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Modeling future U.S. forest sector market and trade impacts of expansion in wood energy consumption

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A B S T R A C T

This paper describes an approach to modeling U.S. forest sector market and trade impacts of expansion in domestic wood energy consumption under hypothetical future U.S. wood biomass energy policy scenarios. The U.S. Forest Products Module (USFPM) was created to enhance the modeling of the U.S. forest sector within the Global Forest Products Model (GFPM), providing a more detailed representation of U.S. regional timber supply and wood residue markets. Scenarios were analyzed with USFPM/GFPM ranging from a baseline 48% increase to a 173% increase in annual U.S. consumption of wood for energy from 2006 to 2030, while consumption of fuelwood in other countries was assumed to increase by around 65% in aggregate. Results indicate that expansion in wood energy consumption across the range of scenarios may have little impact on U.S. forest sector markets because most of the expansion can be supplied by logging residues that are presently not being utilized and also mill residues that will increase in supply with projected expansion in wood product output in the decades ahead. However, analysis also suggests that forest sector markets could be disrupted by expansion in wood energy if much higher levels of wood energy consumption occur, or if projected recovery in housing demand and wood product output does not occur, or if more restrictive constraints or higher costs are imposed on wood residue utilization.

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Introduction

This paper describes an approach to modeling future U.S. forest product sector market and trade impacts of alternative wood energy scenarios that feature hypothetical policy-driven expansion in wood energy consumption. Such scenarios are relevant to current policy direction and policy choices, including the recently enacted U.S. Renewable Fuels Standard (RFS) promoting use of biomass for expanded production of advanced biofuels, and the possibility of a national renewable energy standard (RES) that could promote additional use of biomass fuel for electrical energy generation.

World energy markets are in transition, and a general consensus has emerged that suggests production of biomass energy could expand significantly in the coming decades, especially if global petroleum production peaks and declines (IPCC, 2000). A number of global studies have predicted this trend – for example, a recent MIT study projecting world biomass energy production increasing from 45 exajoules (45×10^{18} J) currently to a range between 221 and 267 exajoules by 2050 (Gurgel et al., 2007), and an IEA study predicting potential biomass energy production increasing to 200–300 exajoules by 2050 (Faaij, 2007). In general, global energy studies that project such large increases in biomass energy production share a common view that global petroleum production will peak sometime within the next couple of decades, resulting ultimately in market-driven global expansion of biomass energy and other forms of renewable energy.

In the meantime, national energy policies are beginning to promote expansion of biomass energy consumption, and hypothetical impacts of such policies may be analyzed by modeling market impacts of policy-driven expansion in wood energy consumption. In the United States, for example, national policies have been enacted, such as the 2007 Energy Independence and Security Act (EISA), or are proposed (a national renewable energy standard for electric power) that could expand wood use for liquid fuel production, electric power production, and thermal energy production. The purpose of this paper is to assess potential forest sector market and trade impacts that could result from increased wood energy consumption as influenced by current and potential national policies. In this study we varied projected wood energy consumption only for the United States, while we maintained constant growth rates for fuelwood consumption in all other countries though 2030. Our scenarios used the U.S. renewable energy projections from the 2010 U.S. Department of Energy Annual Energy Outlook (USDOE, 2010a), which incorporates the impact of the U.S. Renewable Fuel Standard (under EISA), and we also introduced a hypothetical national renewable energy standard (RES) for electric power.

Methodology

The U.S. Forest Products Module (USFPM) was created recently to enhance the modeling of the U.S. forest sector within the Global Forest Products Model, or GFPM (Ince and Buongiorno, 2007). We refer to the combined model as USFPM/GFPM, and we use it to provide more detailed analysis of regional U.S. timber supply, timber markets and wood energy markets within the context of global forest product markets. USFPM/GFPM is based on the most recent version of the GFPM, which was also recently used to analyze global wood energy scenarios (Raunikar et al., 2010). USFPM/GFPM retains general features of the GFPM methodology, which are briefly reviewed here, but USFPM introduces also some unique features as explained subsequently.

The GFPM is an economic model of the global forest sector that has been documented in detail (Buongiorno et al., 2003; Turner et al., 2006; Raunikar et al., 2010). USFPM/GFPM retains all global features of the GFPM, including modeling of global production, consumption and trade in 14 principal categories of forest products for 180 individual countries. The model represents supplies in each country of wood and non-wood fiber raw materials in the form of roundwood, recovered paper and non-wood pulp, and also production of intermediate wood pulp products, mechanical and chemical wood pulp, and production and consumption of forest product commodities including sawnwood (lumber), plywood, particleboard, fiberboard, newsprint, printing and writing paper, other paper and paperboard, and fuelwood. All product demands, except for fuelwood demand, are represented by price-elastic and GDP-driven demand functions in each country, while fiber raw material supplies are represented by price-elastic supply functions. Fuelwood demand in each country is represented by a price-elastic demand function with exogenously specified long-run shifts of demand based on scenario assumptions about global expansion in fuelwood consumption. Projected U.S. single-family housing starts are also included with U.S. GDP as an additional driver of U.S. demand for softwood lumber, softwood plywood and OSB (products that are used heavily in U.S. housing construction). Forest product production activities are modeled with fiber raw material input coefficients and other non-fiber unit manufacturing costs, while transportation activities are modeled with unit transport costs.

USFPM/GFPM solves a global spatial market equilibrium problem for selected years at periodic intervals over a multi-decadal time frame, and also simulates dynamic changes in supplies, demands, input coefficients and costs from period to period. Computation of the annual market equilibrium relies on Samuelson's (1952) observation that a spatial market equilibrium can be found by maximization of "social surplus", which is represented in USFPM/GFPM as the sum of producer and consumer surplus, the value of all end products in all countries minus the costs of raw material supply, the manufacturing costs, and costs of transportation (Raunikar et al., 2010; Buongiorno et al., 2003). Following Samuelson (1952) and Takayama and Judge (1971), the sum of producer and consumer surplus is given by the area under all of the demand curves up to the quantities demanded (Z_d) minus the area under all of the supply curves up the quantities supplied (Z_s), minus the sum of net manufacturing costs or marginal costs of production (Z_m) and minus the transportation costs (Z_t). Thus the objective function in USFPM/GFPM is summarized by the following formula (1):

$$\max Z = Z_d - Z_s - Z_m - Z_t \tag{1}$$

where

$$Z_d = \sum_k \sum_j \int_0^{D_{jk}} P_{jk}(D_{jk}) dD_{jk}$$

is total area under all product demand curves, or integrals of demand price (P) over the demand curves (D) for all forest products (k) that are consumed in all countries (j),

$$Z_s = \sum_k \sum_j \int_0^{S_{jk}} P_{jk}(S_{jk}) dS_{jk}$$

is total area under all supply curves, or integrals of supply price (P) over supply curves (S) for all fiber raw materials (k) that are supplied in all countries and subregions (j),

$$Z_m = \sum_k \sum_j \int_0^{Y_{jk}} m_{jk}(Y_{jk}) dY_{jk}$$

is total manufacturing costs or marginal costs of production for all intermediate and final products (k), computed as unit cost of production (m) times production quantity (Y) in all countries and subregions (j), and

$$Z_t = \sum_k \sum_j \sum_i c_{ijk} T_{ijk}$$

is total transportation costs for all intermediate and final products (k), computed as unit transportation cost (c) from origin country or region (i) to destination country or region (j) times the quantity transported (T), and in which all prices (P) and all costs (m and c) are expressed in a common real currency unit (real 2006 U.S. dollars).

Both the GFPM and USFPM/GFPM utilize the same modeling system, known as PELPS, which has been extensively documented and modified since the 1980s but has always employed Samuelson's approach to regional market modeling (Gilless and Buongiorno, 1985; Calmels et al., 1990; Zhang et al., 1993; Lebow et al., 2003). The latest version of PELPS used by USFPM/GFPM is called "qPELPS" (Zhu et al., 2009), and it employs quadratic programming and uses LINDOAPI©software to maximize the objective function subject to constraints (earlier versions of PELPS used linear programming).

The principal constraints in USFPM/GFPM are material balance constraints, which ensure in each period for each commodity and each country or region that total demand quantity plus the quantity used in manufacturing other products plus exports must be less than or equal to total supply quantity plus production quantity plus imports, as represented in general by the following inequality (2),

$$D_{ik} + \sum_{n} a_{ikn} Y_{in} + \sum_{j} T_{ijk} \leq S_{ik} + Y_{ik} + \sum_{j} T_{jik} \tag{2}$$

which includes on the left side the demand quantity (D_{ik}) of commodity k in region i, plus total quantity of commodity k consumed in manufacturing other products computed as the product of input coefficient (a_{ikn}) for commodity k in producing another commodity (n) times the quantity of other product produced (Y_{in}), plus total quantity of commodity k exported (T_{ijk}) to other regions or countries (j); and on the right hand side includes the quantity of commodity k supplied (S_{ik}), plus the quantity of commodity k produced (Y_{ik}), plus the total quantity of commodity k imported (T_{jik}) from other regions (j) to region i.

In addition to material balance constraints, USFPM/GFPM also employs for all other countries the same constraints on dynamic shifts in trade that were employed in the most recent version of the GFPM (Raunikar et al., 2010), in particular "trade inertia" constraints that limit annual changes in forest product trade flows for each country to small percentages that vary by commodity but are generally much less than ±10% per year. However, we found that such trade inertia constraints are excessively binding on U.S. trade, particularly from 2006 to 2010 when larger annual changes occurred in U.S. forest product trade flows during the global economic recession. Therefore, to permit less constrained and more realistic U.S. trade responses to shifts in global market conditions we relaxed the U.S. trade inertia constraints in USFPM/GFPM, allowing adjustments up to ±10% per year in U.S. trade flows for each forest product (imports and exports). The relaxation of U.S. trade inertia constraints significantly improved model accuracy in projecting U.S. forest product trade from 2006 to 2010. We applied the same ±10% inertia constraints for U.S. trade in roundwood and fiber raw materials. USFPM/GFPM also employs for all other countries the same model of long-run change in roundwood supply in relation to change in forest stock, and the same model of growth in forest stock and changes in forest land area for other countries as employed in the latest version of the GFPM (Raunikar et al., 2010; Turner et al., 2006).

However, USFPM introduces a number of unique modifications that provide much more detail in modeling U.S. forest product markets and U.S. regional timber supply and demand. These modifications equip USFPM/GFPM to provide a unique analysis of the U.S. forest sector market impacts of expansion in U.S. wood energy consumption, such as for example impacts on wood residue markets, stumpage markets, and resulting impacts on forest product revenues and trade.

USFPM is structured to provide a more detailed forest sector market analysis for the U.S. region within the GFPM (Ince et al., forthcoming). Each country in the GFPM is normally represented as a single region (Buongiorno et al., 2003). However, to model U.S. timber markets and trade in greater detail, several subregions of the United States are included in USFPM. New structural features were also introduced, including regional U.S. timber stumpage supply, timber harvest activities, delivered timber product outputs, and wood residue supplies, while the original GFPM data, assumptions, and structural features that apply to all other countries were retained. Thus, USFPM models U.S. forest product markets and timber markets in greater detail within an established global modeling framework, with USFPM entirely integrated into the GFPM. In other words, the GFPM is run each time that we run USFPM, producing a partial market equilibrium analysis of the entire global forest sector including global forest product trade.

In USFPM, we model U.S. timber supply and forest product production in three U.S. subregions – North, South, and West. Final product demand of the United States is modeled at the national level, and final products are imported to the U.S. national demand region. However, each U.S. subregion can import and export roundwood, recovered paper, and wood pulp as well as trade these raw material inputs amongst themselves. Each subregion can also export final products (lumber, plywood, etc.) to the rest of the world. This permits more accurate model solutions in cases where the United States is both an exporter and importer of products, such as wood pulp. For example, USFPM simulates accurately that the U.S. South and West are net exporters of wood pulp, while the U.S. North is a large net importer of wood pulp from other countries and from the other U.S. regions.

Another feature of USFPM is the addition of agricultural short-rotation woody crop (SRWC) supply. Potential SRWC supply is modeled by region based on regional estimates of feasible delivered wood costs, crop yields, and upper bounds on available acreage. Hardwood SRWC cost data and yields (circa 1990s) were based on Oak Ridge National Laboratory data for hybrid poplars (Walsh, 1998), while conventional softwood SRWC costs and yields were based on author estimates. We conservatively did not adjust SRWC costs or yields to reflect future gains in crop yields in this study, although such gains may be likely (and could increase SRWC supply for energy). Based on yield studies for hybrid poplar plantations, SRWC harvest volume was specified to be 75% pulpwood and 25% fuel feedstock (and all can go to fuel, depending on markets).

Detailed modeling of wood residue supply and demand is another unique feature of USFPM. The original GFPM models only roundwood supply (harvested timber products) and accounts for wood residue use only by adjustment of roundwood input coefficients for those products that use residues as inputs in addition to roundwood, such as particleboard or wood pulp. On the other hand, wood residues and potential impacts on wood residue markets of increasing wood energy use are important considerations in the U.S. forest sector. USFPM models supply of several different categories of wood residues: logging residues generated as by-products of timber harvesting, softwood and hardwood fiber residue by-products from lumber and plywood/veneer production (utilized as pulpwood or as input to particleboard production), and finally fuel residue by-products from lumber, plywood/veneer, and pulp production (representing bark, wood fines, and other residues typically used as fuel). Fiber residues are important feedstocks to U.S. particleboard, fiberboard, and pulp products, while fuel residues provided 60% of total U.S. wood fuel feedstock consumption in 2006. Logging residues can be recovered and used for energy in model projections whenever increasing demand for fuel feedstock makes the marginal cost of recovering residues economical. In this study we did not assume any subsidies for recovery of logging residues, but the marginal cost of logging residue recovery was specified to be just slightly higher than 2006 fuelwood prices (just above $25 per cubic meter including bark), and costs can also decline with increased logging residue output, so expansion in logging residue recovery will occur in scenarios with increasing demands for wood energy. However, we constrain recovery of logging residues to not more than 60% of available residue volume for practical forest management reasons (e.g., nutrient cycling, wildlife habitat protection).

In addition, USFPM includes cascading raw material substitution possibilities that allow higher value wood raw materials to be substituted for lower value materials if their market values change sufficiently to permit economic substitution. Ordinarily, higher value materials such as sawlogs are too expensive to be utilized in place of lower value materials such as pulpwood, and typically pulpwood is too expensive to be used for fuelwood. However, increasing demand for fuel feedstock or excess supplies of roundwood such as pulpwood could impact relative prices enough to make such product substitution economical. Thus, USFPM allows for example pulpwood and fiber residues to be used as fuel feedstock, if it becomes economical to do so.

We summarize unique aspects of wood energy modeling in USFPM by comparison to the modeling of fuelwood supply in other countries of the GFPM. For countries other than the United States, fuelwood supply consists of roundwood fuelwood plus any industrial roundwood that may be used as fuelwood if it becomes economical to do so (substitution of industrial roundwood for fuelwood can occur if projected equilibrium price of fuelwood becomes high enough). In USFPM, supplies of sawtimber and non-sawtimber tree volumes are converted by timber harvest activities into timber product outputs, including sawlogs–veneer logs, pulpwood, other industrial roundwood, and fuelwood, along with by-product logging residues. A fraction of logging residue (60%) can be recovered for energy if economical to do so, or otherwise is left in the forest. In USFPM we also model wood fiber and fuel residue supply as by-products from mills, such as the wood and bark residues of sawmills and plywood mills, some of which may be used for energy. Timber products such as pulpwood and materials such as fiber residues can be used for fuel feedstock but only if it becomes economical to do so (substitution can occur if relative prices converge). Wood fuel feedstock demand does not include energy generated from black liquor at kraft pulp mills, but the pulpwood and fiber input to pulp mills in our model fully accounts for supply and demand of all wood that is used at U.S. pulp mills, including wood used to generate black liquor energy at pulp mills.

In effect, UFSPM represents all important links in the wood energy supply chain for the United States, including traditional roundwood fuelwood and wood residues, plus potential future supplies of logging residues (if economical to recover), and other potential sources of wood energy such as pulpwood and agricultural SRWC. All U.S. timber supplies, residue supplies, and timber product outputs are calibrated to match actual data on regional timber harvest and residue output volumes as reported by the U.S. Forest Service (Smith et al., 2009). Roundwood fuelwood and industrial roundwood may be traded with other GFPM countries, but not residues, since only roundwood markets are modeled in other countries.

Wood energy demands are represented in USFPM/GFPM by price-elastic demand functions in each country, with long-run shifters of demand growth that we can vary by scenario. We adopted specific assumptions about future expansion in U.S. and global wood energy consumption for alternative scenarios. We adjusted wood energy demand growth for each scenario, in effect shifting the demand curves outward, until equilibrium wood energy consumption levels matched specified levels for each scenario.

Alternative scenarios

To project market impacts of alternative policies that affect U.S. wood energy demand, we developed a set of four alternative future scenarios based in part on U.S. renewable energy projections from the 2010 U.S. Annual Energy Outlook (AEO) (USDOE, 2010a).

Renewable energy projections and other key economic assumptions of our four scenarios are summarized in Table 1. Our scenarios differ from one another mainly in terms of assumptions about future expansion in U.S. wood energy consumption through 2030.

All of our scenarios include projected U.S. cellulosic biofuel output under the U.S. Renewable Fuels Standard policy (RFS) as projected by the 2010 Annual Energy Outlook (AEO) (USDOE, 2010a). However, the scenario labeled “HP” has a higher cellulosic biofuel demand projection from the AEO “High Oil Price” (HP) case, while the other three scenarios use the RFS biofuel projection of the AEO Reference Case. All of our scenarios include also additional biomass energy consumption under hypothetical national renewable energy standards (RESs) requiring either 10% (RES10) or 20% (RES20) of electric power to be generated from non-hydroelectric renewable energy sources by 2030. The scenario labeled “RES20 + EFF” assumes a similar energy policy but allows half of the non-hydro renewable energy to be in the form of more efficient combined heat and power, therefore requiring somewhat less biomass input to attain the 20% renewable energy requirement.

Our RFS + RES10 scenario is a likely baseline scenario because it largely reflects existing U.S. energy policies. It includes projected U.S. cellulosic biofuel output under the U.S. Renewable Fuels Standard policy (RFS) as projected by the 2010 Annual Energy Outlook (AEO) (USDOE, 2010a). It also includes additional biomass consumption sufficient to meet a national Renewable Energy Standard (RES) requiring 10% of electric power to be non-hydro renewable by 2030. This reflects the fact that some but not all U.S. states have RES policies, known as renewable portfolio standards, which vary by state but cluster generally in the area of a 20% requirement by 2020.

We assumed in all our scenarios that wood will account for 1/3 of the biomass required in the United States to meet RFS and RES energy goals (other sources of biomass, chiefly agricultural, are assumed to account for the remaining 2/3). Our assumption that wood will account for one-third of projected expansion in U.S. biomass energy is consistent with estimates from recent national energy studies. For example, wood was projected to account for about 30% of expansion in U.S. biomass energy according to the 2010 Annual Energy Outlook (USDOE, 2010b). Also, in a separate study, wood biomass supply needed to meet a 25-percent renewable portfolio standard for electric power combined with a 25-percent renewable fuel standard for transportation fuels was projected to be 28% of total biomass, while energy crops were 41% – a portion of which were short rotation woody crops (USDOE, 2007). The same study also projected wood energy use at about 160 million cubic meters above current use which is also close to the expansion projected in our highest wood energy demand scenario (an expansion of about 200 million cubic meters by 2030 in our RFS + RES20 + HP scenario).

Table 1
Renewable energy projections and other key economic assumptions.

Scenario	RFS + RES10	RFS + RES20 + EFF	RFS + RES20	RFS + RES20 + HP
Basis for U.S. wood energy projections	AEO Reference Case RFS, and RES10	AEO Reference Case RFS, and RES20 + EFF	AEO Reference Case RFS, and RES20	AEO High Oil Price Case RFS, and hypothetical RES20
Wood % of U.S. primary energy consumption in 2030	1.30%	1.60%	1.80%	2.50%
U.S. housing starts	AEO Reference Case			
U.S. GDP growth	AEO Reference Case			AEO High Oil Price Case
Global GDP growth	IMF (2006–2014), IPCC B2 Message (2015–2030)			
Fuelwood consumption in countries other than U.S.	Fuelwood consumption as a percentage of primary energy consumption remains constant (2006–2030) while energy consumption increases based on IEA projections, resulting in 65% increase in fuelwood consumption volume in total for all other countries			

Abbreviations for U.S. wood energy assumptions based on U.S. 2010 Annual Energy Outlook (AEO):
RFS, U.S. cellulosic biofuel output under the U.S. Renewable Fuels Standard (RFS) as projected by AEO; RES10, Hypothetical Renewable Energy Standard, 10% of electric power is non-hydro renewable by 2030; RES20, Hypothetical Renewable Energy Standard, 20% of electric power is non-hydro renewable by 2030; RES20 + EFF, Similar energy policy but half of biomass energy is efficient combined heat and power; HP: U.S. GDP growth and higher biofuel output based AEO High Oil Price case.

Our baseline RFS + RES10 scenario projects a 48% expansion in U.S. consumption of wood fuel feedstock from 2006 to 2030. That represents a modest increase in the wood energy share of total U.S. primary energy consumption from 1.0% in 2006 to 1.3% in 2030, based on total U.S. energy consumption as projected by IEA (Table 1). Our alternative policy scenarios project the wood energy share of total U.S. energy consumption by 2030 to be 1.6% in the RFS + RES20 + EFF scenario, 1.8% in the RFS + RES20 scenario, and 2.5% in the RFS + RES20 + HP scenario. Thus, our policy-driven scenarios for U.S. wood energy consumption vary from an expansion of 48% (from 2006 to 2030) in the RFS + RES10 baseline scenario to 89% in the RFS + RES20 + EFF scenario, 100% in the RFS + RES20 and 173% in our RFS + RES20 + HP scenario.

For all scenarios, future U.S. GDP growth and U.S. housing starts assumptions (key drivers of U.S. forest product demands) were based on projections of the 2010 Annual Energy Outlook (AEO) (USDOE, 2010a). Our housing starts data include the historical decline in U.S. housing starts of over 70% from 2005 to 2009, along with projected gradual recovery in housing starts from 2010 to 2015. The first three scenarios use the U.S. real GDP growth projections of the AEO Reference Case, while the “HP” scenario uses the slightly different U.S. GDP projections of the AEO “High Oil Price” case. All our scenarios use real GDP data and projections from 2006 to 2014 for other countries from IMF (World Economic

Outlook), coupled with longer-term GDP growth assumptions of the IPCC B2 Message scenario (IPCC, 2000). Since we included actual historical GDP data from 2006 to 2009 for all countries, our scenarios take into account the recent global recession, and our scenarios also incorporate an assumption of gradual economic recovery in U.S. and global GDP growth as projected by AEO and IMF.

We applied several other general assumptions in our analysis. First, for U.S. regions, we assumed an elasticity of timber supply with respect to timber growing stock inventory ($\varepsilon = 1.5$), and we applied initial timber growth assumptions that matched recent data for timber growing stock by U.S. region and species group (Smith et al., 2009). Future changes in regional U.S. timber growth rates are modeled endogenously as a function of growing stock density using the same general approach used for other countries in the GFPM, where growth in forest stock is a function of forest stocking density and industrial roundwood supply has a long-run supply elasticity of 1.5 with respect to change in forest stock (Raunikar et al., 2010; Turner et al., 2006). Second, we did not include any biomass supply policies or incentives in our scenarios, such as biomass subsidies, carbon credits or offset values for forest carbon sequestration, or any constraints on use of pulpwood or mill residues for energy. We plan to evaluate impacts of biomass supply and climate policies in future studies. Lastly, we applied projections of U.S. forest land area changes by region as derived recently by Alig et al. (2010) rather than using the endogenously determined projection of forest land area based on the "Kuznets curve" approach that is applied to other countries in the GFPM.

Finally, fuelwood demands in all other countries were programmed to grow at rates that would maintain a constant fuelwood share of the total energy consumption in each country from 2006 to 2030 (based on IEA global energy projections). Under this assumption the volume of fuelwood consumption of all other countries increases in aggregate by around 65% by 2030 because of projected increases in total energy consumption. This assumption is actually a departure from historical fuelwood trends for most countries, where their fuelwood share of total energy consumption has generally declined in recent decades, although trade in certain wood energy products such as wood fuel pellets has increased in recent years (Spelter and Toth, 2009).

Results

Before we explain our results regarding market impacts of expansion in wood energy consumption, it is necessary to briefly explain the baseline USFPM/GFPM projections of U.S. forest product market trends, because our analysis of U.S. wood fuel feedstock supply is highly contingent on projections of conventional forest product market trends. For example, this analysis assumes a strong recovery in U.S. housing construction that propels recovery in wood product demand over the next five years. Recovery in demand results in expanded wood product output and timber harvest, which in turn generate larger volumes of mill residues and logging residues that can satisfy much of the projected expansion in U.S. demand for wood energy.

Fig. 1 illustrates our baseline projection for U.S. production of solid sawn (lumber) and plywood/veneer products relative to historical trends, showing a substantial recovery following the decline in output that occurred from 2006 to 2009 because of the downturn in housing construction and recent economic recession. The robust recovery in solid sawn and veneer product output is of course largely contingent on the assumed recovery in housing construction, which is based on U.S. housing starts projections from the 2010 Annual Energy Outlook (USDOE, 2010a). The robust recovery in output of lumber and veneer products is also contingent on GFPM projections of continued expansion in U.S. net exports. Fig. 2 shows our baseline projections for U.S. solid sawn and veneer product net exports relative to historical trends. Net exports have increased (imports have decreased) in recent years, and the global model projects continued expansion of net exports in the decades ahead. The projected recovery in U.S. solid sawn and veneer product output contributes to significant projected increases in the supply of mill residues and also logging residues that can be used for energy (as sawlog/veneer log harvest is projected to increase), but of course the increase in output and residue supplies is contingent on the assumed recovery in housing construction and projected expansion in net exports.

Meanwhile, our baseline scenario results in very modest projected growth in U.S. pulpwood and fiber residue consumption (used mainly at wood pulp mills), because of very little projected growth

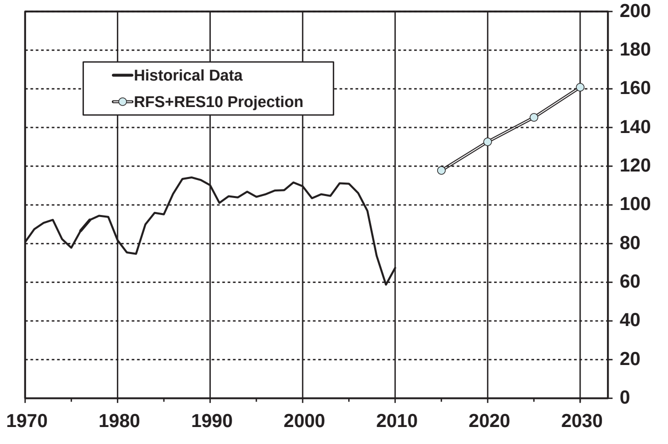

Fig. 1. US solid-sawn and veneer product production (million cubic meters).

in U.S. paper and paperboard demand, which limits growth in wood pulp production. Fig. 3 shows our baseline projections for U.S. paper and paperboard production relative to historical trends. Although there are projected increases in U.S. net exports of paper and paperboard and also projected increases in use of pulpwood and fiber residues for composite wood panels (OSB, particleboard and fiberboard), the overall outlook for U.S. pulpwood demand is rather subdued. The limited growth in U.S. pulp and paper output coupled with continued expansion in U.S. timber growth over the next couple of decades contributes in all U.S. regions to excess supplies of pulpwood and mill residues, which can be used alternatively for energy.

A key result of our analysis is that U.S. wood energy supply sources are projected to change as wood fuel feedstock demand increases. Fig. 4 shows historical data on annual U.S. wood fuel feedstock consumption and future trends as projected under the four alternative scenarios. Table 2 shows historical quantities of U.S. wood fuel feedstock production by supply source in 2006, and projected equilibrium supply quantities by source in 2030 for the alternative scenarios. The largest traditional source of wood fuel feedstock (mill fuel residues) increases over the projection period because of substantial projected increases in U.S. forest product output (with assumed recovery in housing starts and rising net exports driving expansion in lumber and wood panel production). Traditional fuelwood har-

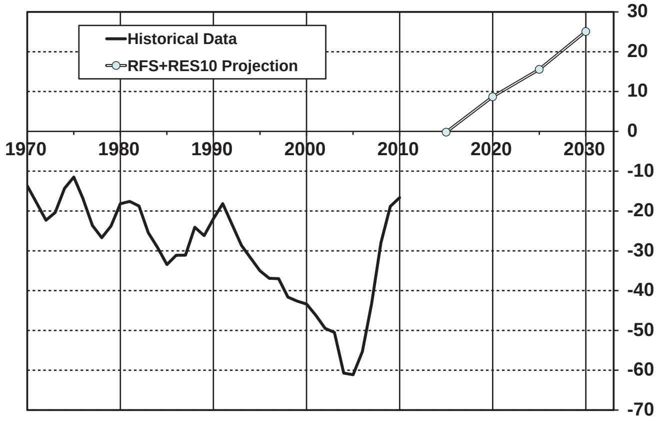

Fig. 2. US solid-sawn and veneer product net export (million cubic meters).

Table 2
U.S. Forest sector projections to 2030 for four alternative wood energy scenarios, along with historical dat.

MCM = thousand m^3	Units	Historical 2006	RFS+RES10 2030	RFS + RES 20 + EFF 2030	RFS + RES20 2030	RFS + RES 20 + HP 2030
Production						
Total U.S. fuel feedstock of which:	MCM	112,865	167,670	214,506	227,001	308,671
Logging residue	MCM	7	62,119	100,543	108,319	130,771
Mill fuel residue	MCM	67,402	87,084	87,912	88,156	90,066
Mill fiber residue	MCM	0	197	311	875	10,416
Traditional fuelwood	MCM	45,456	18,270	25,740	29,652	63,882
Pulpwood	MCM	0	0	0	0	13,536
Agricultural SRWC	MCM	0	0	0	0	0
Solid-sawn and veneer	MCM	108,488	160,852	162,738	163,220	165,095
OSB and non-structural panels	MCM	27,599	45,664	45,881	45,890	45,895
Wood pulp	M tonnes	53,211	34,582	34,772	34,686	33,959
Paper and paperboard	M tonnes	82,892	78,832	79,329	79,317	79,007
Consumption						
Fuel feedstock	MCM	113,255	167,511	214,347	226,841	308,511
Solid-sawn and veneer	MCM	163,831	135,761	135,497	135,462	136,140
OSB and non-structural panels	MCM	39,811	45,821	45,922	45,931	46,081
Paper and paperboard	M tonnes	91,031	68,553	68,610	68,615	68,866
Net export						
Fuel feedstock	MCM	−390	160	160	160	160
Solid-sawn and veneer	MCM	−55,343	25,091	27,241	27,758	28,956
OSB and non-structural panels	MCM	−12,212	−157	−41	−41	−186
Wood pulp	M tonnes	−687	−1,776.5	−1,781.4	−1,860.5	−2,367.4
Paper and paperboard	M tonnes	−8139	10,280	10,719	10,702	10,141
Prices						
SW sawtimber (w)(s)	$/CM	$50	$38	$39	$39	$40
HW sawtimber (w)(s)	$/CM	$37	$28	$29	$29	$30
SW non-sawtimber (w)(s)	$/CM	$9	$7	$7	$7	$7
HW non-sawtimber (w)(s)	$/CM	$2	$2	$2	$2	$3
SW sawlogs (w)(d)	$/CM	$74	$62	$63	$63	$62
HW sawlogs (w)(d)	$/CM	$77	$65	$66	$67	$64
SW pulpwood (w)(d)	$/CM	$36	$34	$33	$34	$33
HW pulpwood (w)(d)	$/CM	$46	$42	$42	$42	$42
Fuel feedstock (d)	$/CM	$25	$24	$24	$24	$28
Fuel feedstock (d)	$/Mmbtu	$2.75	$2.57	$2.61	$2.62	$3.08
SW lumber	$/CM	$193	$183	$175	$173	$177
SW plywood/veneer	$/CM	$306	$269	$272	$269	$270
OSB	$/CM	$214	$203	$203	$203	$203
Nonstructural panels (w)	$/CM	$308	$329	$326	$326	$328
Wood pulp (w)	$/tonnes	$429	$427	$420	$419	$421
U.S. timber inventory						
Softwood growing stock	MMCM	14,766	19,612	19,558	19,556	19,545
Hardwood growing stock	MMCM	11,180	15,366	15,317	15,309	15,271

w, weighted; s, stumpage.

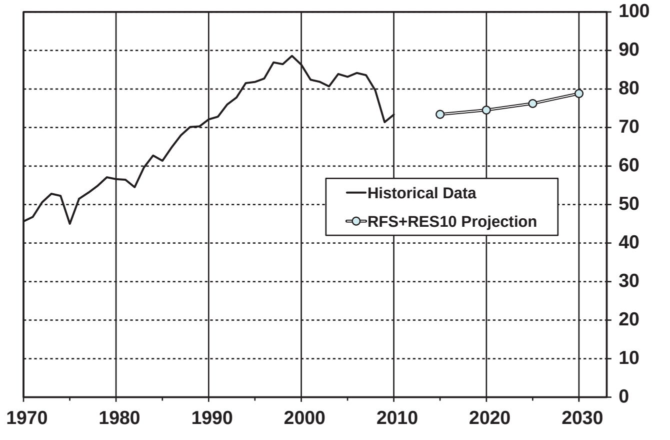

Fig. 3. US paper and paperboard production (million metric tonnes).

vest also accounts for a large share of wood fuel feedstock, but the conventional sources of wood fuel feedstock are supplemented by other sources, especially in the higher wood energy demand scenarios.

Fig. 5 shows projected shifts in wood energy supply sources for the baseline scenario (RFS + RES10), which features a 48% policy-driven expansion in U.S. wood fuel feedstock consumption. In that scenario, virtually all of the projected expansion in U.S. wood fuel feedstock production by 2030 consists of expansion in use of logging residues and fuel residues from mills.

Fig. 6 illustrates projected shifts in wood energy supply sources for the highest wood energy demand scenario (RFS + RES20 + HP). With higher wood energy demands, pulpwood use for energy increases at first, partly due to excess pulpwood supplies with recent declines in U.S. wood pulp production. However, as wood fuel feedstock demand increases, use of logging residue for energy increases along with mill fiber residue. Traditional sources of wood energy (mill fuel residues and traditional fuelwood harvest) account for only about one-fifth of the projected expansion from 2010 to 2030 in U.S. wood energy supply in the RFS + RES20 + HP scenario, while logging residues account for about two-thirds, and pulpwood and mill fiber residue account for the remainder.

Our analysis does not project any market expansion in agricultural short-rotation woody crop (SRWC) supply for pulpwood or fuel feedstock by 2030 (Table 2), even in the highest wood energy demand scenarios (basing our analysis on 1990s cost and productivity data for SRWC). Of course higher

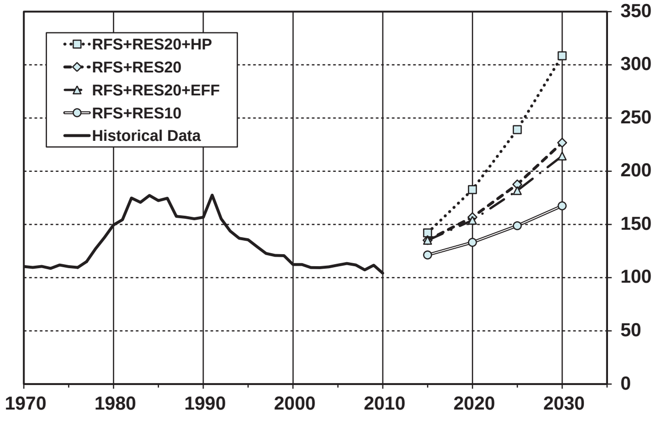

Fig. 4. US wood fuel feedstock consumption (million cubic meters).

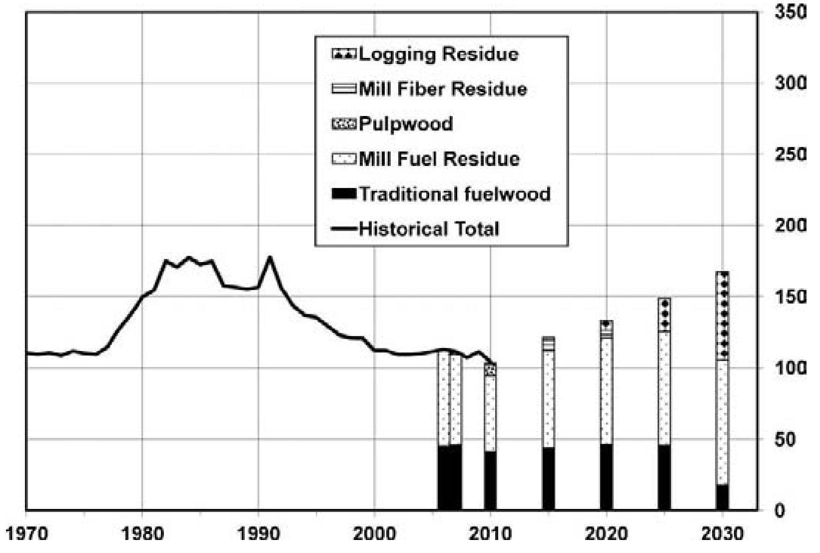

Fig. 5. Historical U.S. fuel feedstock production and RFS + RES10 projection by source (million cubic meters).

future productivity levels and reduced future production costs could facilitate a more robust market expansion of SRWC.

In our view the most important result of our analysis is that long-run market impacts of expansion in wood energy consumption are projected to be very small for timber and forest products, as indicated by small differences in projected U.S. forest product production, consumption and trade quantities and prices across the range of scenarios (Table 2). Impacts on projected timber growing stock inventories are also fairly small across the alternative scenarios (Table 2). Because we assume a rebound from the recent housing construction downturn, there is a projected rebound in solid wood product output over

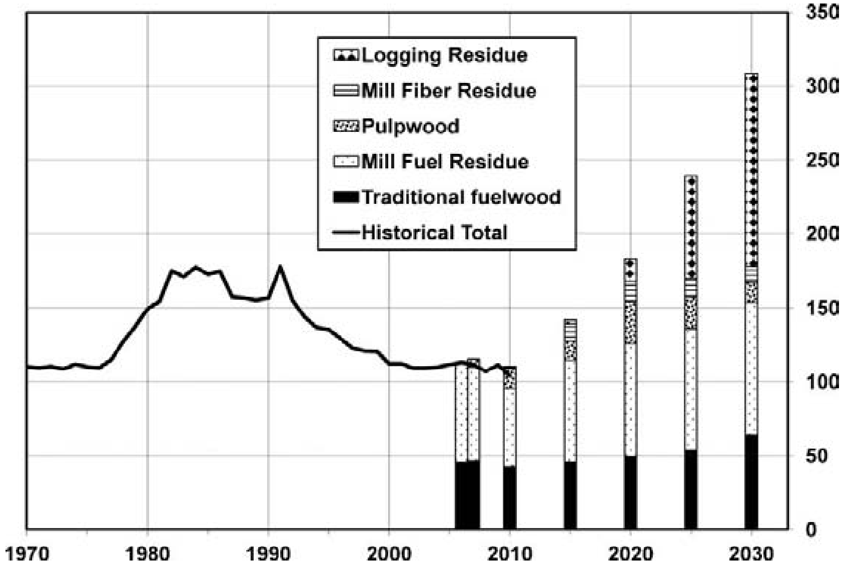

Fig. 6. Historical U.S. fuel feedstock production and RFS + RES20 + HP projection by source (million cubic meters).

the period from 2010 to 2015. Hence there is a projected resurgence in supply of mill residues and increased output of logging residues over that period, after residues were in relatively short supply from 2006 to 2009. As shown in Table 2 the projected 2030 equilibrium prices for most U.S. forest sector commodities are fairly consistent across the four scenarios, with only very modest increases in fuel feedstock prices. Results indicate that the assumed policy-driven levels of expansion in U.S. wood energy consumption have little disruptive impact on forest sector markets because expansion is supplied mostly by logging residues that are presently not being utilized and mill residues that will increase in supply with projected economic growth in the decades ahead. However, as discussed in the following section, this result is sensitive to changes in assumptions about economic growth and future supplies of wood residues.

In addition, a finding regarding policy options is that there is a small difference in market impacts between the RFS + RES20 and RFS + RES20 + EFF scenario results. The latter scenario includes a policy choice allowing that 50% of new wood biomass power comes from high-efficiency plants producing both heat and power. By 2030 this policy difference results in a 6% reduction in annual U.S. fuel feedstock production (about 12 million cubic meters per year) relative to the former scenario, and small impacts on projected market prices (Table 2).

Discussion and conclusions

Our USFPM/GFPM analysis addressed U.S. forest sector market and trade impacts of alternative policy-driven U.S. wood energy scenarios in the context of specific global forest product market assumptions. From a global perspective a drawback to our analysis is that we did not model alternative global fuelwood demand scenarios per se, but we can run such scenarios and such scenarios have been explored with the GFPM and documented elsewhere (Raunikar et al., 2010). A strong point of our analysis is that we analyzed in greater detail the U.S. forest sector market impacts of domestic policy-driven expansion in U.S. wood energy consumption in the context of forest product markets with specific global economic growth and fuelwood demand assumptions. We can note also that we are presenting general conclusions from a broad national perspective, which could mask some important local or sub-regional differences in wood markets.

There is at present little unused mill residue in the United States, but fairly large volumes of unused logging residues, which are conventionally left in the forest. Across our four scenarios, increased use of logging residue accounts for most of the projected expansion in U.S. wood energy production. The large expansion in use of logging residue is shown for example in Figs. 5 and 6, and in the projected fuel feedstock production by source in 2030, shown in Table 2. There is a smaller projected increase in use of mill residues for energy, as wood product output recovers from the housing downturn and provides more mill residues. Pulpwood is used for energy only in our highest wood energy demand scenario (Fig. 6). The use of logging residues for energy adds some revenues to timber harvest, which modestly enhances supply of harvested sawlogs and sawnwood production (Table 2).

We conclude that if biomass energy policies result in expansion of U.S. wood energy consumption reaching 1.3–2.5% of total U.S. primary energy consumption by 2030 (up from 1.0% in 2006) there would likely be small impacts on U.S. forest product markets and net trade, all else being equal (assuming fixed growth rates for fuelwood demands in other countries). This is because most of the U.S. expansion is projected to be supplied by logging residues that are presently not being utilized for products, and mill residues that will increase in supply with projected expansion in wood product output in the decades ahead. Thus, the conclusions are contingent on market assumptions for other products, such as the assumption that lumber and wood panel production will expand in the decades ahead along with a rebound in housing demand. Without future expansion in forest product output there would obviously be less available logging residues and mill residues that could be used for energy, and in that case expansion in wood energy demand would likely have more disruptive market impacts.

We explored other assumptions about future trends that could cause more disruptive impacts on U.S. forest product markets. For example, we analyzed scenarios where we assumed hypothetically that wood will account for 2/3 of the biomass required in the United States to meet RFS and RES energy goals (twice as high as the 1/3 assumption that we applied in this study). In that case the doubling of projected expansion in U.S. wood energy consumption has much more disruptive impacts, resulting in considerably higher volumes of pulpwood being utilized for energy and displacing production of wood pulp and pulpwood-based products such as OSB and composite wood panels. However, interestingly in that case U.S. output and revenues for lumber and plywood producers were boosted by the higher demands and prices for mill residues, and timberland owners would also obtain higher timber prices.

We also looked at cases where the supply of logging residues was more restricted (less than the 60% availability that we assumed in this study) or where the cost of logging residue recovery was higher. The results were predictably greater use of pulpwood and fiber residues for energy, again disrupting fiber supply for wood pulp and composite panel producers.

Finally, we examined the sensitivity of results to the assumption of recovery in housing construction activity, by running USFPM/GFPM with no assumed recovery in U.S. housing starts as an extreme case, and in that case there is only about half as much increase in projected U.S. lumber and structural wood panel output by 2030, and of course much less expansion in supply of logging residues and mill residues. The net result was about twice as much pulpwood being consumed for energy by 2030 in the RFS + RES20 + HP scenario as shown in Fig. 6.

In summary, we can conclude that likely near-term levels of policy-driven expansion in U.S. consumption of wood for energy will have fairly small impacts on forest sector markets and trade over the next couple of decades, because a substantial cushion of wood residue supplies are likely to be available in the form of logging residues and mill residues, assuming a recovery in housing construction and expansion in wood product output, along with excess supply of pulpwood. That cushion of wood residue and excess pulpwood supply can mostly absorb the impact of projected expansion in wood energy consumption. However, forest sector market disruptions could occur with much higher levels of wood energy consumption, more limited growth in supply of wood residues, more restrictive constraints on supplies of logging residues, or higher costs for residue supply. Conclusions tend to reinforce the view that policies to support bioenergy use should continue to focus on facilitating recovery and utilization of wood residues for energy. Policies should also recognize the contingency of wood fuel feedstock supply on future market trends for other forest products, notably the contingency of expansion in wood residue supplies on recovery in housing construction, along with increases in production and net exports of solid sawn and veneer products.

Lastly, we conclude that a modeling system capable of analyzing forest product markets, trade, and the corresponding wood residue supply implications (such as USFPM/GFPM) is necessary to fully represent and analyze the U.S. forest sector market and trade impacts of expansion in wood energy consumption.

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