UNITED STATES WOOD BIOMASS FOR ENERGY AND CHEMICALS: POSSIBLE CHANGES IN SUPPLY, END USES, AND ENVIRONMENTAL IMPACTS

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ABSTRACT

As U.S. population and energy consumption increase, accompanied by growing concerns about global change and atmospheric pollution, there may be an opportunity for wood biomass to play a greater role in energy production if fossil fuel prices increase as projected by the U.S. Department of Energy. Forest biomass inventory is substantial in the United States and significant amounts of wood residue are generated from processing, construction, demolition, and municipal solid waste. Prospects for expanding the use of wood biomass for producing electrical power or ethanol will be enhanced by environmental needs and improvements in technology. Environmental needs include 1) reducing carbon emissions from fossil fuels and sequestering carbon; 2) removing wood from forests to improve forest health; 3) diverting urban waste streams from landfills; and 4) generating oxygenates, possibly from ethanol, for gasoline. Technology needs include improvement of short-rotation intensive culture techniques for plantations and improvement of electrical power and ethanol production processes. These efforts can help improve the comparative advantage of wood biomass feedstocks relative to fossil fuel feedstocks. Key environmental concerns will constrain the supply of wood biomass from forests and plantations; particularly concern for the effects of management for wood fuel on the diversity of plants and animals and on the depletion of soil and water resources.

In recent years, total U.S. energy and wood energy consumption have increased at a slower rate than have worldwide energy and fuelwood consumption. Total U.S. energy consumption has increased 1.3 percent per year since 1980 compared to 1.9 percent per year for world consumption (4,8). The United States consumes about 25 percent of the world energy total (91 exajoules (EJ) for the U.S. compared to 363 EJ for the world in 1992). Since 1980, wood energy consumption in the United States has increased 1 percent per year while world fuelwood use has increased about 2 percent per year. Currently, U.S. wood energy is about 3.2 percent of total energy consumption (3 of 93 EJ for 1993) (4,9,1 1). This percentage is about the same as in 1980.

The future of wood biomass use for energy and chemicals in the United States will be determined by a range of factors that include the following:

- changes in comparative price advantage of using current wood fuel sources in a range of end-uses (e.g., pulpwood) rather than as energy feedstocks;
- increasing general demands for energy and chemicals;
- abundance and availability of wood biomass sources;
- the need to reduce fossil fuel consumption because of negative environmental impacts.

Wood biomass is physically abundant in U.S. forests, and there are potential new and expanded sources from woodwaste production and short-rotation intensive culture (SRIC). A range of economic influences and environmental concerns will both promote and restrict the use of these sources. These include an increasing wood supply, new uses of biomass for energy, and certain environmental constraints.

The comparative advantage of wood feedstocks will change with changes in price for fossil fuels and with advances in technology to supply wood from plantations or to convert wood (improved combustion or electrical generation systems, or improved methods for converting wood to ethanol and other liquid, gaseous, or solid fuels). If pulpwood and oriented strandboard (OSB) continue to offer higher prices, then the wood will not be used for fuel. But wood fuel prices may become more competitive as fossil fuel prices increase.

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Even though fossil fuel prices have remained relatively low (below $20/barrel of oil (bbl); all figures are in 1994 dollars) since the mid- 1980s, and may remain low through the year 2000, the U.S. Department of Energy (DOE) projects that deflated world oil prices could increase 23 percent or more between 2000 and 2010: from $19/bbl in 2000 to $24/bbl for the Reference case, or from $26/bbl in 2000 to $33/bbl in the High Price case (9). Detailed projections in **Table 1** indicate which sectors may have the highest fuel prices.

The DOE has launched major research and development efforts to support production of ethanol from biomass to substitute for motor gasoline because gasoline prices may increase 15 to 28 percent by 2010, and to support electric power production from biomass because petroleum and natural gas prices may increase 33 to 84 percent for petroleum and 20 to 25 percent for natural gas by 2010 (9). However, the price of coal will remain relatively low for electrical utilities.

TABLE 1. — Energy prices by end-use sector: U.S. DOE Reference case projections to 2010.

Sector and fuel type	1993	2000	2010
	($/million BTUs)		
Residential			
Petroleum	7.92	8.84	9.63
Natural gas	6.07	6.08	5.89
Electricity	24.87	24.49	24.63
Commercial			
Petroleum	4.90	5.54	6.29
Natural gas	5.11	5.14	5.03
Electricity	23.24	22.43	22.27
Industrial			
Petroleum	4.24	4.77	5.52
Natural gas	2.82	2.57	3.66
Steam coal	1.45	1.30	1.33
Electricity	14.76	14.33	14.14
Transportation			
Motor gasoline	9.11	10.51	11.04
Electric utilities			
Petroleum	2.83	3.27	4.04
Natural gas	2.55	2.19	2.44
Steam coal	1.38	1.26	1.26

[a] Source: (9, pp. 78-79); 1994 dollars.

TABLE 2. — U.S. forest resources and removals.[a]

Category of land or biomass	Quantity[b]
Land area in 1992	
Timberland[c]	198×10^6 ha
Other forest land[d]	86×10^6 ha
Biomass on timberland	
Growing stock,[e] 1992	$10{,}575 \times 10^6$ tons
All live and cull trees, 1987	$16{,}179 \times 10^6$ tons
Saplings, 1987	$2{,}214 \times 10^6$ tons
Net growth of biomass on timberland in 1991	
Growing stock	292×10^6 tons
All live and cull trees[f]	950×10^6 tons
Roundwood removed in 1991	
Harvested for products	239×10^6 tons
Logging residue	47×10^6 tons
Other removals[g]	22×10^6 tons

[a] Sources: (5,21).
[b] Ovendry tons.
[c] Forest capable of producing 1.4 m^3/ha/year or more.
[d] Forest not capable of producing 1.4 m^3/ha/year or more.
[e] Volume in boles of trees 12.7 cm diameter inside bark or larger.
[f] Includes tops.
[g] Volume removed for noncommercial silvicultural treatments or land clearing.

These price trends, when compared to price levels and trends for wood fiber, may support increased wood production for fuel. This paper discusses factors that will influence the likelihood of an increase in the use of wood for fuel. We do not suggest a conclusive answer about a possible increase, but indicate the magnitude and direction of influences: the physical availability of forest and waste biomass, some recent Forest Service projections of forest roundwood and mill residue for fuel, the potential for expansion of wood supply from short-rotation plantations, potential expanded demand for wood exports, new uses of biomass for energy, and environmental constraints and concerns that influence wood burning.

Current levels of forest biomass in the United States

Wood for energy and chemicals can come from many sources. Forest sources of supply compete with non-forest sources to satisfy demands in many sectors: residential uses, heating of commercial buildings, and energy for industry. In addition, forest and woodwaste resources may be used as a feedstock for alcohol fuel production.

Wood sources, including forest sources, vary widely in abundance and availability. These sources include:

- forest roundwood;
- plantation wood grown by SRIC;
- wood residue from primary wood products mills (wood and bark from pulp- and papermills, sawmills, and panel mills);
- wood residue from secondary wood products mills (e.g., furniture, crafts);
- wood residue from construction, demolition, and discarded wood products;
- black liquor from wood pulpmills.

Current biomass availability

The forest biomass inventory of the United States is large and continues to increase. In addition to timberland, biomass includes tree tops, cull trees, and saplings. **Table 2** shows forest resources in terms of area of forested land and biomass on timberland. In 1991, net annual growth of growing stock on timberland was $612 \times 10^6 m^3$ (292×10^6 tons). In 1992, the growing stock on timberland was about 22,233 × $10^6 m^3$ (10,575 × 10^6 tons).

The volume of roundwood products harvested and removed from forests in 1991 was 506 × $10^6 m^3$ or about 239 × 10^6 tons (**Table 2**). A portion of this wood came from nongrowing stock on timberland and a small portion from other forest land. If we assume that the portion of growth from other forest land was small, then the net annual growth of biomass (live and cull trees) over removals on timberland was about 642 × 10^6 tons.

Only a small portion of the excess growth of biomass over removals is likely to be available for fuel with modest increases in the price of wood fuel. One category of roundwood that is somewhat more accessible is logging residue, i.e., wood left behind after logging operations. In 1991, logging residue was 98 *x* $10^6 m^3$ (47 × 10^6 tons) (**Table 2**) (22). Another accessible portion is wood cut for silvicultural operations but not made into products or wood cut for land clearin g (called "other removals" in **Table 2**). The remainder of the net excess growth over removals would only be accessible through harvest operations specifically for fuelwood.

DISPOSITION OF WOOD REMOVED FROM FORESTS

An estimated 19 percent (about 46 × 10^6 tons or 90 × $10^6 m^3$) of the roundwood removed from forests in 1991 was used directly for fuel (**Table 3**). This included use by all end-use sectors: households, commercial buildings, industry, and utilities. In addition, wood residue from primary wood processing was used for fuel: about 41 × 10^6 tons, or an additional 17 percent of roundwood harvested (21). A substantial portion of wood used in pulping was converted to black liquor and burned for energy. In all, up to half of the energy content of roundwood harvested may be converted to energy each year.

Another potential source of fuelwood is woodwaste. In 1993, construction and demolition generated 29 × 10^6 tons of woodwaste (**Table 4**). An estimated 12 × 10^6 tons could have been recoverable for energy or recycled products. Municipal solid waste (MSW) also contains wood. There was an estimated 12 × 10^6 tons of wood in MSW, and about one-third or 3 × 10^6 tons was burned in 1993 (16).

TABLE 3. — Disposition of roundwood harvested for products, 1992.[a]

Category of harvest/residue	Quantity
Roundwood harvested, total	239 × 10^6 tons
Roundwood fuelwood	46 × 10^6 tons
Roundwood for other products	193 × 10^6 tons
Wood and bark residue from primary wood processing, total	101 × 10^6 tons
Fiber products	38 × 10^6 tons
Fuel	41 × 10^6 tons
Other uses	16 × 10^6 tons
Not used	6 × 10^6 tons

[a] Source: (21).

TABLE 4. — Solid woodwaste by wood product use, 1993.

Category	Amount generated	Potentially recoverable
Woodwaste in municipal solid waste	12 × 10^6 tons	7 × 10^6 tons
Construction waste	6 × 10^6 tons	5 × 10^6 tons
Demolition waste	23 × 10^6 tons	7 × 10^6 tons

PROJECTIONS OF FOREST BIOMASS USE

GENERAL TRENDS

Overall, demand for forest products will continue to increase and the increase will be determined in part by growth in U.S. population, gross domestic product, and personal disposable income. The USDA Forest Service makes 50-year projections of supply and demand for roundwood and wood products, based in part on these economic determinants. For the 1993 Resources Planning Act (RPA) Assessment projections to the year 2040, the Forest Service used the following trends (13):

- population is projected to increase from 255 million in 1992 to 327 million in 2040;
- gross domestic product is projected to increase 2.6 to 2.7 percent per year;
- disposable personal income is projected to increase an average 2.3 percent per year.

Demands for roundwood and wood products will be moderated by improvements in wood-conserving technology, including recycling of paper and solid wood products, and by substitution of nonwood products for wood products.

Given projected macroeconomic and technological changes, the Forest Service projection for the 1993 RPA Assessment shows that growing stock growth will exceed growing stock removals for both softwoods and hardwoods. Inventory of growing stock (and total live tree plus cull tree) biomass will continue to increase at a rate of about 0.4 percent per year.

WOOD ENERGY USE PROJECTIONS

Forest Service projections for the 1993 RPA Assessment suggest that wood energy use could increase 39 percent between 1986 and 2040, from 2.8 EJ in 1986 to 3.6 EJ in 2030 and 3.9 EJ in 2040 (20) (**Fig. 1**). These projections are driven by projected increases in fossil fuel prices (6) that will gradually make wood fuel somewhat more competitive with fossil fuels. In contrast, the U.S. Department of Energy National Energy Strategy (NES) projects 5.8 EJ of use by 2030 (6,7). The projections exclude the use of wood to make alcohol fuels. The key differences between the projections appear to be: 1) electrical power production in the NES case will be 0.5 EJ in 2030, which is much higher than the Forest Service projection; and 2) NES uses projection methods that do not take into account the effect of expected increases in wood fuel prices (13,20). The Forest Service projection model recognizes that increased demand will raise wood fuel prices.

The portion of wood energy coming from roundwood is projected to increase more than the portion coming from woodwaste or black liquor. The supply of black liquor and mill waste will be restricted by paper and solid wood production. Therefore, the projected increases in wood energy will come more from roundwood. The projected increase in roundwood use is 55 percent between

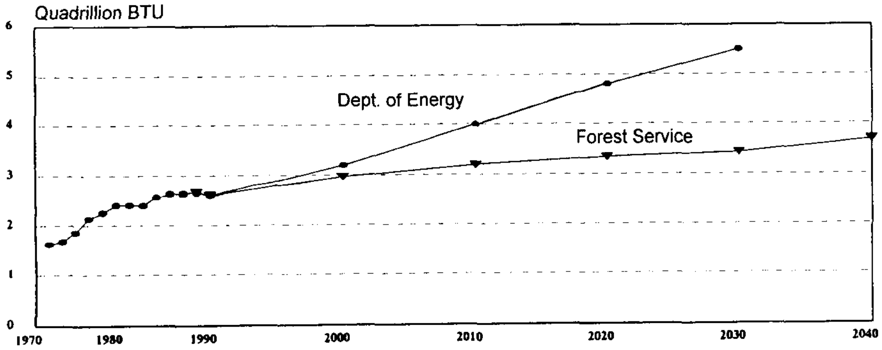

Figure 1. — U.S. wood energy use, 1972-1986, with projections to 2040 (6,14,20). 1 BTU = 1055 J.

1986 and 2040, or 88 to 136 × $10^6 m^3$. In contrast, total wood energy use is projected to increase 39 percent over the same period (20). There are limited opportunities to increase use of mill waste, construction and demolition waste, or wood in MSW, as indicated in the previous section. Thus, increases in wood for fuel use, if they are to occur, must come primarily from increases in roundwood, either from forests or from short-rotation plantations. The projected increase in roundwood use over the projection period is the same as the projected rate of increase for pulpwood use. However, 74 percent of pulpwood will come from growing stock compared to only 26 percent of fuelwood.

The fact that fuelwood can be derived to a great extent from nongrowing stock means that it could be used in operations to improve forest health where a large portion of the material to be removed is nongrowing stock. Harvest of wood for fuel may aid in improving forest health where there are attacks of insects or disease, or where there is buildup of wood that may lead to a forest fire.

Expansion of wood supply

Researchers in the United States have studied SRIC plantations in the United States since the 1970s. Cultural practices could involve various combinations of coppice production, intensive site preparation and weed control, high plant densities of from 1,500 to 4,000 treed/ha, fertilization, irrigation, and short rotation of ≤ 5 years to ≥ 8 years, All these variables result in uncertain and usually high costs of production compared to costs associated with use of other wood fuels from woodwastes and forest clean-up. Pricing is further complicated by varying land rents and tax treatment.

Because of the high cost of SRIC production, use of this technique for the sole production of fuelwood has been restricted to experimental plots in the United States. However, the situation could change and SRIC plantations, as well as plantations with longer rotations, could become important for the production of energy and other purposes.

A main reason for the increased interest in tree plantations is for their ability to lower carbon emissions to the atmosphere. The need to reduce carbon emissions was emphasized at the U.N. Framework Convention on Climate Change in Rio de Janeiro in June 1992. Nearly 120 countries and the European Union ratified the convention, and a sequel to the convention was held in Berlin in the Spring of 1995. The Berlin meeting imposed further pressures on industrial nations to reduce carbon dioxide emissions. The United States and others have pledged to reduce emissions by the year 2000 and thereafter.

The use, recycling, and landfilling of wood and paper products are also a good means to sequester carbon. However, given limited demands for wood and paper products, an additional means to offset carbon emissions is to grow some trees for use as energy.

The desire to attain emission-reduction goals could be a major factor in promoting efforts to produce renewable fuels that can replace fossil fuels, which constitute a good portion of the emissions problem. Plantations are a way of increasing wood fuel production. The planting of trees and establishment of plantations will also increase sequestration of carbon in living biomass and reduce carbon in the atmosphere. In 1992, 1×10^6 ha of trees were planted in the United States; there is a proposal to increase this number to 2×10^6 ha per year (17).

Export of wood and wood-derived fuel for energy

The United States currently exports pulp chips from Gulf of Mexico and Pacific ports. Wood fuels are not exported. However, the increased demand for wood fuels resulting from worldwide pressures to reduce fossil fuel consumption could bring prices of wood chip fuels to the level of pulp chips. With such an increase in value, wood fuel chips could become a commodity in international trade. Similarly, liquid fuels such as methanol and ethanol, and fuel enhancers such as ethyl tertiary butyl ether could be competitively manufactured from wood and have export value. Another proposal has been to make charcoal in the United States and ship it to developing countries where demands for charcoal fuel are great and wood supplies are meager.

New uses of biomass for energy

The use of wood biomass materials for energy in the United States has many positive aspects compared to the use of fossil fuels. These benefits include reduced use of nonrenewable fuels, less dependency on foreign fuels, stabilization of income in rural areas, and reduced carbon dioxide emissions to the atmosphere (19).

Electrical power generation

In the United States, wood biomass electrical power generation experienced dramatic growth in the late 1970s and early 1980s as a direct result of federal tax policy and state utility regulatory actions. For example, the Public Utilities Regulatory Policies Act of 1978 guaranteed small electricity producers that the major utility producers would purchase their surplus electricity at a price that is the same as what it would have cost the major utilities to produce the electricity themselves. Since 1979, the wood biomass generating capacity of the United States has more than tripled, to more than 6 GWe (7). Of the nearly 100 wood-fired plants typically ranging from 10 to 25 MWe, only one-third offer electricity for sale. The remainder are owned and operated by paper and wood products industries for their own use. Recent shortages of feedstock and the low price of oil and natural gas as well as hydropower have diminished the attractiveness of small-scale wood biomass electrical power plants.

A joint program by the U.S. Department of Energy and the Department of Agriculture has been initiated with a goal of doubling the capacity for generating electrical power from biomass by the year 2000. The program emphasizes using existing forest mill residues and harvesting specifically for power production (while maintaining sound forest management practices) and the use of dedicated feedstock systems and advanced combustion technologies.

A major difficulty for electrical power generation from biomass is the need for a guaranteed supply of fuel at a competitive price within a reasonable radius of a power plant. Based on the location of existing coal-fired plants that could be replaced or co-fired with biomass feedstocks and the available land area and quality to produce forest biomass, the northeast or northwest United States seem the most promising locations in the country to establish plants dedicated to generating electrical power from biomass (2).

LIQUID TRANSPORTATION FUELS

The impact of transportation fuels on air pollution in many large cities in the United States has been a major technical issue over the last decade. In an effort to reduce excessive ozone and carbon monoxide, amendments to the 1990 Clean Air Act mandated that gasoline contain oxygenates in certain cities with high levels of ozone and carbon monoxide. Ethanol is desirable as an oxygenate for gasoline although there is a controversy over emissions of some chemicals with ethanol use. This possible use for ethanol has renewed scientific interest in ethanol derived from lignocellulosic biomass (23).

The conversion of wood biomass to ethanol can be accomplished by several methods. Since the 1800s, cellulose and hemicellulose have generally been converted to sugars by dilute or concentrated acid-catalyzed hydrolysis and the hexose sugars then fermented to ethanol (15). Recently, technologies have been developed to hydrolyze wood with enzymes and to convert pentose as well as hexose sugars to ethanol. These methods each have positive and negative features based on yields, reaction time, by-products, and capital investment. One recent method that holds promise because of its higher rates and yields is the simultaneous saccharification and fermentation process developed by the Department of Energy's National Renewable Energy Laboratory in Colorado. A mixture of cellulase enzymes and yeasts is added to the cellulose material to catalyze decomposition and simultaneous rapid fermentation of this feedstock to ethanol. This process is in the pilot plant stage.

Although the United States has the potential for supplying enough cellulosic feedstock from wood biomass for ethanol conversion to replace nearly all the gasoline used in the nation, the price would not be competitive in today's marketplace (15). Research and development continues to reduce production costs.

Other types of liquid fuels from wood biomass, such as methanol and biocrude, have been developed, but they have not gained acceptance in the United States because of the relatively low price of petroleum. Methanol from natural gas is used in some city buses, commercial automobile fleets, and race cars.

RAW MATERIAL SOURCES FOR ENERGY AND CHEMICALS

The major change in the use of wood biomass for energy in the United States occurred during the oil shortage in the mid 1970s. Considerable emphasis was placed on making the wood and paper industry self-sufficient in terms of energy. By 1992, 56 percent of the estimated energy use in the paper industry was self-generated from spent pulping liquors, bark, and hogged fuel (l). Overall, the wood products industry generates more than 70 percent of its energy in-house from bark, sawdust, mill residues, and hogged chips.

Many technological advances in wood energy conversion in the last 20 years have focused on more efficient combustion systems, raw material and waste-handling systems, and co-generation operations. Although advanced technologies for producing fuel from wood biomass, such as producing biomass-derived gas and biocrude, have been developed at the research stage, none of these technologies has become commercially viable.

TABLE 5. — Chemicals and chemical derivatives from wood, 1993.[a]

Chemical	Production[b]
Tall oil fatty acids	
2 percent + rosin	98×10^3 tons
< 2 percent + rosin	134×10^3 tons
Tall oil rosin	260×10^3 tons
Tall oil	981×10^3 tons
Turpentine	$33{,}833 \times 10^3$ U.S. gal.

[a] Source: (18).
[b] 1 gal. = $3.785\ m^3 \times 10^{-3}$.

Many chemicals, mainly obtained from the effluent from pulpmills, are produced from wood biomass (**Table 5**). At various times, many other chemicals have been made from wood. Many of these chemicals can also be produced from petroleum as by-products from refineries. These include acetic acid, activated carbon, microcrystalline cellulose, dimethysulfide, ethanol, lignosulfonate, and methanol. Because of the low price of crude oil, many of the biomass-produced chemicals can be more expensive to produce than those from petroleum.

Research has been directed toward deriving other chemicals from wood biomass material. In addition to the work on ethanol, areas of interest include:

- Development of new polymeric adhesives using the carbohydrates in biomass;
- Use of fast pyrolysis to produce selected olefins and aromatic chemicals;
- Integration of energy production with specialized or intermediate chemical production through bioprocessing and more effective extraction of taxol from forest biomass.

ENVIRONMENTAL CONSTRAINTS AND CONCERNS

FOREST MANAGEMENT

The use and management of forests in the United States have been very controversial in recent years. Concerns about the impact of the forests on global climate, diversity of forest habitat, erosion of soils, aesthetic value of forested land,

and forest health have made our society take a new look at how forested land is managed and how humans interact with the forest (3). Since the U.S. population is predicted to increase by 17 percent over the next 25 years, consumption of forest products will necessarily increase as well (13). Greater consumption of forest biomass for energy will compound the impact on the forest. The United States will obviously have to produce or import more wood to satisfy the growing timber needs of the country. Those in the forest products area will be challenged to balance the impacts of the projected demand for more forest biomass in the United States, the increased demand for forest products from the rest of the world, and environmental constraints.

Atomspheric effects

Replacement of oil and coal with wood biomass for generating energy can have local and global effects. Local effects of burning wood include reduction in pollutants emitted to the atmosphere, such as reduced sulfur dioxide in biomass power plants compared to those using coal or oil. Emission factors for renewable fuels such as ethanol and methanol are complex and depend on the fuel mixture and application. Reductions of sulfur dioxide and nitrogen dioxide in liquid fuels from biomass compared to petroleum can be achieved.

In recent years, concerns have escalated about global climate change as a result of burning fossil fuels and deforestation. Scientists have predicted that increases in so-called "greenhouse gases" such as carbon dioxide, methane, and fluorocarbons could increase the average global temperature by 3°C by the year 2100 (19). Carbon dioxide is the greatest contributor to global warming. Forest biomass can serve as a fossil fuel offset, or carbon sink. If grown and used on a renewable basis, forest biomass can mitigate rising levels of atmospheric carbon dioxide.

Waste reduction

Most wastes generated in wood-processing plants are used internally in the industry, either for raw materials for other products or to generate energy. A large source of wood raw material is consumer waste, referred to as municipal solid waste (MSW). More than 178 million metric tons of MSW were produced in 1992; of this, about 38 percent was paper and paperboard and 6 percent was solid woodwaste (10). The pallet, container, and reel manufacturing industry produces more than 500 million new wood units per year. Many of these units are used only once and present a major disposal problem. An estimated 12×10^6 tons of wood was disposed of as MSW and about one-third (3×10^6 tons) was burned in 1993 (16). Using wood fiber from MSW to generate energy or to produce high-value wood fiber products could reduce the landfill problem.

Demolition wood from the destruction of old wood structures and homes contains contaminants such as lead from paint and treating chemicals used to preserve the wood. In 1993, construction and demolition generated 29×10^6 tons of woodwaste. An estimated 12×10^6 tons of construction and demolition waste may be recoverable for energy or recycled products. Effective use of this waste stream for an energy source will require research on economical methods of waste collection and preparation for combustion.

Impact on resource base

Forest biomass for energy can come from two types of forests: natural forest land that is already available and the conversion of nonforested land to plantations.

In recent years, emphasis has been placed on developing a sustainable supply of resources from U.S. forests while ensuring forest health and biological diversity. Not only is energy from wood biomass an important result of forest management, it can also provide new opportunities for management. In many parts of the United States, managing the forests so that the biomass could be used to generate energy would address many environmental and ecological objectives. For example, the removal of diseased and fire-damaged trees and forest slash would improve forest health and reduce the risk of catastrophic fire.

However, large-scale use of wood biomass raises concerns about many forest impacts. For example, the amount of wood biomass required for a 25-MWe power plant is on the order of the supplies needed for a pulp- and papermill. Considerations for impacts on habitat, wildlife, soil, and water must also be taken into account. Major removals from forests require an infrastructure of roads and facilities that affect the forest and, in many instances, adjacent lands. A certain amount of biomass must be left in the forest for soil quality and habitat diversity. The U.S. public is demanding a greater consideration of the interaction of such variables. This issue has generated considerable controversy, which has yet to be resolved.

There is a substantial area of nonforested land that could be used for SRIC plantations. Approximately 91 million ha of non-framed land in the United States is capable of supporting the production of 11 metric tonnes per hectare per year of wood- producing crops without irrigation (12).

The SRIC techniques for producing wood are designed to promote high biomass yields in a very few years. These techniques were developed in the middle 1960s, but the major improvements have been made in the last 15 years. Efforts to grow trees using SRIC have involved many wood species, such as black locust, willow, and silver maple, but the hybrid poplars and eucalyptus have shown exceptionally fast growth rates, up to 43 Mg/ha/year in experimental trials (22). SRIC plantations could provide a large source for energy feedstocks. So far, very few SRIC plantations have been established solely for energy use because they are not economically viable with current low fossil fuel prices.

Concluding remarks

With limited technological advances and current trends in fossil fuel prices, wood energy use in the United States is projected to increase 39 percent by the year 2040. Wood biomass may well play a greater role in energy production in the future. Prospects for expanding the use of forest biomass for producing electrical power or ethanol may be enhanced by such environmental considerations as the need to reduce carbon emissions and by improvements in technology such as SRIC culture for plantations. The large forest biomass inventory in the United States and concerted research efforts can help provide the means for meeting the increasing demand for energy.

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