-based biofuels (shown in green). Finally, it was somewhat surprising to note that lignocellulosic-based biofuels such as ethanol or Fischer-Tropsch fuels may also have an advantage over hydrogen produced from lignocellulosics. This is an early finding, but may have implications for future development of transportation technology. It is pointed out that substituting emissions by utilizing bio-based energy in all aspects of lignocellulosic biofuel production can create an overall negative emission for the fuel (VIEWLS 2005).

4 Land use issues

One issue that is constantly raised regarding forest-based biofuels is that increased demand for cheap biomass to supply these processes may lead to increases in deforestation. There is particular fear that oil-rich species, such as oil palm, might be widely planted on former forest land in order to supply biodiesel production. This section analyzes current trends in deforestation and attempts to relate these trends to new trends in biofuel production.

4.1 Deforestation rates

The ten most significant countries of the world in terms of deforestation rates are listed in Table 3. Of these countries, only two have significant biofuel production rates (Brazil and Indonesia). In most cases, deforestation rates are not explained by the establishment of oil seed plantations specifically for biofuel production. However, in two cases, there is fairly close correlation.

The greatest deforestation is found in Brazil, where about 3.1 million ha are currently being removed from forest every year. This represents about 0.6% of the total forest cover, of which about 21,000 ha is being put back to industrial plantations (FAOStat 2007a). Most of the remaining area is likely going towards non-sugarcane agriculture, and not biofuel production. Corroborating evidence may be found in the establishment of Brazilian sugarcane plantations, which have increased by approximately 190,000 ha per year (FAOStat 2007b); this only would account for about 6% of Brazil's deforestation rate. Brazil's bioethanol production capacity has also not risen dramatically in the past few years (FO Lichts 2006). The relatively low levels of oil palm plantation establishment (about 2,200 ha per year) are also not likely a driver in deforestation in Brazil.

The greatest percent rate of deforestation is found in Nigeria, where 410,000 ha are being removed annually, representing 3.3% of the total forest landbase. However, in Nigeria, the establishment of new oil palm plantations is limited to about 48,000 ha per year, or just over 10% of the total deforestation rate. Thus, oil palm plantations are not likely to be driving significant deforestation in this area. The second most dramatic deforestation rate globally is found in Indonesia, where 1.8 million ha (or 2% of the forest cover) are vanishing annually. Here, there is more of a case for biofuels being (at least in part) the culprit, as there is evidence that some deforestation is being carried out for oil palm plantations (see next two sections). However, determining the actual extent to which biofuels contribute to total deforestation in this country is difficult.

Table 3: Annual deforestation rates and oil palm establishment rates, 2000-2005 (ha/year) (FAO 2006b, FAOStat 2007b, Colchester et al. 2006)

	Deforested Area (Annual removals, ha) *(%)*	Oil palm plantations (Estimated annual gains, ha)
Brazil	3,103,000 *(0.6%)*	2,200
Indonesia	1,871,000 *(2.0%)*	317,200 - 3,917,200
Sudan	589,000 *(0.8%)*	n.a.
Myanmar	466,000 *(1.4%)*	n.a.
Zambia	445,000 *(1.0%)*	n.a.
Tanzania	412,000 *(1.1%)*	n.a.
Nigeria	410,000 *(3.3%)*	48,000
Congo	319,000 *(0.2%)*	8,000
Zimbabwe	313,000 *(1.7%)*	n.a.
Venezuela	288,000 *(0.6%)*	n.a.
Malaysia	140,000 *(0.5%)*	109,000 - 121,000

At least two authors (Carrere 2001; Colchester et al. 2006) report significant expansion of oil palm plantations in Indonesia since 2000. For example, Colchester estimates that as of 2005, 6,000,000 ha was under oil palm plantation, with another 18,000,000 ha cleared for future oil palm production. At the same time, the FAOStat Agricultural database indicates that just over 300,000 ha/year is currently being transformed to oil palm (likely plantations). The discrepancy between the two extreme estimates of oil palm plantation area is a factor of 10 (as indicated in Table 3). Moreover, if Colchester et al. is correct, this area represents 12 years of deforestation at the current rate, meaning that all deforestation observed in Indonesia for more than a decade has been pushed towards oil palm plantations. The claims in the Colchester report should be read with caution given the lack of corroborating evidence from other sources, including the FAO and the Oilworld.biz website; these sources indicate a range of between 300-500,000 ha of land is being converted to oil palm cover annually. Approximately 17-27% of Indonesian deforestation (and 80% of Malaysian deforestation) may be reasonably explained by the establishment of oil palm plantations.

4.2 Oil palm plantations

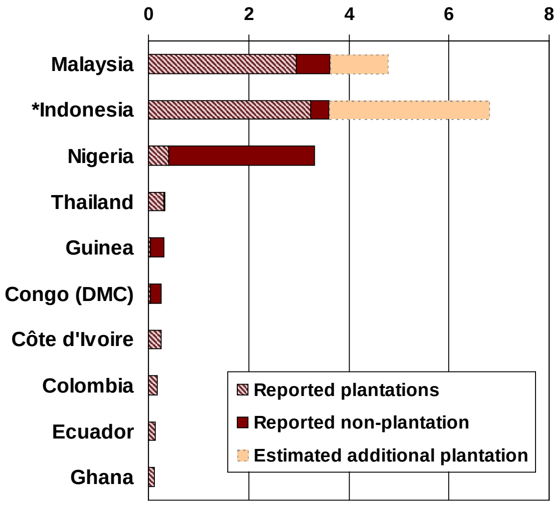

Figure 10: Total oil palm plantations, million ha (2005)

The most significant oil palm plantations in the world are found in Indonesia and Malaysia, as has already been alluded to in the previous section. Malaysia is currently the world leader in the production of palm oil (FAOStat 2007b), although Indonesian capacity should rise with the expected growth in oil palm area. Between 3.6 and 4.8 million ha are currently under oil palm in Malaysia. In Indonesia; between 3.6 and 6.8 million ha of land are under oil palm. The only other significant oil palm areas are found in Nigeria, where the majority of the oil palm is in a natural or semi-natural state, rather than in plantation. The most significant growth rates in oil palm plantations are found in Indonesia (15.7% or more per year since 2000), Côte d'Ivoire (15.8%), Thailand (11.1%), and Malaysia (3.5% or more). As discussed, these plantation establishment rates may explain a good portion of deforestation in both Indonesia and Malaysia (see previous section). The same may be true in Thailand, where plantation establishment reaches 40% of the deforestation rate.

4.3 Planted forest areas

Figure 11: Planted forest areas, million ha (2005) (FAOStat 2006a)

The total area of forest plantations in 2005, reported by FAO through the Global Forest Resources Assessment, was approximately 140 million ha. The greatest plantation areas were found in China (31 million ha), the USA (17 million ha), Romania (17 million ha), Japan (10 million ha), 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 cases, these fibres are destined for the pulp and paper industry. This assessment would seem to indicate that global forest plantations are not being established for the sake of the bioenergy industry.

The total establishment of planted forests in Indonesia from 2000-2005 was reported to be about 80,000 ha per year. In Malaysia, the amount of planted forests actually declined from 2000-2005, by about 17,000 ha per year. In Brazil, planted forests grew by about 21,000 ha per year, while in Thailand planted forests grew by 4,400 ha per year.

4.4 Food vs. fuel issues

There has been rising concern that biofuel production will lead to higher food prices, which could have devastating effect upon the developing world where disposable incomes are lower. The recent 'Mexican tortilla crisis' in January 2007 saw prices for the staple rising by three- or four-fold over summer 2006 prices, to a high of approximately US$1.81 per kilogram from only US$0.63 the previous year (Roig-Franzia 2007). The cause of this crisis was reputedly high corn prices and a shortage of Mexican corn, resulting in increasing imports from the United States, where corn is in high demand for ethanol production. However, some commentators questioned this analysis, citing the fact that most biofuel production is based on 'yellow' or livestock corn, while tortilla production uses 'white' or human-grade corn - the price of which has not risen nearly as quickly (Philpott 2007).

Rosegrant et al. examined the potential impact the growing demand for energy on real world food prices using the IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) model developed by the International Food Policy Research Institute in Washington, DC (Rosegrant et al. 2005, 2006). This model works at the national level to analyze baseline and alternative scenarios for food demand, supply, trade, income and population. The model uses commodity price indices and consumer price indices in order to assess 'real' changes in prices for crops, and takes both producer and consumer subsidies into account at the national level. National figures are then agglomerated to regional and global assessments. The IMPACT model was used to examine the interaction between crop demand for biofuel feedstock and the demand and production of crops for both food and feed, in order to see how scenarios for projected growth in biofuel production could affect food availability, prices, and consumption at global levels until 2020. An 'aggressive biofuel growth' scenario assumed that total biofuel consumption would rise between two- and ten-fold in specific countries or regions around the world, including China, India, Brazil, the USA, and the European Union. This scenario also presumed that oil prices would stay high in real terms. The authors then examined three cases, including a 'business as usual' case in which the focus remains on food-based biofuels, a 'cellulosic biofuel' case in which new development focuses on using energy crops or wood, and an 'agricultural productivity improvement' case in which cellulosic development was combined with improvements in agricultural practices. Scenarios of biofuel growth are compared to baseline scenarios of food availability, prices, and consumption between 2005 and 2020 that are incorporated in the IMPACT model (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. However, offsetting new development with 'cellulosic biofuel' could reduce these increases somewhat, and combining cellulosic biomass with agricultural improvements could result in the lowest possible price increases. Each of these cases, however, suggests higher real crop prices in the future (Rosegrant et al 2006) (Table 4).

Table 4: Food vs. fuel considerations (Rosegrant et al. 2006)

	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%
Sugarcane	66%	49%	43%
Oilseeds	76%	45%	43%
Maize (corn)	41%	29%	23%
Wheat	30%	21%	16%

It is clear from the results of this exercise that each of the three cases presented in Table 4 would entail higher feedstock prices on average in the global food marketplace, although national changes would vary. This will impact food security in some nations, particularly where food is scarce due to poor growing conditions or other environmental factors. Movement to wood-based biofuels can be seen as a tool to strengthen food security in these nations, by minimizing the expected rise in food prices. Some speculate that rising costs for feedstock may actually necessitate subsidies for the biofuel sector, unless significant increases in fuel prices or decreases in production prices are achieved. These subsidies already exist for many countries (such as within the European Union, the USA, Canada, and others). The results suggest that the cost of biofuels could remain high because of high feedstock costs, so there would need to be compelling social or environmental factors for its uptake.

5 Developing biofuels

5.1 Fossil fuel prices and global use of fossil fuels

The price of fossil fuels has remained at a relatively high level for the past two years, peaking in the summer of 2005 after Hurricane Katrina struck the Gulf Coast of the United States. This rise in fossil fuel prices has been exacerbated by continued hostility in the Middle East, ongoing supply issues in the Russian Federation, a lack of new refiner capacity in North America, and continued increases in demand in the developing world, primarily China and India. It is anticipated that prices for fossil fuels will not decline significantly in the short term, although they have dropped away from peak prices and currently trade around US$60 per barrel of West Texas Sweet Crude. In real prices, the all-time high for oil was achieved in the early 1980's following the second oil crisis or 'shock'. The long-term price trend, and the volatility associated with the international market for oil, is shown in Figure 13 below.

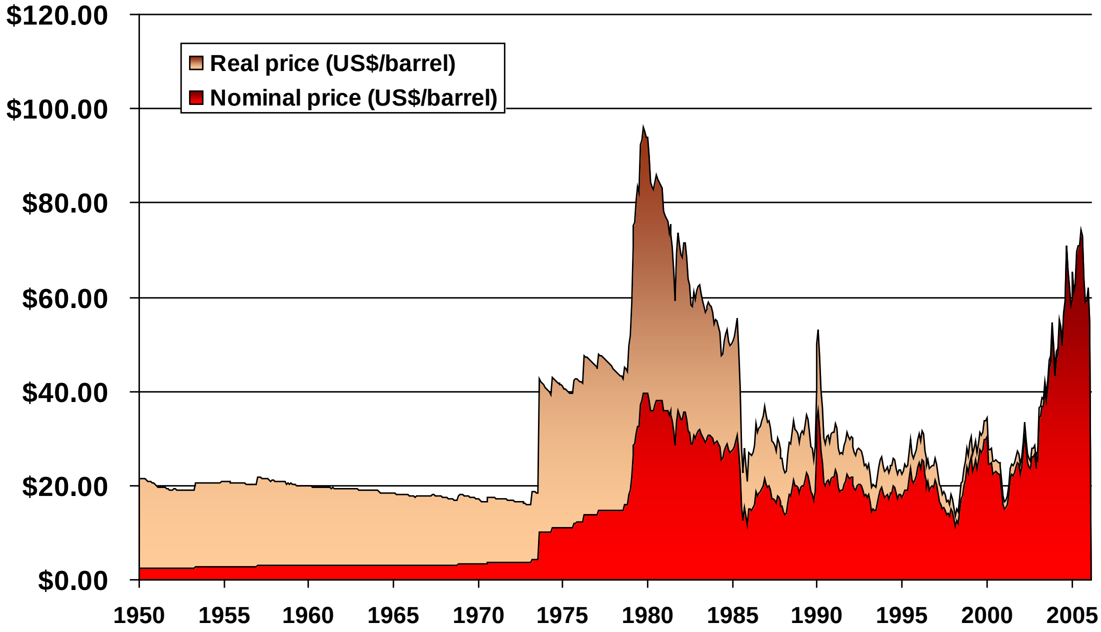

Figure 13: Price trends for oil, 1950-present (WorldOil.com)

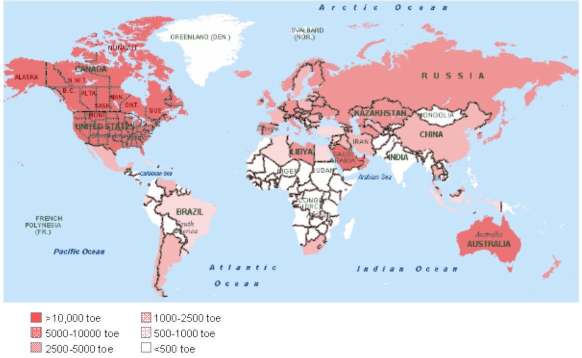

Figure 14: Fossil fuel consumption, per capita (toe) (IEA Statistics 2006a, IEA Statistics 2006b)

The global use of fossil fuels is marked by high levels of consumption in the developed world. The largest consumer of fossil fuels (including oil, gas and coal) is the United States at 2,009 Million tonnes of oil equivalent (Mtoe). This is followed by China (1345 Mtoe), the Russian Federation (580 Mtoe), Japan (441 Mtoe), India (346 Mtoe), Germany (290 Mtoe), the United Kingdom (209 Mtoe), and Canada (204 Mtoe). On a per capita basis, the majority of western countries consume between 2,000 - 21,000 toe per person per year of fossil energy. As shown in Figure 14, consumption is maximized in the north and south of the world, while large regions of Latin America, Asia, and particularly Africa consume less than 500 toe per capita per year. It is in these regions where there is a tremendous potential to substitute fuelwood for fossil energy, utilizing the most advanced bioenergy production systems.

5.2 Potential substitution of wood fuel for fossil energy demand

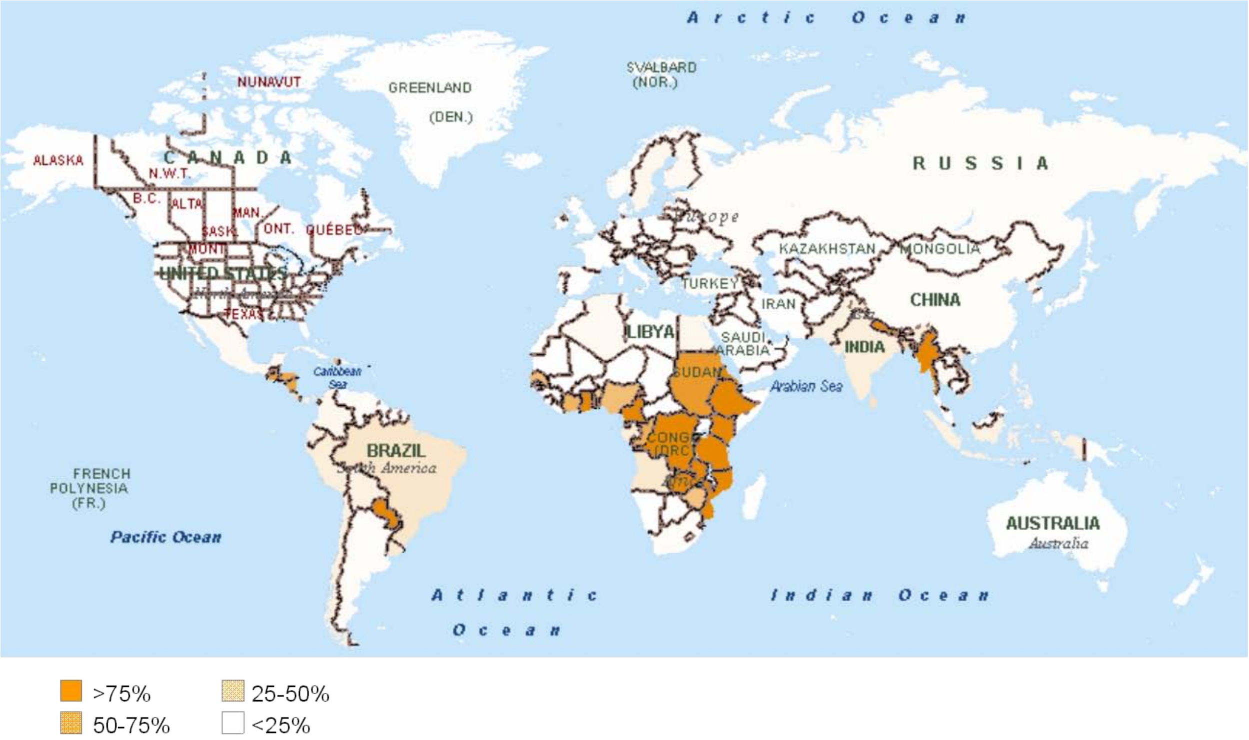

Figure 15: Estimated potential substitution of wood fuel for fossil energy demand (2005) (%)

It is possible to estimate the amount of fossil fuel which could be substituted by diverting fuelwood into technologically advanced bioenergy systems. Given the amounts of fuelwood currently being harvested (FAOStat 2007a), the amount of fossil fuel currently being consumed (IEA Statistics 2006a, IEA Statistics 2006b), and the best conversion technologies described (Combined Heat and Power with flue gas recovery, 80% net energy efficiency), fossil fuel substitution by fuelwood has been estimated (2005 figures). The global potential on a national basis is shown in Figure 15.

Based on these calculations, no less than 22 countries have the potential to substitute all of their current fossil fuel demand with their current fuelwood supplies, including the Democratic Republic of the Congo, Tanzania, Mozambique, Ethiopia, Zambia, Nepal, Paraguay, Cameroon, Kenya, Sudan, Myanmar, Ghana, Togo, Eritrea, Nigeria, Haiti, the Republic of Congo, Guatemala, Côte d'Ivoire, Nicaragua, Zimbabwe, and Honduras. This would offset more than 53 million tonnes of oil equivalent per year. While this is not a great deal of energy when compared to the largest fossil fuel consumers, these countries essentially have the ability to shift all of their energy demand to a potentially renewable, domestic feedstock, fostering independence and reducing their reliance upon foreign oil sources. For some countries, this could also mean increasing the amount of oil they have to sell on the international market.

These countries, which encompass some of the poorest countries on the planet, will need help in adopting high-technology solutions and developing new bioenergy technologies. A network designed for technology transfer, administered through the Food and Agriculture Organization and operating on similar principles to the IEA Bioenergy Implementing Agreement, could serve as the basis for this type of activity.

5.3 Potential substitution of commercial growing stock for fossil energy demand

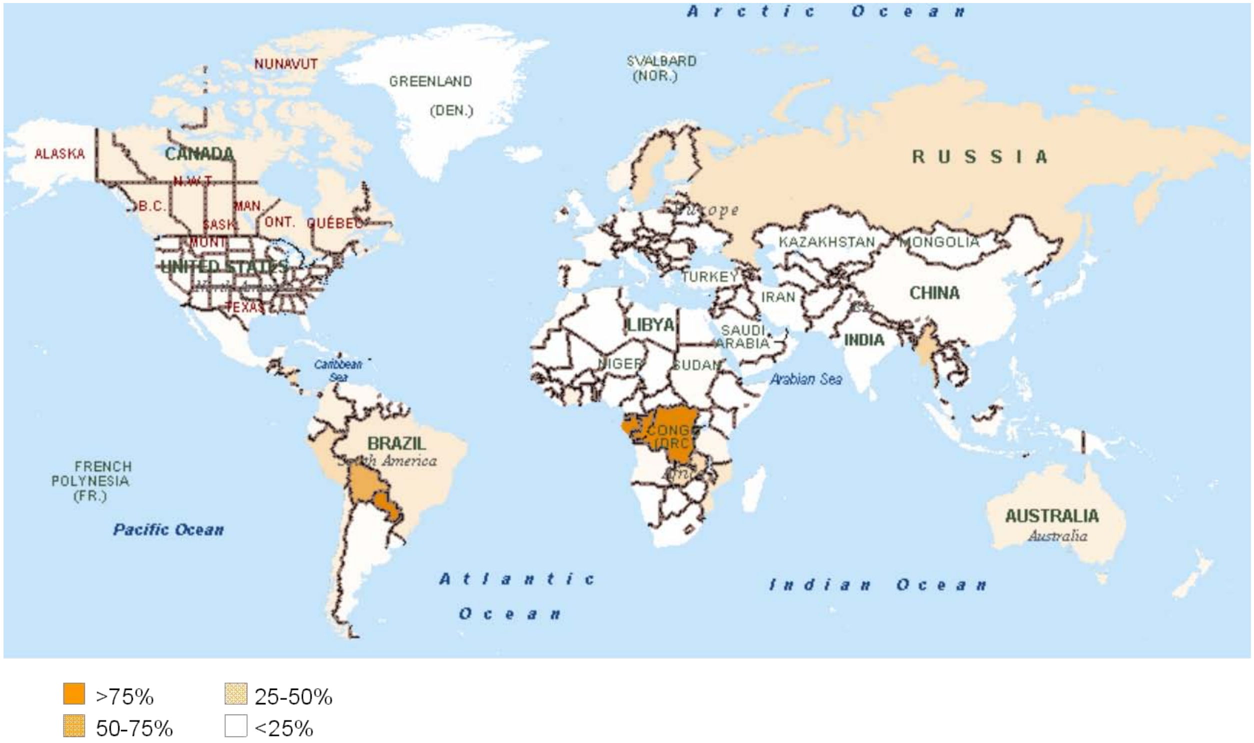

Figure 16: Estimated potential substitution of annual commercial growing stock for fossil energy demand (2005) (%)

Building on the analysis in the previous section, it is possible to estimate the amount of fossil fuel which could be substituted by diverting a portion of the commercial growing stock into technologically advanced bioenergy systems. Given 25% of the reported commercial mean annual increment (FAO 2006a, FAO 1997d), the amount of fossil fuel currently being consumed (IEA Statistics 2006a, IEA Statistics 2006b), and the best conversion technologies described (Combined Heat and Power with flue gas recovery, 80% net energy efficiency), fossil fuel substitution by commercial growing stock has been estimated (2005 figures). The global potential on a national basis is shown in Figure 16.

Based on these calculations, eleven countries have the potential to substitute all of their current fossil fuel demand with one quarter of the commercial mean annual increment, including the Democratic Republic of the Congo, Zambia, Mozambique, Paraguay, Tanzania, the Republic of Congo, Gabon, Myanmar, Bolivia, Brazil and Nepal. Both Sweden and Nicaragua should be able to meet over 95% of their fossil fuel demand. Together, these countries would offset more than 151 Mtoe per year. In fact, many developed countries could make a significant impact on their fossil fuel demand with a portion of commercial growing stock, including Finland (29%), Canada (19%), the Russian Federation (17%), and Australia (17%). If all countries devoted 25% of commercial growing stock to bioenergy production, the offset would be about 470 Mtoe. Again, while this may not be considered a great deal of energy when compared to a consumer like the USA, each of these countries has the ability to greatly reduce their energy demand and diversify their portfolio with a renewable, domestic feedstock.

One interesting aspect to this modeling exercise is that there is a strong mix of developed and developing countries which have the potential to utilize bioenergy as a substantial portion of their total primary energy demand. The addition of countries such as Brazil, Sweden, Finland and Canada could strengthen a network for technology transfer as suggested in the previous section.

6 Implications and summary

6.1 Implications for employment

It is difficult to make accurate assumptions about the role that bioenergy may play in terms of employment. However, most commentators believe that the development of a bioenergy industry will be good news, and that bioenergy and biofuels can be an important tool in improving rural economies. The Renewables 2005 Global Status Report estimated that 1.7 million direct jobs had been created from renewable energy manufacturing, operations and maintenance as of 2004 (REN212005). Some specific examples of employment estimates include the following:

- Within the USA, the US Department of Agriculture has predicted that 4,500 jobs will be created per every million litres of ethanol produced. These figures reflect direct employment within the mill; increased employment should also be observed on the farm and in the creation of secondary jobs to provide equipment and services for these operations (www.eere.energy.gov/biomass)

- The U.S. Department of Energy predicts that advanced technologies currently under development will help the biomass power industry install over 13,000 megawatts of biomass power by the year 2010, with over 40% of the fuel supplied from four million acres of energy crops and the remainder from biomass residues, and create an additional 100,000 jobs. This would significantly help rural economies (www.greenjobs.com)

- In Europe, predictions estimate that the increase in energy provided from biomass fuel production could result in the creation of over 515,000 new jobs by 2020. This prediction took account of the direct, indirect and subsidy effects on employment, and jobs displaced in conventional energy technologies (www.greenjobs.com)

- In Brazil, over 700,000 rural jobs have been created in the sugar-alcohol industry since its inception, at a rate of approximately 30,000 jobs per million litres of ethanol production (AFTA 2000).

6.2 Policy frameworks/tools for bioenergy

At least 48 countries have some kind of renewable energy policy and have introduced renewable energy targets, usually in the range of 5–30% of total electricity use within the next 10–20 years (REN21 2005). A number of policy frameworks have been used in these countries to harness potential bioenergy use. The most common tool is the feed-in tariff, which guarantees that renewable energy (i.e. bioenergy) providers have access to the power grid at a guaranteed price, but where the market determines demand for this energy. As of December 2006, at least 39 nations and subnational jurisdictions were utilizing feed-in policies. Another popular policy tool is the renewable portfolio standard, which mandates the use of renewable energy either as a percentage of total energy production or as an absolute production figure, but which allows the market to set prices. Renewable fuel standards, in particular, are widely used in the primary biofuel producing nations/regions of the world. Examples of RFS implementation include the following:

- Brazil: 23% EtOH in gasoline (today)
    - Varies between 20-25%
- EU: 5.75% renewable fuels by 2012; 10% by 2020 (proposed)
    - Sweden: Fossil free by 2020
- USA: 10% renewable fuels by 2012
    - Replace 75% of Middle East oil by 2020
- Canada: 5% EtOH by 2010; 2% biodiesel by 2012
    - Ontario: 10% EtOH by 2010

A number of other instruments, including research and development funds, green pricing programs, tax incentives, subsidized loans, capital subsidies, energy taxes, market liberalization, information campaigns, training, standardization, and certification, are all utilized in OECD countries to promote biofuels and bioenergy. Moreover, it is clear from some analyses that successful implementation of bioenergy in these countries has depended upon the application of multiple policy tools in a concerted fashion (Mabee 2007).

6.3 Policy tools for the developing world

In the developing world, a number of activities must take place in order to promote the development and use of more advanced forms of bioenergy. As stated in the previous section, there are a number of policy tools and instruments that could be applied to develop bioenergy capacity. The choice of tool should reflect local conditions. For example, it would be foolish to pursue a renewable energy portfolio without ensuring that the institutional capacity exists to monitor and regulate delivery of energy so that it meets the criteria of the portfolio. In countries where institutional capacity to deliver these services are limited, it might make better sense to utilize a feed-in tariff policy, or to choose an energy tax exemption that can be implemented using existing capacity.

While bioenergy may be a desirable energy source, it is unreasonable to assume that developing countries - already constrained in terms of capital for investment - will be able to create a bioenergy sector simply through policy interventions. Both technological and financial inputs will be required in order to implement significant bioenergy capacity in the short term. Some ideas for institutional capacity building include:

- *Strengthening mechanisms for technology transfer*
  The implementation of advanced bioenergy applications in the developing world can be hastened through a programme of technology transfer and demonstration. This can be done on a one-off basis wherein industrial partners approach local governments individually. However, a centralized organization (such as FAO) could act as a liaison between local governments and potential industrial partners, allowing this type of activity to act in a coordinated fashion, and would allow the centralized organization to actively seek out industrial partners who might not be considering this sort of option.
- *Strengthening education and knowledge transfer*
  Information campaigns have been used successful in some countries, including members of the EU, Canada, and the USA, to develop awareness of bioenergy options and to promote consumer use of this material. The FAO has a strong history of developing similar educational programmes targeted at the developing world, such as the Forestry Paper series focused on charcoal production. Institutions which might implement this type of work at a national basis include colleges/universities, ENGOs, and government
- *Enabling Kyoto mechanisms for international investment*
  Powerful tools enabling foreign investment in local projects exist through the Kyoto Protocol. Both the Clean Development Mechanism (CDM) and the Emissions Trading (ET) mechanism offer potential to improve international investment in bioenergy projects in the developing world.
  CDM: Many developing nations, particularly in Latin America, now have a Designated National Authority (DNA) for CDM project approval. In other nations, particularly in Africa, this institutional capacity needs to be advanced. Often, national Ministries of the Environment serve as the DNA. It is also important that bioenergy CDM projects not be seen as ‘spurious’, or projects that would have happened in any event. Enlisting capacity such as the World Wide Fund for Nature’s Gold Standard methodology might be one avenue towards ensuring that new CDM projects take place in a sustainable fashion.
  ET: Emissions trading mechanisms are still developing in many regions of the world. The most advanced programme for ET is the European Union’s Emission Trading Scheme, which has 25 participants. However, no scheme currently exists in the developing world that is equivalent. Institutional capacity, including monitoring and inventory of GHG emissions, must be developed to a much greater degree in order to allow this mechanism to work to its greatest potential.

- *Ensuring sustainable forest management*
  A major issue with the addition of bioenergy as a forest product in the developing world will be increased stress on the natural and semi-natural forest landscape. Institutional capacity in forest management, including training and regulatory ability, should be developed in conjunction with the growth of bioenergy capacity. Since it is possible that bioenergy options will increase biomass utilization, the necessary safeguards for the long-term sustainability of the forest resource should be put in place as well. Institutions which might be used to implement this include government, local ENGOs, and international certification schemes. Local industrial partners engaged in the forest could also be included in this type of discussion.

6.4 Summary

Wood fuel, currently harvested on a global scale but used in an inefficient manner, represents a large, potentially significant energy resource for the world. Bioenergy technology has the ability to greatly increase both small- and large-scale energy recoveries, transforming wood fuel from a small-scale application to a large-scale, efficient energy source. In many developing countries, the potential for wood fuel meets or exceeds the current demand for fossil energy, including oil, gas, and coal. These countries could form the basis of a network designed for technology transfer and bioenergy facilitation.

Biofuels have a positive greenhouse gas (GHG) and energy balance. While there are dissenting opinions in the scientific community, the vast majority of studies have underscored the ability of bioenergy and particularly wood-based biofuels to provide a positive net energy balance. The GHG emissions associated with biofuel production are significantly lower than fossil fuels, and the emission associated with wood-based biofuels are lower than agricultural-based biofuel such as starch- or sugar-based ethanol.

There are still questions to be answered about the sustainability of fuelwood removals and plantations designed for biofuel production. This is particularly true regarding oil palm plantations in countries like Indonesia and Malaysia. While the FAO has done a very good job of improving fuelwood statistics, more resources need to be made available to assess the impacts of fuelwood removals on the landscape. One area of note is Africa, where trees outside forests make up a large portion of the total growing stock; removals of this type of biomass could be costly, and may have ecological impacts that are more severe than fuelwood removals in closed forests.

Most advances have been made in ‘developed’ regions. This is evident by the distribution of bioelectricity generation, and industrial bioenergy use. We need a network to transfer technologies to ‘developing’ partners in order to most effectively utilize the resource. The FAO Programme on Wood Energy and IEA Bioenergy have similar goals and complementary spheres of activity. The IEA Bioenergy Implementing Agreement could be used as a template to develop a participatory network of developing countries interested in technology transfer and development of bioenergy. This type of network could facilitate meetings between member countries, organize seminars and presentations, commission reports on timely topics, and catalyze cooperative research between partners. Moreover, it could engender the type of policy discussion which would identify the most effective policies to develop bioenergy and biofuels in these regions. This type of approach has been highly successful within the IEA Bioenergy Implementing Agreement, and the authors feel that this approach has significant merit and could be applied in this case.

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