Evaluating Economic Impacts of Expanded Global Wood Energy Consumption with the USFPM/GFPM Model

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A U.S. forest sector market module was developed within the general Global Forest Products Model. The U.S. module tracks regional timber markets, timber harvests by species group, and timber product outputs in greater detail than does the global model. This hybrid approach provides detailed regional market analysis for the United States although retaining the broader global market analysis. We describe how the U.S. Forest Products Module is structured within the global model and show projections based on Intergovernmental Panel on Climate Change scenarios with long-range assumptions about economic activity, population growth, and wood energy demands. Results show that real prices for industrial roundwood would increase as a result of significant global expansion in wood energy demands. Expansion of global wood energy demands would influence the comparative economic advantages of U.S. versus foreign producers, with U.S. producers gaining some comparative advantages and increased net exports in scenarios where average foreign industrial roundwood prices are projected to increase more than in the United States. These results suggest that national wood energy policies should consider how the impacts of wood energy use on domestic forest product markets depend on trends in global forest product markets.

Le module du secteur forestier aux États-Unis (USFPM) a été élaboré á partir du modéle mondial du secteur forestier (GFPM–Global Forest Products Model). Le USFPM permet de suivre l'évolution des marchés régionaux du bois d'œuvre, des récoltes de bois d'œuvre par groupe déessences et des produits dérivés de façon plus détaillée que le modéle mondial. Ce modéle hybride offre une analyse détaillée des marchés régionaux aux États-Unis tout en conservant une analyse générale du marché mondial. Dans le présent article, nous décrivons la structure du module du secteur forestier aux États-Unis par rapport au modéle mondial du secteur forestier et présentons des prévisions formulées d'aprés des scénarios élaborés par le Groupe d'experts intergouvernemental sur lévolution du climat (GIEC) et renfermant des hypothéses long terme sur l'activité économique, la croissance de la population et la demande de bois énergie. Nos résultats indiquent que les prix réels du bois rond industriel risquent d'augmenter en raison de la croissance substantielle de la demande mondiale de bois énergie. Cette croissance aurait des répercussions sur les avantages comparatifs des producteurs américains par rapport aux producteurs étrangers, mais les producteurs américains obtiendraient certains avantages comparatifs

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et une hausse des exportations nettes dans les scénarios où les prix moyens du bois rond industriel étranger augmenteraient par rapport aux prix observés aux États-Unis. Ces résultats autorisent à penser que les politiques nationales en matiére de bois énergie devraient examiner de quelle façon les tendances sur les marchés forestiers mondiaux influencent l'utilisation du bois énergie sur les marchés forestiers intérieurs.

INTRODUCTION

The U.S. Forest Products Module (USFPM) was built within the Global Forest Products Model (GFPM) to produce long-range projections of U.S. forest product markets and regional U.S. timber markets using global economic scenarios. The GFPM is a recursive dynamic spatial market equilibrium model of production, consumption, trade, and prices for all major forest products in 180 countries (Buongiorno et al 2003; Raunikar et al 2010). The concept of developing USFPM within the GFPM originated several years ago (Ince and Buongiorno 2007), and USFPM was subsequently developed at the USDA Forest Service, Forest Products Laboratory in Madison, Wisconsin. We describe the important structural features of the U.S. forest sector as represented in USFPM, including the USFPM wood supply structure. We explain assumptions for several alternative global scenarios that we analyzed using the USFPM/GFPM model. Finally, we present USFPM/GFPM projections for those scenarios and compare them with historical trends, and present conclusions based on those results. A detailed description of USFPM is provided in Ince et al (2011a), and another publication describes the GFPM model structure and its recent applications (Buongiorno et al 2011).

MODEL

The USFPM/GFPM modeling system combines the USFPM with the GFPM as a singular model (not two separate models). It differs from the original GFPM in terms of the more detailed model structure for U.S. regions represented in USFPM, with different U.S. timber supply and forest product demand functions, and also a different approach to specifying global fuelwood demands. Thus, results that we obtain with USFPM/GFPM are not precisely the same as obtained by others using the GFPM without USFPM (Raunikar et al 2010; Buongiorno et al 2011), but given that the USFPM/GFPM modeling system retains the same model structure and much of the same data for foreign countries the general behavior is consistent with the GFPM.

In USFPM, timber supply, timber harvest, and forest product production and net exports are modeled for three U.S. subregions—North, South, and West (Figure 1). End product demand of the United States is modeled at the national level (a singular demand region), obtaining products via shipments from U.S. subregions and via imports from the rest of the world (as modeled by the original GFPM). In addition, roundwood, recovered paper, and wood pulp intermediate products can be shipped from one U.S. subregion to another, and each U.S. subregion can export end products to the rest of the world.

The timber commodity structure of the United States as represented in the U.S. subregions of USFPM reflects the structure of regional U.S. forest resource and timber utilization data as reported by the USDA Forest Service for the 2010 Resources Planning Act (RPA) assessment (Smith et al 2009). The Forest Service resource data are from national compilations of state-level forest surveys conducted by Forest Inventory and

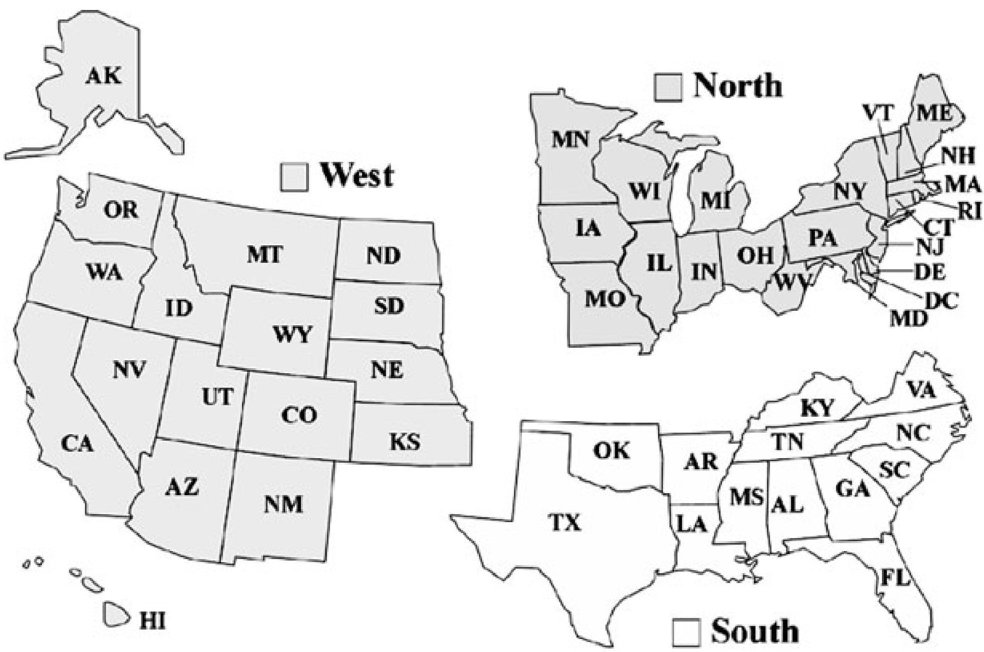

Figure 1. Three USFPM supply and production subregions, North, South, and West

Analysis (FIA) researchers. For USFPM, we use FIA regional data on timber inventory volumes and harvests by timber species group (hardwood [HW] and softwood [SW]) and by merchantability class (sawtimber and nonsawtimber), and we also use FIA data on timber harvest volumes and corresponding timber product output volumes that are used as raw materials for specific forest product categories, including lumber (sawnwood), plywood and veneer, wood pulp, composite wood products, miscellaneous wood products, and fuelwood.

Relative to the original GFPM, we expanded the forest product structure in USFPM by disaggregating several GFPM end products within the U.S. regions to provide a more complete analysis of HW and SW timber markets (Figure 2). The "sawnwood" used in GFPM was expanded into HW lumber and SW lumber, and "plywood/veneer" was expanded into SW plywood/veneer and HW plywood/veneer. "Particleboard" was expanded into oriented strand board (OSB) and industrial particleboard. These disaggregated USFPM end products have rather different end use markets and distinctly different wood raw material input requirements, which we recognize in USFPM. We facilitate USFPM trade in the disaggregated products with other GFPM countries by aggregating those products into GFPM product categories for U.S. export and disaggregating U.S. imports, using product shares obtained from recent U.S. International Trade Commission trade data (product shares are held constant across scenarios and over time).

We acknowledge that the global model (GFPM) does not have an HW/SW (broadleaf/conifer) split for roundwood, sawnwood, or plywood/veneer, which is a weakness of our USFPM/GFPM modeling system to the extent that it contributes to

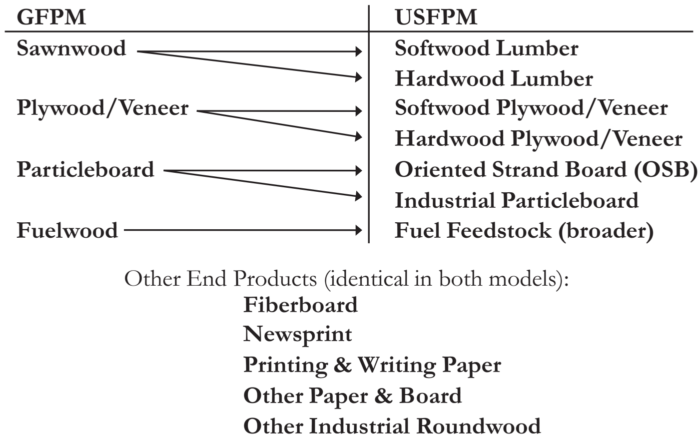

Figure 2. USFPM expansion of the GFPM end product categories

mismatching of U.S. and global supply and demand. U.S. import and export quantities for all forest products vary over time to match U.S. and global market results, but HW/SW ratios in projected U.S. trade flows for roundwood, sawnwood, and plywood/veneer products are held at historical ratios. We recommend that future development of models such as the GFPM should incorporate the broadleaf/conifer split as we do in modeling the U.S. forest sector in USFPM.

Timber harvest and transport activities are modeled in USFPM as the conversion of sawtimber and nonsawtimber stumpage by species group into four categories of delivered timber product outputs: (1) sawlogs/veneer logs, (2) pulpwood/composite, which includes timber for wood pulp and composite wood products, (3) other industrial roundwood, including timber for posts, poles, pilings, and miscellaneous products, and (4) fuelwood. To maintain consistency with FIA data, we model regional U.S. timber supply in USFPM by using the same timber species groups and merchantability classes as described in the FIA data (Smith et al 2009). The addition of this timber supply detail along with regional timber harvest and product recovery rates calibrated to FIA forest resource data (Smith et al 2009) are important features of USFPM because it allows for a precise linkage of USFPM (and the GFPM) to regional models of U.S. forest growth and forest inventory that are likewise calibrated to FIA forest survey data (Ince et al 2011a; Wear 2011).

The FIA forest resource data define sawtimber and nonsawtimber in terms of tree size class and merchantability. Sawtimber is defined as trees that seem capable of yielding sawlogs, are greater than 9 inch diameter at breast height (d.b.h.) for SW trees and greater than 11 inch d.b.h. for HW trees (Smith et al 2009). Smaller trees, trees that do not seem capable of yielding sawlogs, or nongrowing stock trees (live cull trees and dead trees) are categorized as nonsawtimber. In actuality and as programmed into harvest activity parameters of USFPM (based on FIA timber harvest data), sawlogs are recoverable from both sawtimber and nonsawtimber, although the recovery ratio of sawlogs is much higher from sawtimber trees than from nonsawtimber trees, whereas recovery of pulpwood and fuel feedstock is higher from nonsawtimber trees, along with higher output of logging residue.

In USFPM, each U.S. subregion supplies four categories of timber stumpage: HW sawtimber, SW sawtimber, HW nonsawtimber, and SW nonsawtimber. These are converted by harvest activities into the four USFPM categories of delivered timber product outputs (sawlogs/veneer logs, pulpwood/composite, other industrial roundwood, and fuelwood) plus harvest residues conventionally left in the forest that can be used as fuel, although residue recovery adds to harvest costs. All harvest data and conversion factors match FIA timber harvest data (Smith et al 2009). The industrial timber product outputs (sawlogs/veneer logs, pulpwood/composite, and other industrial roundwood) are inputs to USFPM forest product manufacturing activities.

By contrast, the GFPM has a simplified representation of timber supply based on United Nations Food and Agriculture Organization (FAO) roundwood supply data and FAO global forest inventory data. The GFPM models the forest resource sector of foreign countries by modeling net growth of forest inventory as a function of stocking density, whereas forest inventories are adjusted by roundwood production (Turner et al 2006). However, the GFPM does not model timber harvest activities per se. Thus, in all other countries of the USFPM/GFPM model, wood supply consists of three delivered commodities—industrial roundwood, other industrial roundwood, and fuelwood—undifferentiated by species group or source of timber and calibrated to FAO roundwood and fuelwood production data. A more complete model of the timber supply chain for the United States is represented in USFPM, including regional timber stumpage markets, sawtimber and nonsawtimber harvest activities, and conversions into recognized categories of delivered timber product outputs plus harvest residues.

USFPM also provides potential future supply of agricultural short-rotation woody crops (SRWC). Future agricultural SRWC supply is modeled by region using estimates of feasible delivered wood costs and crop yields, along with assumptions regarding limits (upper bounds) on available cropland acreage for SRWC. The SRWC supply represents potential future supply of tree crops that could be grown on agricultural land (as opposed to forest land). The future SRWC wood harvest volume was specified to be 75% pulpwood and 25% fuelwood, but alternatively all the SRWC harvest can go to fuel feedstock, if the projected price of fuel feedstock exceeds pulpwood price. We did not assume any gains in agricultural SRWC yields over the projection period.

Figure 3 compares the U.S. regional wood supply structure of USFPM with the nationwide wood supply structure of the original GFPM, where nationwide supply functions provide supplies of delivered industrial roundwood, fuelwood, and other industrial roundwood. The GFPM also models change in forest stock and forest area and how this influences industrial roundwood supply (Turner et al 2006). USFPM models timber stumpage supply by species group and by tree merchantability class (sawtimber and nonsawtimber) and also models timber harvest activities and delivered timber product outputs of harvest activities (sawlogs/veneer logs, pulpwood, fuelwood, and other industrial roundwood). USFPM also adds harvest residue and mill residue by-products to the wood supply structure. All USFPM timber supply data, wood residue recovery data, and base year solutions for timber harvest, wood residues, and timber product output quantities were calibrated precisely to RPA forest resource data on U.S. regional timber harvest volumes, timber product output volumes, and residue volumes, by species group (Smith et al 2009). U.S. timber stumpage supply functions used in this analysis were based on regional models of U.S. forest growth and inventory (Ince et al 2011a; Wear 2011).

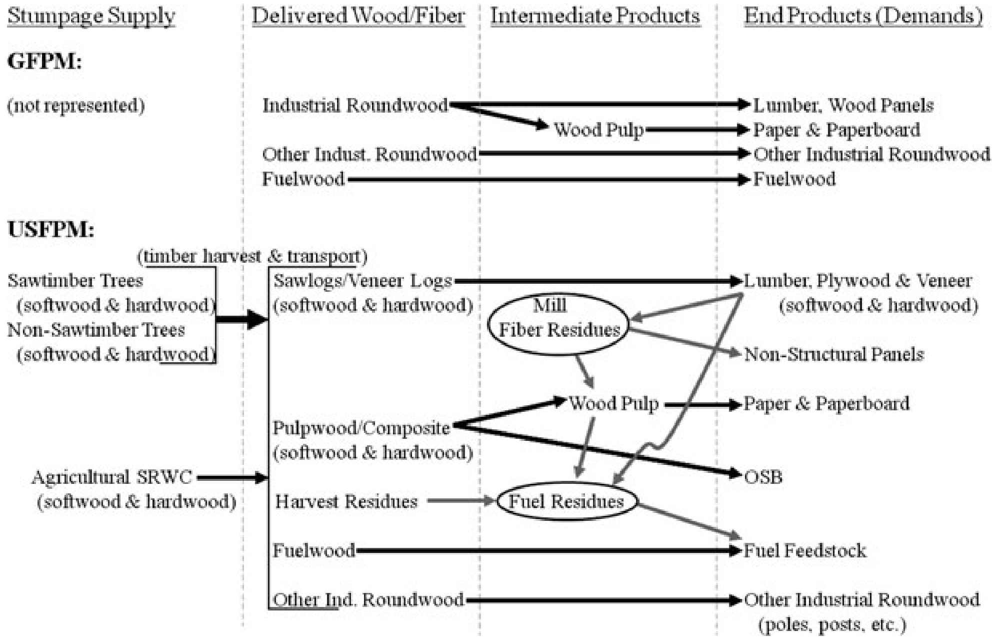

Figure 3. Comparison of the GFPM and USFPM wood supply structures

Table 1. Harvest residue volumes generated by sawtimber and nonsawtimber harvests as percentages of timber volumes harvested in U.S. regions

Region	U.S. North	U.S. South	U.S. West
Hardwood (broadleaf) sawtimber	15%	13%	8%
Hardwood (broadleaf) nonsawtimber	81%	119%	43%
Softwood (conifer) sawtimber	6%	3%	7%
Softwood (conifer) nonsawtimber	119%	56%	125%

Thus, USFPM models all major categories of wood residues including (1) harvest residues generated as by-products of timber harvest activities that require added cost to be recovered; (2) fiber residues from lumber and plywood/veneer production representing wood chips and coarse wood residues used conventionally along with pulpwood as raw material inputs to wood pulp, particleboard, or fiberboard production; and (3) fuel residues from lumber, plywood/veneer, and pulp production representing bark, wood fines, and other wood residues typically used as fuel. Fiber residues are an important feedstock to pulp, particleboard, and fiberboard products in the United States, whereas fuel residues accounted for around 60% of reported U.S. wood fuel feedstock consumption in the base year 2006 (Smith et al 2009).

Harvest residues are the volumes of wood removals currently left in the forest after timber harvest operations and are conventionally uneconomical to recover (typically

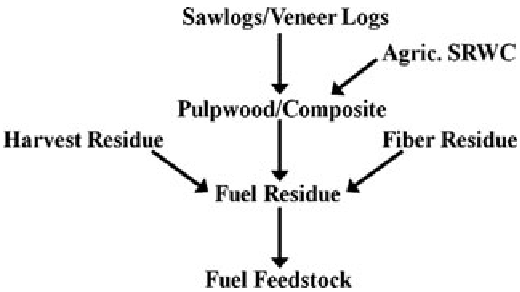

Figure 4. Cascading wood raw material substitution possibilities in USFPM

tops, branches, broken stems, and other logging debris). Harvest residue volumes are modeled in USFPM as by-products of timber harvest activities, with regional output volumes calibrated precisely to actual historical harvest residue volume data from FIA (Smith et al 2009). Table 1 shows harvest residue volumes generated as percentages of actual timber harvest volume in U.S. regions. Future harvest residues may be partially recovered and used as wood fuel feedstock in USFPM if future demand for wood fuel feedstock raises the price high enough to pay the extra cost of recovering harvest residues. However, we constrain future recovery of harvest residues to not more than 60% of available residue volumes for reasons that are both economical (higher costs of recovering additional volumes) and practical in terms of forest management (leaving some residues in the forest for nutrient cycling, wildlife habitat protection, etc.).

In addition to disaggregating several GFPM end products and adding timber stumpage and wood residues to wood supply, USFPM allows for "cascading" raw material substitution possibilities, which means substitution of normally higher value timber products for lower value materials if projected market conditions favor such substitution. Historically, higher value timber product outputs, such as sawlogs or veneer logs, were too valuable to be used in place of lower value materials, such as pulpwood or fuelwood. However, in scenarios with increased demand for lower value products such as fuelwood, their prices can increase enough to make product substitution economical. Thus, USFPM allows sawlogs/veneer logs to be used as pulpwood/composite timber, and in turn pulpwood/composite, logging residues, and fiber residues can be used as fuel feedstock (Figure 4). A similar cascading substitution possibility was also introduced to the GFPM model for other countries (allowing industrial roundwood to substitute for fuelwood if it becomes economical in the projection period).

The cascading wood substitution feature allows USFPM/GFPM to simulate economic substitution that can arise, for example, in scenarios with significant future expansion in wood biomass energy demand. Wood energy demands can potentially compete for the same wood resources as other wood products (i.e., industrial roundwood). This is an important feature of USFPM/GFPM because it means that relative U.S. and global wood energy demands can influence relative prices for industrial roundwood and influence comparative economic advantage in wood costs for U.S. and foreign producers of forest products, as discussed in the results section.

A more detailed technical description of the model parameters, input data, and results is in Ince et al (2011a). We next describe basic assumptions and features of several alternative future global scenarios that we analyzed recently using the USFPM/GFPM modeling system. We then present and discuss the projection results.

ALTERNATIVE FUTURE SCENARIOS

USFPM/GFPM was used previously to make projections for several near-term biomass energy policy scenarios (Ince et al 2011b), but here we focus on longer range global economic scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). The assumptions and story lines for the scenarios are documented in the IPCC Special Report on Emissions Scenarios (SRES; Nakicenovic and Swart 2000). We selected the IPCC marker scenarios for the A1B, A2, and B2 story lines (specifically the A1B AIM, A2 ASF, and B2 MESSAGE scenarios), which we subjected also to some further harmonization and downscaling. We refer to these three scenarios as A1B, A2, and B2. They include a range of assumptions about future economic growth, population growth, energy production, and climate change.

A reason why IPCC scenarios were chosen for our analysis, although they are becoming somewhat dated, is that the IPCC SRES provided a comprehensive global analysis of climate change that was useful in modeling other forest trends such as climate change effects on forest growth. We also observed that recent projections of global gross domestic product (GDP) growth from the International Monetary Fund (World Economic Outlook) were still within the range of projected GDP growth for the IPCC scenarios (roughly in-between the GDP growth projections of A2 and B2 scenarios), and furthermore the higher global GDP growth of the A1B scenario is still consistent with long-run historical GDP growth trends.

The IPCC-based scenarios were implemented in our analysis by applying the IPCC growth assumptions for GDP and population to each country along with fixed trajectories of future wood energy consumption consistent with the IPCC scenarios. We did not have any more specific data on the future trade context for IPCC scenarios such as projected shifts in currency exchange rates or future tariff schedules for IPCC scenarios, so in effect the same general free trade context was applied in all scenarios. IPCC scenarios may actually imply a more varied context for global trade, with a varying emphasis on globalization and free trade versus local solutions or sustainability among different scenarios. Thus, our analysis may be somewhat limited in reflecting all aspects of the trade context associated with IPCC scenarios, but we can note that the GFPM is programmed so that alternative future tariffs and shifts in currency exchange rates could be introduced for any or all countries.

The global energy outlook of the three IPCC scenarios is similar to other global energy studies in that production of renewable energy such as biomass energy is projected to expand, although rates of expansion vary by scenario. Other global studies that have projected a similar trend include a recent Massachusetts Institute of Technology study projecting annual world biomass energy production increasing from 45 exajoules (10^{18} J, or EJ) to a range between 221 and 267 EJ by 2050 (Gurgel et al 2007), and an International Energy Agency (IEA) study predicting potential biomass energy production increasing to 200–300 EJ by 2050 (Faaij 2007). In general, IPCC scenarios and the other global energy studies that project large increases in biomass energy production share a common view that global petroleum production will peak sometime within the next couple of decades

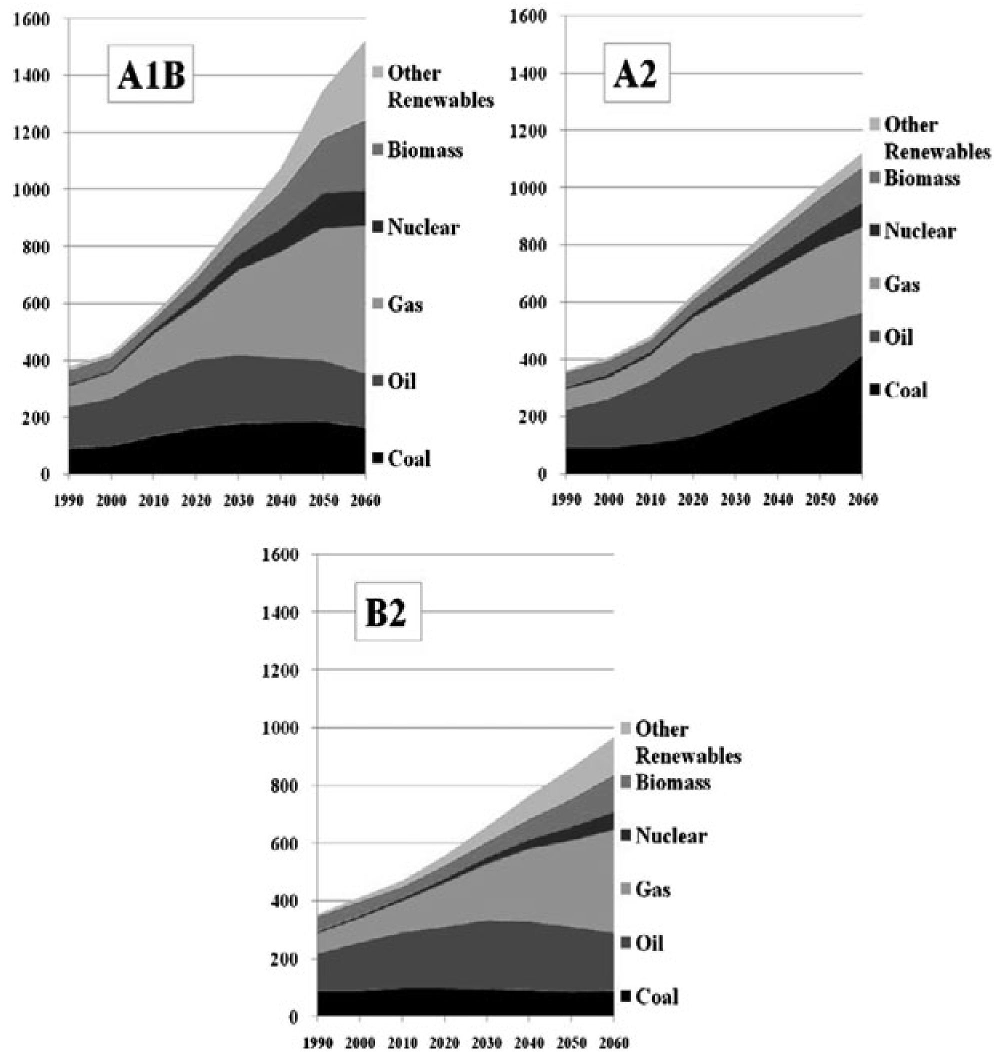

Figure 5. Global primary energy production by source (in exajoules) for three selected scenarios as projected by IPCC SRES, 1990 to 2060 (Nakicenovic and Swart 2000)

(by 2020 to 2030) leading to expansion in other forms of energy production, including renewable energy production.

Figure 5 shows historical and projected global energy production as reported in the SRES database for our three selected scenarios. All three scenarios show a continuity of the historical pattern of expanding global energy production along with shifting sources of energy, but the scenarios vary in overall levels of global energy production and in their responses to peaking oil production. For example, the A1B has the highest projected overall energy production, highest production of energy from gas, and also highest projected expansion in biomass energy production in absolute terms, in line with A1B themes

Table 2. Summary of the three selected IPCC SRES scenarios

Scenario	A1B	A2	B2
General description	Globalization & economic convergence	Heterogenic regionalism, less trade	Localized solutions, slow change
Social development themes	Economic growth & new technologies	Self-reliance, preservation of local identities	Sustainable development & diversified technology
Global real GDP growth (2010–60)	High (6.2×)	Medium (3.2×)	Medium (3.5×)
Global population growth (2010–60)	Medium (1.3×)	High (1.7×)	Medium (1.4×)
U.S. GDP growth (2006–60)	Medium (3.3×)	Low (2.6×)	Low (2.2×)
U.S. population growth (2006–60)	Medium (1.5×)	High (1.7×)	Medium (1.3×)
U.S. housing construction, average single-family housing starts per year (2020–60)	Medium (1.4 million)	High (1.7 million)	Low (0.9 million)
Global expansion of primary biomass energy production (2000–60)	High (5.9×)	Medium (3.1×)	Medium (3.2×)

of continued economic growth and use of new technologies. The A2 has lower overall growth in energy production than the A1B, but higher energy production from coal. The B2 has lowest overall growth in global energy production, and relatively slow changes among energy sources as compared to the other scenarios.

Table 2 summarizes the three scenarios in terms of their general description, economic and social development themes, and basic assumptions related to population growth, economic growth, and future expansion of biomass energy production. The A1B has highest global economic growth coupled with slowing global population growth, generally consistent with global real GDP growth since the mid 19th century (about 3% per year). It assumes continued economic globalization and a trend toward global convergence in terms of GDP per capita. The A2 and B2 scenarios have lower global real GDP growth. The A2 is differentiated by considerably higher global population growth than other scenarios, and lowest global GDP growth. The B2 assumes more diversified global technology and a theme of sustainable development, resulting in lowest global population growth and mid-level global GDP growth, but also the lowest U.S. real GDP growth.

In harmonizing and downscaling the IPCC SRES scenarios, we made minor adjustments to U.S. population and economic growth assumptions. For example, U.S. real

GDP was updated to a 2006 base year, and U.S. GDP projections for the A1B scenario were replaced with similar 2006 projections from the USDA Economic Research Service. The U.S. population projections for the A1B scenario were also adjusted slightly to be consistent with U.S. Census Bureau projections based on 2000 census data. The U.S. GDP and population projections for the A2 and B2 scenarios were then adjusted to maintain the same proportional difference with A1B across the projection period as reported in the SRES. Among the three scenarios, the A2 scenario has highest projected U.S. population growth, with U.S. population reaching just over 500 million by 2060, whereas the B2 has lowest population growth at just fewer than 400 million by 2060. The A1B scenario has mid-range U.S. population growth and housing needs projections, roughly between the A2 and B2 scenarios. U.S. real GDP growth is highest in the A1B, with a 3.3-fold increase from 2006 to 2060, next highest in the A2 with a 2.6-fold increase, and lowest in the B2 with just a 2.2-fold increase. For all other countries in the GFPM, projected changes in real GDP and population were derived from SRES global projections (Raunikar et al 2010). Economic growth assumptions of all three scenarios were not adjusted to reflect the recent economic recession, so as to maintain precise consistency with the original SRES global economic and climate change assumptions (Nakicenovic and Swart 2000). Nevertheless, U.S. GDP growth of the A1B scenario remains consistent with the current long-term U.S. real GDP growth trend line based on polynomial extrapolation of GDP growth data from 1950 through the recent recession (through 2009), whereas U.S. GDP growth projections of A2 and B2 scenarios are well below the trend line.

Developing the exogenous global fuelwood demand assumptions for USFPM/GFPM based on the IPCC scenarios required first adjusting the primary biomass energy production from corresponding IPCC scenarios to common base levels. The IPCC scenarios (A1 AIM, A2 ASF, and B2 MESSAGE) were developed using different economic and biophysical models, and their reported historical biomass energy production levels were not exactly the same (Nakicenovic and Swart 2000). However, we observed that the reported historical global biomass energy production levels of the B2 scenario (46 EJ in 1990 and 43 EJ in 2000) were close to historical global biomass energy production as reported in the literature (e.g., Gurgel et al 2007) and as reported in data adapted from the IEA (Openshaw 2010). Thus, we adjusted base-level biomass energy production levels of the A1B and A2 scenarios to match the B2 scenario for the years 1990 and 2000, but for all three scenarios we retained the same absolute future increases in biomass energy production as projected originally by SRES (Figure 5). We also made adjustments for missing data in some global regions.

USFPM/GFPM models global fuelwood production and consumption but not total biomass energy production, and the IPCC SRES did not specify how much of the projected biomass energy production consists of fuelwood from forests, so we developed methods to estimate the portion of biomass energy production that is derived from fuelwood in the IPCC scenarios (Ince et al 2011a). The SRES report and its supporting database (Nakicenovic and Swart 2000) included projections of total primary biomass energy production globally and in four large global "macro" regions. For example, the macro region encompassing South America and Africa was projected to account for the largest share of expansion in global biomass energy production in all three scenarios, similar to findings of other global biomass energy outlook studies (e.g., Faaij 2007; Gurgel et al 2007). In addition, the SRES report and database provided projections of land use

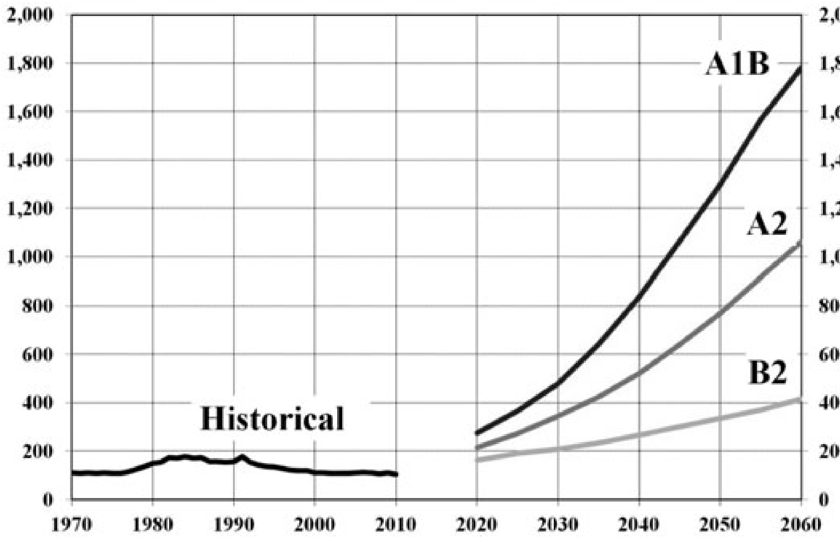

Figure 6. Annual U.S. wood fuel feedstock consumption, 1970–2010, and USFPM/GFPM projections for selected scenarios (million cubic meters/year)

for each scenario by macro region, including projected areas of forest land, cropland, and nonforest land dedicated to energy crops ("energy biomass land"). Thus, we modeled global fuelwood demands by SRES macro region, taking into account regional land use projections and regional biomass energy projections provided by SRES for each scenario. Additional details on the fuelwood demand assumptions and other aspects of the selected global scenarios are described in the more detailed USFPM research report (Ince et al 2011a).

RESULTS

USFPM/GFPM was used to make projections for the three selected scenarios. Our results focus on projections for the U.S. forest sector from 2020 to 2060, rather than the global forest sector outlook. A parallel global outlook was developed using the GFPM based on the same scenarios (but without USFPM) and published separately (Raunikar et al 2010).

A striking feature of the three global scenarios is the large projected expansion of U.S. wood fuel feedstock consumption relative to historical trends (including fuelwood, fuel residues, and other solid wood and bark projected to be used for energy), as shown in Figure 6. The projected rate of expansion for U.S. fuelwood consumption is lower than previously reported for these scenarios (Raunikar et al 2010), but we interpreted the IPCC SRES to indicate that forests will provide a large share of biomass for future energy production within the Organization for Economic Cooperation (OECD) region (including United States) whereas nonforest energy plantations will provide a larger share of future biomass production in other regions (particularly in Latin America and Africa). In addition, the U.S. share of OECD region fuelwood consumption in 2060 is assumed to match the large U.S. share of regional GDP by 2060. The general technique used to allocate growth in global wood energy demands to each country in the GFPM for IPCC scenarios has been to do so according to projected GDP shares of each country (Raunikar et al 2010). This theory is supported by historical correlation between primary energy consumption (such as oil consumption) and GDP, along with recognition that biomass is expected to become a more important element of primary energy consumption according to IPCC scenarios, especially as global oil production peaks within the next decade or two. The linkage of future wood energy demands to GDP results in a relatively large expansion in wood energy consumption for the United States, because the United States currently consumes only a small fraction (less than 3%) of global fuelwood but the United States has a large share of projected global GDP in all scenarios. Thus, U.S. consumption of wood fuel feedstock is projected to expand from 2006 to 2060 by a factor of 15.8× in the A1B scenario, 9.4× in the A2 scenario, and 3.7× in the B2 scenario.

Although global timber supply and fuelwood trade can influence global allocation of fuelwood production in USFPM/GFPM, most of the projected expansion in U.S. consumption of wood energy is met by domestic production rather than imports according to our analysis, and thus projected U.S. wood fuel feedstock production follows closely the projected U.S. wood fuel feedstock consumption. Historically, U.S. wood fuel feedstock production has consisted mostly of roundwood fuelwood harvest and fuel residues (mill residues used as fuel). Fuel residues accounted for about 60% of U.S. wood fuel feedstock production in 2006, whereas roundwood fuelwood harvest including bark accounted for about 40% (Smith et al 2009). However, nonconventional sources of fuel feedstock (chiefly harvest residue and pulpwood) are used much more in the projections, especially in scenarios with large increases in wood energy consumption.

For the A1B scenario, Figure 7 shows that conventional fuelwood harvest and fuel residues expand, but more costly nonconventional sources of wood fuel feedstock become dominant in the projections as consumption and price of fuel feedstock increase. Nonconventional sources include harvest residues and HW and SW pulpwood along with mill fiber residues that would be conventionally used at wood pulp mills and particleboard mills. Projections for the other scenarios are generally lower, as shown in Figure 8 for the B2 scenario, where projected wood fuel feedstock consumption is much lower than for the A1B and where expansion of fuel feedstock consists mainly of harvest residues.

The three scenarios encompass a wide range in projected U.S. production of wood energy from nonconventional sources, such as pulpwood and fiber residues, ranging from very little expansion in use of those sources for energy in the B2 scenario (Figure 8) to large expansion in the A1B scenario (Figure 7). In the A1B scenario, the projected consumption of pulpwood and fiber residues for energy climbs to over 900 million cubic meters per year by 2060, more than twice as high as recent historical U.S. timber harvest volume. Pulpwood and fiber residue use for energy competes directly for wood that could be used to make pulp or panels. Thus, projected impacts on timber and industrial roundwood markets are significant in the A1B scenario. On the other hand, in the B2 scenario, projected consumption of pulpwood and fiber residues for energy is less than one-tenth as large as in the A1B scenario (Figure 8). For the B2 scenario, harvest residues provide most of the projected expansion in U.S. wood energy consumption, so the impacts on conventional timber markets and conventional forest product markets are much smaller.

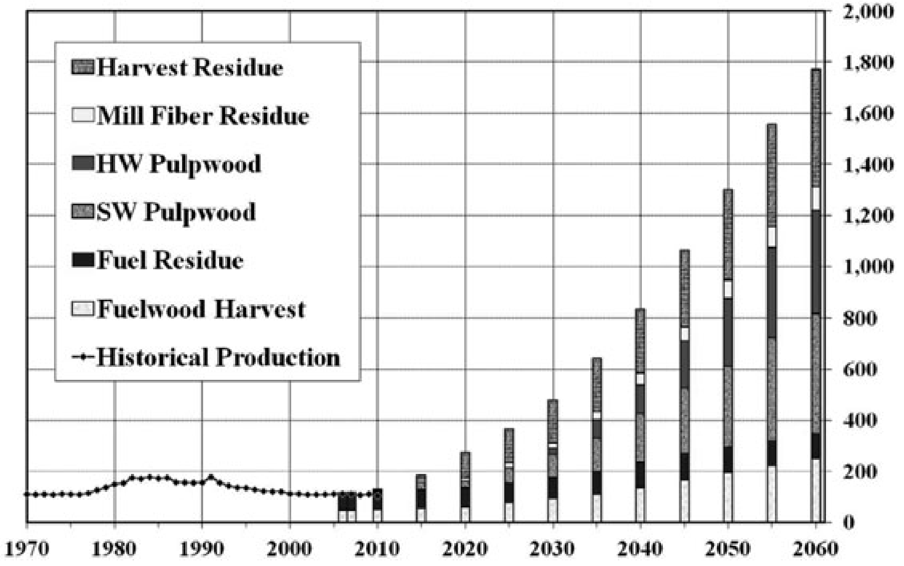

Figure 7. Annual U.S. wood fuel feedstock production, 1970–2010, and USFPM/GFPM projection of production by feedstock source for A1B scenario (million cubic meters/year)

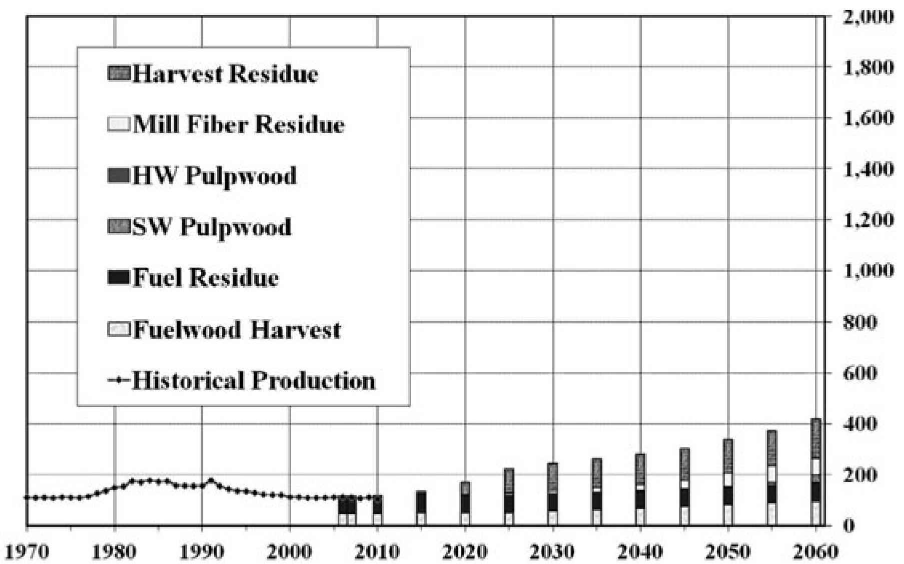

Figure 8. Annual U.S. wood fuel feedstock production, 1970–2010, and USFPM/GFPM projection of production by feedstock source for B2 scenario (million cubic meters/year)

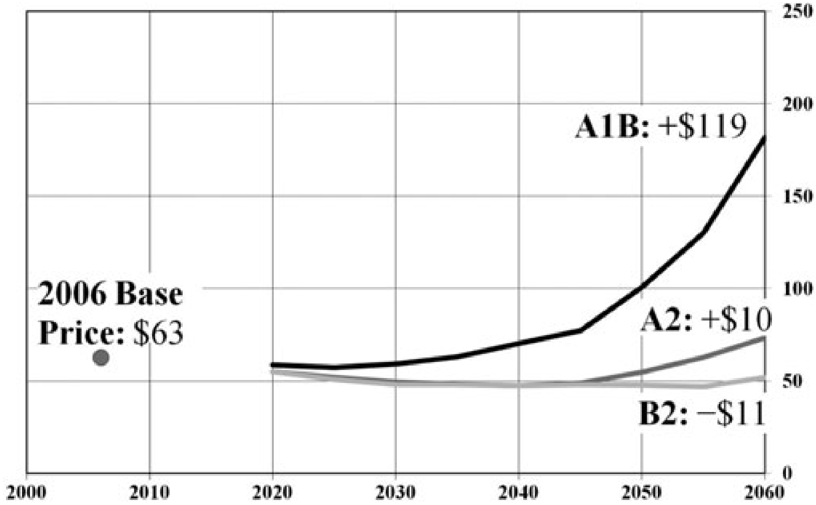

Figure 9. USFPM/GFPM projected trends in average U.S. real prices of industrial roundwood for selected scenarios (2006 $/cubic meter)

Across the scenarios, variation in economic growth assumptions and wood energy consumption result in a wide range of projected real prices for industrial roundwood (Figure 9), with nearly a threefold increase in average U.S. industrial roundwood price by 2060 in the A1B scenario, whereas average U.S. real price for industrial roundwood is projected to modestly decline in the B2 scenario. Projected industrial roundwood prices vary widely mainly because we imposed fixed trajectories of expansion in wood energy consumption that varied widely across the scenarios; with expansion in U.S. wood energy consumption by 2060 varying from nearly fourfold (3.7×) in the B2 scenario to nearly 16-fold (15.8×) in the A1B scenario. Price projections are in 2006 dollars.

USFPM/GFPM projections of the average foreign industrial roundwood prices outside the United States are shown in Figure 10. As in the United States, clearly the highest global roundwood prices are projected in the A1B scenario with highest projected global fuelwood consumption, but notably the A2 scenario has the lowest projected global price for industrial roundwood. This is because the A2 scenario has the lowest projected global expansion in fuelwood consumption (whereas the B2 scenario has the lowest projected expansion in U.S. wood energy consumption).

The alternative U.S. and global wood energy demand assumptions and projected trends in industrial roundwood prices have large and divergent impacts on the U.S. forest product production and trade outlook, because relative industrial roundwood prices directly influence comparative economic advantages in forest product production and trade. In particular, U.S. producers of forest products gain some comparative advantages in the A1B and B2 scenarios because the projected increase in average foreign industrial roundwood price is higher than the average for U.S. industrial roundwood price (Figures 9 and 10). However, foreign producers tend to gain comparative advantages in the A2 scenario, which has the least expansion in global fuelwood demand and a decrease in projected foreign average industrial roundwood price (Figure 10), whereas the average U.S. industrial roundwood price increases in that scenario (Figure 9).

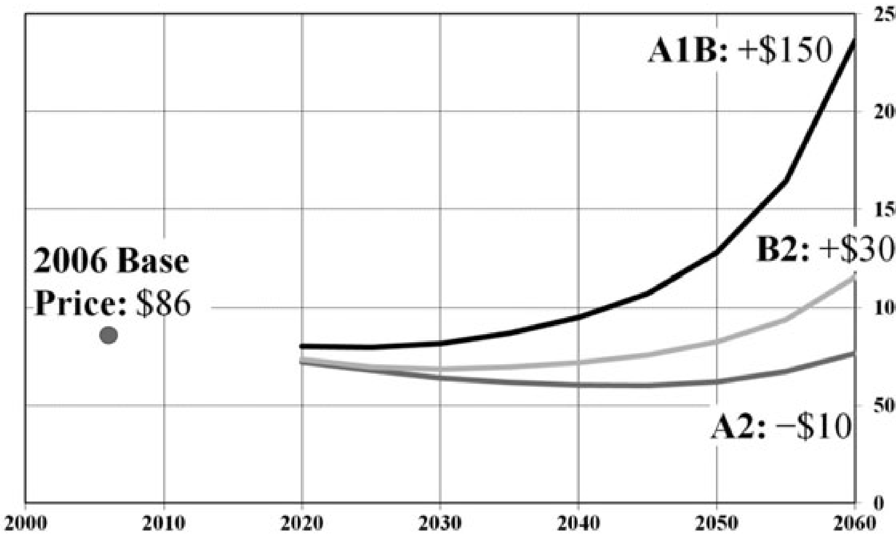

Figure 10. USFPM/GFPM projected increases in average foreign real prices of industrial roundwood for selected scenarios (2006 $/cubic meter)

Forest Product Projections

Before discussing timber market projections, we present U.S. forest product market projections for the three scenarios. Projections of U.S. forest product production and net exports are strongly influenced by projected average U.S. and foreign industrial roundwood prices (Figures 9 and 10).

Figure 11 shows the historical trend and projections of U.S. lumber (sawnwood) consumption. U.S. lumber consumption was severely impacted in recent years by the collapse in U.S. housing starts from 2005 to 2009 and the recent economic recession, with total lumber consumption dropping by around 50% from 2005 to 2009, and just beginning to recover in 2010. For the three future scenarios, the primary drivers of projected U.S. lumber demand include projected U.S. housing starts and GDP growth (Table 2), which vary by scenario and result in divergent lumber consumption projections (Figure 11).

Projections of U.S. lumber production (Figure 12) differ from consumption because of the impact of differing industrial roundwood prices on U.S. trade. The A1B has highest projected U.S. lumber production, not only because A1B has high projected lumber consumption (Figure 11) but also a high level of net exports (Figure 13). High net exports are because the A1B scenario has the highest projected global fuelwood demand and the highest foreign industrial roundwood prices (Figure 10). In contrast, the A2 has lowest expansion in global wood energy consumption and lowest projected foreign industrial roundwood prices (Figure 10), because there is less competition from wood energy for industrial roundwood in foreign countries in the A2 scenario. Thus, foreign lumber producers retain comparative advantage in the A2 scenario, resulting in lower projected levels of U.S. lumber production and net exports.

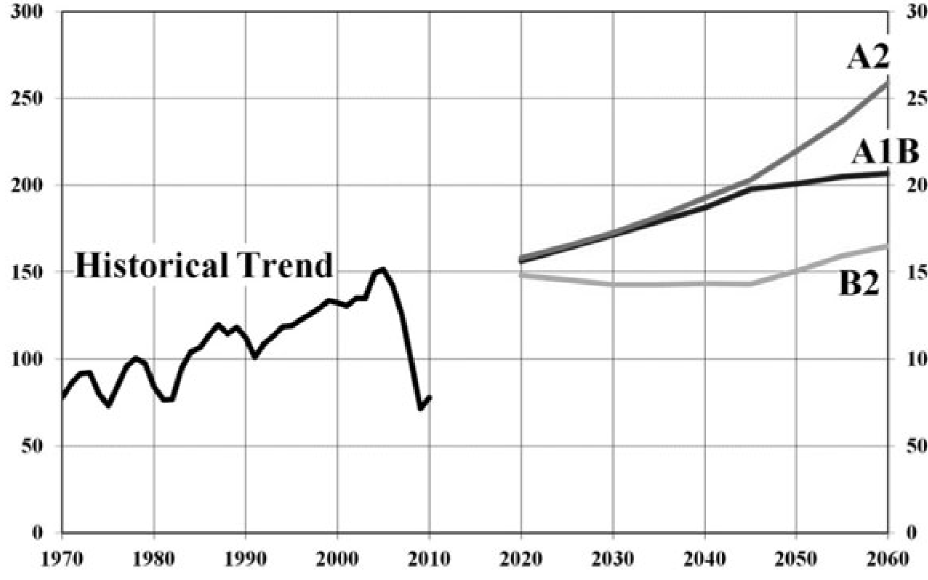

Figure 11. Annual U.S. lumber consumption, 1970–2010, and USFPM/GFPM projections for selected scenarios (million cubic meters/year)

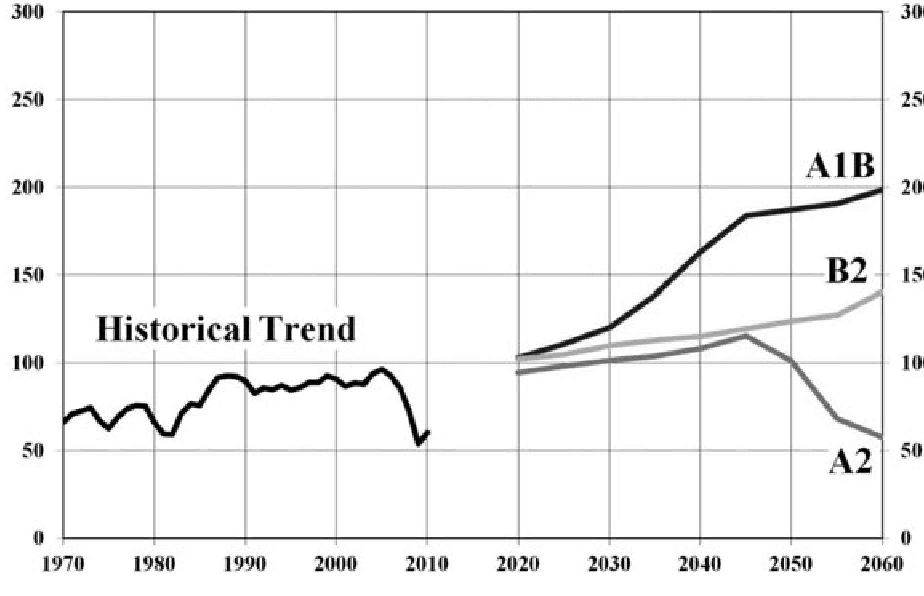

Figure 12. Annual U.S. lumber production, 1970–2010, and USFPM/GFPM projections for selected scenarios (million cubic meters/year)

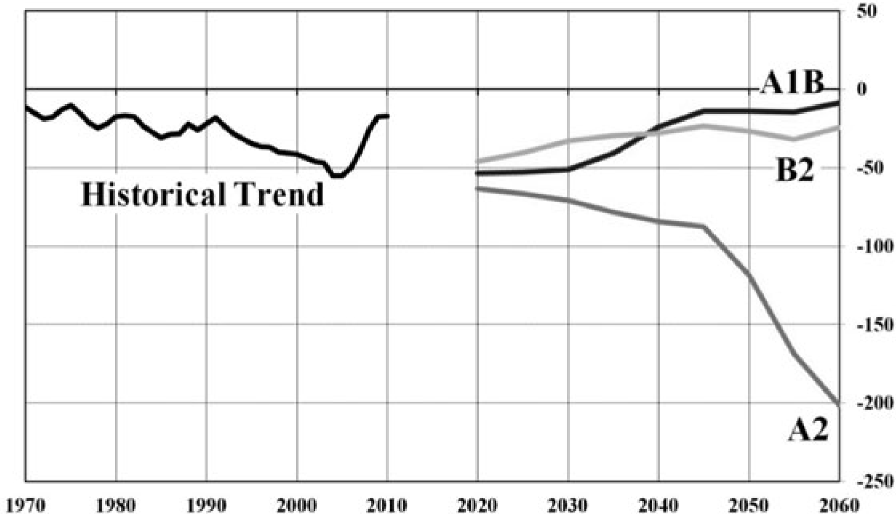

Figure 13. Annual U.S. net exports of lumber, 1970–2010, and USFPM/GFPM projections for selected scenarios (million cubic meters/year)

Beyond lumber, the next leading category of U.S. solid-wood products are structural wood panel products, including chiefly OSB and SW plywood, both of which are used primarily in housing and other construction, as well as various industrial end uses. As was the case for lumber, the A1B and A2 scenarios have highest projected structural wood panel consumption (Figure 14) because those scenarios have highest projected GDP growth and housing starts (Table 2), whereas the B2 has lowest GDP growth and lowest housing starts.

Projected structural wood panel production does not exactly follow consumption (Figures 14 and 15) because of raw material competition from wood energy. As for lumber production, the A1B scenario affords economic advantage to U.S. producers because of larger increases in foreign industrial roundwood prices than U.S. industrial roundwood prices, but U.S. structural wood panel production is dampened after 2040 in the A1B because of expanded use of pulpwood for energy in that scenario (Figure 7), which competes for the raw material used for U.S. production of OSB. The A2 scenario affords the most comparative advantage to foreign wood panel producers because the A2 has the least global expansion in wood energy consumption and least global competition for industrial roundwood from wood energy. The A2 also has the highest levels of U.S. housing starts, which propel high levels of structural wood panel demand and high levels of wood panel imports, or lowest U.S. net exports (Figure 16).

Figure 17 shows the historical trend for paper and paperboard consumption of the United States, along with projections of total U.S. paper and paperboard consumption for the three scenarios. The variation in projections is influenced by both variation in GDP growth assumptions and variation in competing consumption of pulpwood for wood energy, especially in the A1B scenario.

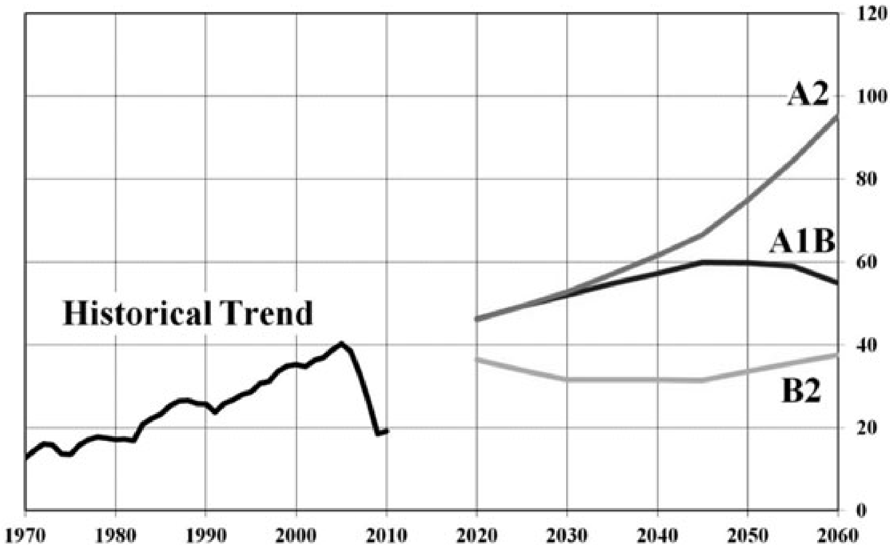

Figure 14. Annual U.S. structural wood panel consumption, 1970–2010, and USFPM/GFPM projections for selected scenarios (million cubic meters/year)

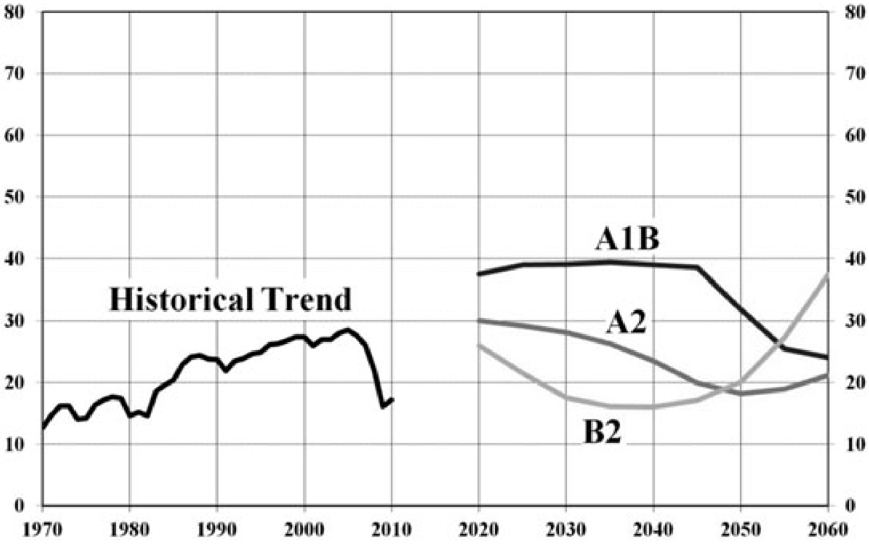

Figure 15. Annual U.S. structural wood panel production, 1970–2010, and USFPM/GFPM projections for selected scenarios (million cubic meters/year)

Of the three scenarios, A1B has highest U.S. GDP growth, so A1B has highest projected U.S. consumption of paper and paperboard (Figure 17), but consumption in the A1B is only slightly higher than in the other scenarios. This is because high levels of wood energy production in the A1B scenario consume large volumes of

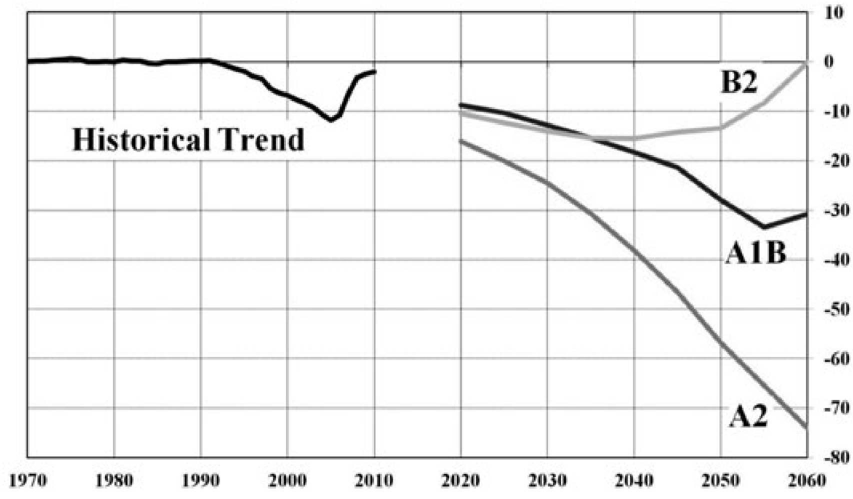

Figure 16. Annual U.S. net exports of structural wood panel products, 1970–010, and USFPM/GFPM projections for selected scenarios (million cubic meters/year)

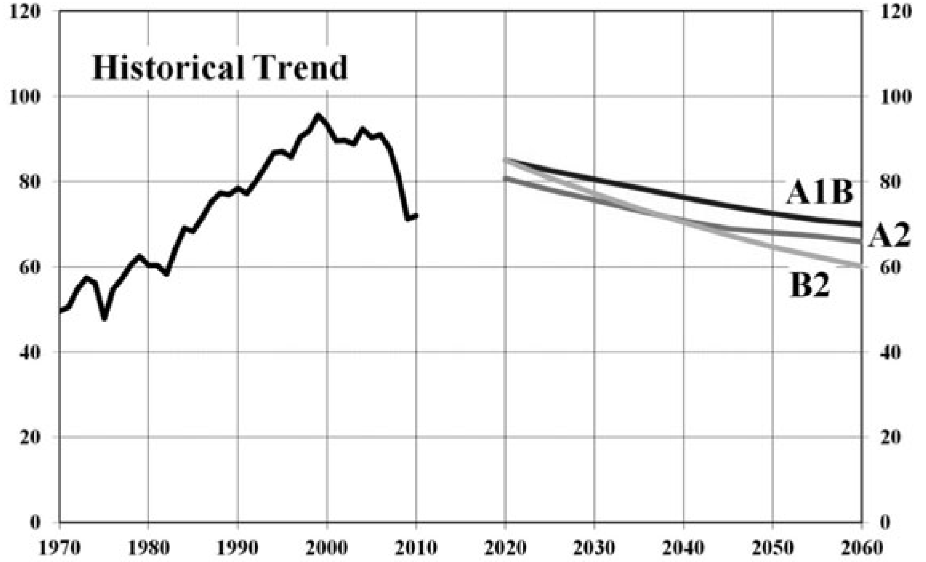

Figure 17. Annual U.S. paper and paperboard consumption, 1970–2010, with USFPM/GFPM projections for selected scenarios (million metric tons/year)

pulpwood (Figure 7), which increases prices for pulpwood and pulp, paper and paperboard products, and dampens projected growth in U.S. paper and paperboard consumption (although relative inelasticity of paper and paperboard demands with respect to price tends to limit the lessening in demand because of higher wood costs). There is less competition for pulpwood from wood energy use in the A2 and B2 scenarios.

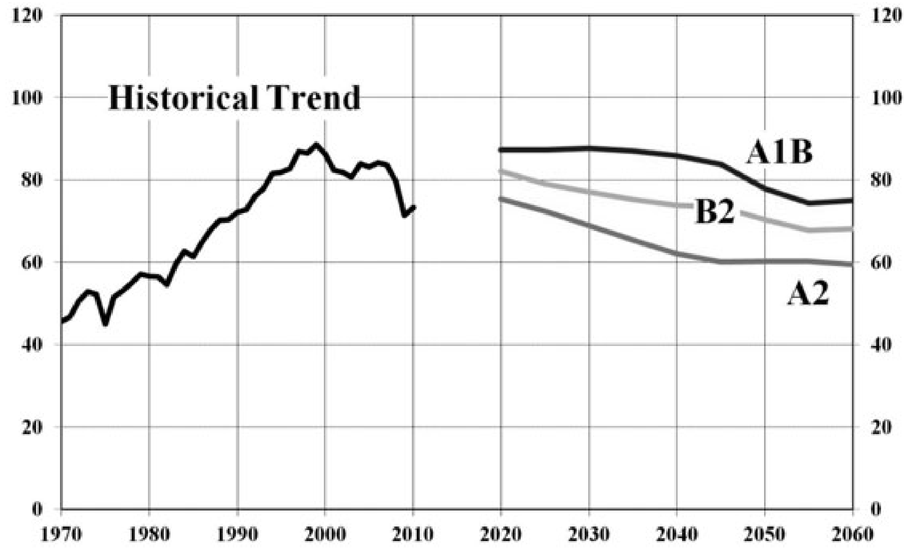

Figure 18. Annual U.S. paper and paperboard production, 1970–2010, and USFPM/GFPM projections for selected scenarios (million metric tons/year)

Total U.S. paper and board consumption is projected to gradually decline in all scenarios, with consumption declining primarily in newsprint and printing and writing paper grades.

Figure 18 shows the historical trend for total U.S. paper and paperboard production, along with USFPM/GFPM projections. U.S. paper and paperboard production peaked historically in 1999. Although there was relatively little divergence in U.S. paper and paperboard consumption among the three scenarios (Figure 17), there is nevertheless a wider divergence in projected U.S. production, especially between A1B and A2 scenarios (Figure 18). The wider divergence in production is again attributable to the divergent trade impacts of global wood energy demands, with the A1B scenario having highest net exports because of high projected global fuelwood consumption and highest foreign industrial roundwood prices, whereas the A2 has low net exports with the lowest foreign roundwood prices. Thus, U.S. producers of pulp and paper products gain comparative advantage relative to foreign producers because of strong global competition for roundwood in the A1B scenario. The A2 scenario has the least global competition for roundwood for energy, so U.S. producers of pulp, paper, and paperboard do not gain any comparative advantage in that scenario.

The historical trend in U.S. net exports of paper and paperboard are shown in Figure 19 along with projections of U.S. net exports for the three future scenarios. Historically, the United States has been a net importer of paper and paperboard, but U.S. net exports have turned positive in the past couple of years. Projections of U.S. paper and paperboard production and net exports are highest in the A1B and B2 scenarios because of competitive advantages in industrial roundwood prices, whereas production and net exports are lowest in the A2 scenario without advantages in roundwood costs. Thus,

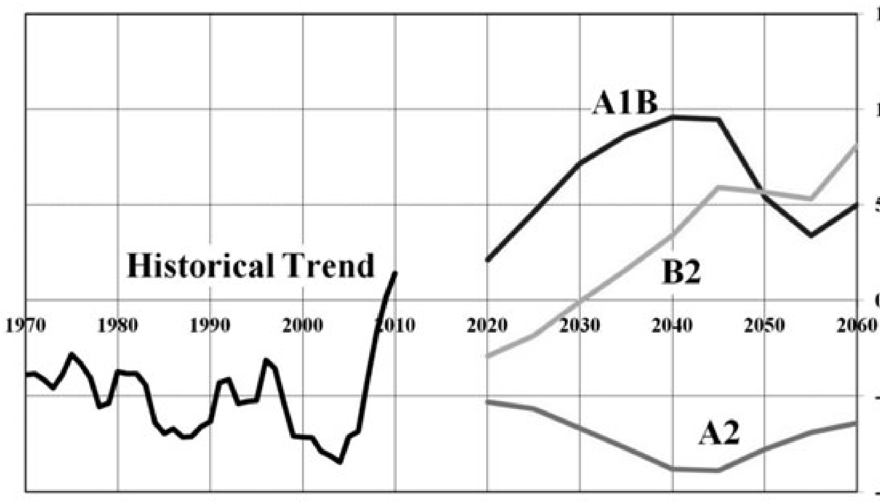

Figure 19. Annual U.S. net exports of paper and paperboard, 1970–2010, and USFPM/GFPM projections for selected scenarios (million metric tons/year)

the results indicate there could be a positive relationship between expansion in global fuelwood consumption and U.S. production and net exports of paper and paperboard to the extent that global wood energy demands create higher competing demands and higher global prices for roundwood. This is evident even in the A1B scenario, which features very high levels of U.S. and global wood energy consumption, indicating that relative comparative advantage in wood prices may have more direct influence on trade, competitiveness, and domestic production than the absolute level of wood energy consumption *per se*. However, as noted previously for OSB, the projected U.S. production and net exports of paper and paperboard products are dampened in the A1B scenario by expanded consumption of pulpwood for energy, particularly in the latter decades of the projection period.

A key finding is that projected U.S. consumption, production, and net trade in the major forest product categories are all heavily influenced by assumptions about relative future expansion in U.S. and foreign wood energy demands. This finding extends to both the solid-wood products (e.g., lumber and wood panel products) and to the pulp and paper sector. Higher U.S. wood energy consumption and higher prices tend to dampen domestic consumption of forest products, as competing energy demands for wood biomass generally drive up the projected U.S. prices for timber and forest products. This is especially true for products that rely on pulpwood as raw material, such as OSB or pulp and paper products, because higher wood energy demands would compete for pulpwood and fiber residues (unless the use of pulpwood or fiber residues for energy were restricted). On the other hand, high levels of global fuelwood consumption (as in the A1B scenario) may also increase global competition for wood, causing larger increases in foreign prices for industrial roundwood and yielding some comparative advantages for U.S. producers of forest products. Thus, even though the expansion in U.S. and global wood energy consumption dampens expected growth in forest product consumption (because of price impacts on

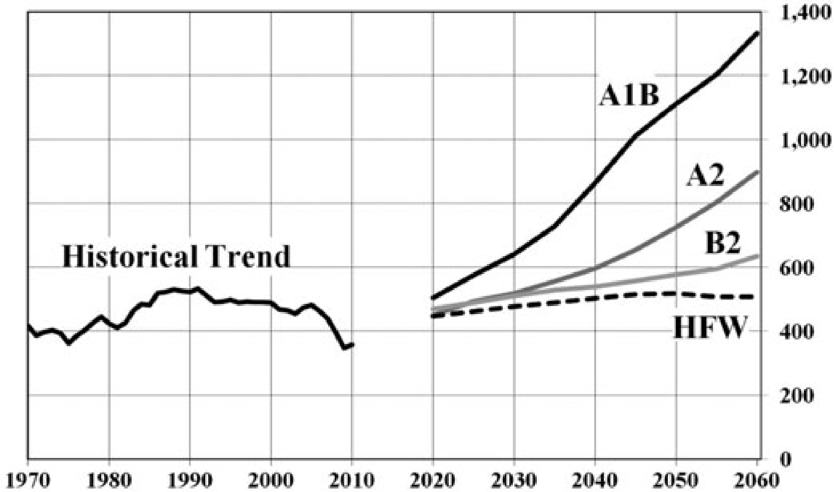

Figure 20. Historical annual total U.S. timber harvest volume, 1970–2010, and USFPM/GFPM projections for selected scenarios (million cubic meters/year)

demands) such increases may potentially provide some comparative advantages for U.S. producers and result in higher net exports, particularly in scenarios with higher increases in foreign industrial roundwood prices.

U.S. Timber Harvest and Market Projections

The projected U.S. timber harvest trends for the IPCC scenarios depart from historical timber trends of recent decades because of the projected expansion in wood energy consumption. Total U.S. timber harvest has declined since the late 1980s, but projections for the IPCC scenarios generally point to future expansion of U.S. timber harvest, mainly attributable to expansion in use of wood for energy. Figure 20 shows historical annual U.S. timber harvest volumes based on interpolation of FIA timber harvest data (Smith et al 2009) along with USFPM/GFPM projections of U.S. timber harvest for the three scenarios. Among the scenarios, by far the largest projected expansion in U.S. timber harvest occurs in the A1B scenario, followed by the A2 and B2 scenarios. Even in the B2 scenario, U.S. timber harvest is projected to reach levels well above the peak harvests of recent decades (in the 1980s) because of the nearly fourfold (3.7×) projected expansion in wood energy production of the B2 scenario. For comparison, we show timber harvest projections for an alternative "Historical Fuelwood" (HFW) scenario, which we based on the same high global economic growth assumptions as the A1B scenario, but instead of using IPCC biomass energy projections the U.S. and global fuelwood demands in the HFW scenario were predicated on historical relationships to GDP. In that case the projected U.S. timber harvest is much lower than the A1B (where wood energy consumption is based on the IPCC biomass energy projections). The "HFW" results show that most projected expansion in U.S. timber harvest of the A1B scenario is attributable to expanded wood energy consumption, and without such expanded wood energy consumption the projected U.S. timber harvest of the HFW scenario remains mostly within the range of historical harvest levels (Figure 20).

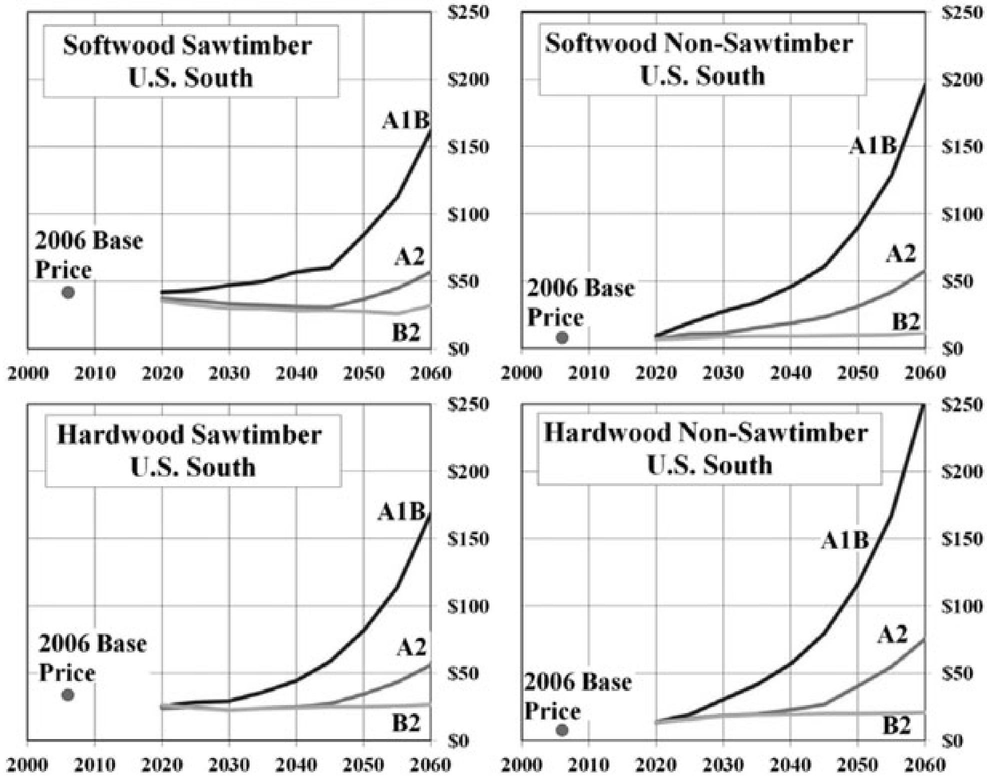

Figure 21. USFPM/GFPM projections of real sawtimber and nonsawtimber stumpage prices for hardwoods and softwoods in the U.S. South (2006 $/cubic meter)

Expansion of U.S. wood energy demand and timber harvest results in higher projected timber stumpage prices and particularly nonsawtimber stumpage prices that have been historically much lower than sawtimber stumpage prices. Nonsawtimber consists primarily of pulpwood and fuelwood, which traditionally have had lower value than sawlogs and veneer logs that make up a larger share of sawtimber volume. However, as wood fuel feedstock demand increases in the IPCC scenarios, there are greater demands and higher prices for fuelwood and pulpwood (for energy), and thus more significant increases in prices for nonsawtimber stumpage. Eventually the higher prices and timber substitution drives up sawtimber prices, but the proportional increases in sawtimber prices are generally less than the increases for nonsawtimber prices. A set of charts in Figure 21 shows USFPM/GFPM projections of real sawtimber and nonsawtimber stumpage prices for HWs and SWs in the U.S. South, which is the principal timber-producing region of the United States. All prices shown in Figure 21 are in 2006 dollars.

By far the largest increases in real timber stumpage prices occur in the A1B scenario, which has the largest projected expansion in U.S. and global wood energy demand. Both sawtimber and nonsawtimber prices are projected to increase prodigiously, and the price of nonsawtimber climbs higher than the price of sawtimber in the A1B scenario by around

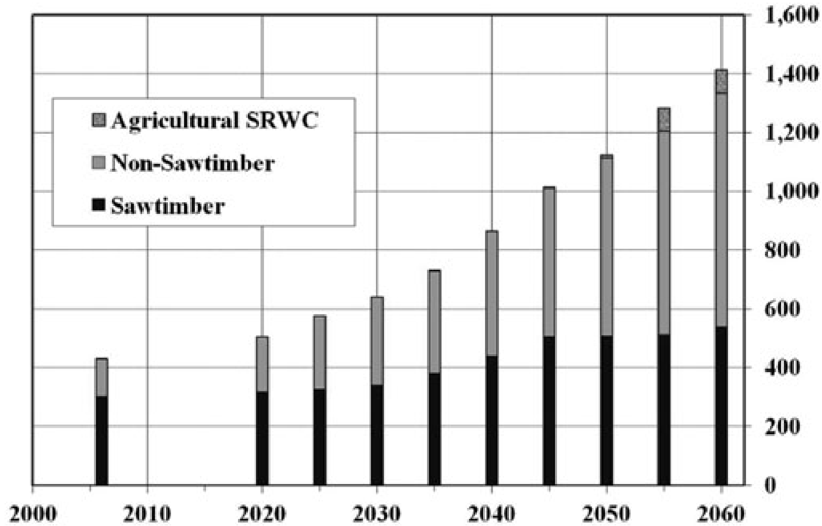

Figure 22. USFPM/GFPM projections of U.S. roundwood supply by source for A1B scenario, excluding bark and harvest residue volumes (million cubic meters per year)

2040 and beyond. This is a result of the larger harvest residue component and higher bark content of nonsawtimber (Table 1), which eventually affords a higher market value to nonsawtimber (per cubic meter of solid wood) in a scenario with very high wood energy demands. On the other hand, the projected sawtimber price trends are relatively flat in the A2 and B2 scenarios, and nonsawtimber prices are projected to increase much less than in the A1B scenario. In the B2 scenario, the projected real price trends for timber are mostly flat to declining, despite the fact that total U.S. timber harvest volume is projected to increase in the B2 scenario (Figure 20). Results suggest that projected U.S. timber supply will be adequate to meet projected timber and wood energy demand in the B2 scenario without significant real timber price increases.

Increases in timber demand and stumpage prices in the A1B scenario result also in a projected structural change in U.S. wood supply. The A1B scenario includes significant expansion in the area of pine plantations in the U.S. South and also expansion in supply of agricultural SRWC on agricultural lands, as higher prices for wood biomass make tree plantations more economically feasible in latter decades of the projection period. In the A1B scenario, planted pine area in the U.S. South expands by about 70%, from currently 16 million hectares to 27 million hectares by 2060, whereas about 8 million hectares of agricultural land are also planted in agricultural SRWC nationwide by 2060 in the A1B scenario. Figure 22 shows the projected U.S. roundwood supply by source for the A1B scenario, including agricultural SRWC supply. These structural changes in timber supply help offset impacts of expanded timber harvest on forest inventory, although U.S. timber inventory volume is nevertheless projected to gradually decline toward the end of the projection period in the A1B scenario. By contrast, with much lower projected timber demand and lower projected timber prices, the B2 scenario does not result in any appreciable expansion of agricultural SRWC supply and only about 20% expansion of pine plantation area in the South.

SUMMARY AND CONCLUSIONS

We tested and calibrated the USFPM/GFPM model to obtain accurate base-period solutions for U.S. timber markets, and we produced projections for a set of selected IPCC scenarios, and also other near-term wood energy scenarios described elsewhere (Ince et al 2011b). We believe the model behaves appropriately, providing rational behavioral responses to market stimuli, and reasonable projections of forest product and timber market trends in response to wide-ranging assumptions about future U.S. and global economic growth and future wood energy demands. We acknowledge that some future scenario assumptions may be outside the bounds of historical experience, such as future levels of U.S. and global wood energy consumption in the A1B scenario. However, we showed that global energy trends of the IPCC scenarios are in line with historical expansion in global energy output and shifting energy resources (Figure 5).

The projected effects on forest product markets of large-scale expansion in wood energy consumption are to dampen growth in forest product consumption (because of price impacts on demands) but could also provide some comparative economic advantages and enhanced U.S. net exports in scenarios where fuelwood demand drives up industrial roundwood prices for foreign producers more than U.S. wood prices.

Our analysis points to a primary conclusion, that expansion of wood energy consumption within the context of biomass energy projections developed for IPCC could result in either very substantial increases in wood energy demand and real timber prices (e.g., in the A1B scenario), or more modest increases in wood energy demand and little change in real timber prices (as in the A2 or B2 scenarios). Projected trends in U.S. real timber prices range from a relatively flat trend in the B2 scenario (with lowest but still significant projected expansion in U.S. wood energy consumption) to a steeply upward price trend in the A1B scenario (with highest projected expansion in U.S. wood energy consumption). In the A1B scenario, real timber stumpage prices reach levels that are far higher than the historical range of U.S. timber prices in modern times, indicating that wood energy demands of the A1B scenario could lead to unprecedented timber market conditions, but also questionable outcomes in terms of wood use for energy.

Results suggest that sustainability of using wood for energy might become questionable if U.S. wood fuel feedstock consumption were to expand by as much as projected in the A1B scenario given projected declines in forest inventory and increases in wood prices. With a nearly 16-fold (15.8×) expansion of U.S. wood energy consumption by 2060 in the A1B scenario, the real price of wood fuel feedstock reaches more than $150 per cubic meter (or several hundred dollars per dry ton) in constant 2006 dollars, about six times higher than current U.S. wood fuel feedstock prices. At that price the minimum cost of wood fuel pellets in 2060 would be about $410/ton, or two to three times current U.S. wood fuel pellet prices that range from around $140 to $200 per ton (in 2006 dollars), assuming that production costs remain the same apart from the higher feedstock costs. At $410 per ton the wood fuel pellet price would be equivalent in gross energy value to a heating oil price of about $0.95 per liter, or not much higher than recent U.S. price levels for heating oil (in 2006 dollars). However, wood fuel pellets currently sell at prices only about half the price of heating oil in terms of gross energy value, so it would be questionable whether wood fuel pellets could sell for two to three times as much by 2060.

Nevertheless, high wood energy prices may be plausible if fossil energy prices increase after global oil production peaks within the next decade, as projected by IPCC in the A1B scenario. The economic sustainability of using wood for energy at such high prices depends on fairly uncertain future outcomes, such as future improvements in efficiencies of biomass energy technologies, future prices for energy in general, and the effectiveness of future mandates or incentives for development of biomass energy.

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