Utilization of Forest Derived Biomass for Energy Production in the U.S.A.: Status, Challenges, and Public Policies

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Utilization of forest derived biomass for energy production in the U.S.A.: status, challenges, and public policies

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SUMMARY

Due to various environmental and economic benefits, renewable energy has been developed rapidly in the United States over the past several decades. In this study, the status, challenges, and public policies related to the development of bioenergy products from forest-derived woody biomass were reviewed. At present, existing utilization of forest biomass for energy purpose in the United States has been dominated by the forest products industry in generating heat and power for internal use. Proposed forest biomass utilization for energy has focused on producing motor biofuels. Key conversion technologies for woody biomass are still undergoing research and development and are not yet fully viable for commercial production. Other challenges for forest biomass utilization include high harvesting and transportation costs, overlapping demand for some forest biomass, and market promotion for new bioproducts. Since the 1970s, many laws and polices have been passed to help and guide the development of bioenergy in the United States. Woody biomass utilization has received increasing attention and assistance in recent years.

Keywords: bioenergy, forest landowner, legislation, public policies, woody biomass

Utilisation de la biomasse dérivée des forêts pour la production de l'énergie aux Etats-Unis: status, défis et lignes de conduites publiques

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Du fait des bénéfices économiques et environnementaux variés, l'économie renouvelable a connu un développement rapide aux Etats-Unis durant ces dernières décénnies. Dans cette étude, le status, les défis et les lignes de conduite reliés au développement des produits de la bio-énergie dérivés de la biomasse boisée provenant de la forêt sont examinés. L'utilisation actuelle de la biomasse forestière pour l'énergie aux Etats-Unis a été dominée par l'industrie des produits forestiers pour produire chaleur et énergie à usage interne. L'utilisation de la biomasse forestière pour l'énergie s'est concentrée sur la production des moteurs à fuel biologique. Les technologies de conversion-clé de la biomasse forestière sont encore en recherche et en développement, et ne sont pas encore viables pour la production commerciale. D'autres défis pour l'utilisation de la biomasse comprennent les coûts élevés de récolte et de transport, des demandes superposées pour certaines biomasses forestières, et la promotion des nouveaux produits-bio sur le marché. Depuis les années 70, de nombreuses lois et lignes de conduite ont été passées pour aider et guider le développement de l'énergie-bio aux Etats-Unis. L'utilisation de la biomasse forestière a reçu attention et assistance croissantes ces dernières années.

Utilización de biomasa de origen forestal para la producción de energía en Estados Unidos: situación actual, desafíos y políticas gubernamentales

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Debido a sus varias ventajas medioambientales y económicas, la energía renovable se ha desarrollado rápidamente en Estados Unidos en las últimas décadas. En este estudio se examina la situación actual, los desafíos y las políticas gubernamentales acerca del desarrollo de productos de bioenergía a partir de biomasa leñosa. En Estados Unidos, el uso de biomasa forestal para fines energéticos hasta ahora ha sido dominado por la industria de productos forestales, que genera energía para uso interno, y las propuestas para la utilización de biomasa forestal para la generación de energía se han centrado en la producción de biocombustibles para el transporte automóvil. Hay tecnologías importantes de conversión de biomasa leñosa que se encuentran todavía en investigación y desarrollo, y aún no están listas para la producción comercial. El uso de biomasa forestal debe afrontar también otros desafíos, como los altos costos de cosecha y transporte, la demanda de biomasa forestal en otros sectores, y los gastos de promoción para bioproductos nuevos. Desde los años 70, se han aprobado muchas leyes y políticas para fomentar y guiar el desarrollo de la bioenergía en Estados Unidos, y en los últimos años la utilización de la biomasa leñosa ha sido objeto de una mayor atención y ha recibido mayor apoyo financiero.

INTRODUCTION

Benefits associated with bioenergy products have greatly driven their development in the United States over the past several decades. These benefits can largely be classified into three groups: energy supply and national security, environmental protection, and economic development. Subsequent to the energy crisis in the 1970s, the supply of oil and its price have become increasingly volatile (Duffield and Collins 2006). As a result, the bioenergy industry in the United States has been expected to diversify energy supply sources and reduce the reliance of the economy on imported oil. In contrast to fossil fuels, the environmental benefits of bioenergy in terms of reduction of greenhouse gas, acid rain, and smog have been widely documented (Cook and Beyea 2000). Furthermore, new bioenergy industries can also boost economic development by creating innovative technologies and increasing employment and income nationwide (Domac *et al.* 2005).

Bioenergy has become a major component of the move toward renewable energy. Renewable energy can be produced from several sources: hydroelectric power, biomass, geothermal, solar, and wind (Energy Information Administration 2006). Biomass includes any sort of organic materials, such as trees, grasses, agricultural crops and residues, and animal wastes (Nazzaro 2005). In particular, woody biomass has ligno-cellulosic content and differs in this from some agricultural crops (e.g., corn, soybean). Woody biomass mainly includes forest biomass, woody and perennial herbaceous crops as well as agricultural residues. In this study, woody biomass mainly refers to forest biomass.

Among various renewable energy sources, biomass is the only one that can produce liquid fuels. Bioethanol converted from corn and biodiesel from soybean have been produced commercially (Eidman 2006). However, both the current and future potential supply of agricultural crops for energy production is relatively small in the United States, compared to the large demand for motor fuels (NRC 1999, Collins 2006). Therefore, other biomass sources for renewable energy production are needed. In this regard, the utilization of woody biomass from forests is especially promising. With 504 million acres of timberland and other forest land, there are abundant forest resources available for bioenergy production in the United States (Smith *et al.* 2004, Perlack *et al.* 2005, Energy Information Administration 2006). The forestry community also perceives the utilization of forest biomass as an opportunity for improving forest health and stimulating the economic development in rural America.

The objective of this paper was to review the status, challenges, and public policies related to the development of bioenergy products from forest-derived woody biomass in the United States. Specific objectives were to: (1) understand existing and potential technologies related to forest biomass and its utilization; (2) identify major challenges of utilizing forest biomass; and (3) review public policies promoting the development of bioenergy since the 1970s and, in particular, the utilization of forest biomass over the last 10 years. The focus of this study is the public policies for forest biomass utilization in the United States. An understanding the technology choices and challenges of utilizing forest biomass will help us comprehend the logics behind the evolution of these public policies. In addition, while woody biomass can be supplied by replanting energy crops such as short-rotation poplar on forest land (Sedjo 1997, Volk *et al.* 2004), forest-derived woody biomass in this study mainly refers to these from a joint production process on existing forests (i.e., timber versus tree branch/top).

METHODOLOGY

To fulfill the study objectives, an extensive review of the literature and governmental documents were conducted to collect relevant information. Specifically, the development of conversion technology and challenges for utilizing forest-derived biomass have been documented and discussed in the literature comprehensively. For public polices related to forest biomass, both the literature and governmental websites were searched. Major governmental websites were scrutinized, including these for the United States Congress (http://www.senate.gov; http://www.house.gov), the Library of Congress (http://thomas.loc.gov), and similar state legislative websites.

Several statistical sources provided the descriptive data for the study. The statistics from U.S. Department of Energy (Energy Information Administration 2006) provided detailed statistics of renewable energy production by source and over time in the United States. The Timber Mart-South database (Norris 2006) has reported timber price data for the southern United States since 1977. In addition, U.S. Bureau of Census (2005) reported statistics of the forest products industry. Wear *et al.* (2007) analyzed the timber market in the southern United States, including the price and quantity of pulpwood.

BIOPRODUCTS FROM FOREST BIOMASS AND CURRENT UTILIZATION

Technology choices and bioproducts from woody biomass

There are several technologies for converting woody biomass to bioenergy products. In spite of various subtle differences, existing and potential technology choices can be classified into four major categories: combustion, fermentation, gasification, and pyrolysis (Gallagher 2006). Bioproducts resulting from woody biomass conversion include biopower (heat or electricity), biofuels (e.g., ethanol, diesel and oil), biochemicals, and others. These technologies usually generate several bioproducts simultaneously (Table 1).

Combustion of woody biomass is a mature technology and produces heat and electricity. It has been widely used in residential and industrial sectors (Bain and Overend 2002, Energy Information Administration 2006, Gallagher 2006).

TABLE 1 *Status and characteristics of primary existing and potential technologies used throughout the world for converting woody biomass to bioenergy products*

Technology	Products	Status and characteristics
Combustion	Heat, steam, and electricity	Commercially operated; widely employed by the forest products industry and electric sector to generate energy for industrial use
Fermentation	Ethanol, syngas, glucose, electricity	Technically feasible; various hydrolysis techniques for pretreatment available; cheap and efficient techniques under development
Gasification	Heat, electricity, methanol, ethanol, diesel, syngas, chemicals	Technically feasible; application limited by relatively high costs of gas cleaning and yield optimization
Pyrolysis	Biooil, gas, chemicals	Technically feasible; mostly considered as pretreatment option for longer distance transport

Sources: Bain and Overend (2002), Faaij (2006), Gallagher (2006)

Currently, both co-firing and direct-firing combustion technologies have been developed for industrial use. Co-firing refers to the practice of introducing forest biomass as a supplementary energy source in boilers. Mixed with coal and burned in existing boilers, forest biomass can extend conventional fuels for producing electricity and heat, and simultaneously reduce pollution from carbon dioxide, sulfur, and nitrogen oxides. In comparison, direct combustion of forest biomass can also produce steam in the heat exchange sections of boilers, and both electricity and heat can be generated (Bain and Overend 2002).

Fermentation is a biochemical transformation process of carbohydrate materials to yield products such as alcohol. After 30 years of development, fermentation technology of ethanol production from corn has become mature and widely adopted in the corn-ethanol industry in recent years (Gallagher 2006). Similarly, fermentation of woody biomass can also produce ethanol. However, conversion is much more difficult for woody biomass than for corn and starch due to the presence of lignin component of wood. Hydrolysis is usually applied prior to fermentation of sugars (Faaij 2006). For example, a water-based technology for wood chips and ethanol production has been proposed for wood-based biorefineries in New York state (Liu *et al*. 2006). At present, cheap and efficient hydrolysis techniques are still under development and some fundamental issues (e.g., pre-treatment of woody biomass materials) need to be resolved (Yacobucci 2001, Gallagher 2006). As a result, fermentation technology with hydrolysis pretreatment techniques for woody biomass is still not yet commercially viable.

Gasification as a general means to convert a diversity of solid fuels (e.g., coal) to combustible gas has received considerable attention for many decades in the U.S. and worldwide (Bain and Overend 2002, Faaij 2006). After high-temperature gasification, biomass may yield an array of products, including heat, electricity, methanol, ethanol, diesel, syngas, and a variety of chemicals. To produce heat and power, gasification technology involves devolatilization and conversion of biomass in an atmosphere of steam to produce a medium or low calorific gas. This gas then becomes fuel for combined cycle power generation. A number of factors influence gasifier design, including gasification medium, gasifier operating pressure, and gasifier type. Besides heat and power production, in recent years, there has been increasing interest in using gasification to produce vehicle fuels from biomass. Technologically, that is even more challenging because gas cleaning needs to be more effective to protect downstream catalytic gas processing equipment. At present, the main challenges for commercial biomass gasification are gas cleaning, scale-up of processes, yield optimization, and process integration.

Pyrolysis is a chemical decomposition process occurring under high temperatures (Faaij 2006). For pyrolysis treatments, woody biomass inputs are reduced to approximately sawdust size and heated up to 650 °C for 0.25 to 2 seconds in the absence of oxygen, followed by rapid cooling to condense resultant vapors. This treatment fractures the molecular bonds and converts the biomass to liquid, termed pyrolysis oil or biooil. Yields of biooil vary but generally range from 60% to 70%. Non-condensable vapors exit into the atmosphere; it can be flared off or often heated and rerouted into the reactor as a heat carrier. About 10% to 15% of the pyrolyzed biomass is charcoal. The charcoal can be used as fuel to produce the required high temperature so that the process is nearly energy neutral. Biooil from pyrolysis can be used as fuel in any static heating or electricity generation applications, and for production of a range of specialty and chemical commodities (Faaij, 2006). In recent years, given the high energy density of biooil compared to untreated woody biomass, reducing transportation costs has greatly motivated the development of this technology. Currently, small and transportable pyrolysis equipment are in the pilot phase and some centralized pyrolysis facilities have started commercial biooil production (Bridgwater 2005).

Current bioenergy production and woody biomass utilization

At present, utilization of biomass for renewable energy production has two focuses: heat/ electricity from forest biomass for the industrial/utility sectors, and bioethanol and biodiesel from agricultural crops for the transportation sector. Statistics from the Energy Information Administration (2006) in the Department of Energy bear this out well. In 2004, renewable energy production reached 6.1 quadrillion, or 6% of all energy supply and consumption in the United States. By source, 47% of renewable energy was from biomass (i.e., approximately 3% of the total energy supply), 45% hydroelectric power, 6% geothermal, 2% wind, and 1% solar. Biomass became the leading source of renewable energy production over hydroelectric power for the first time in history, with 70% of bioenergy produced from wood.

In 2004, by energy use sector, the industrial and utility sectors continued to dominate both renewable energy production and consumption. Most industrial biomass utilized was black liquor and wood waste by the forest products industry for the production of heat and steam (Energy Information Administration 2006). In the pulp and paper industry alone, wood waste produced 339 trillion BTUs of energy while black liquor produced 820 trillion BTUs. In total, the forest products industry (i.e., mainly the lumber and paper and allied products industry) consumed 89% of the total industrial biomass energy produced in 2004. In the utility sector, biomass also played an important role even though conventional hydroelectricity still dominates renewable energy production in this sector. In 2003, 106 electricity generating plants burned both biomass and coal. Many plants also used biomass as a small fraction of inputs in attempting to reduce emissions, without making major retrofit investments.

Compared with the industrial and utility sectors, the transportation sector had the greatest increase in consuming renewable energy in 2004, even though the total amount was still small (Eidman 2006). Biofuels utilized include ethanol, diesel, methanol, and others. Currently, only bioethanol from corn and biodiesel from soybean and grease are commercially produced on an industrial scale. Bioethanol has been of key interest, especially in its role as an alternative to methyl tertiary butyl ether (MTBE), which may leak from underground gasoline storage tanks into ground water and has been determined as a potential health risk to human beings (Yacobucci 2006). Bioethanol contains 35% oxygen and can improve fuel combustion, thus reducing the emission of carbon monoxide and harmful air pollutants (Duffield and Collins 2006). Bioethanol has been used either as an additive in gasoline (e.g., E10 – 10% ethanol and 90% gasoline blend), or as a substitute for gasoline (e.g., E85 – fuels with at least 85% of ethanol). In addition, biodiesel, a diesel fuel substitute from soybean, vegetable oils, or animal fats, is also of interest. It is environmentally friendly, being nontoxic and bio-degradable.

The production of bioethanol and biodiesel has increased rapidly in recent years. In 1990, only 850-million gallons of ethanol was produced in the United States (Graf and Koehler 2000). In 2000, 6% of corn crops were converted into 1.6 billion gallons of ethanol. In 2006, about 20% of corn crops were converted into 5 billion gallons of ethanol (Collins 2006). For the first time, corn used in ethanol production has been equal to the amount of corn exported in 2006/07. In addition, according to U.S. Department of Agriculture (USDA), 0.91 billion gallons of biodiesel were produced in 2005, tripling the production in the previous year (USDA 2006).

In summary, forest biomass has been mainly used by the forest products industry and the utility sector for generating heat, steam, and electricity for industrial use. The successful development of the bioethanol and biodiesel industry in the U.S. has clearly demonstrated that the market for bioenergy products from woody biomass is also promising. In fact, the amount of bioethanol and biodiesel from agricultural crops is relatively small, compared to the 140 billion gallons of fossil-based motor fuels consumed in 2005. The Biomass Research and Development Technical Advisory Committee, a panel established by the U.S. Congress, envisioned a 30% replacement of current petroleum consumption in the United States with biofuels by 2030 (Perlack *et al.* 2005). Such large scale liquid-fuels replacement must utilize all available biomass resources, including these derived from forests.

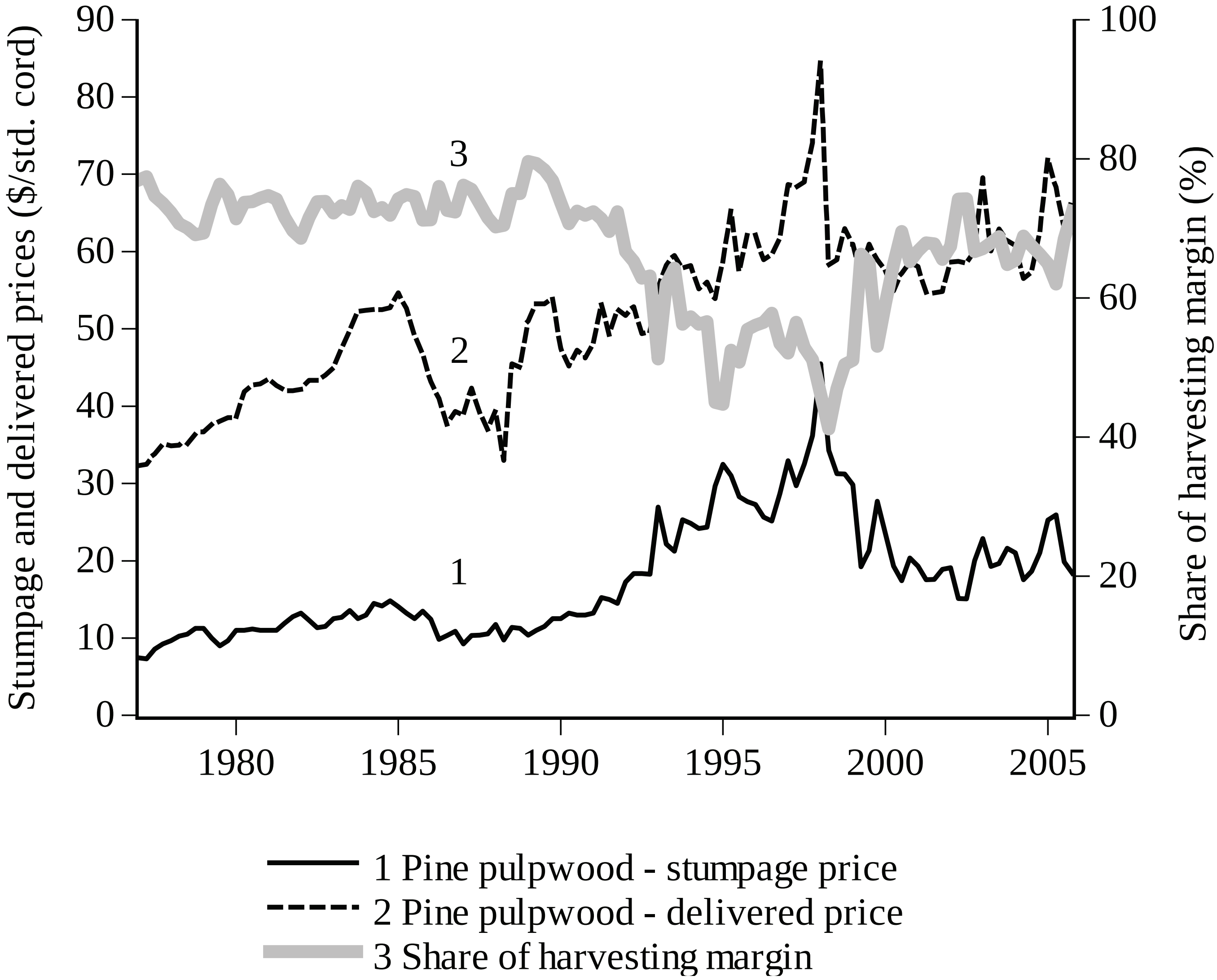
CHALLENGES OF FOREST BIOMASS UTILIZATION

Given the large demand for renewable energy, understanding the challenges to fully utilizing forest biomass is imperative for guiding successful development. At present, among the various challenges that forest biomass utilization faces, some (e.g., technology constraints) are similar to those that have occurred in the utilization of other renewable materials (e.g., corn). However, some are unique to forest resources.

The first major challenge of utilizing forest biomass is the relatively high costs of harvesting and transportation, also referred to as harvesting margin (Grado and Chandra 1998, Sun and Zhang 2006). Pine pulpwood can provide a good base for comparison (Figure 1). From 1977 to 2005, the average value of pine pulpwood in Mississippi was \$17.6/standard cord (std. cord) for standing timber and \$51.7/std. cord for delivered timber (Norris 2006). Defined as the difference between the stumpage and delivered prices, the harvesting margin ranged from \$23.3 to \$48.4, with a mean of \$34.1/std. cord. The share of the harvesting margin in delivered price ranged from 41.2 to 79.6%, with a mean of 67.1%. Therefore, on average, two-thirds of the delivered price of pine pulpwood in Mississippi has been harvesting and transportation costs.

In comparison, forest-derived biomass materials for bioenergy usually have small sizes. In an aggregate evaluation of biomass supply, Perlack *et al.* (2005) reported that with modest changes in land use and forestry practices, U.S. forest lands (excluding parks and wilderness) could sustainably produce 368 million dry tons (MDT) of biomass annually. This projection included 145 MDT of residues from sawmills and paper/pulp mills, 64 MDT from logging and site clearing operations, 60 MDT from fuel treatment operations to reduce fire hazard, 52 MDT of fuelwood harvested from forests, and 47 MDT of urban wood residues. This implies that similar to pulpwood, many forest biomass materials are

FIGURE 1 *Stumpage prices, delivered prices, and the share of harvesting margin in delivered price of pine pulpwood in Mississippi from 1977 to 2005. Source: Norris (2006)*



costly to be collected, and some of them (e.g., tree branches) may be even more expensive (Nazzaro 2005).

The second challenge of forest biomass utilization is technology constraints. Combustion of forest biomass can produce heat or electricity, which has been widely employed in the forest products industry and utility sector (Faaij 2006). However, other existing and potential technologies for woody biomass (e.g., fermentation, gasification, pyrolysis) may still be years away from commercialization at an industrial scale in the U.S. The scale and time schedule of forest biomass utilization will critically depend on current investments and ongoing progress of related technology development. Both the public and private sectors can play an important role in the process.

In developing various conversion technologies and related systems for woody biomass, it is noteworthy to consider simultaneously how to reduce the high harvesting and transportation costs constraints associated with forest biomass. Wood contains a lot of water so local processing can reduce the cost greatly. In this regard, pyrolysis has inherent advantages over other technologies. Pyrolysis systems can be modular in nature, allowing for factory construction near the input source, thus greatly reducing transportation costs. In contrast, fermentation and gasification facilities need to be built and operated like paper and pulp mills. In addition, to collect and handle biomass more efficiently in forests, systems and technologies for harvesting small trees and forest residues have been developed in North America and Scandinavia in recent years (Gingras 1995, Karha *et al.* 2003, Spinelli *et al.* 2007). These harvesting technologies will need to keep pace with the progress in conversion technologies (e.g., fermentation) to competently supply biomass as input.

Third, there may be overlap of demand for some forest resources between the existing forest products industry and the proposed forest biomass industry. As a vital sector of the U.S. economy, the forest products industry had 1.63 million employees in 2002, or 11.1% in total manufacturing industries, and $319 billion of the value of shipments, or 8.1% in total (U.S. Bureau of Census 2005). One possible demand overlap is about mill residues. U.S. wood processing mills generate approximately 91 million dry tons of residues each year (e.g., bark, chunks, slabs, sawdust) (Perlack *et al.* 2005). These materials are desirable for bioenergy production in terms of physical properties: clean, uniform, concentrated and low moisture content. However, most of these materials have already been used as inputs for manufacture or as boiler fuel for energy (Perlack *et al.* 2005).

The other potential overlap is about small diameter trees. At present, both the demand and price for pulpwood are low in the United States (Wear *et al.* 2007). For instance, inflation-adjusted prices for softwood pulpwood in the southern United States had fallen to their lowest level since 1997. Therefore, in the short term, demand of small trees

TABLE 2 *Major incentives and regulations related to biomass utilization in the United States since the 1970s*

Year	Public Law #	Name	Key provisions
1976	94-580	Resource Conservation and Recovery Act	Set up mandates and requirements to create demand for biofuels
1978	95-617	Public Utility Regulatory Policies Act	Encouraged the use of new technologies and alternate fuel sources
1978	95-618	Energy Tax Act	Exempted the full gasoline excise tax for 10% gasohol
1980	96-223	Crude Oil Windfall Profits Tax Act	Provided tax credits to biofuel producers and retailers
1980	96-294	Energy Security Act	Authorized insured loans, price guarantees and purchase agreements for alcohol production
1982	97-424	Surface Transportation Assistance Act	Raised the excise tax exemption for 10% gasohol and provided a full exemption for E85
1984	98-369	Deficit Reduction Act	Increased excise tax exemption for 10% gasohol
1986	99-514	Tax Reform Act	Reduced the tax exemption for E85 from $0.09 to $0.06 per gallon
1988	100-494	Alternative Motor Fuels Act	Promoted federal government acquisition of alternative fueled vehicles; Established commercial demonstration programs for alternative fuel heavy-duty trucks
1990	101-508	Omnibus Budget Reconciliation Act	Offered a tax credit to ethanol producers and reduced the gasohol excise tax exemption
1990	101-549	Clean Air Act Amendments	Established Clean Fuel Fleet Program
1992	102-486	Energy Policy Act	Established alternative-fueled-vehicle purchase requirements for federal, state, and fuel provider fleets; Established tax incentives for private purchase of alternative-fueled vehicles
1998	105-388	Energy Conservation Reauthorization Act	Provided Biodiesel Fuel Use Credits to fleet operators using neat biodiesel or B20 over certain amount
2000	106-224	Biomass Research and Development Act	Established a Biomass Research and Development Initiative to improve productivity and sustainability of production
2002	107-171	Farm Security and Rural Investment Act	Promoted production and consumption of bioproducts; Stimulated biomass production and biorefinery technology improvement
2003	108-148	Healthy Forests Restoration Act	Established grant programs to reduce the risk of catastrophic wildfires on forestlands
2004	108-357	American Jobs Creation Act	Provided tax credits to encourage the sale of ethanol and biodiesel
2005	108-447	Consolidated Appropriations Act	Authorized funds to encourage using biomass from national forest lands
2005	109-59	Transportation Equity Act-A Legacy for Users	Reauthorized major highway and transit programs; Provided credits on alternative fuels
2005	109-190	Energy Policy Act	Provided tax credits and set up programs to encourage biofuel production; Foster the research and development of woody biomass conversion technology

Source: Duffield and Collins (2006), Gielecki et al. (2001), Nazzaro (2005), EESI (2006), FNS (2005) for bioenergy production is particularly welcomed by forest landowners and it can certainly be met by the market supply. In the long term, the potential competition will depend on the scale of forest biomass utilization, similar to the current competition for corn between food processing and ethanol production.

Fourth, as a latecomer to the bioenergy industry, increased production of liquid fuels from forest biomass must develop an industry and market share of critical mass. For the corn-ethanol industry, it has taken many years for enzyme costs used for fermentation to fall to a level low enough for commercial production. In addition, the corn-ethanol industry also has acquired many public subsidies to grow to its current size. Similarly, it may take years for the commercial utilization of woody biomass for bioenergy to develop core technologies, demonstrate the potential for large-scale industry production, promote bioproducts, and compete with existing products for a market share. Public policies, similar to the corn-ethanol industry, have been expected to play a positive role in guiding and assisting the development of woody biomass utilization.

PUBLIC POLICIES AND PROGRAMMES FOR BIOENERGY AND FOREST BIOMASS

Public policy is the purposeful action that governments take to deal with an issue whereby it commits the authority of governments to a course of action over time (Cubbage *et al.* 1993). In recent years, with the increasing demand for bioenergy products and various challenges of biomass utilization, public policy has played a great role in the United States.

Since the 1970s, many government policies, laws, and programmes have been enacted or established for bioenergy development, and particularly, for forest biomass utilization in the last 10 years. These policies can be viewed from several perspectives: incentives vs. mandates, federal vs. state initiatives, and research vs. industry development. Their evolution can also be summarized by individual bioproducts or over time. To achieve the study objectives as stated, early bioenergy policies in the United States were examined as background information and forest biomass polices in recent years were analyzed as the focus. The following reviews were classified into several groups: early federal incentives for bioenergy and ethanol, recent federal incentives for woody biomass utilization, federal regulations, and state incentives and regulations. Major U.S. laws for biomass utilization have been summarized in Table 2.

Early federal incentives for bioenergy from agricultural crops

Financial incentives have been widely adopted by the federal government to promote the production and consumption of bioenergy products. They include tax incentives such as tax deductions, exemptions and credits, as well as loans and rebate programmes. These incentives can lower the cost of production or services, increase prices received by sellers, reduce prices paid by buyers, or create or expand the bioproduct market (Gielecki *et al.* 2001).

Since the 1970s, various policies have been enacted to promote biofuel production and consumption to secure energy supply and protect environment (Gielecki *et al.* 2001). Bioethanol and biodiesel fuels have been the focus of early legislation because of relatively mature technologies. As a result, much success of the corn-ethanol industry in the United States can be attributed to governmental incentive polices starting in the 1970s (Duffield and Collins 2006). One of the earliest energy statutes was the Energy Tax Act of 1978. It initially exempted the federal gasoline excise tax of 4¢ per gallon through 1984 on gasoline blended with at least 10% ethanol produced from biomass, acting as an effective subsidy of $0.40 per gallon for pure ethanol. Subsequent legislations raised, lowered, or extended the subsidy. The Crude Oil Windfall Profits Tax Act of 1980 established several alcohol fuel tax credits for biofuel producers and retailers. Moreover, it also allowed blenders to receive the same tax benefit via an income tax credit instead of the fuel tax exemption. The tax credit level currently stands at $0.51 per gallon through 2010. In addition, the Energy Security Act of 1980 provided insured loans to small ethanol plants that produced less than one million gallons per year. It also authorized price guarantees and purchase agreements for alcohol production. In addition, both the Surface Transportation Assistance Act of 1982 (STAA'82) and the Deficit Reduction Act of 1984 raised the gasohol excise tax exemption by $0.01 per gallon sequentially. The STAA'82 also provided a full excise tax exemption of $0.09/gallon for E85, fuels having an 85% content of ethanol.

After the late 1980s, rates of tax exemption and credit decreased somewhat, but various federal incentives have been extended and emphasis has been shifted to fostering growth of the ethanol market. The Tax Reform Act of 1986 and the Omnibus Budget Reconciliation Act of 1990 (OBRA'90) reduced the tax exemption for E85 from $0.09 to $0.06 per gallon and the gasohol excise tax exemption to $0.054 per gallon (Gielecki *et al.* 2001). However, the Alternative Motor Fuels Act of 1988 encouraged auto manufacturers to produce cars that could be fueled by alternative ethanol fuels. It offered credits to automakers that could meet certain fuel efficiency standards. The OBRA'90 also provided a tax credit of $0.1 per gallon to ethanol producers of up to 15 million gallons in a year. Furthermore, the Energy Policy Act of 1992 extended the gasohol excise fuel tax exemption and the income tax credit to blenders containing less than 10% ethanol. It also created a new federal tax deduction for individuals or businesses purchasing alternative-fueled vehicles, and a tax deduction for investing in equipment for storing and dispensing clean fuels.

Similar to bioethanol, tax credits for biodiesel were also offered. The Energy Conservation Reauthorization Act of 1998 provided one alternative-fueled-vehicle credit to fleet operators for using 450 gallons of neat biodiesel, or 2 250 gallons of B20 (i.e., at least 20% biodiesel blended). Overtime, these laws have expanded the technologies covered, increased the credit amount, or extended the time period (Gielecki *et al.* 2001).

Recent federal incentives related to woody biomass utilization

In recent years, increasing federal policies have addressed the utilization of forest biomass for bioenergy production. First of all, the Biomass Research and Development Act of 2000 (Title III of the Agricultural Risk Protection Act) addressed the utilization of trees, wood, wood wastes and residues as feedstock for bioproducts. Grants were awarded to improve cellulosic biomass conversion technologies to biobased fuels and biobased products. The Biomass Research and Development Initiative provided annual funding of $49 million from 2000 to 2005.

The Farm Security and Rural Investment Act, commonly referred to as the Farm Bill, was first developed in the 1920s and has been reviewed approximately every six years. The 2002 Farm Bill included an energy title for the first time in history (Nazzaro 2005). It set up several programmes promoting bioenergy production and consumption (e.g., Federal Biobased Product Procurement Preference Program). It gave financial assistance to use trees, wood waste and wood residues for biobased industrial production. For example, Section 9003 established biorefinery development grants to assist the emerging technologies for the use of biomass, including lingo-cellulosic biomass so as to diversify markets for agricultural and forestry products. Section 9010 authorized annual funding of $23 million for the Commodity Credit Corporation Bioenergy Program from 2003 to 2007.

Severe wildland fires in recent years have motivated the enactment of several acts and polices related to forest health and utilization of small diameter trees. The National Fire Plan of 2000 provided $43 million through the USDA Forest Service Economic Action Programs. A series of pilot projects were funded through the Forest Service Community and Private Land Assistance to promote biomass utilization for energy production. Under the Interior and Related Agencies Appropriations Act of 2001, the National Fire Plan's 10-Year Comprehensive Strategy was developed and addressed the use of small-diameter woody biomass to reduce hazardous fuels from forests. Efforts were also made to promote markets for these forest materials as a value-added outlet. In addition, the Healthy Forests Restoration Act of 2003 authorized $760 million a year for hazardous fuel reduction projects on federal land. It authorized $25 million each year from 2004 to 2008 for grants to improve the commercial value of forest biomass. An annual funding of $5 million was also authorized for developing technologies for forest biomass utilization, and reducing the costs of biomass purchase for wood-based products. Finally, the Consolidated Appropriations Act of 2005 authorized up to $5 million to provide incentives for biomass utilization on national forests to reduce fire risk.

The Omnibus Appropriations Bill of 2003 (Section 323) expanded stewardship contracting authority. It allowed the Forest Service and Bureau of Land Management to enter into contracts up to 10 years with small businesses, communities and nonprofit organizations to conduct necessary thinning and remove small trees/ undergrowth to reduce wildfire risk. Stewardship contractors can keep part of what they remove for value-added commodities or bioenergy production. In addition, the American Jobs Creation Act of 2004 contained tax incentives to foster utilization of forest biomass such as mill/ harvesting residues as well as precommercial thinnings materials.

The Energy Policy Act of 2005 reflected the energy policy of increasing and diversifying domestic energy production (Nazzaro 2005, Duffield and Collins 2006, EESI 2006). It established various programmes to foster research and development of woody biomass conversion technologies and biofuel production. It addressed the development of conversion technologies of making fuels from lignocellulosic feedstocks. It encouraged the demonstration of lignocellulosic feedstocks, as well as collection and treatment of various biomass feedstocks. Through the Advanced Biofuel Technologies Program, annual funding of $550 million from 2005 to 2009 has been authorized for demonstrating technologies for alternative transportation fuels production. The Cellulosic Biomass Program was created to encourage cellulosic ethanol production and provide for loans up to $250 million per production facility.

In particular, the Energy Policy Act of 2005 included stipulations specific to forest biomass utilization to prevent hazardous fires, reduce disease and insect infestation, and restore forest health. Section 210 established two grant programmes and $50 million was authorized each year from 2006 through 2016 to improve the commercial value of non-merchantable forest materials or precommercial thinnings for bioenergy production. The Biomass Commercial Use Grant Program has been intended to offset the costs incurred to purchase biomass as a raw material for electricity/ heat generation and transportation fuels production. It has provided grants at $20 per green ton to biomass facility owners for biomass procurement. The Improved Biomass Use Grant Program has targeted to improve project efficiency or develop cleaner technologies for biomass utilization, increase job creation, and reduce the hazardous fuels from forests.

Several administration agencies are behind these biomass utilization statutes for implementation. At present, the Environment Protection Agency and the Departments of Agriculture, Energy, and Interior are the major federal agencies involved. These agencies award grants, conduct research, and provide education and technical assistance (Nazzaro 2005). In 2005, the USDA Forest Service developed a woody biomass policy and assigned responsibility for overseeing and coordinating its woody biomass activities. It also created the Biomass Utilization Steering Committee to provide direction and support for agency biomass utilization. The Department of Energy has investigated the transformation of woody biomass to ethanol, and also supported demonstration production facilities through leveraged partnerships with private ethanol producers (Gielecki *et al.* 2001).

Federal regulations for production and consumption of bioproducts

In contrast to federal incentives, federal regulations have been another vital public policy instrument for biomass utilization. These regulations have provided directions and set up legal requirements for biofuel production and consumption. As early as 1976, the Resource Conservation and Recovery Act mandated all federal agencies and their contractors to purchase products designated by the Environmental Protection Agency when federal funds were used for purchases of $10 000 or more (FNS 2005). This action has created a great demand for biofuels because purchases from the federal government in total are a large share of the gross domestic product. Federal agencies were also required to establish affirmative procurement programmes for recycled content products and use fuels derived from waste as a primary or supplementary fuel. In addition, as part of the National Energy Act of 1978, the Public Utility Regulatory Policies Act of 1978 was enacted as a major mandate for renewable energy. It was intended to restructure the utility industry and encourage the use of new technologies and alternative fuel sources.

The Energy Policy Act of 1992 required certain government and state motor fleets to acquire alternative fuel vehicles that could operate on non-petroleum fuels (FNS 2005). Under this Act, consumption of 450 gallons of B100 or 2 250 gallons of B20 per year has been considered the same as acquiring one alternative fuel vehicle. In addition, up to 50% of the annual requirement could be met by biodiesel consumption. Furthermore, the Energy Policy Act of 2005 has included provisions that would have impacts on federal fleets (FNS 2005). It also had extensive coverage of renewable fuels such as cellulosic biodiesel. In particular, the Renewable Fuels Standard was enacted to require that a minimum amount of renewable fuel should be produced each year in the United States, increasing from 4 billion gallons in 2006 to 7.5 billion gallons by 2012. After 2012, the growth rate of renewable fuel production should equal that of gasoline production. It also required that at least 250 million gallons of renewable fuel be produced from woody biomass each year from 2013 on. Under the Cellulosic Biomass Program, one gallon of cellulosic ethanol would be counted as 2.5 gallons towards satisfying the Renewable Fuels Standard.

In addition to energy policies, environmental policies also have addressed biofuel consumption. The Clean Air Act Amendments of 1990 mandated oxygenated gasoline use to reduce air pollution from vehicles (Duffield and Collins 2006). The Oxygenated Fuels Program and the Reformulated Gasoline Program were established to control carbon monoxide and ozone problems, and both programmes required fuels of 2% oxygen. As a result, blending ethanol became a popular way for gasoline producers to meet new oxygen requirements. In addition, the Acid Rain Program set tighter restrictions on sulfur dioxide and nitrogen oxides and offered bonus emission allowances to utilities for biomass energy use.

The 2002 Farm Bill required federal agencies to establish affirmative procurement programmes to purchase USDA designated bioproducts when purchasing decisions would involve $10 000 or more (Duffield and Collins 2006). In addition, recent diesel fuel regulations by the Environmental Protection Agency could impact biodiesel demand as a lubricity additive. The low sulfur highway diesel fuel regulations have become effective since July 2006 and non-road diesel fuel regulations will be effective after June 2010. Reducing sulfur in diesel usually decreases fuel's lubricity. Fortunately, biodiesel could work as an excellent fuel lubricity agent and a small amount of biodiesel could restore the lubricity level of ultra-low-sulfur diesel fuel. This demand from the lubricity additive market will help increase the overall biodiesel demand.

President's Executive Orders, such as Executive Order 13101, 13149, and 13423, have also been strengthening the federal government's commitment to recycled and environmentally preferable products, including bioproducts. For example, Executive Order 13423 of 2007 mandated that at least half of statutorily required renewable energy consumed by federal agencies should come from new renewable sources. It also required agencies operating more than 20 vehicles to reduce annual petroleum consumption by 2% through 2015, relative to 2005 agency baselines. Moreover, it directed agencies to increase total consumption of non-petroleum-based fuels by 10% each year.

State incentives and regulations

State governments have played an increasing role in the development of biofuels. Individual states have created a range of incentives, regulations, and programmes to help spur the growth of biofuel production and utilization. Until the beginning of 2006, 45 states have provided various tax incentives, such as property or sales tax exemptions, corporate or personal tax credits, and excise tax incentives; 25 states have offered various loan or grant programmes; 37 states have enacted some categories of rules and regulations (NCSC *et al.* 2006). These biofuel policies have been diverse because individual states have different resource endowments and concerns.

Many states, such as California, Maryland, Missouri, Nevada, Ohio, Utah, Washington, and Wisconsin, have provided incentives to help establish new production facilities, or to create and expand market demand. One of the most aggressive states in stimulating renewable fuels has been Minnesota (Duffield and Collins 2006). In Minnesota, numerous loan programmes have been established, such as the ethanol production facility loan programme and the Agricultural Improvement Loan Program. These programmes have provided financial assistance to individuals, partnerships, or corporations, for either capital improvements, or the design and development of innovative energy conservation processes. Besides loan programmes, other programmes and incentives have also worked effectively. For example, the E85 Flexible Fuel Vehicle Program in Minnesota has helped construct a pilot market for E85. Accelerated depreciation tax incentives for renewable energy equipment have allowed corporate entities to use the double-declining balance and five-year depreciation schedule for renewable energy systems on state tax returns.

In Iowa, state legislation has been passed to provide tax incentives for biomass utilization and bioenergy production, and grants for E85 distributors (Gielecki *et al.* 2001, Duffield and Collins 2006). These actions have resulted in considerable in-state ethanol consumption and a significant export of ethanol to other states. In North Carolina, tax credits and grants have been provided for deployment of bio-refineries to small facilities, through direct cost-share payments or corporate tax credits for bio-refinery construction. In Texas, biodiesel has been exempted from the state diesel tax. The Texas Emissions Reduction Plan has provided grants for various types of clean air projects (e.g., new or re-powered alternative fueled vehicles and engines) to improve air quality in the state's non-attainment areas.

In Mississippi, the Department of Agriculture and Commerce has been authorized to make direct payments to ethanol and biodiesel producers for 10 years from the start date of production (Gielecki *et al.* 2001). The payment amount for each producer's annual production has been set at \$0.20 per gallon, with a maximum annual payment \$6 million and up to 30 million gallons per year for each producer. In Oregon, a residential energy tax credit has been provided to homeowners and renters purchasing alternative fuel vehicles or fueling systems. The tax credit has been 25% of the total cost of the vehicle or device, not to exceed \$750, and it might be claimed for a vehicle and a fueling system for a total of \$1 500.

Some states also have mandates on biofuel utilization (Gielecki *et al.* 2001). For instance, in Minnesota, the Renewable Fuels Standard was established in the Energy Policy Act of 2005 and has been followed and required for both ethanol and biodiesel. An Executive Order for biodiesel production in Minnesota also required that all diesel fuel sold must contain at least 2% biodiesel and new state vehicles must be able to be powered by clean fuels. Minnesota also has mandated that state ethanol plants must attain a total annual production of 240 million gallons per year to completely satisfy in-state demand. In Iowa, Executive Order 41 required state facilities to use E85 in flexible fuel vehicles, and increase the amount of biodiesel blended in all bulk diesel fuel purchases.

SUMMARY

A variety of benefits associated with bioenergy products have greatly driven their development over the past several decades in the United States. Currently, bioenergy accounts for nearly half of the renewable energy production and 3% of the total national energy supply. Bioethanol and biodiesel from agricultural crops have already been produced on an industrial scale, and their consumption has greatly increased as vehicle fuel. For forest-derived woody biomass, most energy has been generated as heat and electricity from wood by the forest products industry and utility sector using combustion technology.

As the supply of agricultural crops for energy production is limited relative to the huge energy demand in the United States, forest-derived woody biomass has been perceived as a major alternative source for renewable energy. At present, it has attracted great attention and the prospect looks promising. Nevertheless, this great potential of development still faces several challenges. First of all, among the major conversion technologies, only combustion has been relatively well developed. Fermentation, gasification, and pyrolysis technologies all have been under intensive research and development, and they have not yet reached commercial viability. In addition, the development of forest biomass utilization also needs to address the high harvesting and transportation costs, the overlapping demand of some biomass such as mill wood residues, and the market development for products from forest biomass.

Both federal and state governments have played a critical role in promoting the bioenergy development. The rapid growth of the crop-based biofuel industry in the United States can at least be partially accredited to government incentives and regulations. Since the 1970s, numerous legislations and regulations have been enacted to boost its development to secure national energy supply and improve air quality. Subsidies as well as technical and education assistance have been provided through various federal and state grant and assistant programmes.

Woody biomass utilization, especially for these from forest resources, has received growing attention from public policies in recent years. Grants and assistances have been provided through governmental programmes to foster the utilization of thinning materials and hazardous fuels from forests. Legislations have addressed the challenges of forest biomass utilization, such as biomass procurement, improvement of lingo-cellulosic technologies, and bioproduct market development. Yet these incentives are modest compared to those available for the corn-ethanol and biodiesel industry. Moreover, many programmes are not specifically designed for forest-derived woody biomass. This reflects the fact that bioenergy production from crops has been the emphasis for many years in the United States while as a new comer, forest biomass utilization will have a great potential to be supported in the future.

In summary, the crop-ethanol industry in the U.S. has established a good precedent for the ongoing development of forest biomass utilization. To assist technological development and the establishment of woody biomass industry, much stronger incentives as available for corn-ethanol and biodiesel industry are needed. Federal as well as state regulations are also critical in product consumption and market establishment. The enactment and implementation of legislations should also consider the diversity of forest biomass resources and forest ownership in different regions. With the further development of conversion technologies and supportive public policies for woody biomass, a forest biomass industry can be well expected in the United States in the near future.

REFERENCES

BAIN, R.L., and R.P. OVEREND. 2002. Biomass for heat and power. *Forest Products Journal* 52(2): 12-19.

BRIDGWATER, A.V. 2005. *Fast Pyrolysis of Biomass: A Handbook*. Vol. 3. Bio-energy Research Group, Birmingham, UK. 221 pp.

COLLINS, K. 2006. Hearing statements before U.S. Senate Committee on environment and public works. Washington, D.C. 7 pp.

COOK, J., and J. BEYEA. 2000. Bioenergy in the United States: progress and possibilities. *Biomass and Bioenergy* 18(6): 441-455.

CUBBAGE, F.W., J. O'LAUGHLIN, and C.S. BULLOCK. 1993. *Forest Resource Policy*. New York, NY. John Wiley & Sons, Inc. 562 pp.

DOMAC, J., K. RICHARDS, and S. RISOVIC. 2005. Socio-economic drivers in implementing bioenergy projects. *Biomass and Bioenergy* 28(2): 97-106.

DUFFIELD, J.A., and K. COLLINS. 2006. Evolution of renewable energy policy. *Choices* 21(1): 9-14.

EESI. 2006. U.S. biomass energy policy: 2005 year in review. Environmental and Energy Study Institute. 5 pp.

EIDMAN, V.R. 2006. Renewable liquid fuels: current situation and prospects. *Choices* 21(1): 15-19.

ENERGY INFORMATION ADMINISTRATION. 2006. Renewable energy annual 2004. Energy Information Administration, Washington, DC. 92 pp.

FAAIJ, A.P.C. 2006. Bio-energy in Europe: Changing technology choices. *Energy Policy* 34(3): 322-342.

FNS. 2005. Biodiesel Technical Reference Guide. The Federal Network for Sustainability. 32 pp.

GALLAGHER, P.W. 2006. Energy production with biomass: What are the prospects? *Choices* 21(1): 21-25.

GIELECKI, M., F. MAYES, and L. PRETE. 2001. Incentives, mandates and government programs for promoting renewable energy. U.S. Department of Energy, Energy Information Administration. 27 pp.

GINGRAS, J. 1995. Harvesting small trees and forest residues. *Biomass and Bioenergy* 9(1): 153-160.

GRADO, S.C., and M.J. CHANDRA. 1998. A factorial design analysis of a biomass to ethanol production system. *Biomass and bioenergy* 15(2): 115-124.

GRAF, A., and T. KOEHLER. 2000. Oregon cellulose-ethanol study: an evaluation of the potential for ethanol production in Oregon using cellulose-based feedstocks. Oregon Department of Energy. 96 pp.

KARHA, K., A. JOUHIAHO, A. MUTIKAINEN, and S. MATTILA. 2003. Mechanized energy wood harvesting from early thinnings. *International Journal of Forest Engineering* 16(1): 23-36.

LIU, S., T.E. AMIDON, R.C. FRANCIS, B.V. RAMARAO, Y. LAI, and G.M. SCOTT. 2006. From forest biomass to chemicals and energy: biorefinery initiative in New York State. *Industrial Biotechnology* 2(2): 113-120.

NAZZARO, R.M. 2005. Natural resources: federal agencies are engaged in various efforts to promote the utilization of woody biomass, but significant obstacles to its use remain. GAO-05-373 Uses of Woody Biomass. United States Government Accountability Office. 51 pp.

NCSC, EESI, and NUC. 2006. Development of workable incentive systems for biobased products, biofuels and biopower. North Carolina Solar Center, Environmental and Energy Study Institute, New Uses Council. 147 pp.

NORRIS, F. 2006. Timber Mart-South. Highlands, NC: Timber Mart-South, Inc.

NRC. 1999. *Review of the research strategy for biomass-derived transportation fuels*. Washington, D.C. National Research Council. National Academy Press. 60 pp.

PERLACK, R.D., L.L. WRIGHT, A.F. TURHOLLOW, R.L. GRAHAM, B.J. STOKES, and D.C. ERBACH. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply. Oak Ridge National Laboratory. Oak Ridge, Tennessee. 59 pp.

SEDJO, R.A. 1997. The economics of forest-based biomass supply. *Energy Policy* 25(6): 559-566.

SMITH, W.B., P.D. MILES, J.S. VISSAGE, and S.A. PUGH. 2004. Forest Resources of the United States 2002. USDA Forest Service Gen. Tech. Rep. NC-241, St. Paul, Minnesota. 137 pp.

SPINELLI, R., E. CUCHET, and P. ROUX. 2007. A new feller-buncher for harvesting energy wood: results from a European test programme. *Biomass and Bioenergy* 31(4): 205-210.

SUN, C., and D. ZHANG. 2006. Timber harvesting margins in the southern United States: A temporal and spatial analysis. *Forest Science* 52(3): 273-280.

U.S. BUREAU OF CENSUS. 2005. 2002 Economic Census, Manufacturing, Subject Series, General Summary. EC02-31SG-1. Department of Commerce, Washington, D.C.

USDA. 2006. Energy and Agriculture. United States Department of Agriculture. 31p.

VOLK, T.A., T. VERWIJST, P.J. THARAKAN, L.P. ABRAHAMSON, and E.H. WHITE. 2004. Growing fuel: a sustainability assessment of willow biomass crops. *Frontiers in Ecology and the Environment* 2(8): 411-418.

WEAR, D.N., D.R. CARTER, and J.P. PRESTEMON. 2007. The U.S. South's timber sector in 2005: a prospective analysis of recent change. Gen. Tech. Rep. SRS-99. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 29 pp.

YACOBUCCI, B.D. 2001. Alternative transportation fuels and vehicles: energy, environment, and development issues. Congressional Research Service. CRS Report for Congress. 25 pp.

YACOBUCCI, B.D. 2006. Alternative fuels and advanced technology vehicles: issues in congress. Congressional Research Service. CRS Issue Brief for Congress. 11 pp.