U.S. Forest Products Module

A Technical Document Supporting the Forest Service 2010 RPA Assessment

Peter J. Ince, Andrew D. Kramp, Kenneth E. Skog,
Henry N. Spelter, and David N. Wear

Abstract

The U.S. Forest Products Module (USFPM) is a partial market equilibrium model of the U.S. forest sector that operates within the Global Forest Products Model (GFPM) to provide long-range timber market projections in relation to global economic scenarios. USFPM was designed specifically for the 2010 RPA forest assessment, but it is being used also in other applications. Within the GFPM framework of global forest product markets and trade, USFPM models aggregate U.S. forest product demands and regional forest product production, timber harvest, and timber stumpage markets in three U.S. subregions: North, South, and West. In each subregion, USFPM models timber stumpage markets for four categories of timber, including hardwood and softwood sawtimber and hardwood and softwood non-sawtimber. USFPM models regional timber harvest and transport activities as the conversion of timber stumpage supplies into delivered timber product outputs (sawlogs/veneer logs, pulpwood/composite timber, other industrial roundwood, and fuelwood) plus logging residues. USFPM also adds more complete product detail in U.S. regions, by differentiating hardwood lumber and softwood lumber, OSB structural panels and industrial particleboard, and hardwood and softwood plywood. In addition, USFPM models potential future supplies of agricultural short-rotation woody crops (SRWC) for energy and fiber, along with wood residue byproducts of sawmills and plywood mills, and the utilization of those materials in production of pulp, wood panels, and energy. USFPM thus models all forms of wood biomass feedstock that could be used potentially for future energy production in the United States, including fuelwood harvest, other roundwood, mill residues, agricultural SRWC, and logging residues. This report describes the structure of USFPM in detail and presents some examples of results and conclusions about future trends in wood energy demands and U.S. timber markets based on USFPM and GFPM projections. A key finding is that projected future trends in U.S. consumption, production, and net trade in forest products are heavily influenced by assumptions about future expansion in U.S. and global wood energy demands. The projected effects of expansion in U.S. and global wood energy consumption are to dampen growth in forest product consumption (because of price impacts on demands) but also to provide greater comparative advantages and enhanced net exports for U.S. producers of forest products (because of price impacts on foreign producers). Prodigious expansion in wood energy demands could cause significant escalation in real U.S. timber prices, but on the other hand, real U.S. timber stumpage prices are not projected to increase without fairly substantial increases in wood energy consumption.

Keywords: forest biorefinery model, economic feasibility, biomass gasification, biofuels

Conversion Table

English	Conversion factor	SI unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.305	meter (m)
acre	4,046.86	square meter (m^2)

Contents

September 2011

Ince, Peter J.; Kramp, Andrew D.; Skog, Kenneth E.; Spelter, Henry N.; Wear, David N. 2011. U.S. Forest Products Module: A Technical Document Supporting the Forest Service 2010 RPA Assessment. Research Paper FPL-RP-662. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 61 p.

A limited number of free copies of this publication are available to the public from the Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726–2398. This publication is also available online at www.fpl.fs.fed.us. Laboratory publications are sent to hundreds of libraries in the United States and elsewhere.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

U.S. Forest Products Module

A Technical Document Supporting the Forest Service 2010 RPA Assessment

Peter J. Ince, Research Forester, Forest Products Laboratory
Andrew D. Kramp, Associate IP Consultant, University of Wisconsin-Madison
Kenneth E. Skog, Supervisory Research Forester, Forest Products Laboratory
Henry N. Spelter, Economist (ret.), Forest Products Laboratory
David N. Wear, Supervisory Research Forester, Southern Research Station

Introduction

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) mandates that the U.S. Forest Service shall develop nationwide assessments of forest resource demand, supply, and forest resource conditions every 10 years. Since the 1970s, the Forest Service has developed and applied forest sector market models to produce long-range forest resource projections for the periodic RPA Assessment. The TAMM-NAPAP-ATLAS (TNA) modeling system evolved as the primary tool used for projecting North American timber trends in RPA assessments from the late 1970s to 2005 (Adams and Haynes 2007). For the 2010 RPA forest assessment, the Forest Service conceptualized a new modeling system consisting of a group of sub-models or modules collectively called the United States Forest Assessment System (USFAS).

This report describes the U.S. Forest Products Module (USFPM), a partial market equilibrium model that operates within the Global Forest Products Model (GFPM) to produce long-range projections of U.S. forest product markets and regional U.S. timber markets in the context of global economic scenarios for the RPA Assessment. We designed USFPM also to operate within the GFPM, a recursive dynamic spatial market equilibrium model of production, consumption, trade, and prices for all major forest products in 180 countries (Buongiorno and others 2003). The concept of developing USFPM within the GFPM originated several years ago (Ince and Buongiorno 2007), and USFPM was subsequently developed at the U.S. Forest Products Laboratory (FPL) in Madison, Wisconsin.

We designed USFPM to model U.S. forest product markets and regional U.S. timber stumpage markets as part of USFAS. Specifically, we designed USFPM to be linked to the separate USFAS forest dynamics model developed at the USDA Forest Service Southern Research Station to simulate dynamics of forest growth and changes in forest inventory by forest survey plot, including projected timber harvests in relation to projected regional timber prices, and forest plot conditions, and associated land use changes.

In the next section of this report, we begin by providing some background on development of USFPM in the RPA context, and then in subsequent sections we describe in more detail the structure of the U.S. forest sector as represented in USFPM, including USFPM input data and parameters. Data inputs or assumptions can be varied to produce alternative scenarios for projected U.S. market equilibria and trade flows in the GFPM framework. We explain data and assumptions for several alternative global economic scenarios examined by the 2010 RPA. These scenarios were based on global economic scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). We also describe another set of scenarios that we developed to project near-term market impacts of alternative biomass energy policies in the United States. Last, we present examples of results in the form of USFPM/GFPM projections for various scenarios in comparison with historical data trends, and we present conclusions and a summary based on those results. Details regarding IPCC storylines and their adoption in the RPA Assessment framework are described in USDA Forest Service (In preparation).

Background

RPA Assessments and supporting research are mandated by Congress in the Forest and Rangeland Renewable Resources Planning Act of 1974 (PL 93-378, United States Code Title 16). The RPA Assessment mandate is recognized also in the National Forest Management Act of 1976, the Forest and Rangeland Renewable Resources Research Act of 1978, and subsequent amendments (United States Code Title 16, Chapter 36). RPA Assessments are required every 10 years. RPA forest assessments are periodic research reports prepared by the U.S. Forest Service that describe in detail the nationwide forest resource situation, with long-range projections of timber market and forest resource trends that extend 50 years into the future. The accomplishments of RPA forest sector market modeling are well documented in a recently published book (Adams and Haynes 2007), and in previous RPA timber assessment reports (e.g., Haynes and others 2007, Haynes 2003).

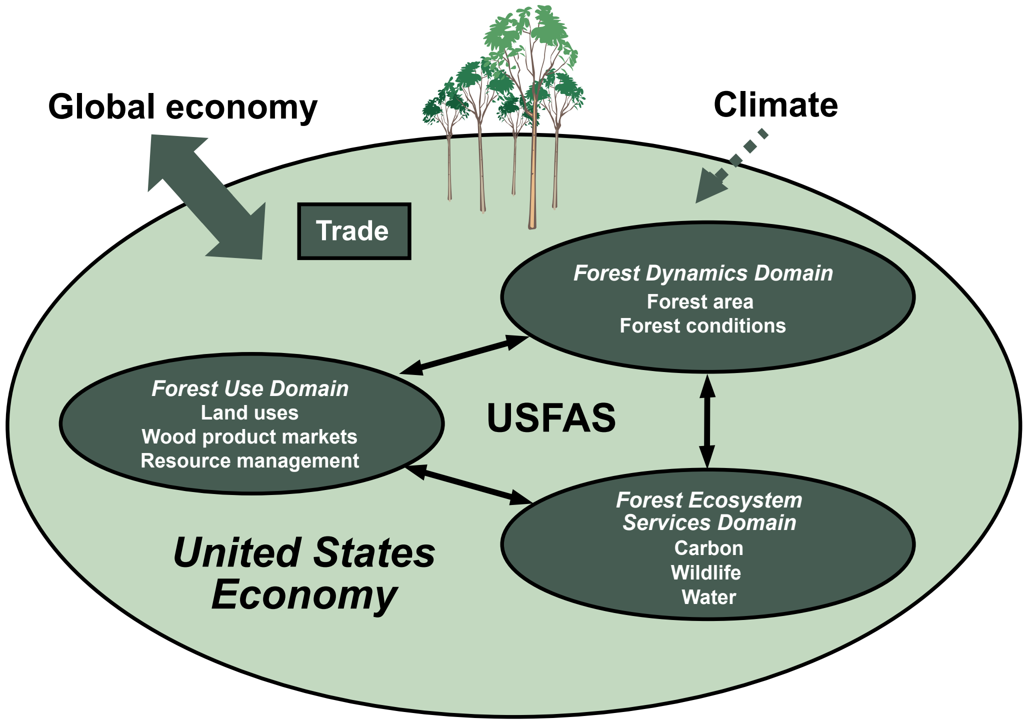

Figure 1—Conceptual structure of U.S. Forest Assessment System (USFAS).

The GFPM was developed in the 1990s at the University of Wisconsin-Madison (UW). The GFPM has been used by the Food and Agriculture Organization of United Nations (FAO) and other organizations (Buongiorno and others 2003). The current version of the GFPM is based on QPELPS, Quadratic Price-Endogenous Linear Programming System (Zhu and others 2006). The GFPM projects production, consumption, trade, and prices for forest products among 180 countries, with 14 products that include industrial roundwood, fuelwood, sawnwood, several categories of wood panels, several categories of paper and paperboard, and also intermediate wood fiber products such as wood pulp and recycled paper. The GFPM is a spatial market equilibrium model with endogenously derived shifts in timber supplies and exogenously specified shifts in product demands. It calculates spatial market equilibria among all countries linked by trade in a base year (2006) and in subsequent years over a multi-decade projection period. The primary source of market quantity and price data for the GFPM is the FAO online statistical database, FAOSTAT (http://faostat.fao.org/site/626/default.aspx#ancor).

The U.S. Forest Assessment System (USFAS) was conceptualized and designed as a new modeling framework for the 2010 RPA forest assessment (Wear 2011). USFAS was designed to link analyses in three separate domains: Forest Uses, Forest Dynamics, and Ecosystem Services. Figure 1 illustrates conceptually the three domains of USFAS. The Forest Uses Domain focuses on timber demand, prices, and consumption, while also projecting future land uses in relation to projected timber markets and other economic assumptions. The Forest Dynamics Domain focuses on simulating resource management decisions such as timber harvest in relation to price and simulating biological and physical development of forest resource conditions in response to projected changes in forest uses and the environment (such as projected climate change, for example). The Ecosystem Services Domain focuses on translating projected changes in forest conditions and land use into meaningful estimates of effects on the ecosystem services of forests such as water resources, biodiversity, and carbon storage. The USFPM operating within the GFPM is intended to be an integral element of the Forest Uses Domain, providing projections of U.S. and global wood product markets and regional U.S. timber market trends, and interacting via market projections with the Forest Dynamics Domain and Forest Ecosystem Services Domain.

Figure 2 further illustrates how RPA models and analysis were organized to produce projections of future forest resource trends in support of the 2010 RPA Assessment. RPA future scenarios were derived largely from IPCC and included basic economic assumptions (e.g., U.S. and global GDP growth), technology assumptions (e.g., U.S. and global expansion of biomass energy production), population growth assumptions, future climate data, and forest inventory data, including Forest Service Forest Inventory and Analysis (FIA) data for the United States and FAO global forest inventory data. The RPA scenario assumptions are fed into the RPA models, which include the USFPM/GFPM

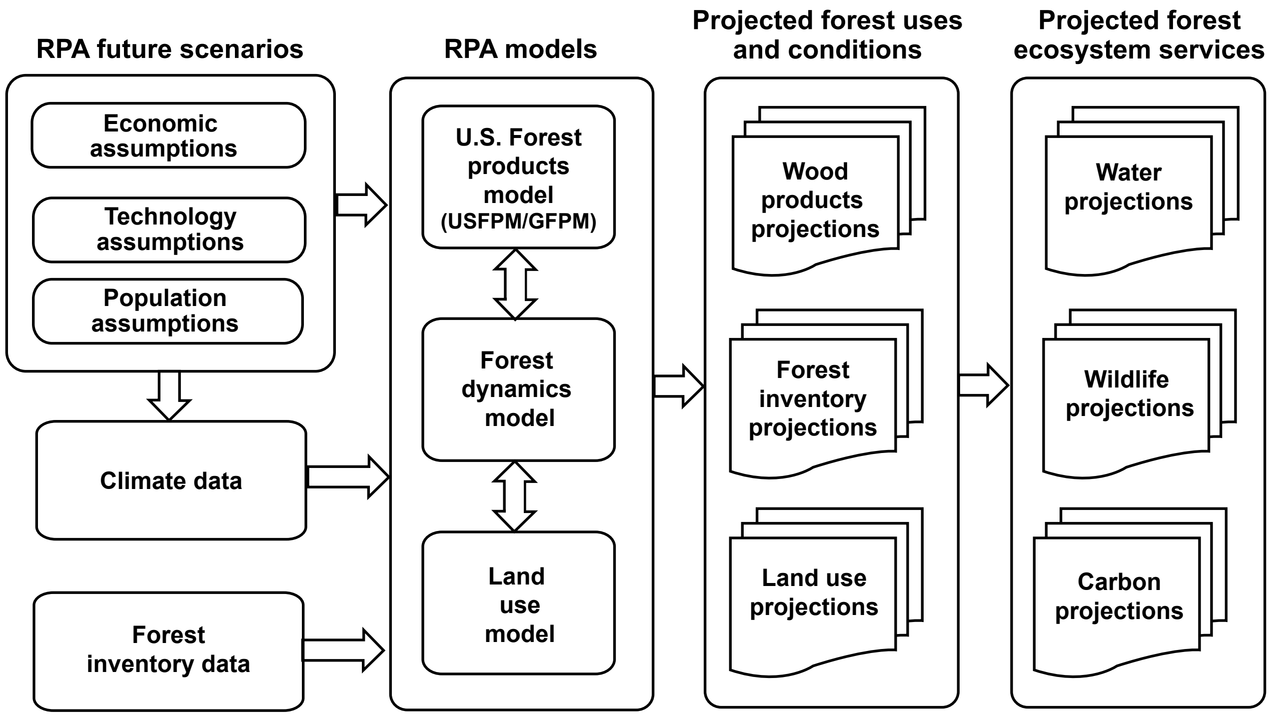

Figure 2—RPA models and analysis in support of the 2010 RPA Assessment.

forest product and timber market models, the Forest Dynamics Model that models dynamics of U.S. forest growth, forest inventory, and timber harvests, and the Land Use Model, which projects changes in land use in response to urbanization as driven by projected population and income changes. The RPA models are used to analyze the scenarios and project future U.S. forest uses and conditions, including future wood product output, regional timber harvests, and timber market trends, changes in U.S. forest inventory, and changes in U.S. forest land use. The RPA scenarios and projected changes in forest uses and conditions are then used to project trends in forest ecosystem services in the United States, including for example water resource projections, wildlife projections, and forest carbon projections.

U.S. Forest Sector Structure in USFPM

The USFPM provides much more regional and commodity detail for the United States than the UW version of the GFPM. In the UW version of the GFPM, each country including the United States, is represented as just a single region. In building USFPM within the GFPM, we started by creating several U.S. subregions in order to model U.S. timber markets in more complete regional detail as required for RPA. USFPM is thus basically an expansion of the U.S. market region within the GFPM. We also added a new timber commodity structure for U.S. subregions, featuring a more complete representation of timber stumpage supply and harvest activities. Because USFPM is entirely integrated into the GFPM, we run an entire global analysis of trade with GFPM whenever we run USFPM. For all other countries, we generally retained the existing structure of the GFPM along with the original GFPM data for all the other countries, although we modified the global fuelwood demand assumptions to reflect IPCC biomass energy projections. In essence, USFPM fits a more disaggregated regional U.S. forest sector market model for the RPA assessment into the broader global modeling framework of the GFPM. For reference, note that the UW still maintains the original version of the GFPM (which does not contain USFPM) and of course, the UW version of GFPM can be run independently without USFPM, although results and data assumptions are different (such as assumptions about global fuelwood demands).

The structure of USFPM reflects important diverse elements of the U.S. forest products industry and unique requirements of RPA assessments. In U.S. regions for example, unlike the original GFPM, USFPM differentiates hardwood timber from softwood timber, and also differentiates hardwood lumber from softwood lumber, OSB structural panels from industrial particleboard, and hardwood plywood from softwood plywood. In addition, USFPM models logging residues as byproducts of timber harvest activities, and wood mill residues as byproducts of sawmills, plywood mills, and pulp mills, and it models current and future use of those residues in production of pulp, wood panels, and energy. Note that assessment of potential for increased use of forest and wood product wastes (i.e., wood residues) is among the specific requirements of RPA legislation, which necessitates many of the unique structural features of USFPM

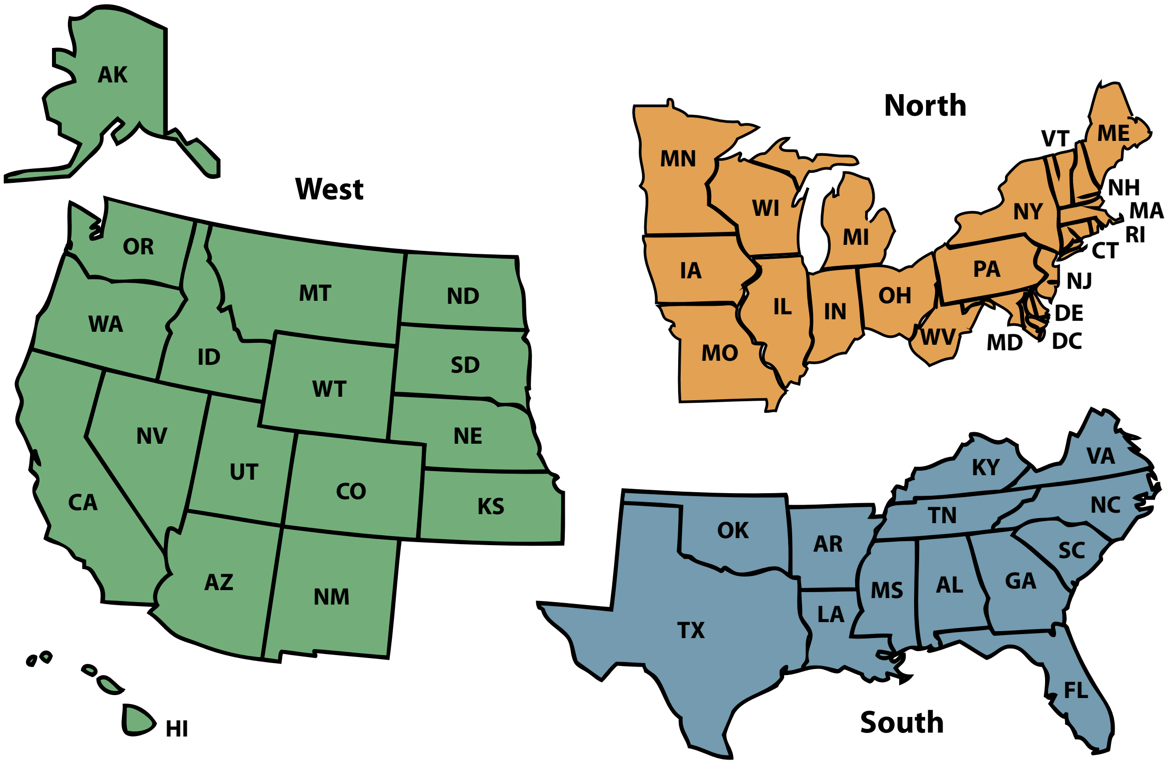

Figure 3—Three U.S. Forest Products Module (USFPM) supply and production subregions: North, South, and West.

(Renewable Resources Planning Act of 1974 (RPA). Title 16 United States Code §1600(c)(2)).

In USFPM, we model timber supply, timber harvest, and forest product production in each of three U.S. subregions: North, South, and West. Figure 3 shows state boundaries of the three U.S. subregions. End product demand of the United States is modeled at the national level as a single demand region, obtaining products via shipments from U.S. subregions and via imports from the rest of the world (as modeled by the 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 also exports 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 was designed to reflect the basic structure of regional U.S. forest resource and timber utilization data as reported by the U.S. Forest Service for the 2010 RPA Assessment (Smith and others 2009). The Forest Service resource data derive from national compilations of state-level forest surveys conducted by Forest Inventory and Analysis (FIA) researchers. In USFPM, we use FIA regional data on timber inventory volumes and harvests by timber species group (hardwood and softwood) and by merchantability class (sawtimber and non-sawtimber), 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, veneer, wood pulp, composite wood products, miscellaneous wood products, and fuelwood.

In addition, we expanded the forest product structure in USFPM by disaggregating several GFPM end products within U.S. regions to provide a more complete analysis of hardwood and softwood timber markets. Expansion of the GFPM end product categories in USFPM is illustrated in Figure 4. Within U.S. regions, we expanded the "sawnwood" product of the GFPM into hardwood lumber and softwood lumber, and we expanded "plywood/veneer" into softwood plywood/veneer and hardwood plywood/veneer. In addition, "particleboard" was expanded into oriented strandboard (OSB) and industrial particleboard. These disaggregated USFPM end products actually have rather different end use markets and distinctly varied wood raw material input requirements, which we recognize in USFPM. We facilitate USFPM trade in the disaggregated products with other GFPM countries by aggregating 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 (USITC) trade data (product shares could be changed but in this report they are held constant across scenarios and over time).

We model timber harvest and transport activities in USFPM as the conversions of sawtimber and non-sawtimber stumpage by species group into four aggregated categories of

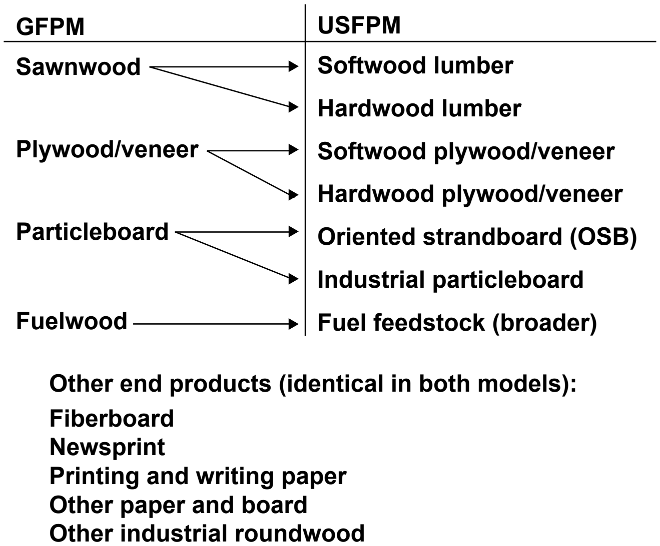

Figure 4—USFPM expansion of the GFPM end product categories.

delivered timber product outputs: (1) sawlogs/veneer logs, (2) pulpwood/composite, including timber for pulp and composite wood products, (3) other industrial roundwood, including posts, poles, pilings, and miscellaneous products, and (4) fuelwood. To maintain precise consistency with FIA data, we model regional U.S. timber supply in USFPM by precisely the same timber species groups and merchantability classes as described in the FIA data, with base-year (2006) USFPM regional timber harvest volumes and timber product output data calibrated precisely to the FIA data (Smith and others 2009).

The Forest Service RPA forest resource data specifically define sawtimber and non-sawtimber in terms of tree size class and merchantability. Sawtimber is defined as trees that appear capable of yielding sawlogs, and greater than 9-in. dbh for softwood trees and greater than 11-in. dbh for hardwood trees (Smith and others 2009). Smaller trees, trees that do not appear capable of yielding sawlogs, or non-growing stock trees (live cull trees and dead trees) are categorized as non-sawtimber. In actuality and as programmed into harvest activity parameters of USFPM (based on FIA timber harvest data), sawlogs are recoverable from both sawtimber and non-sawtimber, although of course the recovery ratio of sawlogs is much higher from sawtimber trees than from non-sawtimber trees, whereas recovery of pulpwood and fuel feedstock is proportionately higher from non-sawtimber trees.

In USFPM, each U.S. subregion supplies four categories of timber stumpage: hardwood sawtimber, softwood sawtimber, hardwood non-sawtimber, and softwood non-sawtimber. These are converted by harvest activities into four USFPM categories of delivered timber product outputs (sawlogs/veneer logs, pulpwood/composite, other industrial roundwood and fuelwood) plus logging residues (which can be used as fuel, although residue recovery adds to harvest costs). All harvest data and conversion factors match FIA timber harvest data (Smith and others 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 does not model timber harvest activities. In all other countries in the GFPM, 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. Thus, a more complete model of the timber supply chain for the United States is represented in USFPM than in the original GFPM, including timber stumpage markets, sawtimber, and non-sawtimber harvest activities, and conversions into recognized categories of delivered timber product outputs plus logging residues.

The addition of timber supply detail with regional timber harvest and product recovery calibrated to FIA forest resource data (Smith and others 2009) are important features of USFPM in the RPA assessment context because it allows for analysis of potential for increased wood residue utilization (a legal requirement of the RPA), and it allows for a more precise linkage of USFPM (and the GFPM) to the USFAS forest dynamics model, which models dynamics of U.S. forest growth, forest inventory, and timber harvests by species group and merchantability class based on FIA forest survey data. The plot transition model is designed, for example, to simulate regional forest growth, forest inventory, and harvests of hardwood and softwood sawtimber and non-sawtimber by forest plot in relation to regional timber stumpage prices by species group while accounting for climate, natural succession, and land-use change effects. USFPM provides projected regional timber stumpage demand and prices for the forest dynamics model, and in turn the forest dynamics model provides to USFPM the regional timber supply functions in terms of projected price elasticities of timber stumpage supply and projected shifts in timber stumpage supply curves. An iterative solution procedure can be used to derive convergent solutions of USFPM and the forest dynamics model for specific RPA scenarios.

Another feature we added to USFPM was the potential future supply of agricultural SRWC. We model future agricultural SRWC supply by region using regional estimates of feasible delivered wood costs and crop yields, along with assumptions regarding limits (upper bounds) on available cropland acreage for SRWC. The agricultural SRWC supply represents potential future supply of tree crops that could be grown on agricultural land (as opposed to forest land). Based on historical yield studies with hybrid poplars on agricultural land, the future SRWC wood harvest volume was specified to be 75% pulpwood and 25% fuelwood, but

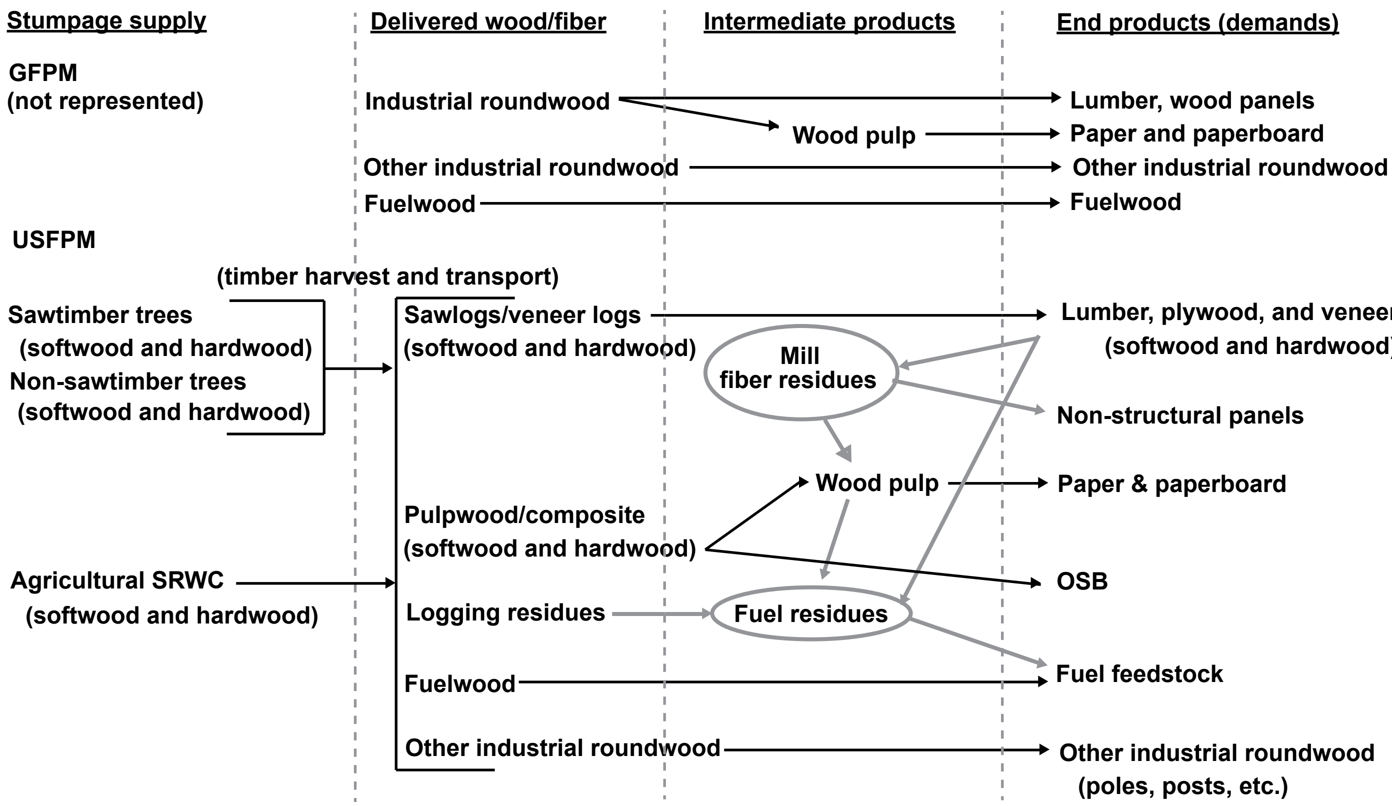

Figure 5—Comparison of the GFPM and USFPM wood supply structures.

alternatively all of the SRWC harvest can go to fuel feedstock depending on projected market demands (e.g., if the projected price of fuel feedstock exceeds pulpwood price).

Figure 5 compares the U.S. regional wood supply structure that we developed in USFPM with the nationwide wood supply structure of the original GFPM, where nationwide supply functions represent delivered industrial roundwood, fuelwood, and other industrial roundwood. Note that the GFPM also models change in forest stock and forest area, and how this influences industrial roundwood supply (Turner and others 2006). USFPM represents timber stumpage supply functions and tree harvest volumes by species group and by tree merchantability class (sawtimber and non-sawtimber), along with harvested and delivered timber product outputs (sawlogs/veneer logs, pulpwood, fuelwood and other industrial roundwood timber products). USFPM also adds logging residue and mill residue byproducts 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 and others 2009).

USFPM includes all primary categories of wood residues, identical in quantity and definition to FIA data:

- *logging residues* generated as byproducts of timber harvest activities that require added cost to be recovered
- *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
- *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 and others 2009).

Logging residues (typically branches, broken stems, and other logging debris) are the volumes of wood removals currently left in the forest after timber harvest operations and are conventionally uneconomical to recover. Logging residue volumes are modeled in USFPM as byproducts of timber harvest activities, with regional output volumes calibrated to actual historical logging residue volume data from FIA. Future logging 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 logging residues. However, we

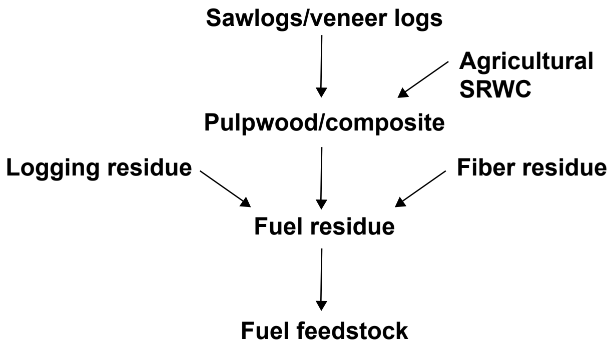

Figure 6—Cascading wood raw material substitution possibilities in USFPM.

constrain future recovery of logging 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.) Note that the 60% recovery limit on logging residue volumes is not a suggested regulatory limit, nor does it imply that logging residue recovery above or below 60% would be infeasible or inappropriate in some cases. The assumption is simply a reasoned approximation of likely but unknown future limits on logging residue recovery, consistent with assumptions by Conner and Johnson (2011) and Perlack and others (2005).

In addition to disaggregating several GFPM end products and adding timber stumpage and wood residues to wood supply, we also added to USFPM the feature of "cascading" raw material substitution possibilities, which means allowing economic substitution of higher value timber product outputs for lower value materials if projected market conditions favor such substitution. Historically, higher value timber product outputs like sawlogs or veneer logs were too valuable to be used in place of lower value materials like pulpwood or fuelwood. However, in scenarios with increased demand for lower value products like fuelwood, their prices can increase enough to make such 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, but only if it becomes economical to do so (if projected equilibrium prices for fuel feedstock reach levels that permit economical substitution). The cascading (one-way) wood raw material substitution possibilities in USFPM are illustrated in Figure 6.

Cascading wood raw material substitution is a feature that enables USFPM to simulate economic substitution possibilities that could arise, for example, in scenarios with significant future expansion in wood biomass energy demand. Higher wood energy demands generally tend to increase projected market competition and prices for wood. If projected equilibrium prices for fuel feedstock increase sufficiently, then logging residues, pulpwood, agricultural SRWC, and fiber residue may be utilized for energy, and ultimately sawlogs/veneer logs will be too, but only if projected equilibrium wood energy demands and prices are high enough. Thus, in USFPM, wood energy demands potentially compete for the same wood resources as other wood products, and USFPM is designed to model the market consequences of such potential competition.

We can also simulate hypothetical biomass supply policies in USFPM by constraining or enhancing the cascading substitution activities. For example, we could simulate policy restrictions on use of commercial timber for energy by constraining the use of sawlogs/veneer logs and pulpwood for energy, or we could simulate a policy promoting the use of logging residues by adding a subsidy value to the logging residue byproducts of harvesting activities.

In addition, through our collaboration with developers of the GFPM at UW, researchers there followed our lead and have incorporated a similar cascading substitution possibility for all other countries in the GFPM, allowing industrial roundwood in the other countries to be substituted for fuelwood whenever it becomes economical to do so in the projection period. This feature has important implications for the future wood market outlook, as discussed later in the results section.

USFPM Input Data and Parameters

In this section, we describe USFPM input data and model parameters in detail. The input data include U.S. regional supplies of timber (timber harvest volumes and prices), regional timber product output volumes and input/output coefficients for timber harvest activities, timber harvest costs, supplies of other fiber inputs used in the forest product sector (recovered paper used for recycling, mill residues, and non-wood pulp), forest product production volumes, manufacturing costs and fiber input requirements, and U.S. demand quantities and prices for forest products. Parameters of U.S. demands include price elasticities and elasticities with respect to national income (U.S. real GDP) and other demand drivers, whereas timber supply parameters include price elasticities and relationships to regional timber growth and timber inventory. In this section, we also explain how USFPM commodities are aggregated or disaggregated to model trade between the United States and the rest of the world in the GFPM framework.

Timber Supply

USFPM models regional timber supply by *four* categories of standing timber, differentiated by species group (hardwood and softwood) and by tree merchantability class (sawtimber and non-sawtimber). Sawtimber is defined by the Forest Service as live growing stock trees above a minimum size and capable of yielding sawlogs, specifically hardwood trees

Table 1—Timber product output and logging residue volumes associated with regional sawtimber and non-sawtimber harvest activities (2006)[a]

	Sawtimber harvest ($\times 10^3$ m^3)		Non-sawtimber harvest ($\times 10^3$ m^3)	
	Hardwood	Softwood	Hardwood	Softwood
U.S. North				
Sawlogs/veneer logs	21,563	8,243	3,193	1,655
Pulpwood/composite	12,577	4,890	12,552	3,927
Other industrial roundwood	411	398	204	301
Fuelwood	3,087	80	12,292	841
Logging residue	5,829	771	23,580	7,135
U.S. South				
Sawlogs/veneer logs	27,569	88,066	2,762	8,536
Pulpwood/composite	14,673	29,242	16,505	40,466
Other industrial roundwood	216	2,691	204	1,130
Fuelwood	5,759	572	3,641	552
Logging residue	6,181	4,067	27,708	28,415
U.S. West				
Sawlogs/veneer logs	2,360	68,617	113	4,910
Pulpwood/composite	1,380	3,255	42	300
Other industrial roundwood	13	908	76	656
Fuelwood	26	1,420	2,674	8,924
Logging residue	292	4,926	1,261	18,473

[a]Forest Service Timber Products Output (TPO), Smith and others 2009.

Table 2—Timber harvest volumes by timber category and species group (2006)[a]

Timber harvest ($\times 10^3$ m^3)	U.S. North	U.S. South	U.S. West
Hardwood			
Sawtimber	37,638	48,218	3,779
Non-sawtimber	28,240	23,113	2,905
Softwood			
Sawtimber	13,610	120,570	74,201
Non-sawtimber	6,724	50,684	14,791

[a]Sources: Forest Service Timber Products Output (TPO) and RPA Forest Resources report (Smith and others 2009, table 39).

above 11-in. dbh and softwood trees above 9-in. dbh. Non-sawtimber refers to all other trees, including poletimber growing stock (smaller live trees) plus non-growing stock (live cull or dead trees). Timber harvest data show that harvest of sawtimber yields proportionately more sawlog and veneer log volume, whereas harvest of non-sawtimber yields less sawlog and veneer log volume and proportionately more pulpwood and fuelwood volume.

USFPM also models timber harvesting as activities that consume timber supplies and jointly produce *four* categories of timber product outputs: 1) sawlogs/veneer logs (which include both sawlogs and veneer logs), 2) pulpwood/composite timber (which includes pulpwood for pulp mills plus timber for composite wood products such as OSB), 3) other industrial roundwood, and 4) fuelwood. Timber product outputs represent timber raw materials harvested and delivered to market—e.g., sawlogs/veneer logs delivered to lumber and plywood mills, pulpwood/composite timber delivered to pulp mills and OSB mills, etc.

Base-year (2006) regional U.S. timber harvest data and timber product output data in USFPM incorporate the industrial timber harvest data and fuelwood harvest data reported in the latest Forest Service RPA forest resources report (Smith and others 2009, table 39). The RPA data account primarily for domestic timber product outputs, whereas USFPM must account also for roundwood exports. Thus, we also added independent estimates of regional roundwood export volumes from the USITC trade database, http://dataweb.usitc.gov/) as needed to more fully account for all regional U.S. timber harvest in USFPM.

We used the Forest Service timber product output (TPO) reporting tool (RPA database available on-line at http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int1.php) to compile the basic data on regional timber harvest by sawtimber and non-sawtimber categories in 2006 for both hardwoods and softwoods and to determine corresponding volumes of timber product outputs (sawlogs/veneer logs, pulpwood/composite timber, other industrial roundwood, and fuelwood), plus corresponding logging residue volumes. Table 1 shows the 2006 U.S. regional timber product output and logging residue data from the TPO reporting tool for sawtimber and non-sawtimber harvest.

Table 2 shows aggregated regional timber harvest data for 2006, as reported in the RPA forest resources report, corresponding to regional sums of timber product outputs shown in Table 1 (not including logging residues). Regional totals of timber product output volumes in Table 1 precisely match regional timber harvest volumes as reported in the latest Forest Service RPA forest resources report (Smith and others 2009, table 39), although the TPO reporting tool was needed to disaggregate timber product output and logging residue data into the sawtimber and non-sawtimber categories as shown in Table 1.

To measure regional roundwood, wood chip, and fuelwood import and export volumes, we obtained USITC trade volume data by U.S. Customs Districts. We aggregated the data to U.S. subregions similar to the way that published historical Forest Service regional trade data have been aggregated (Daniels 2008). Daniels (2008) shows that RPA regions place Maryland (MD) in the North and North Dakota (ND) in the West, whereas previous Forest Service compilations placed MD in the South and ND in the North (Daniels 2008). Table 3 shows the distribution of U.S. Customs Districts by RPA region, used for aggregating USITC trade data.

Table 3—Distribution by RPA region of U.S. customs districts, as applied in aggregating USITC trade data for USFPM

North	South	West
Baltimore, MD	Norfolk, VA	Columbia-Snake River Basin
Portland, ME	Wilmington, NC	Seattle, WA
St. Albans, VT	Charleston, SC	Anchorage, AK
Boston, MA	Savannah, GA	Other West
Providence, RI	Tampa, FL	San Diego, CA
Bridgeport, CT	Mobile, AL	Nogales, AZ
Ogdensburg, NY	New Orleans, LA	Los Angeles, CA
Buffalo, NY	Port Arthur, TX	San Francisco, CA
New York, NY	Laredo, TX	Honolulu, HI
Philadelphia, PA	El Paso, TX	Great Falls, MT
Minneapolis, MN	San Juan, PR	Pembina, ND
Duluth, MN	U.S. Virgin Islands	
Milwaukee, WI	Miami, FL	
Detroit, MI	Houston/Galveston, TX	
Chicago, IL	Washington, DC	
Cleveland, OH	Dallas/Fort Worth, TX	
St. Louis, MO	Savannah, GA/Wilmington, NC, Norfolk, VA/Mobile, AL/Charleston, SC	

Table 4—Trade volume data for roundwood, wood chips, and fuelwood by species group and U.S. subregion (2006)[a]

Commodity	U.S. North	U.S. South	U.S. West
Roundwood exports ($\times 10^3$ m^3)			
Softwood roundwood	2,929	331	3,633
Pulpwood fraction	463	240	32
Hardwood roundwood	1,118	824	249
Pulpwood fraction	216	398	16
Roundwood imports ($\times 10^3$ m^3)			
Softwood roundwood	117	40	2,253
Pulpwood fraction	25	0	24
Hardwood roundwood	252	9	10
Pulpwood fraction	72	0	0
Wood chip exports ($\times 10^3$ t, dry)			
Softwood chips	202	106	881
Hardwood chips	124	224	37
Wood chip imports ($\times 10^3$ t, dry)			
Softwood chips	15	1	38
Hardwood chips	13	433	118
Fuelwood trade ($\times 10^3$ t, dry)			
Fuelwood exports	14	3	1

[a]U.S. International Trade Commission (USITC).

Table 4 shows USITC trade volume data for roundwood, wood chips, and fuelwood, aggregated by species group (softwood or hardwood) and U.S. subregion (USITC roundwood data are in cubic meters, and wood chips and fuelwood data are in metric tonnes (t) dry weight basis). We compiled USITC trade data by Harmonized Tariff Schedule code, similar to previous Forest Service compilations (Daniels 2008), and not by Standard Industrial Classification (SIC) code. We combined exports data with Forest Service data on timber product outputs to more fully account for regional timber supply in USPM. We also included imports data in total wood consumption to more fully account for all wood inputs used in forest product production activities in USFPM (discussed later in more detail).

Regional surveys provide Forest Service timber harvest and timber product output data (Smith and others 2009, table 39), but survey scope and methods differ slightly among U.S. regions (North, South, and West). In the South, Forest Service timber product output data derive primarily from surveys of domestic mills but not exporters of roundwood. We recognized also that exports of roundwood, wood chips, and fuelwood from the South derive primarily from timber harvest, so we made adjustments to timber harvest for the South to account for exports of roundwood, wood chips, and fuelwood. Specifically, we added Southern export volumes from USITC (Table 4) to Southern timber product output volumes as reported in the RPA forest resources report (Smith and others 2009, table 39). We added Southern fuelwood exports to Southern fuelwood harvest, Southern wood chip exports to Southern pulpwood harvest, and Southern roundwood exports to Southern sawlog/veneer log and pulpwood harvest according to USITC specifications (USITC identifies pulpwood fractions of roundwood exports as shown in Table 4).

In other USFPM regions (North and West), Forest Service timber product output surveys include some roundwood export volumes, so we assumed that USITC roundwood and fuelwood export volumes were included in the timber harvest and timber product output data for the North and West as reported in the RPA forest resources report (Smith and others 2009, table 39). Also, unlike the South, wood chip exports in the other regions may derive from fiber residues, particularly in the West (where most pulpwood supply derives from mill residues). Thus, in the North and West, base-year quantities of fiber residues available for domestic use in USFPM include regional fiber residue output volumes as reported in the RPA forest resources report (Smith and others 2009, table 42) minus the regional net exports of wood chips (Table 4).

In addition, we used USITC roundwood, wood chip, and fuelwood trade data to specify in USFPM the base-year U.S. regional import and export volumes for roundwood and fuelwood, replacing the aggregated U.S. trade data from FAO that were in the original version of the GFPM. The aggregate U.S. import and export volumes reported by FAO for roundwood and fuelwood are nearly identical to the sums of the regional imports and exports from USITC. Although wood chip trade is not modeled in the GFPM framework, we adjusted base-year regional U.S. roundwood export volumes in USFPM to include wood chip exports derived from timber harvest (all wood chip exports from the South and a

Table 5—USFPM base-year (2006) estimates of total timber product output and logging residue volumes associated with sawtimber and non-sawtimber harvest activities

Commodity	Sawtimber harvest ($\times 10^3$ m^3)		Non-sawtimber harvest ($\times 10^3$ m^3)	
	Hardwood	Softwood	Hardwood	Softwood
U.S. North				
Sawlogs/veneer logs	21,563	8,243	3,927	1,655
Pulpwood/composite	12,577	4,890	12,552	3,193
Other industrial roundwood	411	398	204	301
Fuelwood	3,087	80	12,292	841
Logging residue	5,829	771	23,580	7,135
U.S. South				
Sawlogs/veneer logs	27,956	88,149	2,801	8,544
Pulpwood/composite	14,860	29,342	16,715	40,605
Other industrial roundwood	216	2,691	204	1,130
Fuelwood	5,777	573	3,652	554
Logging residue	6,181	4,067	27,708	28,415
U.S. West				
Sawlogs/veneer logs	2,360	68,617	113	4,910
Pulpwood/composite	1,380	3,255	42	301
Other industrial roundwood	13	908	76	656
Fuelwood	26	1,420	2,674	8,924
Logging residue	292	4,926	1,261	18,473

Table 6—USFPM base-year (2006) timber supply or timber harvest (excluding logging residue) by region, species group, and timber category (sawtimber and non-sawtimber)

Commodity	Timber harvest ($\times 10^3$ m^3)	
	Hardwood	Softwood
U.S. North		
Sawtimber	37,638	13,610
Non-sawtimber	28,240	6,724
U.S. South		
Sawtimber	48,810	120,754
Non-sawtimber	23,373	50,833
U.S. West		
Sawtimber	3,779	74,201
Non-sawtimber	2,905	14,791

share of exports from other regions). This is a minor adjustment, because Southern wood chip exports have declined to fairly negligible volumes in recent years, and in the West, timber harvest accounts for only a small fraction of wood chip exports.

Table 5 shows the USFPM base-year data for timber product output and logging residue volumes associated with sawtimber and non-sawtimber harvest, which take into account Forest Service data on timber product outputs and logging residues (from Table 1), plus our additions of regional exports of harvested roundwood, wood chips, and fuelwood.

Table 6 shows USFPM base-year estimates of total timber supply (or timber harvest) by species group and region and by sawtimber and non-sawtimber categories. Timber harvest volumes in Table 6 correspond to the total output of industrial timber products and fuelwood shown in Table 5, but do not include logging residues (which are conventionally not part of timber harvest). USFPM base-year timber harvest estimates (Tables 5 and 6) are somewhat higher than the Forest Service timber harvest data (Tables 1 and 2) because the USFPM data include our adjustments for regional exports of roundwood, wood chips, and fuelwood.

In addition to regional timber supply quantities (Table 6), USFPM base-year timber supply data include regional sawtimber and non-sawtimber stumpage prices. There is no singular source of nationwide data on timber stumpage prices, although there are various regional timber price reporters and also various sources of nationwide data on delivered timber product output prices such as pulpwood. We considered a variety of sources on timber prices (Cochran 2007, International Woodfiber Report 2007, Log Lines 2006, Timber Mart North 2006, and Timber Mart-South 2006). For USFPM, we derived regional timber stumpage price estimates using a residual value method by calculating the average value of delivered timber product outputs recovered

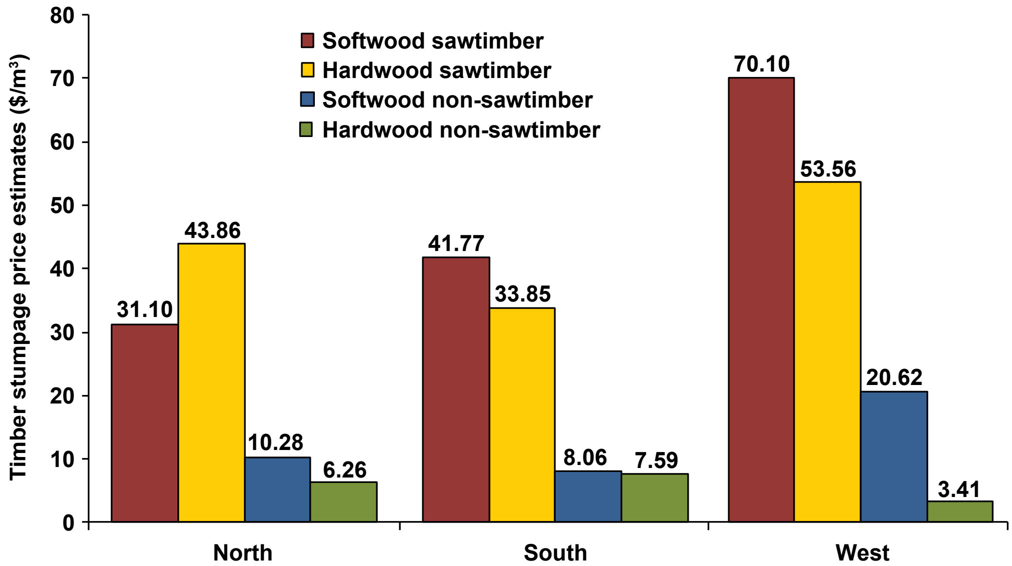

Figure 7–USFPM base-year (2006) timber stumpage price estimates ($/m³) by region, for sawtimber and non-sawtimber.

from sawtimber and non-sawtimber in each region (Table 5), and subtracting estimated harvest and delivery costs.

Figure 7 shows our derived base-year regional stumpage price estimates for sawtimber and non-sawtimber. We adjusted USFPM harvest cost assumptions so that our derived base-year stumpage price estimates for sawtimber and non-sawtimber in the South would be closest in value to reported "sawtimber" and "pulpwood" stumpage prices for the Southern region (2006 stumpage prices as reported in Timber Mart-South).

In general, timber supply models provide estimates of future timber harvests in response to price indices and other variables describing the condition of forest inventories. Supply relationships aggregate the response of multiple decision makers, in this case the response of forest land owners controlling forests with a variety of conditions (i.e., forest types, ages, productivity) and timber prices.

Timber supply is estimated in two ways for the USFPM regions. For the South, supply functions are constructed by summarizing harvest results of the forest dynamics model simulations. Harvest responses are modeled using an econometric model of harvest choices for all FIA plots in the region across multiple price realizations for all 13 southern states (Polyakov and others 2010). These models estimate the probability of harvests as a function of potential revenues for harvest of two types (partial and full harvest) or for delaying harvest. These stochastic models are run several times to generate multiple estimates of harvests in response to future price conditions and the results are summarized using the aggregator function.

The regional response is then aggregated using constant elasticity models for each time period to provide estimates of the aggregate South-wide supply elasticities for the four categories of timber supply (hardwood and softwood sawtimber and non-sawtimber). Because the harvest model is embedded in the Southern forest dynamics model, the harvest choice models yield different supply outcomes in the various periods of the simulations. In effect, the price quantity relationship shifts in response to changes in the inventory that are caused not only by harvesting but also by changes driven by climate, forest succession, plot aging, and forest type changes. These supply shifts are summarized by horizontal shifts (shifts in the quantity intercept) of the constant-elasticity aggregation functions (see Table 7 for average projected supply shifts).

In the South, supply responses are also scaled by projections of land-use changes. For each RPA storyline (A1B, A2, and B2), population and income forecasts drive forecasts of urbanization at the county level. Resulting forest land-use changes are also influenced by the price path of timber products and each simulated price realization engages a land-use forecast consistent with that price path (Wear 2011). Supply functions for the South therefore depend on the population, income, and climate forecasts specified for the given storyline. In developing the timber supply models, we considered only one climate projection for each storyline. Our analysis indicated that removal forecasts were not substantially influenced by the climate model used. Gross changes in forest land area (2010–2060) are also summarized in Table 7.

For the North and the West, harvest choice modeling approaches comparable to the South proved infeasible for estimating timber supply. In the North, harvest models yielded

Table 7—Regional timber supply parameters, including stumpage price elasticities, average shifts of timber supply, changes in timberland area, and base-year timber inventory data

	U.S. North	U.S. South	U.S. West
Price elasticities of stumpage supply[a]			
Softwood sawtimber	0.5	0.22	0.34
Softwood non-sawtimber	0.5	0.19	0.34
Hardwood sawtimber	0.48	0.31	0.34
Hardwood non-sawtimber	0.64	0.26	0.34
A1B scenario average annual shifts of stumpage supply, 2006–2060 (%)			
Softwood sawtimber	0.0	0.24	0.42
Softwood non-sawtimber	0.0	1.40	0.42
Hardwood sawtimber	0.0	0.73	0.42
Hardwood non-sawtimber	0.47	0.10	0.42
A2 scenario average annual shifts of stumpage supply, 2006–2060 (%)			
Softwood sawtimber	0.0	0.67	0.44
Softwood non-sawtimber	0.0	1.20	0.44
Hardwood sawtimber	0.0	0.79	0.44
Hardwood non-sawtimber	0.52	0.15	0.44
B2 scenario average annual shifts of stumpage supply, 2006–2060 (%)			
Softwood sawtimber	0.0	0.51	0.71
Softwood non-sawtimber	0.0	1.15	0.71
Hardwood sawtimber	0.0	0.79	0.71
Hardwood non-sawtimber	0.56	0.15	0.71
Gross changes in private timberland area, 2010–2060 (%)			
A1B scenario	–6.6	–10.0	–5.1
A2 scenario	–5.5	–8.1	–5.3
B2 scenario	–3.3	–5.5	–3.3
Estimated timber inventories, 2006 ($\times 10^6$ m^3)			
Softwood growing stock	1,547	3,293	9,927
Hardwood growing stock	5,295	4,757	1,128
Net annual growth in timber inventories, 2006 (% change)			
Softwood growing stock	2.72	6.56	1.75
Hardwood growing stock	2.72	3.36	1.95

[a]Price elasticities in Table 7 were applied to all three RPA scenarios, except for the B2 scenario where price elasticities of non-sawtimber supply were adjusted slightly to 0.18 for softwood and 0.27 for hardwood in the South.

no significant price impacts on harvest choices.We posit that this may be because plot data were less frequently measured in the North or that product specialization, especially in hardwoods, precludes a precise estimate of revenues from harvests. Irrespective of cause, price variables using various specifications did not yield significant price responses. In the West, especially Rocky Mountain West, the interval between FIA inventories was too infrequent to support estimation of comparable models. For these two regions then, we adopted more traditional aggregate supply models to simulate timber supply. A time-series model of timber harvests as a function of stumpage price and other “shifter” variables provides an aggregate model of these regions’ supply responses.

In the North and West, timber supply models have significant but inelastic price responses. In the West, variables describing total standing timber inventory also shift supply of timber from the Pacific Northwest. Whereas price responses are significant in the North, estimated models revealed no clear relationship between aggregate supply of timber and aggregate quantities of various inventory variables. These findings are likely related to the small shares of inventories harvested annually in those regions or confounding effects of other types of land uses. In other words, at least over the range of inventory conditions observed the past 30 years, harvests responded to price signals but supply did not shift outward in response to expansion of timber inventory. Other variables that might explain the availability of inventory for harvest or management, such as population density and land uses, also proved insignificant in explaining aggregate supply responses. In these regions then, little change in supply would be expected except as dictated by demand-driven scarcity.

Table 7 summarizes our regional timber supply functions including own-price elasticities for the four categories of timber in each of the three U.S. regions. These derive from the supply models described above but assume that the estimated elasticity for softwood sawtimber applies to all other products in the U.S. West. The harvest quantities of those other products are very small relative to national totals, so data were unavailable to develop empirical models. Average annual shifts recorded for the simulation period in the South reflect a variable time path of supply shifts across the decades. For the West, supply shifts outward based on a projected average growth trajectory for forest inventories. The supply functions in Table 7 govern total public and private timber supply in USFPM, although shifts in supply were determined largely by analysis of supply on private lands.

For non-RPA scenarios, USFPM can alternatively employ the GFPM approach to endogenously model timber inventory growth and related supply shifts in U.S. regions. Endogenous shifts in timber inventories are computed by region in USFPM on the basis of specified annual timber growth rates minus depletions of inventory that result from projected regional timber harvests, while also adjusting timber inventory to account for any projected changes in forest land area (see Appendix A, or Turner and others 2006). Thus, endogenously computed timber growth, timber harvest, and land area changes may be used optionally as long-run shifters of timber supply, using a fixed elasticity of supply with respect to timber inventory (e.g., an elasticity of 1.5 that is used for other GFPM countries).

Initial forest inventory data at the beginning of year 2006 for all other countries in the GFPM were obtained from the

Table 8—U.S. timber growing stock inventory by USFPM region (2007), based on the RPA Forest Resources report[a]

	Timber inventory ($\times 10^6$ m^3)		
	U.S. North	U.S. South	U.S. West
Softwood growing stock	1,582	3,355	10,049
Hardwood growing stock	5,441	4,815	1,153

[a]Smith and others 2009, table 17.

FAO Global Forest Resources Assessment (FAO 2006, table 11). FAO's U.S. forest inventory data include commercial and non-commercial "growing stock." For example, the "growing stock" of the United States was reported by FAO to be 35,118 million cubic meters in 2005, and 78.7% (or 27,640 million cubic meters) was reported to be "commercial" (FAO 2006, table 11). The latest RPA forest resources report indicates that the volume of timber growing stock on all U.S. timberland was 932,096 million cubic feet in 2007, or 26,394 million cubic meters (Smith and others 2009, table 17). Thus, the FAO "commercial" forest inventory data appear to be roughly consistent with the RPA data on timber growing stock volume on all timberland. Areas such as national parks or wilderness areas where commercial timber harvesting is not permitted are not considered "timberland" by the Forest Service, and trees in those areas are not considered to be commercial timber.

Regional timber inventories modeled endogenously in USFPM are calibrated to Forest Service data on timber growing stock on timberland (Smith and others 2009; Smith and others 2004). Thus, USFPM timber inventories do not include non-commercial tree volumes on non-timberland areas (such as parks, wilderness areas, other reserved areas, or unproductive lands), nor do the USFPM inventories include non-growing stock timber volumes. Table 8 shows, for example, 2007 timber growing stock inventory data by USFPM region and species group as reported in the RPA forest resources report (Smith and others 2009, table 17).

Timber Harvesting Activities

Timber harvesting activities in USFPM broadly represent all commercial harvesting of timber (sawtimber and non-sawtimber), including also the joint recovery, transport, and delivery of all timber product outputs from timber harvest (in the categories of sawlogs/veneer logs, pulpwood/composite timber, other industrial roundwood, and fuelwood). USFPM timber harvesting activities are thus defined by material input and output coefficients and estimated harvest costs.

The timber harvest input and output coefficients in USFPM reflect the harvesting efficiencies and timber product output ratios that are embodied in actual historical timber harvest and timber product output data. The harvesting efficiencies and product recovery coefficients could be changed over the projection period (e.g., to reflect technological changes in harvesting systems) but in lieu of such assumed future changes, the model operates with a set of harvest coefficients that were calibrated to the USFPM base-year data on timber product outputs and timber harvest volumes by region (Table 5).

In USFPM, harvesting of sawtimber is always accompanied by simultaneous (joint) harvesting of non-sawtimber, the smaller trees, thinnings, and cull trees that are typically harvested along with sawtimber harvest within a given region. However, USFPM allows flexibility in the future to harvest less sawtimber than the historical sawtimber harvest ratios, via the activity of harvesting only non-sawtimber. Thus, there are four timber harvest activities modeled in each U.S. region, including joint harvesting of hardwood sawtimber and non-sawtimber, joint harvesting of softwood sawtimber and non-sawtimber, harvesting of only hardwood non-sawtimber, and harvesting of only softwood non-sawtimber. The input and output coefficients for all four timber harvesting activities are determined precisely by actual ratios of timber product outputs to timber harvest volumes by region for each category of timber (Table 5).

Table 9 shows USFPM material input and output coefficients for the four alternate timber harvest activities. In all four harvest activities, the primary timber products are sawlogs/veneer logs (those are generally the most valuable timber products), whereas the other timber products are modeled as "co-products" of the timber harvest activities. Thus, USFPM input coefficients for harvest activities (Table 9) specify volumes of sawtimber and/or non-sawtimber input needed per unit of primary product output (sawlogs/veneer logs); in other words, the cubic meter volume of sawtimber and/or non-sawtimber trees that must be cut down in order to harvest one cubic meter of sawlogs/veneer logs. For example, in the joint harvest of hardwood sawtimber and non-sawtimber in the U.S. North, 1.496 cubic meters of hardwood sawtimber plus 1.1 cubic meters of hardwood non-sawtimber must be cut to yield one cubic meter of hardwood sawlog/veneer log output. In addition, the harvest activity yields the co-products of 0.979 cubic meters of hardwood pulpwood, 0.594 cubic meters of hardwood fuelwood, 0.024 cubic meters of other industrial roundwood, and 1.135 cubic meters of logging residue. All coefficients are calibrated to FIA timber harvest and timber product output data (Smith and others 2009).

Pulpwood/composite timber, fuelwood, other industrial roundwood, and logging residues are modeled in USFPM as "byproducts" of timber harvest activities, while sawlog/veneer log output is the primary product. Thus, output coefficients for the harvesting activities (Table 9) are the cubic meters of pulpwood/composite timber, fuelwood, other industrial roundwood, and logging residue "byproducts" that are produced per cubic meter of primary product (sawlog/

Table 9—Material input and output coefficients for USFPM timber-harvesting activities by region and species group

	U.S. North	U.S. South	U.S. West
	(m^3 harvest/m^3 sawlog–veneer output)		
Joint harvest of hardwood sawtimber and non-sawtimber			
Timber harvest (input) coefficients			
Hardwood sawtimber	1.496	1.587	1.562
Hardwood non-sawtimber	1.100	0.760	1.081
Co-product (output) coefficients			
Hardwood pulpwood/composite	0.979	1.027	0.611
Hardwood fuelwood	0.594	0.305	0.998
Other industrial roundwood	0.024	0.014	0.033
Logging residue	1.135	1.101	0.574
Joint harvest of softwood sawtimber and non-sawtimber			
Timber harvest (input) coefficients			
Softwood sawtimber	1.293	1.249	1.037
Softwood non-sawtimber	0.599	0.526	0.196
Coproduct (output) coefficients			
Softwood pulpwood/composite	0.760	0.724	0.081
Softwood fuelwood	0.075	0.012	0.132
Other industrial roundwood	0.057	0.040	0.020
Logging residue	0.648	0.336	0.299
Harvest of hardwood non-sawtimber only			
Timber harvest (input) coefficients			
Hardwood non-sawtimber	8.529	8.344	23.557
Co-product (output) coefficients			
Hardwood pulpwood/composite	3.790	5.973	0.390
Hardwood fuelwood	3.678	1.298	21.552
Other industrial roundwood	0.061	0.073	0.615
Logging residue	7.055	9.881	10.161
Harvest of softwood non-sawtimber only			
Timber harvest (input) coefficients			
Softwood non-sawtimber	3.583	5.953	2.938
Co-product (output) coefficients			
Softwood pulpwood/composite	2.024	4.756	0.102
Softwood fuelwood	0.412	0.065	1.710
Other industrial roundwood	0.147	0.132	0.126
Logging residue	3.495	3.329	3.540

veneer log) output. Again, all harvesting activity coefficients (Table 9) are based precisely on actual timber harvest and timber product output data (Table 5), and thus USFPM timber harvest coefficients reflect actual regional averages for timber harvesting efficiency, timber product recovery, and logging residue output.

Timber harvest cost parameters in USFPM are based on a timber harvest cost formula that takes into account average tree diameter, stand density, and log skidding distance to roadside (Keegan and others 2002). The timber harvest cost equation is the following:

$$\text{Harvest Cost} = \beta_0 + \beta_1 \times (\text{Avg. Tree Diameter}) + \beta_2 \times (\text{Tons/Acre}) + \beta_3 \times (\text{Skidding Distance}) \quad (1)$$

Equation (1) computes timber harvest cost per thousand cubic feet, with β_0 a numeric constant (28.04), β_1 a coefficient (–1.272) multiplied by average tree diameter in inches, β_2 a coefficient (–0.058) multiplied by stand density in green tons per acre, and β_3 a coefficient (0.0069) multiplied by log skidding distance from stump to roadside in feet. We increased costs from the formula by 52% to account for timber product transport from roadside landing to the mill (transport costs are about one-third of total harvest and delivery cost). Table 10 shows total timber harvest and transport costs for USFPM for sawtimber and non-sawtimber ($\$/m^3$). The harvest and transport costs are applied to the four discrete timber harvesting activities in proportion to the quantities of sawtimber and non-sawtimber harvested. Tree diameter, stand density, and skidding distance assumptions used in the formula are shown also for reference in Table 10. We adjusted average tree diameter assumptions to calibrate the harvest costs and obtain accurate estimates of residual timber stumpage values (shown previously in Fig. 7).

Table 10—USFPM timber harvest and delivery costs ($\$/m^3$) and related assumptions by region and species group for sawtimber and non-sawtimber (2006)

	U.S. North	U.S. South	U.S. West
Sawtimber harvest and transport costs[a]			
Hardwood	24	19	19
Softwood	18	16	13
Non-sawtimber harvest and transport costs			
Hardwood	37	34	29
Softwood	35	31	30
Assumptions for computing harvest costs			
Average tree diameter (in., dbh[b])			
Hardwood sawtimber	14.0	15.0	14.5
Softwood sawtimber	15.0	15.5	15.5
Hardwood non-sawtimber	9.2	9.7	10.3
Softwood non-sawtimber	7.8	8.9	8.5
Stand density (green t/acre)	36	51	85
Skidding distance (ft)	450	450	550

[a]2006$\$/m^3$ of timber harvest.
[c]Diameter at breast height.

Agricultural Short-Rotation Woody Crop Supply

In addition to supply of timber from timberland, USFPM also models potential future supply of agricultural SRWC from agricultural land. SRWC supply in USFPM represents potential supply of fast-growing tree crops on agricultural land, such as hybrid poplars or genetically selected loblolly pine. The area of agricultural land dedicated to such tree crops in the United States is currently rather small. The 2007 USDA Census of Agriculture reported that the acreage of SRWC on farms with 250 acres or larger was about 136,000 acres, or less than one-tenth of 1% of U.S. agricultural land area. However, agricultural SRWC could potentially expand under certain economic circumstances; for example, if wood energy demands escalated and wood feedstock prices

Table 11—Regional supply parameters and assumptions for agricultural short-rotation woody crops (SRWC) in USFPM

	U.S. North	U.S. South	U.S. West
Reserve prices for production[a]			
Hardwood SRWC	75	65	80
Softwood SRWC	75	65	80
SRWC yields (average dry t of harvestable wood/acre/y)			
Hardwood SRWC	6	7	6
Softwood SRWC	4	8	5
Available agricultural land area (thousands of acres)			
Hardwood SRWC	3,000	5,000	1,000
Softwood SRWC	1,000	10,000	1,000
Land area dedicated to SRWC in 2006 (thousands of acres)			
Hardwood SRWC	60	30	40
Softwood SRWC	1	5	1
Cost of capacity expansion (2006 $/acre)			
Hardwood SRWC	500	500	500
Softwood SRWC	500	500	500

[a] 2006 $/dry t of harvested and delivered wood.

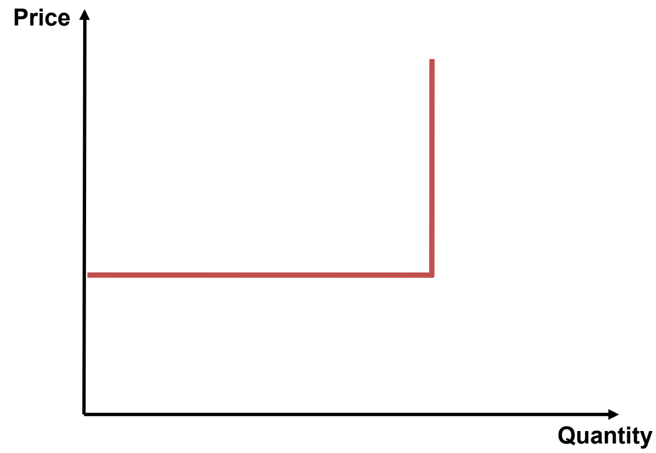

Figure 8–Conceptual illustration of "L-shaped" supply curve in USFPM.

reached levels where it would become feasible for U.S. farmers to shift more agricultural land from conventional food and fiber crops to fast-growing tree crops.

We modeled potential SRWC supply in each U.S. subregion using regional estimates and assumptions regarding the reserve prices for production of SRWC on agricultural land, the regional SRWC yields, limits on agricultural land available for SRWC, assumed distributions of land area dedicated to SRWC by species group and region, and costs of capacity expansion for SRWC on agricultural land. Table 11 summarizes the regional supply parameters and assumptions for SRWC in USFPM.

The reserve prices for production of SRWC (Table 11) are estimates of real price levels at which production becomes economically attractive, i.e., minimum prices needed for farmers to produce SRWC. In addition, future expansion of SRWC output is limited in USFPM by a dynamic capacity constraint, with production capacity changing over time according to a Tobin Q-formula approach, where capacity change is proportionate to the ratio of the shadow price of new capacity to cost of capacity expansion, such that SRWC output capacity will increase in proportion to its profitability (Zhang and others 1993).

Potential SRWC supply in both the short-run and the long-run in USFPM may be illustrated conceptually by an "L-shaped" supply curve as shown in Figure 8, where the flat horizontal portion of the supply curve is defined by the reserve price, and the vertical portion of the supply curve is an upper bound on supply. In effect, the upper bound is determined in the short run by the dynamic production capacity constraint, which may increase over time, but in the long run, the upper bound is ultimately limited by the assumed regional area of agricultural land available for SRWC and the estimated average yields of SRWC per unit of land area (Table 11).

SRWC harvest volume in USFPM is assumed to be 75% pulpwood/composite timber and 25% fuelwood, based on harvest recovery studies for short-rotation hybrid poplar (Hartsough and others 2000). Alternatively, all of the volume can go to bioenergy in USFPM via the cascading wood raw material substitution possibilities (Fig. 6), so projected supply and utilization of SRWC in USFPM really depends on projected demands and market conditions, which will vary with alternative economic scenarios. In any case, projected regional prices of either pulpwood or wood fuel feedstock must reach the reserve prices before any supply of SRWC occurs in USFPM. The reserve prices are actually higher than real prices of pulpwood or fuelwood in the base-year, and thus SRWC supply will expand in the model only if real prices of either pulpwood or fuel feedstock are projected to increase in the future (an outcome that depends on supply and demand growth assumptions of a particular economic scenario).

Supply of Recovered Paper and Other Fiber Pulp

In addition to wood supply from timber harvesting activities and potential SRWC supply, USFPM includes also the regional supplies of two other categories of fiber inputs used in papermaking, recovered paper (used for paper recycling) and other fiber pulp (chiefly cotton fiber pulp used for specialty printing and writing paper products in the United States). Recovered paper is an important fiber input to paper and paperboard production in the United States, and also a large U.S. export item, while the non-wood fiber is a relatively small fiber input in the United States (but proportionately a larger and more important fiber input in some other countries modeled in the GFPM).

Table 12—USFPM regional recovered paper supply estimates (2006)

	U.S. North	U.S. South	U.S. West
Supply quantities ($\times 10^3$ t)	17,172	15,734	14,070
Supply prices (2006 $/t, average)	123	123	123

The tons of recovered paper consumed for recycling at U.S. paper and paperboard mills has stabilized at a level equal to 37% of total paper and paperboard output in recent years, after having experienced a 10% gain in the 1990s when U.S. mills expanded their use of recovered paper (AF&PA 2009). However, the tons of paper recovered for recycling and exported from the United States has continued to increase, with increasingly efficient paper recovery systems, reaching a recovery rate equal to 53% of paper and paperboard consumption in 2006 and over 57% by 2008 (AF&PA 2009). Exports accounted for 33% of U.S. recovered paper supply in 2006 and 38% of supply by 2008 (AF&PA 2009). Exports to China in particular have increased significantly in recent years, and according to data from U.S. Department of Commerce, China consumed about two-thirds of total U.S. recovered paper exports in 2009.

Following the GFPM approach, regional recovered paper supply in USFPM is modeled as a single commodity, with a price elasticity of 1.0 and an exogenously specified growth rate (equal to just above 1%/y in U.S. regions). This supply growth rate assumes continued gains in efficiency of paper recovery for recycling. Thus, the U.S. paper recovery rate climbs from around 60% to around 80% to 90% by 2060 (highest in the B2 scenario), whereas projected consumption of recovered paper for recycling is determined by specified fiber input coefficients in paper and paperboard production (discussed later). We derived base-year (2006) regional supply quantities of recovered paper for USFPM from data on domestic recovered paper consumption by U.S. subregion plus net exports of recovered paper by region (AF&PA 2007). Base-year average supply price for recovered paper was adapted from the GFPM data (based on recovered paper commodity values reported by FAO). Table 12 shows the USFPM base-year recovered paper supply estimates.

Among U.S. regions, production of other fiber pulp (non-wood pulp) occurs only in the U.S. South as cotton fiber pulp, which is relatively small in comparison to wood pulp output, at just 245 thousand metric tonnes in 2006 (equivalent to less than one-half of 1% of Southern U.S. wood pulp production). In the U.S. paper industry, the cotton fiber pulp is used mainly in producing specialty grades of printing and writing paper (e.g., cotton bond paper). In USFPM, the supply of cotton fiber pulp in the South is represented by a fixed reserve price ($850/t) and an upper bound on supply, which effectively creates an “L-shaped” supply curve (Fig. 8). The upper bound starts at the base-year production level in 2006 and increases at about 1% per year (in line with the GFPM assumption for expansion of non-wood pulp). As with recovered paper, the projected consumption of other fiber pulp is determined by specified fiber input coefficients in paper and paperboard production (discussed in the following section).

Forest Product Production Data and Parameters

Forest product production data and parameters in USFPM include base-year (2006) forest product production volumes, wood and fiber raw material input coefficients, manufacturing costs, and wood and bark residue byproduct coefficients. Base-year forest product production data in USFPM correspond to actual 2006 volumes of forest product output as reported for the United States by leading forest industry trade associations and by U.S. Department of Commerce. Forest product production activities are represented in USFPM by a combination of wood and fiber raw material input coefficients (specified quantities of wood or other fiber inputs required per unit of forest product output), wood and bark residue byproduct coefficients, and estimates of other manufacturing costs per unit of product output (a singular net cost factor for each product representing all other production costs besides the costs of the wood and fiber inputs).

In developing USFPM for RPA we wanted to ensure that projected regional volumes of wood and fiber inputs consumed and volumes of residue byproducts produced would match regional data on wood and fiber supply, including data on wood harvests, residue supplies, and wood raw material imports. Thus, we calibrated the wood and fiber input coefficients and fiber residue byproduct coefficients in USFPM so that regional wood and fiber input volumes and residue output volumes determined by regional production of all forest products in the base year (2006) matched precisely the totals of actual data on timber product outputs from timber harvesting and data on fiber residue outputs by region as reported in the RPA forest resources report (Smith and others 2009, tables 39 and 42) plus added regional roundwood and wood chip import data from USITC. We also calibrated the fuel residue byproduct coefficients so that fuel residue output volumes determined by regional production of all forest products in the base year matched precisely the actual aggregate data on fuel residue outputs by region as reported in the RPA forest resources report (Smith and others 2009, table 42) plus regional fuelwood import data from USITC. In the calibration process, we also took into account regional differences in wood densities by species group and corresponding conversions from volume to weight measures.

Estimated forest product production quantities by U.S. subregion for 2006 are shown in Table 13 for all forest products represented in USFPM. Miscellaneous wood products produced from “other industrial roundwood” (posts, poles,

Table 13—U.S. forest product production volumes by USFPM region (2006)

	U.S. North	U.S. South	U.S. West
Solid-wood products ($\times 10^6$ m^3)			
Softwood lumber	3,465	31,645	30,438
Hardwood lumber	15,411	10,471	1,074
Softwood plywood/veneer	32	9,933	4,416
Hardwood plywood/veneer	581	966	54
Oriented strandboard (OSB)	3,321	9,919	0
Industrial particleboard	578	3,422	3,177
Fiberboard	1,821	3,305	2,056
Pulp, paper, and board products ($\times 10^6$ t)			
Chemical/semi-chemical wood pulp	7,553	36,411	5,285
Mechanical wood pulp	1,092	2,088	782
Newsprint	409	2,862	1,468
Printing and writing paper	13,224	8,162	1,267
Other paper and paperboard	15,089	35,794	5,897

cooperage, etc.) are not represented as products in USFPM, but USFPM models aggregate U.S. demand for other industrial roundwood, as the GFPM models trade and demand in other countries for “other industrial roundwood.”

Table 13 was based primarily on production data from industry trade associations. Data sources included the Western Wood Products Association for softwood lumber (WWPA 2006), APA-The Engineered Wood Association for softwood plywood and OSB (APA-The Engineered Wood Association 2007), Composite Panel Association for particleboard and medium density fiberboard (Howard 2007), and the American Forest & Paper Association for pulp, paper, paperboard and insulating board (AF&PA 2009). Production data for solid-wood products in the United States are reported in various units of measure (nominal board feet for softwood lumber, full-dimension board feet for hardwood lumber, and square feet of various thickness standards for wood panels). We used standard conversion factors (Howard 2007) to translate production data into solid cubic meters, the unit of measure for solid wood products in the GFPM and USFPM. Similarly, U.S. production data for pulp, paper, and paperboard are reported in short tons, which we converted to metric tonnes (1 short ton = 0.90718 t). In some cases (e.g., softwood lumber and structural wood panels) the production data were reported by U.S. subregion, while in other cases, production data were available only for the United States as a whole (not by subregion), and in those cases we allocated U.S. production data to the subregions according to regional distributions of production capacity, with some minor adjustments for wood pulp production. We shifted the equivalent of 2% of U.S. chemical and semichemical wood pulp output from the West to the North and South (1% each) to balance fiber supply with mill closures and downtime in the West. Production data for some products such as hardwood lumber were derived from U.S. Department of Commerce (Howard 2007).

Wood and fiber input coefficients and residue byproduct coefficients for the various forest products are among the more complex data incorporated into USFPM, partly because there are real structural differences among U.S. subregions and products in terms of wood or fiber inputs. For example, newsprint production in the U.S. North utilizes mainly recovered paper and little wood pulp as fiber input, whereas in the South and West newsprint utilizes a larger share of wood pulp. Oriented strandboard (OSB) uses only harvested pulpwood/composite timber as input, whereas particleboard uses primarily fiber residues. We incorporated such differences into the wood and fiber input coefficients of USFPM, so that the model has an accurate representation of regional variations in wood and fiber consumption relative to forest product output. As mentioned previously, we calibrated all input and output coefficients in USFPM so that computed base-year wood raw material consumption and residue outputs by region match actual data on U.S. timber consumption, trade, and wood residue production by region. Table 14 summarizes the calibrated base-year (2006) wood and fiber input coefficients and residue byproduct coefficients that we programmed into USFPM.

We included some alternative wood or fiber input coefficients in USFPM to allow raw material substitution possibilities in some products where appropriate. For example, the primary raw material for particleboard and fiberboard production in the United States is fiber residues (mill residues from sawmills and plywood mills), but it is technically feasible to substitute harvested pulpwood/composite timber for fiber residues (although residues are currently cheaper and therefore the primary raw material for particleboard and fiberboard). In USFPM, we allow substitution of harvested pulpwood/composite timber for fiber residues in particleboard and fiberboard production to facilitate future economic substitution if projected prices change. Similarly, for wood pulp production we allow the option of using either harvested pulpwood/composite timber or fiber residues. We programmed this type of raw material flexibility into the model by allowing particleboard, fiberboard, and wood pulp production activities to use either harvested pulpwood/composite timber or fiber residues, as alternative “input mix” options. Of course, we do not allow technologically infeasible substitution possibilities, such as direct substitution of pulpwood for saw logs/veneer logs as inputs to lumber or plywood production, to occur in USFPM.

We also introduced production efficiency gains for most forest products over the 50-year projection period in USFPM, based on global efficiency gains that were programmed by UW researchers into the GFPM. A general theory about efficiency gains is that global free trade makes access to advanced production technology more globally diffuse. Globalization and the prolific worldwide spread of advanced forest product production technology is a recognized structural change that has been under way in the forest sector for some time (Ince and others 2007). Therefore, less efficient

Table 14—Base-year (2006) wood and fiber input coefficients and residue by-product coefficients for forest product production activities by region in the USFPM[a]

	Coefficients		
	U.S. North	U.S. South	U.S. West
	(m^3/m^3 product output)		
Softwood (SW) lumber			
SW sawlog/veneer log input	2.142	2.378	2.026
SW fiber residue byproduct	0.352	0.754	0.662
Fuel residue byproduct	0.388	0.589	0.348
Hardwood (HW) lumber			
HW sawlog/veneer log input	1.669	2.086	2.465
HW fiber residue byproduct	0.256	0.486	0.391
Fuel residue byproduct	0.359	0.637	0.082
Softwood plywood/veneer			
SW sawlog/veneer log input	2.640	2.567	2.796
SW fiber residue byproduct	0.352	0.754	0.662
Fuel residue byproduct	0.388	0.589	0.348
Hardwood plywood/veneer			
HW sawlog/veneer log input	2.526	2.526	2.526
HW fiber residue byproduct	0.256	0.486	0.391
Fuel residue byproduct	0.359	0.637	0.082
Oriented strandboard (OSB)			
HW pulpwood/composite timber input	1.651	0.760	1.572
SW pulpwood/composite timber input	0.019	0.883	0.085
Industrial particleboard			
HW fiber residue input or harvested HW pulpwood/composite timber input	1.468	0.245	0.019
SW fiber residue input or harvested SW pulpwood/composite timber input	0.301	1.309	1.844
Fiberboard			
HW fiber residue input or harvested HW pulpwood/composite timber input	0.714	0.308	0.009
SW fiber residue input or harvested SW pulpwood/composite timber input	0.128	0.483	0.746
Chemical/semi-chemical wood pulp			
HW fiber residue input or harvested HW pulpwood/composite timber input	2.562	0.724	0.079
SW fiber residue input or harvested SW pulpwood/composite timber input	1.078	2.283	3.395
Fuel residue byproduct	0.392	0.325	0.026
Mechanical wood pulp			
HW fiber residue input or harvested HW pulpwood/composite timber input	1.433	1.123	1.620
SW fiber residue input or harvested SW pulpwood/composite timber input	0.907	0.810	0.821
Fuel residue byproduct	0.392	0.339	0.059
Newsprint	(t/t product output)		
Chemical/semi-chemical wood pulp input	0.041	0.070	0.100
Mechanical wood pulp input	0.096	0.365	0.456
Recovered paper input	1.001	0.677	0.573
Printing and writing paper			
Chemical/semi-chemical wood pulp input	0.650	0.756	0.529
Mechanical wood pulp input	0.072	0.133	0.093
Other fiber pulp (non-wood) input	0.012	0.000	0.000
Recovered paper input	0.070	0.015	0.325
Other paper and paperboard			
Chemical/semi-chemical wood pulp input	0.194	0.741	0.793
Mechanical wood pulp input	0.002	0.001	0.000
Recovered paper input	0.718	0.332	0.700

[a]Note that wood and fiber input coefficients for wood pulp, industrial particleboard, and fiberboard in USFPM allow for substitution between fiber residue and harvested pulpwood/composite timber within each species group (HW and SW), as alternative "input mix" options.

producers are expected to adopt more efficient production technology over time. Thus, wood and fiber input coefficients and manufacturing costs in the GFPM and also in USFPM are programmed to gradually shift over the projection period toward the most efficient levels (of the most advanced countries) for each forest product.

USFPM Trade in the GFPM Context

USFPM models and projects net trade flows between the United States and the rest of the world as determined by the GFPM and its market equilibrium solution for global net trade. The GFPM models global forest product production, consumption, and net trade for 180 countries including the United States. The global market equilibrium is solved using economic optimization techniques (Appendix A describes the GFPM formulation, structure, and global market equilibrium solution).

A simplifying structural feature of the GFPM is that instead of modeling all bilateral trade flows among countries, the trade flows of each country are modeled only with respect to an intermediate dummy region (so-called "world" region). The GFPM allows the option of specifying bilateral trade flows between selected subsets of countries (http://fwe.wisc.edu/facstaff/Buongiorno/book/GFPM.htm) but no bilateral trade flows were incorporated in the UW version of the GFPM that we used in developing USFPM. USFPM was developed within the structure of the GFPM, so U.S. trade flows are modeled entirely as trade with the rest of the world in aggregate (not as bilateral trade with individual countries). This structural feature combined with the optimizing solution technique compels each country in the GFPM to become either a global exporter or global importer of any commodity at the market equilibrium, unless trade flows are constrained with GFPM "trade inertia bounds." Trade inertia bounds are constraints on changes in trade flows that can force both imports and exports to remain simultaneously positive. Like the GFPM, USFPM has highly constrained international trade flows in the base year, along with inertia constraints over the projection period. The constraints on U.S. trade are ±5% change per year for import and export quantities (and for pulp transported between regions). Inertia constraints are not applied to U.S. trade in roundwood, logs, other fiber pulp and recovered paper.

End products in USFPM are imported to the U.S. aggregate demand region and exported from U.S. subregions: North, South, and West. U.S. subregions also import intermediate products, logs and pulp, and each subregion can trade pulp with other subregions. This permits more realistic trade solutions in which net trade flows can vary among U.S. subregions. For example, USFPM simulates accurately that the U.S. South and West are net exporters of wood pulp, whereas the U.S. North is a net importer of wood pulp from other countries and from other U.S. subregions. Tables 15 and 16 summarize U.S. base-year (2006) foreign export and import quantities specified in the USFPM data input.

Table 15—U.S. foreign export quantities (2006)

Commodity	U.S. North	U.S. South	U.S. West
	Quantity ($\times 10^3$ m^3)		
Softwood (SW) sawlogs	2,466	91	3,601
Hardwood (HW) sawlogs	902	426	233
SW pulpwood	463	240	32
HW pulpwood	216	398	16
SW lumber	436	911	848
HW lumber	1,843	954	576
SW veneer/plywood	0	427	147
HW veneer/plywood	2,466	91	3,601
Oriented strandboard (OSB)	135	24	0
Industrial particleboard	68	10	273
Fuelwood and charcoal	32	6	2
Fiberboard	343	219	255
	Quantity ($\times 10^3$ t)		
Mechanical pulp	68	0	17
Chemical/semi-chemical pulp	595	4,159	360
Other fiber pulp	32	102	0
Recovered paper	5,210	1,793	8,909
Newsprint	28	262	296
Printing and writing paper	949	532	257
Other paper and paperboard	1,664	4,260	1,397

Table 16—U.S. foreign import quantities (2006)

Commodity	U.S. Aggregate	U.S. North	U.S. South	U.S. West
	Quantity ($\times 10^3$ m^3)			
Fuelwood and charcoal	128	—	—	—
Sawnwood	55,524	—	—	—
Veneer/plywood	7,121	—	—	—
Particleboard	10,247	—	—	—
Fiberboard	3,292	—	—	—
Sawlogs and pulpwood	—	369	49	2,262
	Quantity ($\times 10^3$ t)			
Newsprint	4,923	—	—	—
Printing and writing paper	8,250	—	—	—
Other paper and paperboard	3,329	—	—	—
Mechanical pulp	—	0	85	20
Chemical/semi-chemical pulp	—	4,175	941	666
Other fiber pulp	—	41	2	0
Recovered paper	—	211	9	217

As shown earlier in Table 13, for example, the U.S. North had a fairly large share of U.S. paper and paperboard production in the base year, but a much smaller share of U.S. wood pulp production, necessitating import of wood pulp to the U.S. North from foreign countries and also from other U.S. regions. For example, in the base year, nearly three million tons of wood pulp (market pulp) was shipped from the U.S. South to the U.S. North, and two million tons were shipped from the U.S. West to U.S. North.

In USFPM, U.S. trade in products such as hardwood and softwood lumber, hardwood and softwood veneer/plywood, and OSB and industrial particleboard, are aggregated into corresponding GFPM product categories for export (e.g., sawnwood, veneer/plywood, and particleboard) or disaggregated for import, using base-year product trade shares. U.S. trade data for lumber, plywood, and OSB generally correspond to data sources reported by Howard (2007), while trade data for industrial particleboard, fiberboard, and pulp come from FAO, and paper and board trade data come from the U.S. Department of Commerce (as reported also by AF&PA). Base-year (2006) export and import prices for individual commodities in USFPM match the base-year prices as specified in the UW version of the GFPM (derived from FAO data on value of shipments). Weighted averages of GFPM prices are used in cases where USFPM commodities are disaggregated from GFPM commodities.

End Product Demand Quantities and Elasticities

USFPM data inputs related to end product demands include base-year (2006) U.S. demand quantities (consumption) and prices, price elasticities of demand, GDP elasticities, and other demand elasticities for all end products. The base-year forest product demand quantities are apparent consumption estimates, derived by adding total U.S. production (Table 13) to net imports (imports minus exports) for each commodity (Tables 15, 16). The exceptions were demand quantities for other industrial roundwood and fuel feedstock. Other industrial roundwood products (poles, posts, etc.) are not traded in significant volumes internationally, so the U.S. demand quantity is simply equivalent to the sum of U.S. regional harvest volumes for other industrial roundwood (Table 5). The base-year fuel feedstock demand quantity is a combination of several elements: 1) roundwood fuelwood harvest volumes from regional FIA harvest data, 2) regional mill residue fuel byproduct volumes from FIA data, and 3) net trade in fuelwood.

Table 17 summarizes the base-year (2006) U.S. demand quantities and prices for end products as specified in the USFPM data input. Product demand prices were derived from various sources. Softwood lumber, softwood plywood, OSB, and industrial particleboard prices were derived from U.S. domestic prices reported in Random Lengths Yearbook (2007). The hardwood lumber price was obtained from William Luppold (Luppold and Bumgardner 2007). The hardwood plywood price was calculated as the unit value of imports from the Bulletin of Hardwood Market Statistics. For all other products, we used demand prices from the GFPM model (derived from FAOSTAT product export unit value data). For all of the solid wood products and composite wood products, prices are measured in dollars per solid cubic meter (m^3), and quantities are measured in thousands of solid cubic meters, including lumber, plywood/veneer, other industrial roundwood, fuel feedstock, OSB, particleboard, and fiberboard. For the paper and paperboard products, newsprint, printing and writing paper, and other paper and paperboard, quantities are measured in thousands of dry metric tonnes and prices are measured in dollars per dry metric tonne.

Table 17—U.S. demand prices and quantities for end products (2006)

Commodity	Price ($/m³)	Quantity (×10³ m³)
Softwood (SW) lumber	192	117,077
Hardwood (HW) lumber	271	25,384
SW plywood/veneer	305	16,371
HW plywood/veneer	504	4,999
Oriented strandboard (OSB)	209	22,055
Industrial particleboard	204	8,099
Fuel feedstock	25	113,255
Other industrial roundwood	80	7,208
Fiberboard	345	9,657
	Price ($/t)	Quantity (×10³ t)
Newsprint	587	9,078
Printing and writing paper	908	29,165
Other paper and paperboard	805	52,788

U.S. demand elasticities for end products are summarized in Table 18. Some of the elasticities were obtained from the GFPM, while elasticities for other products were estimated or obtained from different sources, as explained below. The GFPM elasticities were used for non-structural wood panels (industrial particleboard and fiberboard), hardwood lumber, hardwood plywood/veneer, other paper and paperboard, and other industrial roundwood. The GDP elasticity for fuel feedstock demand ("x" in Table 18) is a control variable that is adjusted to create alternative wood energy demand scenarios.

For newsprint and printing and writing paper (communication paper grades), elasticities with respect to price, GDP, advertising spending in print media, and advertising spending in electronic media were obtained from Wongcharupan and Ince (2003, 2004). That analysis revealed that U.S. demands for communication paper grades are primarily dependent on trends in advertising expenditures, and notably the shift in advertising expenditures from traditional print media to electronic media (such as television and the internet). This ongoing structural change in U.S. communication paper demands has been noted also by others (Soirinsuo 2009). Statistical analysis has shown that projected U.S. consumption of communication papers depends on assumed future trends in advertising expenditures in print media and electronic media, and generally more recent trends point toward lower future demands for communication papers. We applied future assumptions in USFPM for change in advertising expenditures as determined by recent historical trends, including, for example, –1% per year for newspaper advertising based on advertising expenditures data from 2000 to 2007 as reported by Newspaper Association of America, and +6% per year for electronic media advertising, based on 2006 average growth for TV, radio, and Internet.

We estimated U.S. demands for softwood lumber and structural panels (softwood plywood and OSB) using annual consumption data and a Cobb-Douglas (CES) equation that included as independent variables the real producer price index for each commodity group (U.S. Bureau of Labor Statistics (BLS)), U.S. real GDP (Bureau of Economic Analysis (BEA)), and U.S. single-family housing starts (U.S. Census Bureau), for the years 1973 through 2008. Before we estimated the demand equations, the Hausman specification test was used to test for endogeneity of the price variable (Hausman 1978). The test determines whether ordinary least squares regression is likely to be statistically inconsistent because of endogeneity, a statistical feedback effect that may occur with price variables in demand equations. The Hausman test was performed by first regressing annual price data (price indexes) for both softwood lumber and structural panels on annual data for the other exogenous variables (GDP and housing starts). The respective consumption data were then regressed on residuals obtained from the previous step. The Hausman test results based on t statistics for the residual coefficients provided only weak evidence of no endogeneity in the case of softwood lumber (*p*-value

Table 18—U.S. demand elasticities for USFPM end products

Commodity	Price	GDP	Housing starts	Advertising spending in print media	Advertising spending in electronic media
Softwood (SW) lumber	–0.14	0.39	0.49	—	—
Hardwood (HW) lumber	–0.10	0.22	—	—	—
SW veneer/plywood	–0.65	0.55	0.69	—	—
HW veneer/plywood	–0.29	0.41	—	—	—
Oriented strandboard (OSB)	–0.65	0.55	0.69	—	—
Industrial particleboard	–0.29	0.54	—	—	—
Fuel feedstock	–0.50	X	—	—	—
Other industrial roundwood	–0.05	–0.58	—	—	—
Fiberboard	–0.46	0.35	—	—	—
Newsprint	–0.68	0.77	—	1.35	–1.00
Printing and writing paper	–0.42	0.60	—	1.00	–0.55
Other paper and board	–0.23	0.43	—	—	—

Table 19—Regression results for U.S. softwood lumber and structural panel demands[a]

	Regression of Producer Price Indexes (first stage)			
	Softwood lumber		Structural panels	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	4.701	3.948	–3.333	4.367
Real GDP	–0.512	0.609	0.395	0.673
Single-family housing starts	0.363	0.121	0.369	0.133
Size of new houses	0.348	1.011	0.543	1.118
PPI	–1.215	0.399	0.361	0.441
CPI[b]	1.093	0.382	–0.799	0.423
Adjusted R^2	0.477		0.377	
	Regression of consumption quantities (second stage)			
	Softwood lumber		Structural panels	
Variable	Coefficient	Standard error	Coefficient	Standard error
Intercept	4.496	0.348	0.552	1.471
Real price	–0.141	(fixed)	–0.652*	0.134
Real GDP	0.386*	0.032	0.551*	0.173
SF housing starts	0.490*	0.045	0.691*	0.070
Size of new homes	—	—	0.387	0.396
Adjusted R^2	0.919		0.975	

[a]Use of the asterisk (*) denotes statistically significant elasticities at 95% or higher confidence.
[b]Consumer Price Index.

of 0.056). However, to avoid the endogeneity issue in any case, we applied the regression method of two-stage least squares (2SLS) with instrumental variables to estimate demand equations for lumber and structural panels.

Using a log-log model in the first stage, annual softwood lumber and structural panel price indexes were first regressed on GDP, single-family housing starts, average size in square footage of new single-family homes (as reported by U.S. Census Bureau), the all-commodities PPI, and the all-commodities CPI. In the second stage, again using a Cobb–Douglas model, softwood lumber and structural panel consumption were separately regressed on the predicted price indexes from the first stage, real GDP, single-family housing starts, and average size of new homes to estimate elasticities for the demand equations. In the case of structural panels, the demand elasticities were all statistically significant (except for the elasticity with respect to size of new homes, which was only marginally significant), and all of the estimated elasticities had the correct or expected sign (negative for price and positive for all other variables). In the case of softwood lumber, demand elasticities for price and size of new homes had incorrect signs (+/–) and were also not statistically significant. However, other studies have mostly found that price elasticity of U.S. softwood lumber demand is fairly inelastic, generally less in absolute value than 1.0 (Song and others 2011). Therefore, in this case we substituted a restricted regression of softwood lumber consumption on real GDP and housing starts in the second stage, fixing lumber demand price elasticity at a value of –0.141. This elasticity value was from a recent U.S. lumber demand and supply analysis using co-integration in dynamic equations (Song and others 2011). We included the size of new homes, although the elasticity for that variable was not statistically significant. Our regression results and resulting estimates of demand elasticities are shown in Table 19, including results of 2SLS regression for both softwood lumber and structural panel demands.

Estimating combined structural panel demand (softwood plywood and OSB together using a consumption-weighted price series) yielded acceptable results (Table 19) but separate regressions tend to yield poor results or results without expected signs on estimated elasticities. This is because the demands are influenced by ongoing product substitution. OSB has been steadily substituting for softwood plywood in housing construction since the late 1970s, with OSB increasing from 0% of consumption in 1976 to 63% in 2006. Thus, softwood plywood's share of structural panel demand has declined steadily since 1976, losing about 2% of market share per year until 1997 when the decline slowed to about 1% per year to 2010. In USFPM, this decline for the plywood market share is projected to continue. However, softwood plywood is projected to ultimately retain a 20% market share because of specialty applications that require plywood (plywood siding, marine plywood, concrete forms, etc.), whereas OSB approaches a market share of 80% by 2060.

The U.S. market shares for OSB and softwood plywood are modeled in USFPM by adding a dummy demand shifter to OSB and softwood plywood demands (reducing the plywood market share to 20% by 2060) while both products still share the same demand elasticities with respect to price, GDP, housing starts, and size of new houses (Table 19). The dummy demand shifter was generated by using a lagged variable Equation (2) with a dampening coefficient to best approximate the current historical product substitution trend beginning in 2011, which is the 2010 point minus 1%. Figure 9 shows the actual historical softwood plywood share of total U.S. structural panel consumption along with the projected share as determined by the lagged variable Equation (2):

$$x_n = x_{n-1} - \frac{(x_{n-2} - x_{n-1})}{1+d} \tag{2}$$

where x_n is softwood plywood percentage of structural panel consumption in year n,

$$x_1 - x_0 = 0.01,$$
$$\text{and } d = 0.05$$

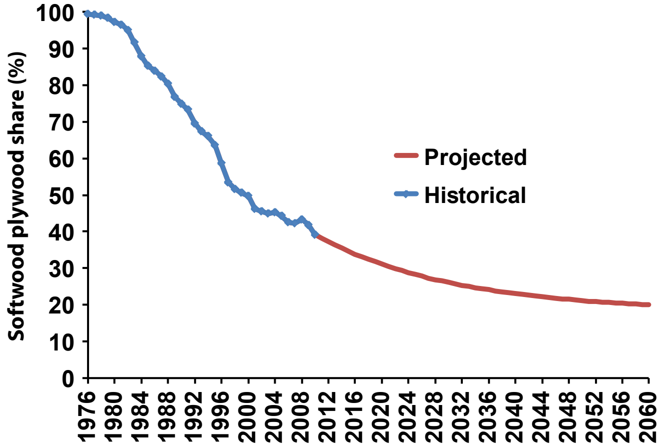

Figure 9–Softwood plywood share (percentage) of U.S. structural panel consumption, historical data 1976–2005 (Howard 2007), and projected trend, 2006–2060 (based on Eq. (2)).

Table 20—Data elements and sources used in single-family housing start projections

Element	Source
U.S. population growth	RPA scenario assumptions based on U.S. Census and IPCC[a]
U.S. population by age	U.S. Census Bureau, Statistical Abstract of United States
Households by age of head	U.S. Census Bureau, Current Population Survey
Net migration	U.S. Census Bureau
Mortality rates	U.S. Center for Disease Control
Ownership per age cohort	H. Spelter estimates (Forest Products Laboratory)
Removals and vacancies	H. Spelter estimates (Forest Products Laboratory)

[a] Intergovernmental Panel on Climate Change.

With housing starts a significant long-run shifter of softwood lumber and structural panel demands (Table 19), USFPM requires long-range projections of U.S. housing starts. Housing projections may be obtained from sources such as the 2010 U.S. Annual Energy Outlook (DOE 2010a) that we used for our RFS+RES scenarios. However, for the 2010 RPA scenarios, we generated preliminary projections of single-family housing starts based on housing needs as determined by RPA population projections and derived demographic trends (explained in the following section of text). Sources for data used in projecting U.S. single-family housing starts for the RPA scenarios are shown in Table 20.

Projections of U.S. single-family (single-unit) housing "needs" were based on RPA population assumptions that were deconstructed into demographic elements. This began by segregating the population into discrete age cohorts or age classes, as follows:

$$\text{Total population} = \text{Pop age class}_1 + \text{Pop age class}_2 + \ldots + \text{Pop age class}_n$$

The n cohorts were arrayed by ascending age with "1" being the youngest and "n" the oldest. Using data from 2000 to 2006, we computed "headship rates" for each age cohort (the fraction of persons who are labeled heads of households) by dividing the number of household heads by the number of people in the cohort as follows:

$$\text{Headship rate age class}_1 = \text{Household heads age class}_1/\text{Pop age class}_1$$

The number of projected households within each cohort at any time is then the number of people in the age cohort times the computed headship rate:

$$\text{Household age class}_1 = \text{Pop age class}_1 \times \text{Headship rate age class}_1$$

Summing households over the age cohorts gives the total number of households:

$$\text{Total households} = \text{Hhold age class}_1 + \text{Hhold age class}_2 + \ldots + \text{Hhold age class}_n$$

To obtain the projected future populations in each age cohort, we started with the initial age distributions and moved them forward through time. Over time an age cohort loses all its graduating members who move into the next older age cohort but gains the survivors from the next younger age cohort (e.g., as follows):

$$\text{Pop age class}_2 \text{ in year}_2 = \text{Pop age class}_1 \text{ in year}_1 - \text{mortality age class}_1 \text{ in year}_1$$

To these were added the net number of people who immigrated into the U.S. (number of immigrants less the number of emigrants):

$$\text{Pop age class}_2 \text{ in year}_2 = \text{Pop age class}_2 \text{ in year}_2 + \text{Net influx in year}_2.$$

The net influx of immigrants was the slack variable we used to make the population totals conform to the various RPA scenarios. By definition, the household count equals the minimum housing stock that is needed. Thus, the new housing needed each year equals the change in the number of households (determined by population's growth and demographic distributions) adjusted for changes in housing vacancies and removals each year. Not all houses are occupied year round (some are seasonal homes) nor do houses last forever. From historical data, we calculated the normal number of housing units that are vacant. The changes in vacancies together with the numbers of houses that are typically demolished each year (removals) represent additional increments of new housing needs:

$$\text{Housing needs in year}_2 = \text{Total households in year}_2 - \text{Total households in year}_1 + \text{Change in vacancies} + \text{Removals in year}_2$$

Next, these data were combined with assumptions derived from historical data regarding the tendency of households of different age classes to occupy single-family (single-unit) dwellings versus dwellings in multi-unit structures. These assumptions generated our projected single-family housing "needs" for each RPA scenario.

RPA scenarios focus on a long-range projection period from 2020 to 2060, rather than the recent historical period from 2006 to 2010 when a significant downturn in U.S. housing construction occurred or the near-term period from 2010 to 2020 (when a rebound in housing is forecast to occur). RPA scenarios assume that housing starts will follow the projected "needs" levels from 2020 to 2060, with housing needs linked demographically to RPA population projections.

Last, we note that projected housing needs or housing starts exhibit wider variation than projected population trends, as expected. This is because housing starts represent marginal inflows of new housing stock relative to a large existing housing stock. For example, with a static population marginal needs for new housing would be essentially zero except for replacement needs arising from removals or vacancies, but small increments of added population growth can greatly multiply the marginal need for new housing. Thus, modest adjustments in population growth translate into more significant adjustments in projected housing needs as illustrated in Figure 10, which shows historical data for U.S. single-family (single-unit) housing starts from 1960 to 2010 along with our preliminary projections of single-family housing needs for the three selected RPA scenarios. In Figure 10, we also show for comparison a December 2010 single-family housing starts forecast to 2012 from the National Association of Home Builders (NAHB).

Our assumption about the future average size of new single-family homes (a shifter of structural panel demands) recognizes that the average size of new homes as reported by the Census Bureau increased historically in recent decades but then leveled out and declined modestly in the past decade. Average size of new homes is therefore generally assumed to remain constant at base-year (2006) levels in most USFPM scenarios. Among RPA scenarios (discussed below in more detail) the B2 scenario has a "sustainable development" theme, so in that scenario we assume that average new home size will continue to gradually decline, by 10% over the decade from 2010 to 2020, and by just 5% in the subsequent 40-year period from 2020 to 2060.

GFPM Modifications for USFPM

We modified the global roundwood supply elasticity for foreign countries in the GFPM to maintain consistency between the GFPM and the RPA timber supply elasticities that were estimated for USFPM. The overall design and structure of the GFPM have been described elsewhere (Buongiorno and others 2003, Turner and others 2007,

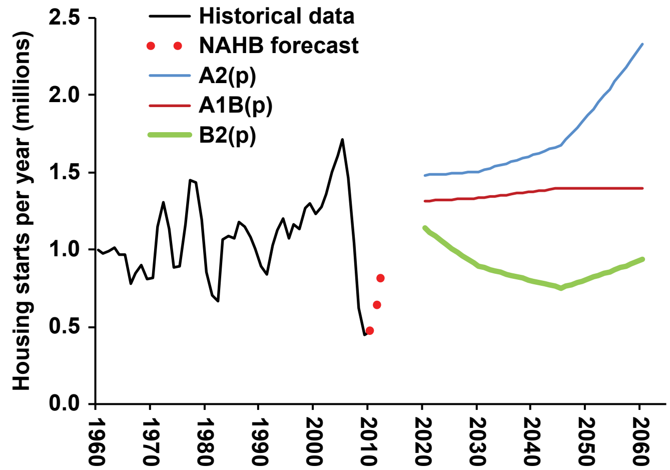

Figure 10—Historical U.S. annual single-family housing starts, 1960–2010, NAHB forecast to 2012, and preliminary (p) projections for three selected scenarios (2020–2060).

and Raunikar and others 2010, Buongiorno and Zhu 2011), and the UW GFPM website provides updates of the GFPM (http://forestandwildlifeecology.wisc.edu/facstaff/Buongiorno/book/GFPM.htm).

In the 2010 UW version of the GFPM, short-run price elasticity of supply was specified to be 1.0 for industrial roundwood and fuelwood in all countries. In addition, the GFPM models change in forest inventory in each country as a long-run determinant of supply, and the initial wood supply quantities, prices, and forest inventories vary among countries, so long-run supply adjustments to price vary from one country to another, even though price elasticities are the same. However, specification of identical price elasticities represents an implicit assumption that relative short-run responsiveness of wood supply quantity to price is proportionately the same for all countries. To maintain the functionality of the GFPM, it is important to retain this feature of the model, but introducing U.S. regional stumpage supplies in USFPM leads to differing short-run timber supply elasticities (not the same as the original 1.0 supply elasticity of the UW GFPM).

Since USFPM and the RPA forest assessment focus mainly on U.S. timber stumpage markets with empirically derived or model-based estimates of U.S. timber stumpage supply elasticities, it was appropriate for us to modify the global industrial roundwood supply elasticity so that foreign countries would share the same relative responsiveness of industrial roundwood supply to price as estimated for commercial timber supply in the U.S. regions. However, that result cannot be obtained by simply applying U.S. timber stumpage price elasticities to industrial roundwood in foreign countries, because prices for delivered industrial roundwood in other countries are not all the same, and the delivered roundwood prices are generally higher than U.S. stumpage prices for timber.

To obtain the same relative price responsiveness for industrial roundwood supply in all countries, we had to modify foreign industrial roundwood price elasticities by taking into account the average U.S. timber stumpage price elasticity and the ratio of foreign industrial roundwood prices to average U.S. timber stumpage price. When we calibrated the USFPM/GFPM model in 2010, the weighted average of our timber stumpage price elasticities for the RPA scenarios was 0.28, and weighted average timber stumpage price was \$34.62/m^3. Multiplying average U.S. stumpage price elasticity (0.28) times the ratio of foreign industrial roundwood price to average U.S. stumpage price resulted in modified industrial roundwood price elasticities for foreign countries ranging from 0.65 (at a roundwood price of \$80/m^3) to 1.03 (at a roundwood price of \$126.90/ m^3).

Alternative Scenarios for USFPM/GFPM

This section explains how we developed alternative global scenarios for USFPM/GFPM. Subsequent sections explain results of analysis for these scenarios. The 2010 RPA scenario data and results presented in this report are preliminary, not final. At the time this report was prepared, the 2010 RPA assessment was in progress and analysis was subject to possible revision. The scenarios presented here include global scenarios developed for the 2010 RPA Forest Assessment, and also other scenarios related to near-term projections of wood energy use.

2010 RPA Global Scenarios

The integrated modeling framework and analysis developed for the 2010 RPA Assessment operates with quantitative assumptions about global economic growth, population changes, and climate change. Consideration of global change led to a decision by RPA staff in 2006 to derive the 2010 RPA scenarios from the set of global climate and carbon emission scenarios developed for the Intergovernmental Panel on Climate Change, or IPCC. The RPA staff decided to use IPCC scenarios in 2006, a year before the IPCC and Albert Gore Jr. were awarded the 2007 Nobel Peace Prize for their efforts to disseminate knowledge about manmade climate change and to lay foundations for the measures needed to counteract such change. Three global scenarios were selected for the 2010 RPA from among global scenarios documented in the Special Report on Emissions Scenarios (SRES) prepared for IPCC (Nakicenovic and Swart 2000). We selected the IPCC marker scenarios for A1B, A2, and B2 storylines (specifically the “A1B AIM,” “A2 ASF,” and “B2 MESSAGE” scenarios), which were subjected also to some further harmonization and down-scaling. We adopted the IPCC storyline names for these scenarios, and hence we describe the three RPA scenarios as A1B, A2, and B2.

The three scenarios include a range of assumptions about future economic growth, population growth, and climate change, expected to have different effects on projected future U.S. resource conditions and trends. In general, the A1B scenario incorporates elements of globalization and economic convergence with social development themes of economic growth and new technologies. The A2 incorporates heterogenic regionalism and less trade with social development themes of self-reliance and preservation of local identities. The B2 incorporates localized solutions and slow change with social development themes of sustainable development and diversified technology. A more in-depth discussion of the RPA scenarios and assumptions is provided in a separate RPA report in process (USDA Forest Service, in preparation).

Global data from the IPCC scenarios were downscaled to U.S. national and sub-national levels to facilitate resource analyses for the 2010 RPA Assessment, and some minor adjustments were made to U.S. population and economic growth assumptions. U.S. GDP was updated to a 2006 base year, and projections for the A1B scenario were based on projections provided by the USDA Economic Research Service. The U.S. population projection for A1B was updated to be consistent with the U.S. Census Bureau projections based on 2000 Census data. The 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.

Although IPCC SRES scenarios and the RPA adjustments to the U.S. GDP and population projections were all developed prior to the recent economic recession (2008–2009), the growth assumptions of all three scenarios were not adjusted in any way to reflect the economic recession, in order to maintain precise consistency with the SRES global economic and climate assumptions. Nevertheless, note that U.S. GDP growth of the A1B scenario remains consistent with the long-term U.S. real GDP growth trendline based on data that extend through the recent recession (through 2009), while U.S. GDP growth projections of A2 and B2 scenarios are lower than the trendline. U.S. GDP growth of the A1B scenario (from USDA Economics Research Service) coincides almost precisely to a logarithmic trendline based on real U.S. GDP data from 1950 to 2006, and inclusion of more recent U.S. GDP data (2006–2009) only slightly changes the trendline. Using annual U.S. GDP data from 1950 to 2006 the logarithmic trendline is: Growth = $-0.0077 \times \text{Ln(Year)} + 0.05685$ (where “Year” starts at 1950 = 0). Recomputed with GDP data from 1950 through 2009, the growth formula changes slightly [Growth = $-0.0091 \times \text{Ln(Year)} + 0.0618$] and still closely matches the U.S. real GDP growth rates of the A1B scenario. On the other hand, unlike the A1B scenario, the A2 and B2 scenarios assume slower per capita real income growth relative to historical income growth since the mid-20th century. Thus, the A2 and B2 both have substantially lower long-term U.S. and global GDP growth rates than the A1B scenario (and lower than the

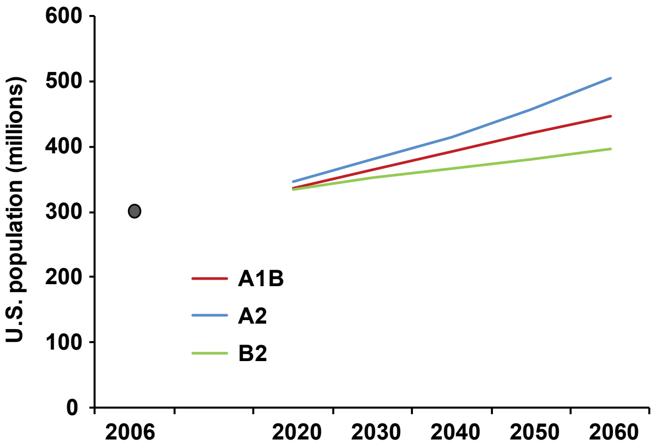

Figure 11–U.S. population projections, 2006 to 2060 for three RPA scenarios.

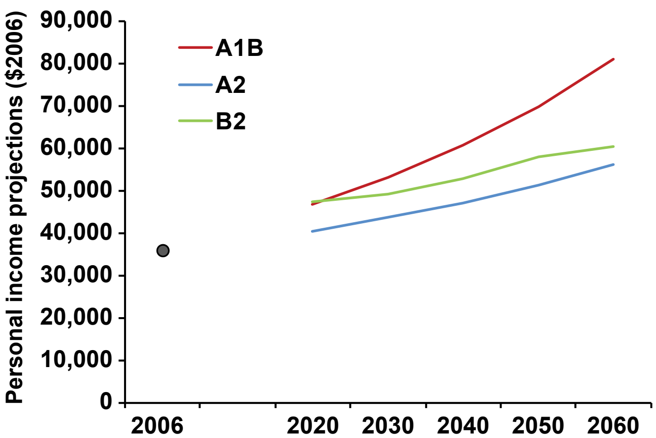

Figure 12–U.S. Per capita personal income projections, 2006 to 2060, for three RPA scenarios.

GDP growth trendline based on data from 1950 to 2009). Thus, even though growth assumptions for all scenarios were developed prior to the most recent economic recession, the three scenarios still subtend a wide range of GDP growth assumptions by current standards, with A2 and B2 below the current trendline.

The A1B scenario has midrange U.S. population growth, whereas A2 has higher population growth, and B2 has lower growth (Fig. 11). However, A1B has the highest projected average personal income, followed by B2 and A2 (Fig. 12). In A1B, by 2060 the United States has 446 million people and real personal income averages nearly $81,000 per capita (in 2006 $). The A2 scenario has the highest projected U.S. population, over 505 million people in 2060, but the lowest real personal income per capita, only around $56,000 by 2060. The B2 has lowest population growth but mid-level personal income, with a U.S. population of 397 million people and real personal income per capita of around $60,000 in 2060.

The energy outlook and climate change projections of the IPCC SRES scenarios also reflect a general consensus among other global energy studies that production of renewable energy such as biomass will expand in the coming decades, although rates of expansion vary by scenario. Other global studies that have similarly predicted this trend include a recent Massachusetts Institute of Technology (MIT) study projecting world biomass energy production increasing from 45 exajoules (1×10^{18} J or EJ) currently to a range between 221 and 267 EJ by 2050 (Gurgel and others 2007), and an International Energy Agency (IEA) study predicting potential biomass energy production increasing to 200 to 300 EJ by 2050 (Faaij 2007). In general, IPCC scenarios and 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 (e.g., by 2020 to 2030) leading generally to expansion in other forms of energy production including renewable energy production.

Meanwhile, the United States and many other countries have established near-term targets and mandates for biofuel production, as noted in the roadmap report on biofuels for transport by the IEA, which determined a global biofuel capacity target of 250 billion gallons of gasoline equivalent by 2030 (IEA 2011). In addition, policies that promote biomass energy use for thermal and electric power generation are also found in various countries and also in the United States, where a majority of states have adopted renewable portfolio standards requiring that electricity providers obtain a minimum percentage of their power from renewable energy resources by a certain date, which vary by state but cluster generally in the area of a 20% requirement by 2020. The U.S. Department of Energy provides an on-line summary of state renewable portfolio standards (see http://apps1.eere.energy.gov/states/maps/renewable_portfolio_states.cfm).

Figure 13 displays charts that show for comparison the historical and projected trends in global energy production (in exajoules) reported in the IPCC Special Report on Emissions Scenarios (SRES) database for each of the three selected RPA scenarios. In all three scenarios shown in the charts there is a continuity of the historical pattern of expansion in global energy production along with shifting sources of energy, but the three scenarios vary in their overall levels of projected global energy production and corresponding levels of biomass energy production.

The three scenarios all project a peaking of global oil production around 2020 to 2030, but as shown in Figure 13, the scenarios vary in their responses to subsequent declines in energy production from oil. For example, A1B has the highest projected overall energy production and therefore the highest projected expansion in biomass energy production, in line with A1B themes of economic growth and new technologies. The A2 has lower overall energy production and also higher energy production from coal, and therefore

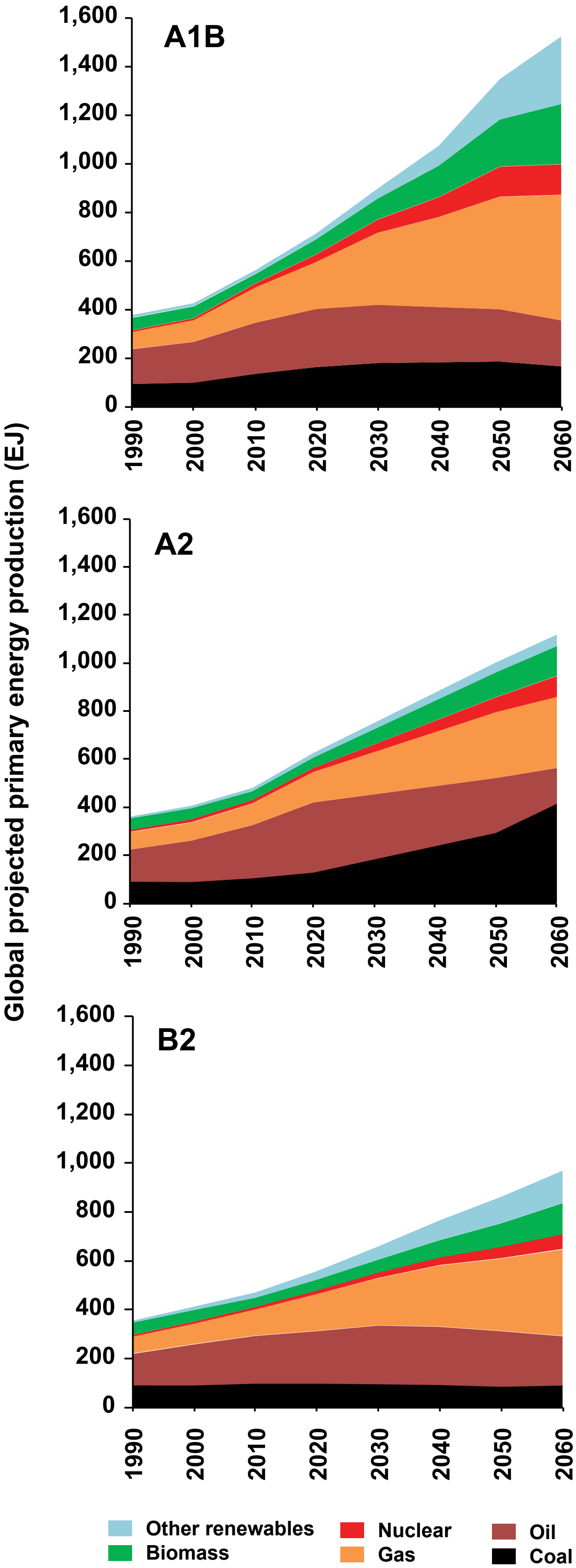

Figure 13–Global primary energy production (EJ) by source, 1990 to 2060, for three RPA scenarios, as projected by IPCC (Nakicenovic and Swart 2000).

the lowest projected global expansion in biomass energy production. The B2 has the lowest overall energy production and consumption, in line with its theme of sustainable development, but B2 has relatively slow changes among energy sources as compared with the other scenarios. Therefore, global biomass energy production levels of B2 are slightly higher than the A2 scenario.

Developing global fuelwood demand assumptions for the RPA scenarios based on the IPCC SRES scenarios required first calibrating the primary biomass energy production from corresponding IPCC scenarios to a common historical basis, because the three selected IPCC scenarios (A1 AIM, A2 ASF, and B2 MESSAGE) were actually developed using different economic and biophysical models, and hence their reported historical biomass energy production levels were not the same (Nakicenovic and Swart 2000). 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 closest to historical global biomass energy production reported in the literature (e.g., Gurgel and others 2007) and as reported in data adapted from the International Energy Agency (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 increases in biomass energy production as projected originally by SRES. We also made adjustments for missing data in some global regions. Table 21 shows the calibrated global primary biomass energy production in exajoules (EJ) for the three RPA scenarios and corresponding global expansion factors from 2000 to 2060.

Table 22 provides a summary of the three alternative RPA scenarios in terms of their general description, their economic and social development themes as outlined by IPCC, and their basic assumptions about population growth, economic growth, and future global expansion of biomass energy production.

To summarize the RPA scenarios, the A1B has the highest global economic growth coupled with slowing global population growth, and it assumes continued economic globalization and global economic convergence, generally consistent with global real GDP growth since the mid-19th century of about 3% per year. Although global crude oil production is projected to peak in the decade between 2020 and 2030, global energy resources are taken to be plentiful in the A1B scenario by assuming large future availability of coal, unconventional oil, and natural gas as well as high levels of improvement in efficiency of energy exploitation, energy conversion, and transport technologies. High economic growth and high energy consumption and energy conversion in the A1B scenario propel the highest levels of biomass energy production according to the SRES (with global expansion of 5.9× from 2000 to 2060).

The A2 and B2 scenarios have considerably lower global real GDP growth, slower growth in energy consumption,

Table 21—Calibrated global primary biomass energy production for RPA scenarios

	Global primary biomass energy production, measured in exajoules (EJ)		
Year	Scenario A1B	Scenario A2	Scenario B2
1990	46.00	46.00	46.00
2000	43.10	43.10	43.10
2020	69.50	52.22	52.60
2060	254.54	131.80	135.90
Expansion factor, 2000–2060	5.9×	3.1×	3.2×

and also more modest expansion in global biomass energy production (3.1× and 3.2×, respectively). The A2 is differentiated by considerably higher global population growth than other scenarios, but the lowest global GDP growth, and hence lowest global per capita income of the three scenarios (Fig. 12). The B2 assumes more diversified global technology and a theme of sustainable development, resulting in the lowest global population growth and mid-level global GDP growth, but also the lowest U.S. real GDP growth.

USFPM/GFPM models global fuelwood production and consumption (not total biomass energy production), and the IPCC SRES did not specify precisely how much of their projected biomass energy production consists of fuelwood from forests, so we had to develop approaches for modeling fuelwood production or consumption that reasonably reflect the biomass energy outlook of the RPA scenarios as projected by SRES. The available information in the SRES report and its supporting database (Nakicenovic and Swart 2000) include projections of total primary biomass energy production globally and in four large global regions, called "macro" regions. The regional information indicated for example that the macro region encompassing South America and Africa was projected to account for the largest share of expansion in global biomass energy production, similar to findings of other global biomass energy studies (e.g., Gurgel and others 2007; Faaij 2007). In addition, the SRES report and database provided projections of land use for each scenario by macro region, including projected areas of forest land, cropland, and non-forest land dedicated to energy crops ("energy biomass land"). Thus, we were able to consider and explore several options for projecting global fuelwood demand in USFPM/GFPM based on the IPCC scenarios (described as follows):

Option 1: One option that has been employed previously in the GFPM is to model fuelwood demands of each country with a common price elasticity of demand (–0.5) and exogenously shift the demand over time so that global expansion in roundwood fuelwood consumption matches the SRES global expansion in primary biomass energy production by scenario, while each country's share of global fuelwood consumption is adjusted to converge upon and match each country's share of global GDP by the end of the projection period (Raunikar 2010). This option results in very large expansion of fuelwood consumption for countries like the United States that have a small current share of global fuelwood consumption but a large share of projected global GDP. Also, this option does not take into account available information from the SRES on regional land use and biomass energy production by macro region, so the projections of fuelwood consumption by macro region do not align with the SRES regional allocation of biomass energy production (e.g., compared with the SRES biomass energy projections, there is proportionately much less expansion of fuelwood production in South America and Africa under this option).

Option 2: Another option is to model fuelwood demands in each country using econometric demand functions that are based on statistical analysis of historical data, with a price

Table 22—Summary of the three alternative RPA 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, capacity building	Self-reliance, preservation of local identities	Sustainable development, diversified technology
Global real GDP growth, (2010–2060)	High (6.2×)	Medium (3.2×)	Medium (3.5×)
Global population growth, (2010–2060)	Medium (1.3×)	High (1.7×)	Medium (1.4×)
U.S. GDP growth, (2006–2060)	Medium (3.3×)	Low (2.6×)	Low (2.2×)
U.S. population growth, (2006–2060)	Medium (1.5×)	High (1.7×)	Medium (1.3×)
Global expansion of primary biomass energy production, (2000–2060)	High (5.9×)	Medium (3.1×)	Medium (3.2×)

elasticity of fuelwood demand and an econometric relationship of fuelwood demand to GDP in each country. This option has also been explored with the GFPM. Under this option, the fuelwood consumption in each country responds to the alternative GDP growth assumptions of the three different RPA scenarios (Table 22), but in general the econometric relationships between fuelwood demand and GDP growth result in very modest expansion of fuelwood consumption because in many countries consumption of fuelwood has been receding as a share of total energy output in recent decades. Thus, under this option the projected expansion of global fuelwood consumption falls far short of the expansion in biomass energy production as projected by SRES in all scenarios.

Option 3: A third option is to model fuelwood demands by SRES macro region, taking into account regional land-use projections and regional biomass energy projections provided by SRES for each scenario. This option is implemented by modeling fuelwood demands of each country with a common price elasticity of demand (–0.5) and exogenously shifting demands over time so that regional expansion in fuelwood consumption follows SRES projections of regional net biomass energy consumption after deducting regional estimates of biomass energy from biomass plantations, agricultural crops, and residues. Biomass energy outputs from biomass plantations are computed by multiplying SRES projections of biomass energy plantation area times conventional yield assumptions for biomass energy crops by region. Biomass energy output from cropland and residues are based on historical output of biomass energy from cropland and residues, with projections based on SRES regional cropland area projections. We deduct the biomass energy of biomass plantations, agricultural crops, and residues from total biomass energy production as projected by SRES within each macro region, yielding as a remainder the imputed regional consumption of forest-based fuelwood. We then compute matching growth shifters for fuelwood demand in each region for each RPA scenario, and we distribute the growth among countries within each region in proportion to each country's share of regional GDP in 2060. We also apply common regional elasticities with respect to the growth shifters to adjust or fine-tune the regional fuelwood projections until USFPM/GFPM projections of regional fuelwood consumption match the regional fuelwood consumption targets. Under this option, we take into account the large share of projected biomass energy production that is supplied by non-forest biomass energy plantations and cropland residues based on SRES land area projections. Thus, option 3 produces projections of global fuelwood consumption in USFPM/GFPM that are somewhat lower than option 1, but higher than option 2. In this report, we focus on USFPM/GFPM results obtained using the option 3 approach, which is described in more detail in Appendix B, but for comparison we also produced results for an "A1B-Low Fuelwood" scenario, where the U.S. and global fuelwood demands were determined by the option 2 approach (via historical GDP growth relationships).

RFS+RES Scenarios

While the 2010 RPA assessment focused USFPM/GFPM on long-range global climate and emissions scenarios developed by the IPCC, we have also explored other alternative scenarios with USFPM/GFPM. This section describes a set of scenarios that we developed recently in collaboration with the Pinchot Institute for Conservation in a special study commissioned by the Forest Service Research Executive Team (Ince and others 2011). These scenarios and related assumptions were developed in collaboration with V. Alaric Sample of the Pinchot Institute for Conservation in Washington D.C. Do-il Yoo (University of Wisconsin graduate student) assisted in structuring the data input and running the scenarios with USFPM/GFPM.

This set of alternative scenarios focuses on potential implications of near-term biomass energy policies, specifically the U.S. Renewable Fuels Standard (RFS) that promotes expansion of advanced biofuels based on biomass, and also potential federal renewable energy standards (RES) for electric power production from renewable sources. We developed four alternative RFS+RES scenarios based in part on U.S. renewable energy projections from the 2010 U.S. Annual Energy Outlook (AEO) (DOE 2010a). The RFS+RES scenarios differ from one another mainly in terms of assumptions about future expansion in U.S. wood energy consumption through 2030. Also, unlike the RPA scenarios, the RFS+RES scenarios take into account the recent economic recession and the downturn in U.S. housing construction from 2006 to 2010, with adjustments in U.S. and global GDP. The sources of basic assumptions for the four RFS+RES scenarios are summarized in Table 23.

All of the RFS+RES scenarios assumed future levels of U.S. cellulosic biofuel output under the Renewable Fuels Standard policy (RFS) as projected by the 2010 AEO (DOE 2010a). The scenario labeled "HP" assumed the higher biofuel output projection of the AEO "High Oil Price" (HP) case, whereas the other three scenarios assumed the RFS biofuel projection of the AEO reference case. All of the scenarios also included additional biomass energy consumption under hypothetical national renewable energy standards (RES) 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" assumed a similar energy policy but allowed half of the non-hydro renewable energy to be more efficient combined heat and power, therefore requiring somewhat less biomass input for energy production than the RES20 scenarios.

We assumed in all RFS+RES 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

Table 23—Four RFS+RES scenarios and their sources of basic assumptions

Scenario	RFS+RES10	RFS+RES20+EFF	RFS+RES20	RFS+RES20+HP
Basis for U.S. wood energy projections	AEO reference case RFS and hypothetical RES10	AEO reference case RFS and hypothetical RES20+EFF	AEO reference case RFS and hypothetical RES20	AEO high oil price case RFS and hypothetical RES20
Wood percentage of U.S. primary energy consumption in 2030	1.3	1.6	1.8	2.5
U.S. GDP growth	AEO reference case			AEO high oil price case
U.S. housing starts	AEO reference case			
Foreign GDP growth	IMF[a] (2006–2014), IPCC B2 MESSAGE (2015–2030)[a]			
Fuelwood consumption in foreign countries	Fuelwood consumption as a percentage of primary energy consumption remains constant (2006–2030) while energy consumption increases based on IEA projections, resulting in a 65% increase in fuelwood consumption volume in total for all other countries.			

[a]Note: Global GDP growth of the B2 scenario after 2015 dovetailed with International Monetary Fund (IMF) growth to 2014.

biomass, chiefly agricultural, were 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 (DOE 2010b). Also, in a separate study, wood biomass supply needed to meet a 25% renewable portfolio standard for electric power combined with a 25% 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 (DOE 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).

In summary, abbreviations applied to the policy scenarios have the following meanings:

RFS—U.S. cellulosic biofuel output under the U.S. RFS obtains the levels projected by AEO 2010; 1/3 of required biomass is wood.

RES10—Hypothetical Renewable Energy Standard, 10% of U.S. electric power output is non-hydro renewable energy by 2030; 1/3 of required biomass is wood.

RES20—Hypothetical Renewable Energy Standard, 20% of U.S. electric power output is non-hydro renewable energy by 2030; 1/3 of required biomass is wood.

RES20+EFF—Similar to RES 20, but half of biomass energy output is more efficient combined heat and power, reducing biomass consumption; 1/3 of required biomass is wood.

HP—U.S. GDP growth and higher biofuel output based AEO High Oil Price case.

Among the RFS+RES scenarios, the RFS+RES10 scenario was posited as a baseline wood energy scenario because it largely reflects existing U.S. energy policies. It included projected U.S. cellulosic biofuel output under the U.S. RFS policy projected by the 2010 Annual Energy Outlook Reference Case outlook (DOE, 2010a). It also included 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 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.

The baseline RFS+RES10 scenario projects a 51% expansion in U.S. consumption of wood for energy by 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. The alternative 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 (Table 23). Thus, our policy-driven RFS+RES scenarios for U.S. wood energy consumption vary from an increase of 51% (from 2006 to 2030) in the RFS+RES10 baseline scenario to 83% in the RFS+RES20+EFF scenario, 101% in the RFS+RES20, and 178% in our RFS+RES20+HP scenario.

For all RFS+RES 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) (DOE 2010a). The AEO housing starts data include also 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"

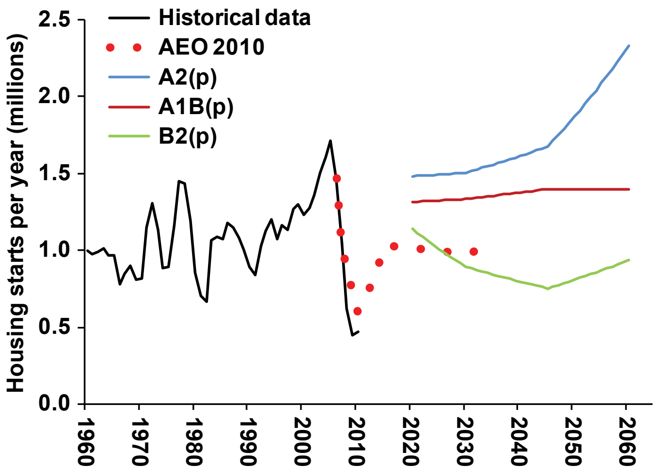

Figure 14— Historical U.S. annual single-family housing starts, 1960–2010, with projections based on Annual Energy Outlook (AEO) 2010, and preliminary (p) projections for RPA scenarios.

scenario uses the slightly different U.S. GDP projections of the AEO "High Oil Price" case. All RFS+RES scenarios use real GDP data and projections from 2006 to 2014 for other countries from the International Monetary Fund World Economic Outlook (IMF 2010), coupled with longer-term GDP growth assumptions of the IPCC B2 Message scenario (IPCC 2000). Because we included actual historical GDP data from 2006 to 2009 for all countries, the RFS+RES scenarios take into account the recent global recession, and also incorporate an assumption of gradual economic recovery in U.S. and global GDP growth as projected by AEO and IMF.

We derived the U.S. single-family housing starts projection for the RFS+RES scenarios from the projection of total U.S. housing starts reported in the AEO 2010 Reference Case (DOE 2010) by adjusting for the multi-family share of housing starts. The total housing starts projections of the AEO High Oil Price scenario and Reference Case scenario were nearly identical (DOE 2010), so we used the Reference Case projections in all RFS+RES scenarios. Not surprisingly, the housing starts projection based on the AEO did not match precisely the preliminary projections of any of the 2010 RPA scenarios, but the AEO housing outlook came closest to the RPA B2 projection after 2015, actually overlapping the preliminary B2 projection as shown in Figure 14. Thus, in the RFS+RES scenarios, the U.S. housing starts assumptions are similar to the projections of the RPA B2 scenario after 2015, but lower than the housing starts projections of the A1B or A2 scenarios. In addition, the U.S. GDP growth assumptions of the RFS+RES scenarios take into account the recent economic recession and therefore the GDP growth of the RFS+RES scenarios is lower than the RPA scenarios from 2006 to 2015, but similar to the B2 scenario from 2015 to 2035.

We also applied several other general assumptions to the RFS+RES scenarios. First, for U.S. regions, we assumed an elasticity of timber supply with respect to timber growing stock inventory (ε = 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 and others 2009). Future changes in regional U.S. timber growth rates are modeled endogenously in relation to changes in growing stock density using the same general approach applied to other countries in the GFPM (Appendix A), where growth in forest stock is a function of forest stocking density and industrial roundwood supplies have a long-run supply elasticity of 1.5 with respect to change in forest stock (Raunikar and others 2010; Turner and others 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. Last, for the RFS+RES scenarios we applied projections of U.S. forest land area changes by region as derived recently by Alig and others (2010) instead of using the 2010 RPA land area projections or the endogenously determined projection of forest land area based on the "Kuznets curve" approach that is applied to other countries in the GFPM.

For the RFS+RES scenarios, 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 for fuelwood is actually a real departure from historical fuelwood trends for most countries, where the 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).

In summary, the RFS+RES scenarios differ from the RPA scenarios in several ways. We designed the RFS+RES scenarios to project impacts of biomass energy policies over a shorter period, from 2010 to 2030 (rather than the longer-range focus of the RPA assessment from 2020 to 2060). Also, unlike the 2010 RPA scenarios, the RFS+RES scenarios take into account the effects of the recent economic recession on U.S. and global GDP, using actual GDP data from 2006 to 2010 along with U.S. GDP projections from the 2010 Annual Energy Outlook (EIA 2010), and global GDP data and projections for foreign countries from the IMF World Economic Outlook database (IMF 2010). Thus, RFS+RES scenarios explicitly incorporate the recent global recession, the downturn in U.S. housing construction since 2006 and resulting impacts on timber markets, as well as assumptions about near-term economic recovery.

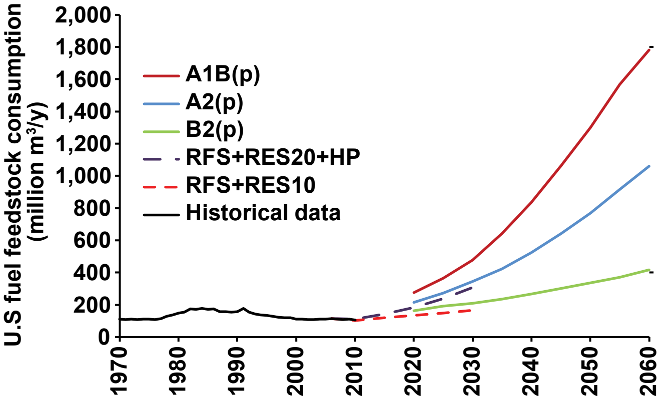

Figure 15—Annual U.S. wood fuel feedstock consumption, 1970–2010, with USFPM/GFPM projections for selected RFS+RES scenarios and preliminary (p) projections for three RPA scenarios (million m³/y).

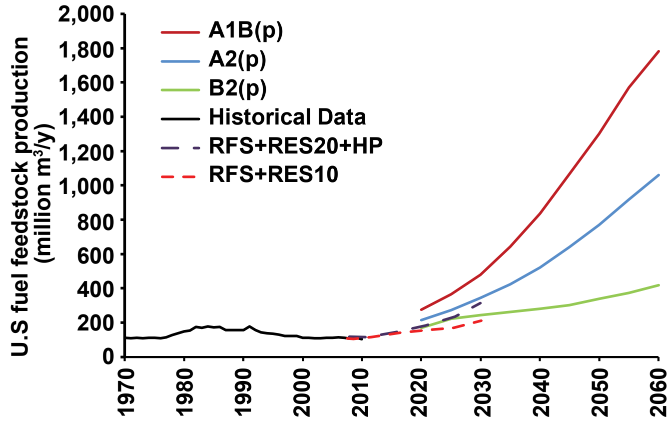

Figure 16—Annual U.S. wood fuel feedstock production, 1970–2010, with USFPM/GFPM projections for selected RFS+RES scenarios and preliminary (p) projections for three RPA scenarios (million m³/y).

Results

Results of analysis are presented here in the form of USFPM/GFPM projections for the 2010 RPA scenarios and selected RFS+RES scenarios. In most cases, projections are shown graphically in charts that also include historical data series for comparison to the projections. Results shown here for the 2010 RPA scenarios are preliminary, as the RPA forest assessment was still in process at the time this report was written. However, these results provide indications of the kinds of projections that USFPM/GFPM produces under the specific scenarios and data assumptions described in this report. Our presentation of results focuses here on USFPM/GFPM projections for the United States rather than the global outlook. A parallel global outlook for wood and forests based on the RPA scenarios was developed with the UW version of the GFPM and published separately (Raunikar and others 2010).

U.S. Wood Fuel Feedstock Projections

A striking feature of USFPM/GFPM scenarios is the large projected expansion relative to historical trends in U.S. consumption of wood fuel feedstock (including fuelwood, fuel residues, and other wood materials projected to be used for energy). Figure 15 shows the historical trend in total U.S. wood fuel feedstock consumption along with preliminary USFPM/GFPM projections of consumption for the three RPA scenarios and also for two selected RFS+RES scenarios (RFS+RES10 and RFS+RES20+HP). The global expansion in fuelwood consumption of the RPA scenarios is similar the GFPM results reported previously (Raunikar and others 2010). However, projected rates of expansion for U.S. fuelwood consumption are generally higher than the global rate of expansion for the RPA scenarios because forests are projected to provide a large share of biomass for energy production in the Organization for Economic Cooperation and Development (OECD) region (including United States) according to the SRES projections, and also because the U.S. share of regional fuelwood consumption in 2060 is assumed to match the relatively large U.S. share of regional GDP by 2060 (see Appendix B for more details). Thus, in the RPA scenarios, U.S. consumption of wood fuel feedstock is projected to expand from 2006 to 2060 by a factor of 15.7× in the A1B scenario, 9.4× in the A2 scenario, and 3.7× in the B2 scenario (Figure 15; see also Appendix Figure B3).

Note also that the RFS+RES scenarios subtend a range of projected expansion in U.S. wood fuel feedstock consumption that overlaps the RPA B2 projection (from 2020 to 2030), but the A1B and A2 projections of fuel feedstock consumption are higher than the RFS+RES projections (Fig. 15). Thus, an implicit result is that the IPCC SRES A1B and A2 scenarios envision higher U.S. wood energy consumption than indicated by the 2010 Annual Energy Outlook, even after taking into account the AEO high oil price scenario for biofuel production and a hypothetical 20% renewable energy standard by 2030.

Although global timber supply and fuelwood trade projections influence global allocation of fuelwood production in USFPM/GFPM, projected U.S. wood fuel feedstock production nevertheless follows closely the projected trends in U.S. consumption. Figure 16 shows historical data on total U.S. wood fuel feedstock production along with USFPM/GFPM projections of U.S. wood fuel feedstock production for the three RPA scenarios and the two selected RFS+RES scenarios (RFS+RES10 and RFS+RES20+HP).

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 and others 2009). However, non-conventional sources of fuel feedstock tend to dominate in the projections, especially in scenarios with

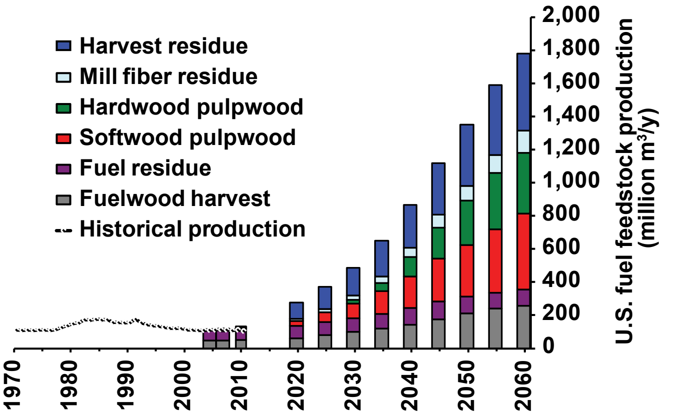

Figure 17— Annual U.S. wood fuel feedstock production, 1970–2010, and USFPM/GFPM preliminary (p) projection of production by feedstock source for A1B scenario (million m³/y).

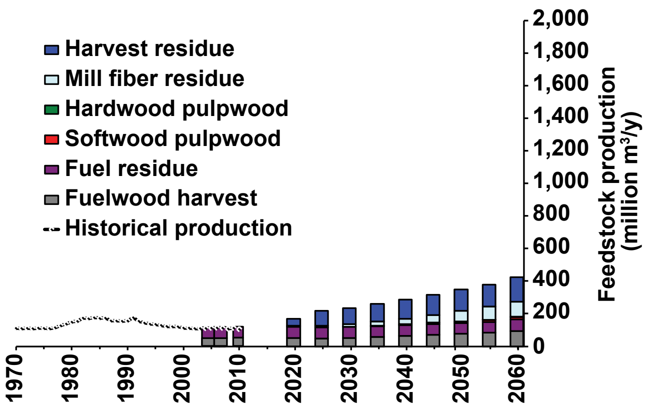

Figure 18—Annual U.S. wood fuel feedstock production, 1970–2010, and USFPM/GFPM preliminary (p) projection of production by feedstock source for B2 scenario (million m³/y).

large increases in wood energy consumption. Figure 17 shows historical data and preliminary projections of U.S. wood fuel feedstock production by source for the A1B scenario. Conventional fuelwood harvest and fuel residues expand, but non-conventional sources of wood fuel feedstock become dominant in the projections as consumption and price of fuel feedstock increase. Non-conventional sources include harvest residues, and hardwood (HW) and softwood (SW) pulpwood along with mill fiber residues that would be conventionally used at wood pulp mills and particleboard mills. Projections for the other RPA scenarios are generally much lower, as shown for example in Figure 18 for the B2 scenario, where expansion of fuel feedstock consists mainly of harvest residues.

Thus, the RPA scenarios encompass a wide range in projected U.S. production of wood energy from non-conventional sources, such as pulpwood, harvest residues, and fiber residues, from modest expansion in use of harvest residue for energy in the B2 scenario (Fig. 18) to really significant expansion in the A1B scenario (Fig. 17). In the A1B scenario, for example, the projected consumption of pulpwood and fiber residues for energy climbs to over 900 million cubic meters per year by 2060 (Fig. 17), a quantity several times higher than current total U.S. timber harvest. Thus, projected impacts on timber 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 (Fig. 18). Furthermore, because harvest residues provide most of the projected expansion in U.S. wood energy consumption in the B2 scenario (Fig. 18), the impacts of wood energy production on conventional timber markets and conventional forest product markets are much smaller in the B2 scenario than in the A1B scenario.

The alternative projections of U.S. wood fuel feedstock consumption in the RPA scenarios result in divergent trajectories for U.S. wood fuel feedstock prices and industrial roundwood prices as projected by USFPM/GFPM. Figure 19 shows the USFPM/GFPM preliminary projections of U.S. wood fuel feedstock demand price and U.S. industrial roundwood price for the three RPA scenarios. All price projections are in terms of 2006 real prices (the model generally ignores inflation). U.S. industrial roundwood price is the average of delivered regional prices for sawlogs, pulpwood, and other industrial roundwood as projected by USFPM. In recent years, bulk wood fuel feedstocks (such as green fuel residues or whole-tree chips) have been selling in the United States at prices in the vicinity of $15 to $25 per cubic meter (Timber Mart-South 2006) and in USFPM the base-period (2006) demand price for wood fuel feedstock was set at $25 per cubic meter (Table 17). The expansion in consumption of wood energy results in a projected real price of wood fuel feedstock more than five times higher by 2060 in the A1B scenario, but the smaller expansion in wood energy demand of the A2 and B2 scenarios results in much smaller increases in wood fuel feedstock price. Parallel price trends are projected for industrial roundwood (Fig. 19).

In the B2 scenario, as noted previously, most of the expansion in U.S. wood fuel feedstock consumption consists of increased use of harvest residues (Fig. 18), which has little impact on conventional timber prices, because the harvest residues are produced as byproducts of conventional timber harvesting activities and only a nominal additional cost is required to recover the harvest residues. In fact, the increased utilization of harvest residues for energy boosts revenues for timber stumpage and harvest activities and thus tends to increase timber supply. Hence, there is little increase in projected U.S. industrial roundwood price in the B2 scenario (Fig. 19), while the price is projected to be somewhat higher in the A2 scenario and much higher in the A1B scenario, with higher wood energy consumption and expanded competition for non-conventional sources of wood fuel feedstock such as pulpwood and fiber residues

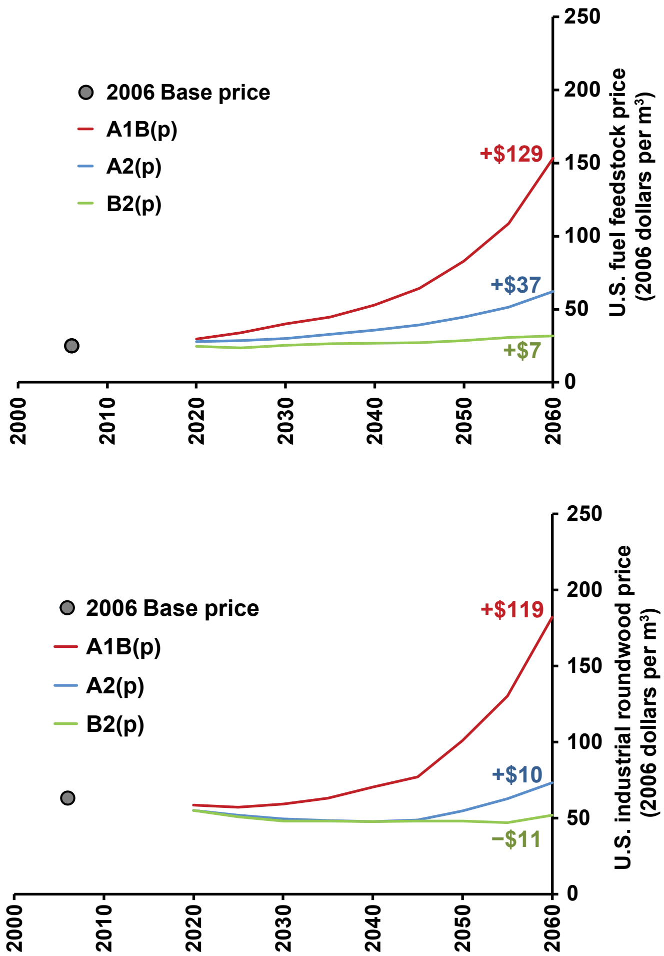

Figure 19—USFPM/GFPM preliminary (p) projections of U.S. wood fuel feedstock real price and industrial roundwood price increases for RPA scenarios (2006 $/m³).

(and eventually agricultural short-rotation woody crops toward the end of the projection period in the A1B scenario). The larger expansion in wood fuel feedstock consumption and expanded use of non-conventional supply sources drives up the projected real price for wood fuel feedstock and industrial roundwood, and most significantly in the A1B scenario (Fig. 19).

USFPM/GFPM projections of average global real price increases for fuelwood and industrial roundwood outside of the United States are somewhat different, as shown in Figure 20. In the A1B scenario, global wood prices increase more than in the United States, but the A2 scenario has the lowest projected increase in global price for fuelwood (just a $32 increase from 2006 to 2060). This is because the A2 scenario has the lowest projected global expansion in fuelwood consumption (Appendix B, Figure B3). Thus, there are notable differences in the RPA scenarios between projected increases for U.S. fuel feedstock and industrial roundwood price (Fig. 19) and projected increases for global fuelwood price (Fig. 20). In the A1B scenario, projected price increases for wood fuel are much higher globally (+$200) than in the United States (+$129). The lowest projected global fuelwood and industrial roundwood prices occur in the A2 scenario, whereas the lowest projected U.S. fuel feedstock and industrial roundwood prices occur in the B2 scenario.

The alternative projections of U.S. and global fuelwood demands and industrial roundwood prices have large and divergent impacts on the overall U.S. forest product production and trade outlook, as explained in the next section, because demands for fuelwood and resulting roundwood price impacts influence comparative advantages in production and trade. In particular, as will be shown in the forest product projections, U.S. producers of forest products tend to gain comparative advantage in the A1B and B2 scenarios, where projected global roundwood prices generally increase much more than the projected increase in U.S. domestic wood prices (see Figs. 19 and 20). On the other hand, foreign producers of forest products tend to gain comparative advantage in wood costs in the A2 scenario where there is less expansion in global fuelwood demand, lower global increases in wood prices, and less global competition for wood raw material.

Forest Product Projections

Before discussing timber market projections, we present the U.S. forest product market projections, which also influence the overall U.S. timber market outlook. Figure 21 shows the historical trend for annual total U.S. lumber consumption (hardwood and softwood sawnwood) along with USFPM/GFPM projections of total U.S. lumber consumption for the RFS+RES10 scenario and preliminary projections for the three RPA scenarios. As shown by the historical trend in Figure 21, U.S. lumber consumption was severely affected 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 USFPM/GFPM, the principal drivers of U.S. lumber demand include housing starts projections (Fig. 10) and GDP growth assumptions (Table 22), which vary by RPA scenario and thus result in divergent lumber consumption projections for the RPA scenarios, as shown in Figure 21. By contrast, the RFS+RES scenarios take into account the housing downturn and economic recession along with gradual recovery as projected by the AEO 2010, resulting in a somewhat lower trajectory for U.S. lumber consumption (illustrated by the RFS+RES10 scenario in Fig. 21).

Projected lumber consumption for all RFS+RES scenarios were nearly identical to the RFS+RES10 projection shown in Figure 21 because of nearly identical housing starts assumptions and GDP growth assumptions among RFS+RES scenarios. Also, harvest residues account for most of projected expansion in wood fuel feedstock production in all RFS+RES scenarios (similar to B2 scenario) so wood

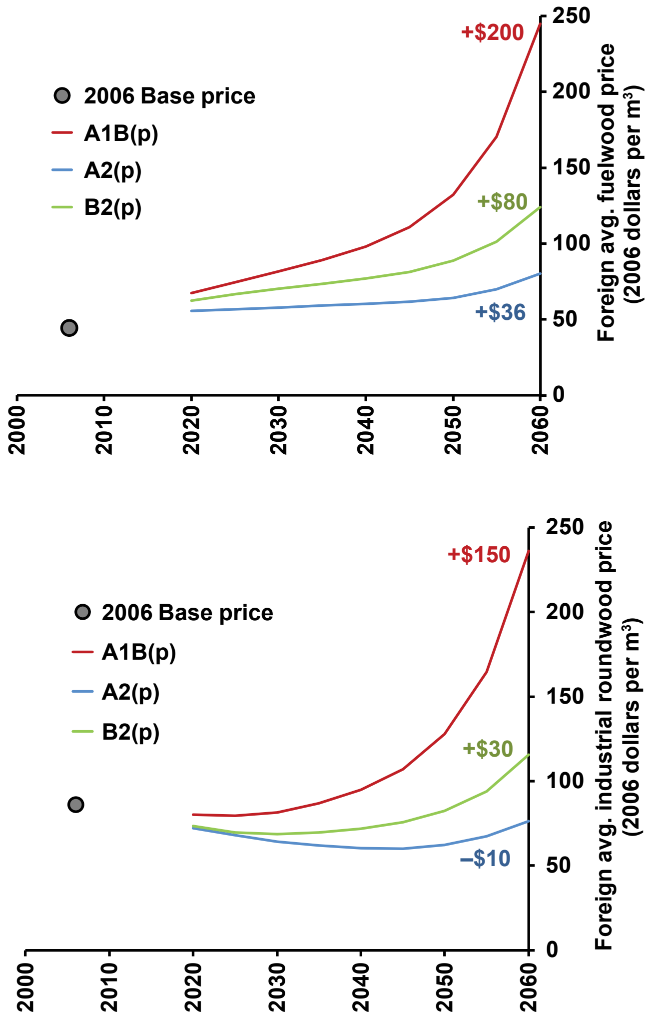

Figure 20—USFPM/GFPM preliminary (p) projections of average global fuelwood real price and industrial roundwood price increases outside of the United States for RPA scenarios (2006 $/m³).

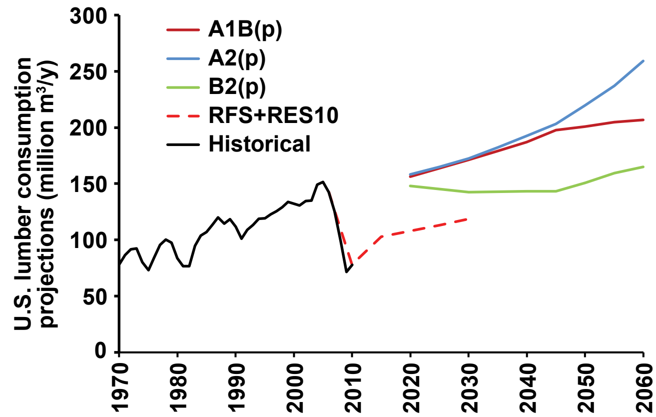

Figure 21—Annual U.S. lumber consumption, 1970–2010, with RFS+RES10 projections and preliminary (p) projections for RPA scenarios (million m³/y).

energy has a small impact on lumber production in the RFS+RES scenarios. RPA scenarios provide a wider range of alternatives in U.S. lumber consumption because the RPA scenarios incorporated higher levels of wood energy consumption and divergent assumptions about U.S. housing starts and U.S. GDP growth.

The basic assumptions of the A1B and A2 scenarios result in relatively high U.S. lumber consumption projections that are also quite similar from 2020 to 2045. This similarity is because U.S. lumber demand is driven both by projected housing starts and real GDP growth (about half of lumber is used in housing construction and half in a broad array of other end uses that follow GDP growth), so the higher U.S. GDP growth of the A1B compensates for the higher housing starts of the A2. Among the RPA scenarios, the B2 has the lowest projections of U.S. lumber consumption because the B2 has the lowest U.S. housing starts projections (Fig. 10) and the lowest rate of growth in U.S. GDP (Table 22).

However, USFPM/GFPM projections of U.S. lumber production do not exactly follow consumption because of the influence of global trade and wood energy demands. Figure 22 shows historical U.S. lumber production along with USFPM/GFPM projections for selected RFS+RES scenarios and preliminary projections for RPA scenarios. Of the RPA scenarios, A1B has the highest projected U.S. lumber production, partly because A1B has high lumber consumption (Fig. 21) but also because A1B has highest projected global fuelwood demand and fuelwood prices (Fig. 20), which create competing global demand and higher global prices for industrial roundwood that limit global lumber exports to the United States. Hence, U.S. lumber producers obtain comparative advantage and high levels of production in the A1B scenario. By contrast, A2 has the lowest projected expansion in global wood energy consumption (Fig. B3) so there is less competition from wood energy for industrial roundwood in foreign countries. Thus, foreign lumber producers do not lose comparative advantage in the A2 scenario, resulting in lower projected levels of U.S. lumber production (Fig. 22). In this regard, the RFS+RES scenarios were more similar to the A1B scenario, but with higher U.S. net exports of lumber. These findings were more in line with recent trends (Fig. 22). The reason for the similarity is that RFS+RES scenarios incorporate the collapse in housing from 2006 to 2010, which affords higher exports in conjunction with lower domestic consumption (Fig. 21).

Figure 23 shows USFPM/GFPM projections of U.S. lumber net exports (annual exports minus imports) again showing clearly that the A2 scenario affords the most comparative advantage to foreign lumber producers, because of lowest global fuelwood consumption and relatively little global competition for industrial roundwood from wood energy.

Beyond lumber, the next leading category of U.S. solid-wood products is the structural wood panel products, including chiefly oriented strandboard (OSB) and softwood plywood, both of which are used primarily in housing and

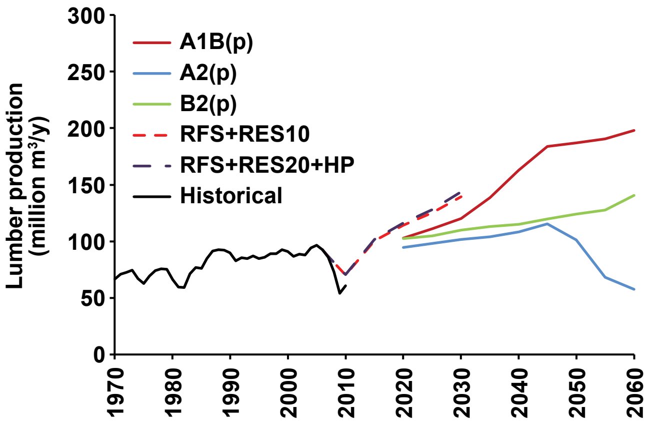

Figure 22—Annual U.S. lumber production, 1970–2010, with RFS+RES projections and preliminary (p) projections for RPA scenarios (million m³/y).

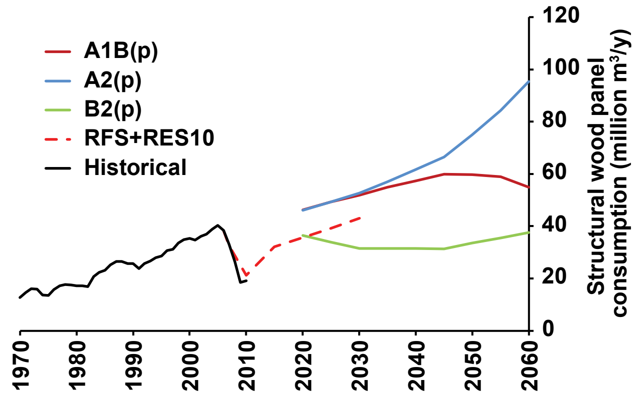

Figure 24—Annual U.S. structural wood panel consumption, 1970–2010, with RFS+RES10 projections and preliminary (p) RPA projections (million m³/y).

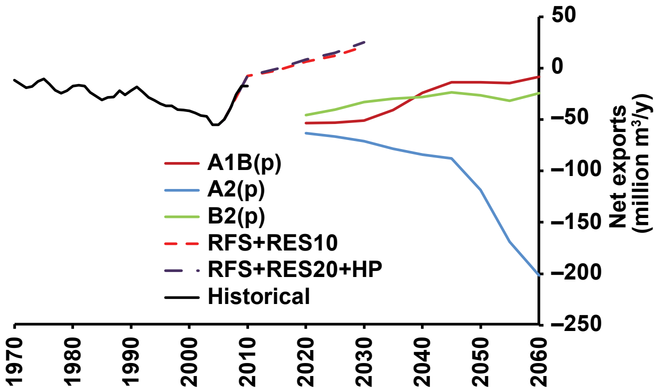

Figure 23—Annual U.S. net exports of lumber, 1970–2010, with RFS+RES projections and preliminary (p) projections for RPA scenarios (million m³/y).

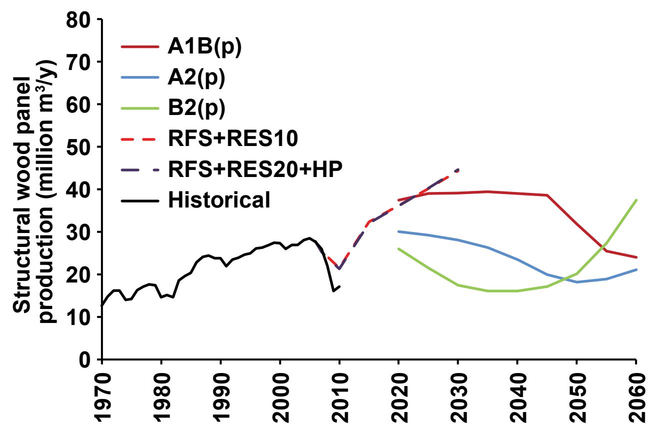

Figure 25—Annual U.S. structural wood panel production, 1970–2010, with RFS+RES projections and preliminary (p) projections for RPA scenarios (million m³/y).

other construction applications, as well as various industrial end uses. Figure 24 shows historical data for total U.S. structural wood panel consumption (OSB and softwood plywood) along with USFPM/GFPM projections of U.S. structural panel consumption for the RFS+RES10 scenario and preliminary projections for the RPA scenarios. As was the case for lumber consumption, the A1B and A2 scenarios have highest projected structural wood panel consumption because those scenarios have the highest GDP growth (A1B) and highest housing starts projections (A2), whereas B2 has the lowest GDP growth and housing starts.

However, as with lumber production, projections of U.S. structural wood panel production do not exactly follow consumption projections because of the influence of trade and global wood energy demands. Figure 25 shows historical U.S. structural wood panel production and USFPM/GFPM projections of production. As was the case for lumber, the A2 scenario affords more comparative advantage to foreign producers of structural panels because the A2 scenario has the lowest projected global expansion in wood energy consumption (Appendix B, Figure B3) and thus there is little global competition for industrial roundwood from wood energy. The A2 scenario also has the highest levels of U.S. housing starts, which propel the highest levels of structural wood panel demand and high levels of wood panel imports (lowest net exports), as shown in Figure 26. As was the case for lumber, the A1B scenario affords comparative advantage to U.S. producers of structural wood panels and high levels of production, at least for several decades, but toward the end of the projection period (after 2040) U.S. production declines in the A1B scenario as OSB output is negatively impacted by high levels of pulpwood consumption for energy (Fig. 17). The RFS+RES scenarios exhibit even higher U.S. net exports of structural wood panels (more in line with recent net export trends, as shown in Fig. 26) because RFS+RES scenarios incorporate the recent collapse in U.S. housing from 2006 to 2010, which affords higher exports in conjunction with lower domestic consumption.

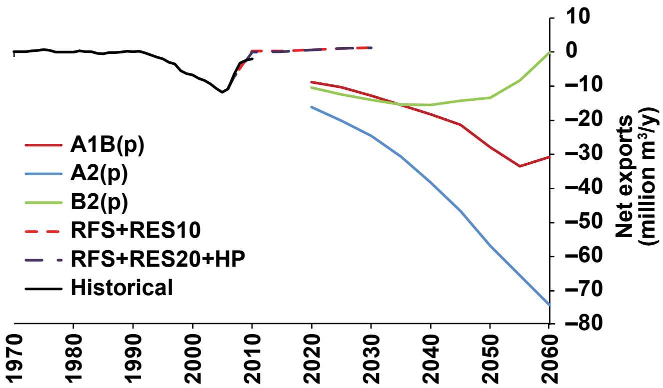

Figure 26—Annual U.S. net exports of structural wood panel products, 1970–2010, with RFS+RES10 projections and preliminary (p) projections for RPA scenarios (million m³/y).

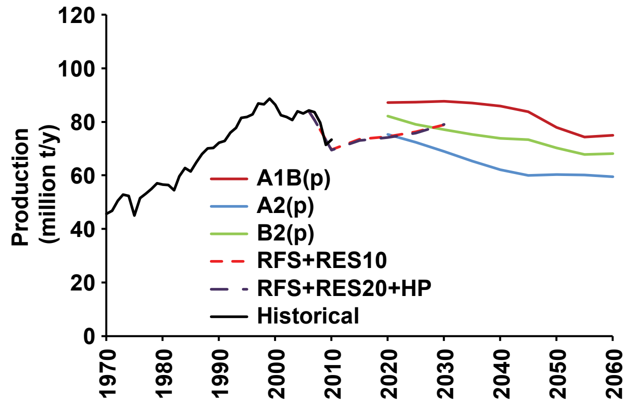

Figure 28—Annual U.S. paper and paperboard production, 1970–2010, with RFS+RES projections and preliminary (p) RPA projections (million t/y).

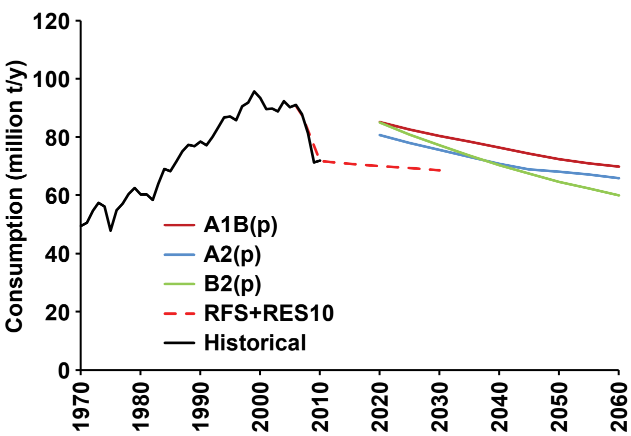

Figure 27—Annual U.S. paper and paperboard consumption, 1970–2010, with RFS+RES10 projections and preliminary (p) RPA projections (million t/y).

Figure 27 shows the historical trend for total paper and paperboard consumption in the United States, along with USFPM/GFPM projections for the RFS+RES10 scenario, and preliminary projections for the three RPA scenarios. Again, in the RFS+RES scenarios, unlike RPA scenarios, projections of product consumption incorporate the recent economic recession and are nearly identical for all RFS+RES scenarios because of nearly identical GDP assumptions. Also wood energy demands exert little influence on timber markets in the RFS+RES scenarios because harvest residues supply most of the expansion in wood fuel feedstock production. Although divergent projections of paper and paperboard consumption would be expected in the RPA scenarios because of divergent GDP growth assumptions, the projections are also impacted by competing consumption of pulpwood for wood energy, especially in the A1B scenario.

Of the three RPA scenarios, the A1B has highest U.S. GDP growth, so not surprisingly the A1B has the highest projected U.S. consumption of paper and paperboard (Fig. 27), but consumption in the A1B is only slightly higher than the other scenarios. U.S. wood energy demands in the A1B scenario consume large volumes of pulpwood (Fig. 18), which increases the price for pulpwood and dampens projected growth in U.S. paper and paperboard consumption, although inelasticity of paper and paperboard demands with respect to price (Table 18) tends to limit the demand response to higher wood costs. There is generally less competition for pulpwood from wood energy in the A2 and B2 scenarios. Total U.S. paper and board consumption is projected to gradually decline in all scenarios, including the RFS+RES scenarios, with consumption declining primarily in newsprint and printing and writing paper grades.

Figure 28 shows the historical trend of total annual U.S. paper and paperboard production, along with USFPM/GFPM projections. U.S. production peaked historically in 1999. Although projected U.S. paper and paperboard consumption is only modestly higher in the A1B than the other RPA scenarios (Fig. 27), there is nevertheless a wider divergence in projected U.S. production, especially between A1B and A2 scenarios (Fig. 28). This divergence is attributable to trade impacts of high global fuelwood demand in the A1B scenario versus low global fuelwood demand in the A2 (Appendix B, Fig. B3).

With highest global fuelwood demands and prices (Fig. 20), A1B has the most global competition for roundwood from fuelwood among the RPA scenarios. 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. There is also similarly a gain in comparative advantage for U.S. paper and paperboard producers in the RFS+RES scenarios because of their prodigious 65% expansion in foreign fuelwood consumption by 2030 (Table 23). The A2 scenario has the least global competition for roundwood from fuelwood demands, so U.S. producers of paper and paperboard do not gain comparative advantage in that scenario. Historical data on U.S. paper and paperboard net exports and projections of net

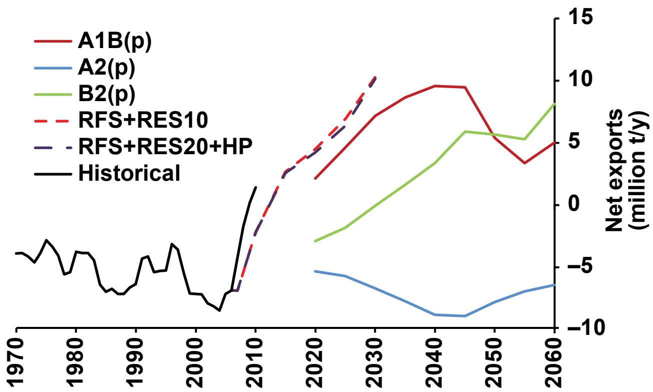

Figure 29—Annual U.S. net exports of paper and paperboard, 1970–2010, with RFS+RES projections and preliminary (p) RPA projections (million t/y).

exports are shown in Figure 29. Some of the recent gains in U.S. net exports of paper and paperboard are attributable to a weaker dollar in recent years, as well as productivity gains for U.S. producers. USFPM/GFPM can analyze effects of changes in currency exchange rates, but future adjustments of currency exchange rates were not programmed into the current version of the model. Projected U.S. production of paper and paperboard is highest in the A1B and RFS+RES scenarios (Fig. 28) because of the positive projected U.S. trade balances for paper and paperboard in those scenarios, while projected production is lowest in the A2 scenario with the lowest projected net exports (Fig. 29). Clearly there is a positive correlation between high global fuelwood consumption (high competing demands for roundwood at the global level) and higher projected U.S. net exports and production of paper and paperboard.

A key finding of this analysis is that projected U.S. consumption, production, and net trade in forest products are heavily influenced by assumptions about future expansion in U.S. and global 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 roundwood prices tend to dampen domestic demands for forest products, as competing energy demands for wood biomass generally drive up the projected U.S. and global prices for timber and forest products. On the other hand, higher global fuelwood consumption (as in the A1B scenario) also increases global competition for industrial roundwood and boosts comparative advantages of U.S. producers of forest products. Across the spectrum of RPA scenarios, the projected effects of expansion in U.S. and global wood energy consumption are to dampen expected growth in forest product consumption (because of price impacts on demands) but also to provide greater comparative advantages and enhanced net exports for U.S. producers of forest products (because of price impacts on foreign producers).

Among the RPA scenarios, projected U.S. real prices for forest products were generally the highest in the A1B scenario (with highest competing demands for wood energy and highest roundwood prices). Projected product prices were generally lower in the A2 and B2 scenarios. For example, projected real prices of softwood lumber were more than 50% higher by 2060 in the A1B as in the B2. Real price of softwood lumber was projected to decline over the projection period in the A2 and B2 scenarios, but projected to increase in the A1B with increasing timber prices. Real prices trends for paper and paperboard products were generally projected to be flat to modestly declining in all scenarios, but were still about 15% to 25% higher by 2060 in the A1B than in the A2 or B2 scenarios. Figure 30 shows charts that illustrate projected U.S. real price trends (weighted averages) for several aggregate categories of primary forest products, including lumber (softwood and hardwood), paper and paperboard (newsprint, printing and writing paper, and all other paper and board), and structural panels (OSB and softwood plywood). With the highest production levels and projected prices, the A1B scenario generates the highest revenues for U.S. forest product producers, whereas the A2 and B2 scenarios have lower prices, lower production levels, and lower projected forest product revenues.

U.S. Timber Harvest and Market Projections

U.S. timber harvest and market projections for most of our USFPM/GFPM scenarios depart from historical timber trends of recent decades because of projected expansion in wood energy consumption. Total U.S. timber harvest has declined since the late 1980s, but projections for the RPA and RFS+RES scenarios generally point to increasing future timber harvest volumes. Figure 31 shows historical annual U.S. timber harvest volumes based on interpolation of FIA timber harvest data (Smith and others 2009) and USFPM/GFPM projections of U.S. timber harvest. Among RPA scenarios, the largest projected expansion in U.S. timber harvest occurs in the A1B scenario, followed by the A2 and B2 scenarios, which mainly reflect relative magnitudes of projected expansion in wood fuel feedstock production (see Fig. 16). However, even in the B2 scenario, harvest is projected to reach levels well above the peak harvests of recent decades (in the 1980s). We also show in Figure 31 the U.S. timber harvest projection for the "A1B-Low Fuelwood" scenario (where fuelwood demands are based on historical relationships and not IPCC SRES global biomass energy projections, but all other assumptions are identical to the A1B scenario). The "A1B-Low Fuelwood" projection shows clearly that most of the projected expansion in timber harvest of the A1B scenario is a result of the projected expansion in fuelwood demand, without which the projected trend for U.S. timber harvest is much more subdued.

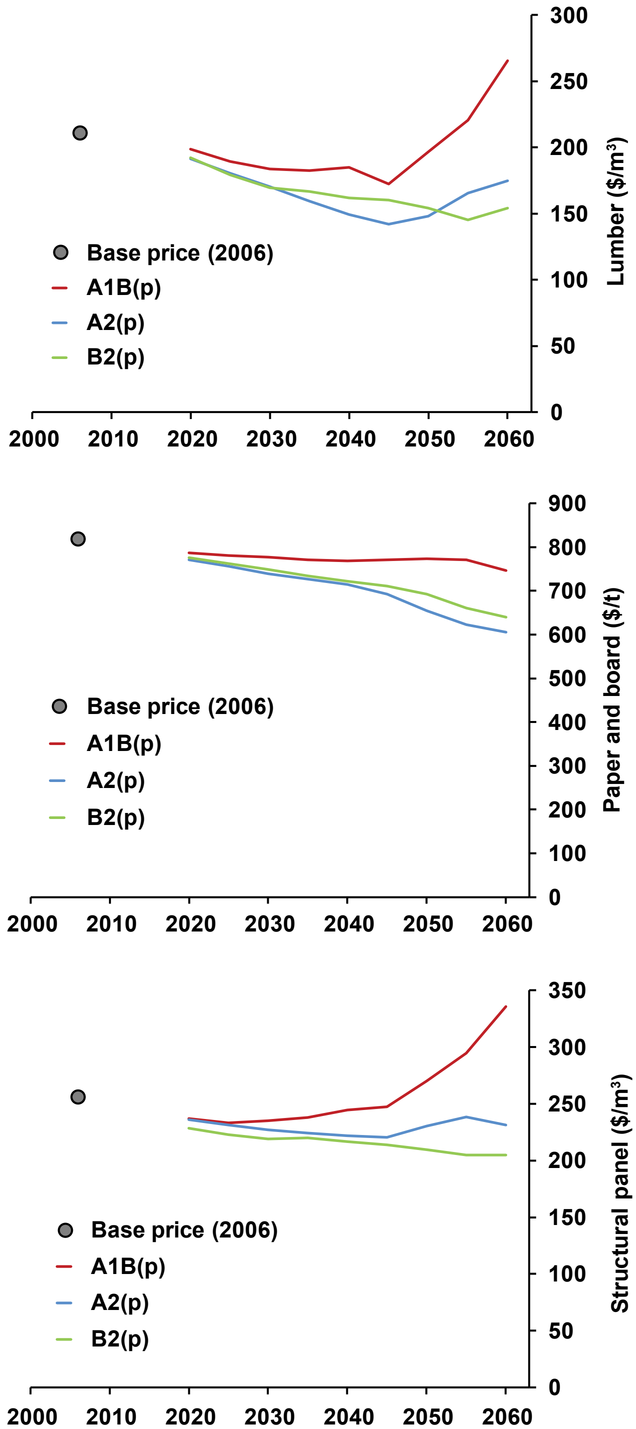

Figure 30—Preliminary (p) RPA projections of average U.S. demand prices for lumber, paper and paperboard, and structural panels.

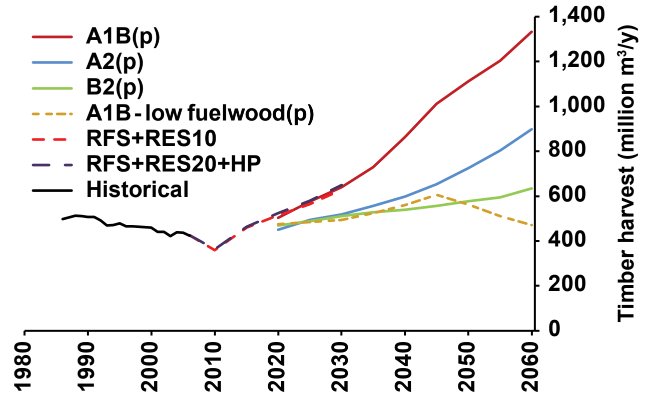

Figure 31—Historical total annual U.S. timber harvest volume, 1986 to 2006, with RFS+RES projections and preliminary (p) RPA projections (million m³/y).

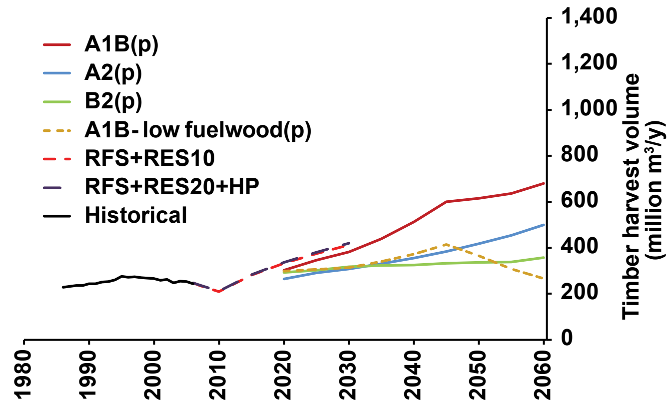

Figure 32—Historical total annual timber harvest volume in U.S. South, 1986 to 2006, with RFS+RES projections and preliminary (p) RPA projections (million m³/y).

Among U.S. regions, the U.S. South has accounted for the largest regional share of U.S. timber harvest in recent decades, accounting for 57% of U.S. timber harvest volume in 2006 for example (Smith and others 2009). Figure 32 shows the historical trend in total timber harvest volume of the U.S. South, along with USFPM/GFPM projections.

Unlike the U.S. timber harvest trend that has been declining since the 1980s, timber harvest in the U.S. South has declined only since the mid-1990s. USFPM/GFPM projections indicate that the U.S. South will continue to be the largest timber-producing region of the United States, generally accounting for around half or more of total U.S. timber harvest throughout the projection period in all three RPA scenarios (Fig. 32). Also, as with total U.S. timber harvest, the projected timber harvest trends of the U.S. South generally reflect the relative magnitudes of projected increases in regional fuel feedstock production, and the South is projected to be the largest regional producer of wood fuel feedstock in the future, as well as largest regional producer of timber in general.

Figure 33 shows historical annual U.S. softwood timber harvest volumes along with corresponding USFPM/GFPM projections, whereas Figure 34 shows historical data and projections for U.S. hardwood timber harvest. Hardwood has some advantages as a wood fuel feedstock because of higher density and thus higher energy content per unit volume,

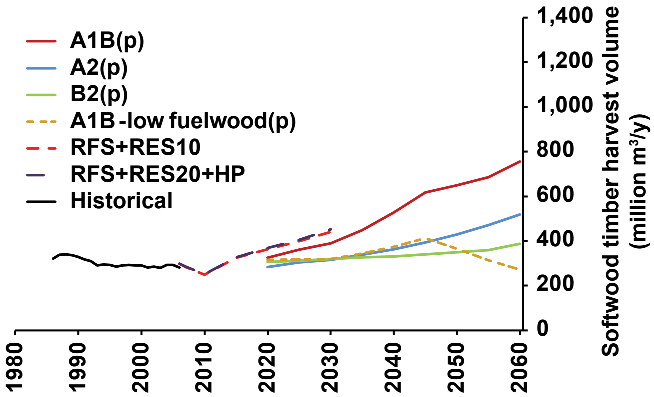

Figure 33—Annual U.S. softwood timber harvest volumes, 1986 to 2006, with RFS+RES projections and preliminary (p) RPA projections (million m³/y).

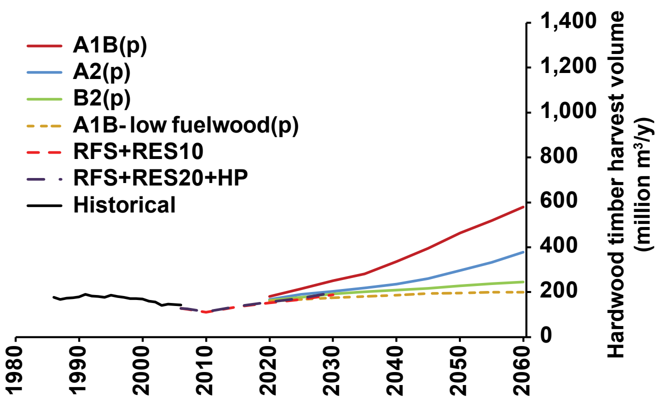

Figure 34—Annual U.S. hardwood timber harvest volumes, 1986 to 2006, with RFS+RES projections and preliminary (p) RPA projections (million m³/y).

although in the United States softwoods have been more commonly grown in industrial timber plantations. Both hardwood and softwood timber harvest are projected to increase with expansion of U.S. wood energy consumption. In the B2 scenario, with the smallest projected expansion in U.S. fuel feedstock consumption, the projected softwood timber harvest is relatively flat, while hardwood timber harvest volume nearly doubles over the projection period. With larger increases in wood energy consumption in the A1B scenario, softwood timber harvest more than doubles and hardwood timber harvest roughly triples. In the A1B scenario, a large share of the projected increase in hardwood and softwood timber harvest is attributable to expanded use of hardwood and softwood pulpwood as fuel feedstock (Fig. 17). The higher softwood timber harvest of the RFS+RES scenarios (Fig. 33) is attributable to higher projected net exports and production of conventional forest products such as lumber and structural wood panel products (Figs. 22 and 25).

High levels of expansion in U.S. timber demand and timber harvest that are associated with high levels of wood energy demand generally result in projected increases in timber stumpage prices, for both sawtimber and non-sawtimber stumpage, but particularly so for non-sawtimber stumpage prices that have been historically much lower than sawtimber stumpage prices. Non-sawtimber consists primarily of pulpwood and fuelwood that traditionally have had lower prices than sawlogs and veneer logs, which make up a larger share of sawtimber volume (Table 5). However, as wood fuel feedstock demand increases, there are greater demands and higher prices for fuelwood and pulpwood (for energy), and thus higher prices for non-sawtimber stumpage. Eventually the higher prices and timber substitution possibilities impinge also upon sawtimber prices, but the proportional increases in sawtimber prices are generally less than the increases for non-sawtimber prices.

A set of charts in Figure 35 shows the USFPM/GFPM projections of real sawtimber and non-sawtimber stumpage prices for hardwoods and softwoods in the U.S. North, whereas similar charts show projected timber stumpage prices for the U.S. South in Figure 36, and for the U.S. West in Figure 37. Again, all price projections are in 2006 real prices (the model generally ignores inflation). By far the largest projected 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 non-sawtimber prices are projected to increase prodigiously in the A1B scenario, and the price of non-sawtimber climbs higher than the price of sawtimber in the A1B scenario by around 2040 and beyond. This is because of larger fuelwood and harvest residue components and higher bark content of non-sawtimber, which eventually afford a higher market value (per cubic meter of wood) for non-sawtimber in a scenario with very high wood energy demands.

On the other hand, the projected sawtimber price trends are relatively flat in the A2, B2, and A1B-Low Fuelwood scenarios, and in those scenarios non-sawtimber prices are projected to increase much more modestly 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 (Fig. 31). Note also that the timber price trend projections of the RFS+RES scenarios (not shown in the figures) were also generally flat to declining (similar to the B2 projections).

Thus, the prodigious projected timber price increases of the A1B scenario must be viewed as counter-balanced by fairly flat to declining price trends of the B2, A1B-Low Fuelwood, and RFS+RES scenarios. In all scenarios, the overall U.S. consumption of industrial roundwood for forest products is projected to gradually decline (coincidentally more or less in line with the historical U.S. timber harvest trends). Thus an important observation here is that U.S. timber demands and timber prices are not projected to increase without

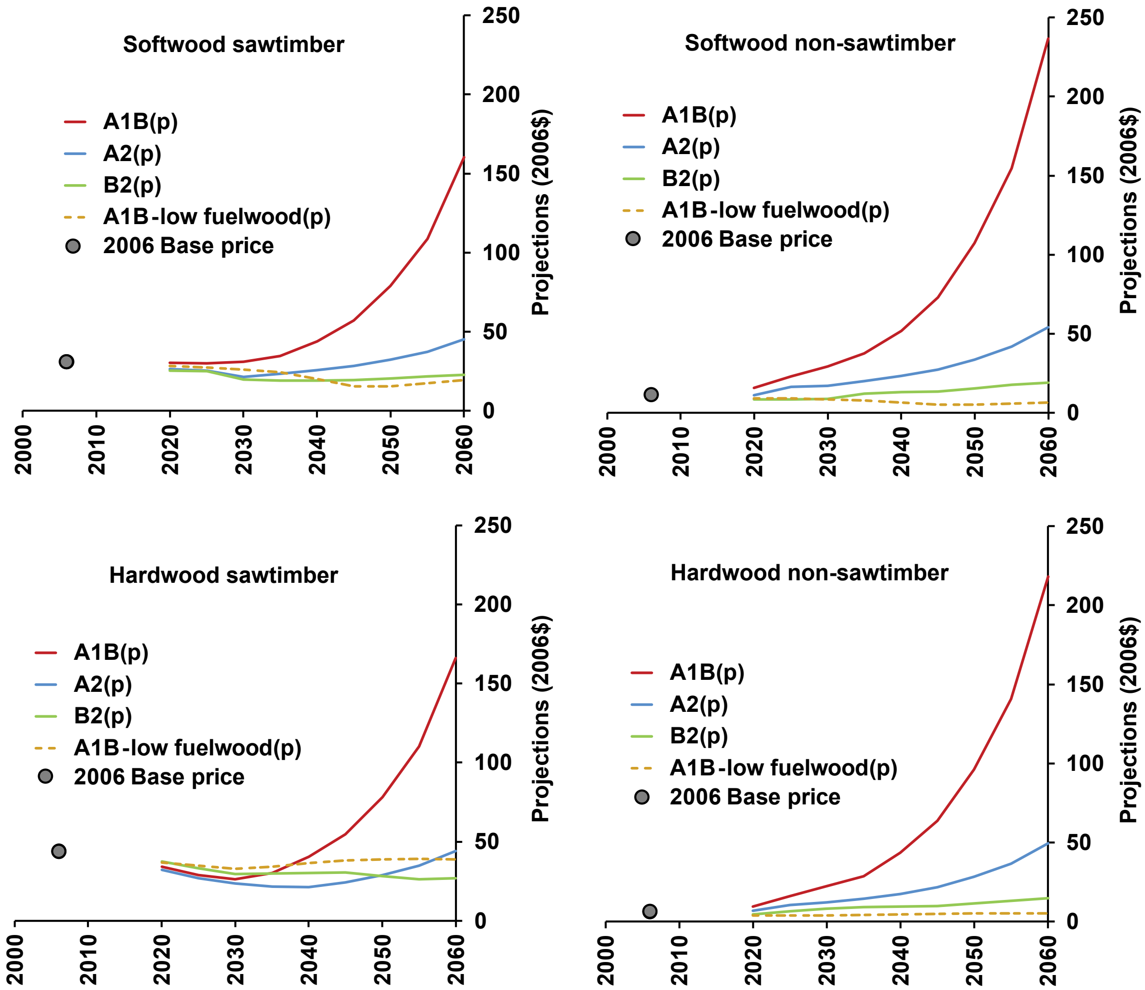

Figure 35— USFPM/GFPM projections of real sawtimber and non-sawtimber stumpage prices for hardwoods and softwoods in the U.S. North (2006 $/m³).

substantial increases in wood energy consumption (e.g., at least equal to or greater than the assumed increases of the B2 scenario). In essence, barring significant and unforeseen structural changes in U.S. forest product demands, substantial increases in real U.S. timber prices are not expected to occur without substantial increases in wood energy demand.

The projected increases in timber stumpage prices in the A1B scenario result also in a projected structural change in U.S. wood supply, specifically expansion in supply of agricultural SRWC as higher prices for wood biomass make agricultural SRWC more economically feasible in the latter decades (beyond 2040) when timber prices rise substantially above historical levels. Figure 38 shows projected U.S. roundwood supply by source for the A1B scenario including agricultural SRWC (but excluding bark and wood residue volumes), while Figure 39 shows projected roundwood supply for the B2 scenario. With much lower projected timber prices, the B2 scenario does not result in any agricultural SRWC supply. However, as noted previously, we applied fixed estimates of SRWC yields and also upper limits on agricultural land available for SRWC (Table 11), and those limits constrain SRWC supply in the A1B scenario. If we were to assume more significant gains in productivity for SRWC or more land available for SRWC, it would tend to increase the future role of agricultural SRWC, especially in the A1B scenario.

Summary and Conclusions

USFPM/GFPM is now operational, providing a tool for detailed analysis of regional U.S. timber markets in the context of global forest product trade and global scenarios for economic development and biomass energy. We tested and calibrated the model to obtain accurate base-period solutions, and we produced preliminary projections for RPA scenarios and other near-term wood energy scenarios (Ince and others 2011). We believe the model behaves appropriately, providing rational behavioral responses to market stimuli and reasonable projections of forest product and timber market trends in relation to wide-ranging assumptions about future U.S. and global economic growth and future wood

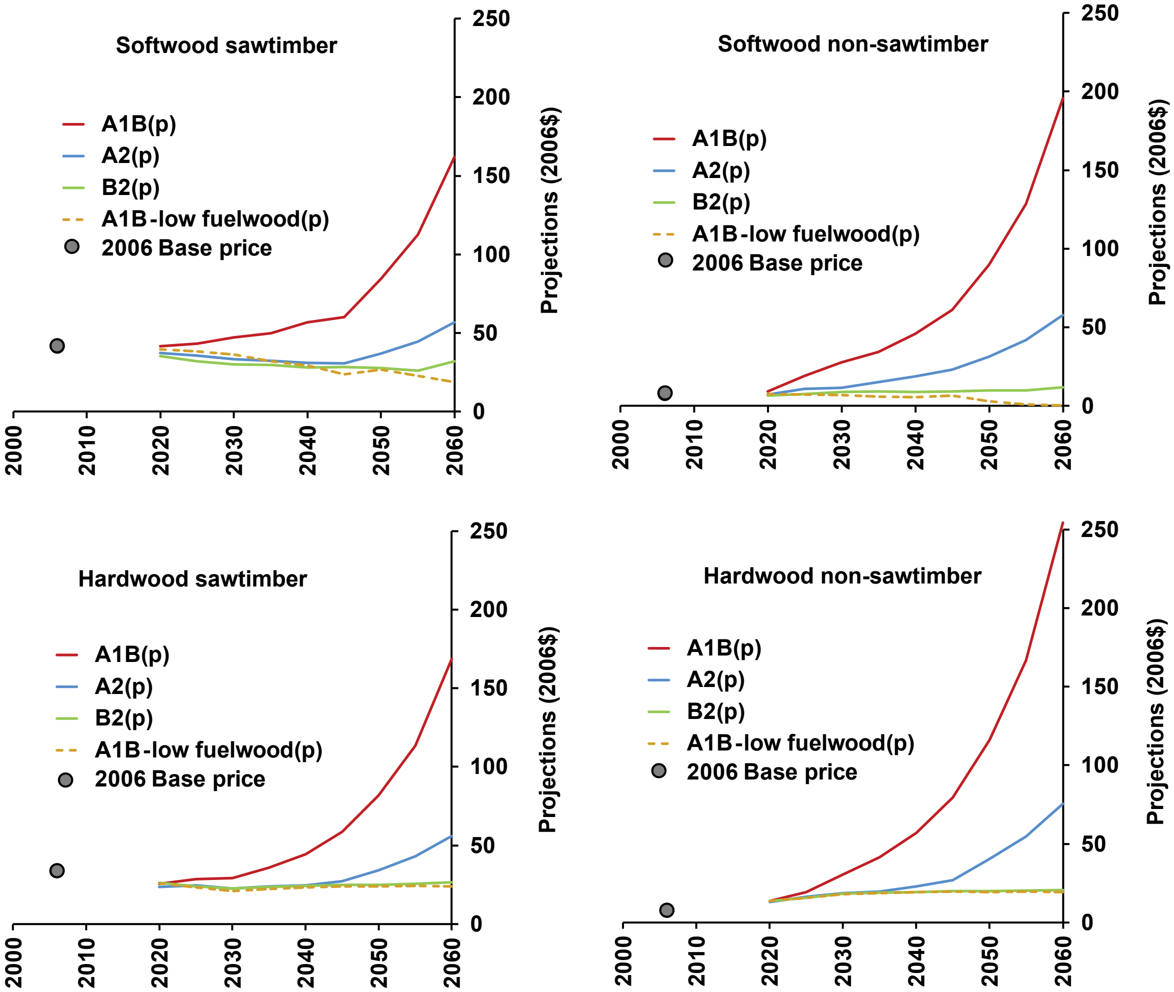

Figure 36— USFPM/GFPM projections of real sawtimber and non-sawtimber stumpage prices for hardwoods and softwoods in the U.S. South (2006 $/m³).

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 RPA scenarios are in line with historical expansion in global energy output and shifting energy resources (Fig. 13). We also showed results for a scenario with much lower projected trends in global fuelwood consumption (A1B-Low Fuelwood scenario).

A key general finding is that projected future trends in U.S. consumption, production, and net trade in forest products and projected timber market trends are heavily influenced by assumptions about future expansion in U.S. and global wood energy demands. The projected effects on forest product markets of expansion in U.S. and global wood energy consumption are to dampen growth in forest product consumption (because of price impacts on demands) but also to provide greater comparative advantages and enhanced net exports for U.S. producers of forest products in scenarios that feature larger increases in foreign roundwood prices because of increased global fuelwood demand. Thus, the advantages of being able to analyse the U.S. forest sector within the global context of the GFPM may be regarded as an advancement of RPA modeling capabilities, with the importance of the global analysis borne out in the results regarding the impact of expansion in global fuelwood demand on U.S. forest sector comparative advantage.

Projected trends in U.S. real timber stumpage prices are generally flat to declining in the B2 scenario (with low but still significant 4-fold projected expansion in U.S. wood energy consumption), but timber stumpage prices follow steeply upward trends in the A1B scenario (with highest projected expansion in U.S. wood energy consumption). On the other hand, in the A1B-Low Fuelwood scenario, with identical economic growth but with global fuelwood demands constrained to historical trends, the timber stumpage price projections are much lower than the A1B (and even lower than the B2 scenario for softwood stumpage prices).

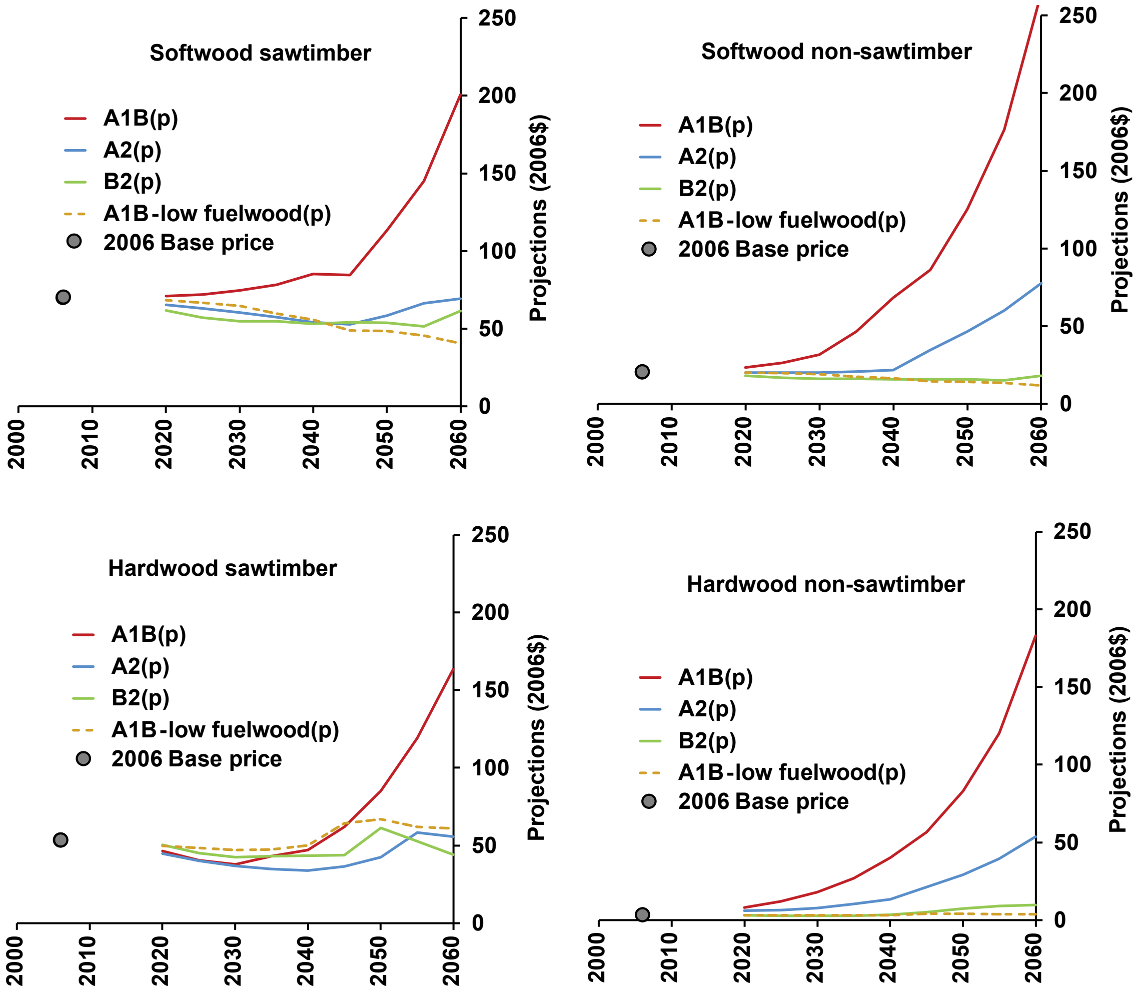

Figure 37— USFPM/GFPM projections of real sawtimber and non-sawtimber stumpage prices for hardwoods and softwoods in the U.S. West (2006 $/m³).

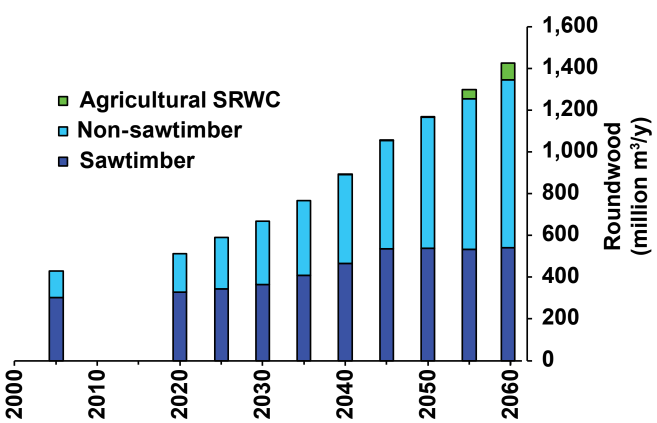

Figure 38— USFPM/GFPM preliminary (p) A1B scenario projections of U.S. roundwood supply by source, excluding bark and harvest residue (million m³/y). SWRC is short-rotation woody crops.

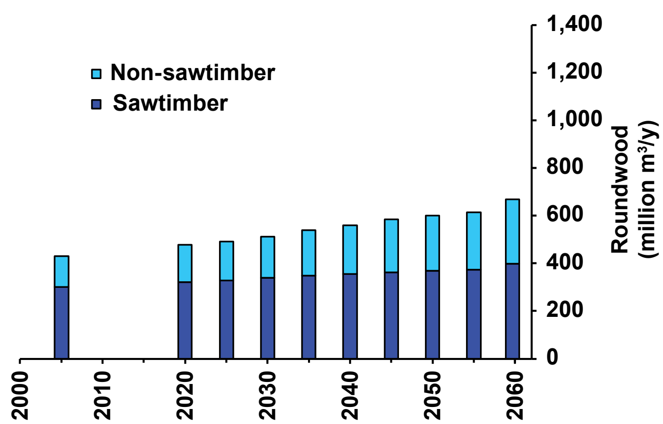

Figure 39— USFPM/GFPM preliminary (p) B2 scenario projections of U.S. roundwood supply by source, excluding bark and harvest residue (million m³/y).

Again, all price projections are in 2006 real prices (ignoring inflation). In the A1B scenario, real sawtimber stumpage prices reach levels that are far higher than the historical range of U.S. sawtimber prices in modern times by around 2040, indicating that wood energy demands of the A1B scenario could lead to unprecedented timber market conditions or otherwise imponderable outcomes during the projection period. Long-run responses to such high timber prices (as in the A1B scenario) would logically include increased investment in timber planting and silviculture to increase timber output capacity, but economic sustainability of such high timber prices is also questionable if the primary future use of wood is energy.

Commercial production of biofuels or energy from wood is currently prohibitive at such high timber prices (e.g., as projected in A1B scenario). Technology capable of profitably transforming such high-priced timber or biomass into commercially viable forms of energy has yet to be demonstrated. Instead, biomass energy technology today relies on relatively low cost feedstock. The affordability of wood for energy at such prices depends on fairly uncertain future outcomes, such as the future efficiencies of biomass energy technologies, future prices for energy in general, and the effectiveness of future mandates or incentives for development of biomass energy. 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 (as in the A1B scenario), or more modest increases in wood energy demand and little change in real timber prices (as in the A2, B2, or A1B-Low Fuelwood scenarios).

Acknowledgments

The authors gratefully acknowledge the collaboration of colleagues who supported and contributed to development of the U.S. Forest Products Module (USFPM) and related applications. We gratefully acknowledge funding from the RPA Assessment (Forest Service Washington Office). We also gratefully acknowledge the contributions of Dr. Linda Langner of the Forest Service Washington Office staff in selecting and developing the 2010 RPA scenarios from the Special Report on Emissions Scenarios of the Intergovernmental Panel on Climate Change. In addition, we gratefully acknowledge the contributions of Professor Joseph Buongiorno and his former graduate Ph.D. students at University of Wisconsin-Madison (UW) who developed the Global Forest Products Model (GFPM), and who assisted us at various stages with understanding how to operate the model, including Dr. Ron Raunikar, Dr. James Turner, and Dr. Shushuai Zhu. Our UW colleagues also wrote the text in Appendix A that describes the mathematical structure of the GFPM. We also acknowledge that recent development of the GFPM at UW for the 2010 RPA was supported and coordinated by Dr. Jeffrey Prestemon of the USDA Forest Service, Southern Research Station. We also acknowledge James L. Howard of the FPL for his contributions of forest product data and assistance in assembling historical data series, and Dr. Prakash Nepal who helped estimate demand equations. Furthermore, we gratefully acknowledge funding we received from the Forest Service Research Executive Team to develop additional analysis of alternative wood energy scenarios (RFS+RES scenarios), and collaboration in development of those scenarios with Al Sample of the Pinchot Institute for Conservation. We also gratefully acknowledge the contributions of UW students who worked with us at the FPL, including Dan Toth, who assisted Henry Spelter in developing projections of U.S. housing needs for various scenarios based on U.S. population projections, and also Do-il Yoo, who helped develop the RFS+RES scenarios. Finally, we acknowledge continued support for our work provided by the FPL from our Director, Christopher Risbrudt (ret.), our Assistant Director, Michael Ritter, and FPL research support staff.

References

Adams, D.M.; Haynes, R.W., eds. 2007. Resource and market projections for forest policy development. In: Twenty-five years of experience with the U.S. RPA timber assessment. New York: Springer Press. 589 p. Series: Managing forest ecosystems, Vol. 14.

AF&PA. 2009. Statistical summary, paper, paperboard, pulp (and earlier editions). Washington, DC: American Forest & Paper Association. 42 p.

AF&PA. 2007. Annual statistical summary recovered paper utilization. 21st ed. Washington, DC: American Forest & Paper Association. 92 p.

Alig, R.J.; Plantinga, A.; Haim, D.; Todd, M. 2010. Area changes in U.S. forests and other major land uses, 1982–2002, with projections to 2062. Gen. Tech. Rep. PNW–GTR–815. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 98 p.

APA–The Engineered Wood Association. 2007. Regional production and market outlook, 2007–2012. APA Economics Report E73. Tacoma, WA: APA–The Engineered Wood Association. 64 p.

Buongiorno, J.; Zhu, S. 2011. Using the global forest products model (GFPM version 2010). Staff Pap. Series No. 69. Madison, WI: University of Wisconsin, Department of Forest and Wildlife Ecology. 35 p. http://fwe.wisc.edu/facstaff/Buongiorno/book/GFPM.htm. (Accessed 7 February 2011).

Buongiorno, J.; Zhu, S.; Zhang, D.; Turner, J.; Tomberlin, D. 2003. The global forest products model. Maryland Heights, MO: Academic Press (Elsevier). 301 p.

Cochran, M. 2007. Bulletin of hardwood market statistics: 2006. Res. Note NRS–8. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 22 p.

Conner, R.C.; Johnson, T.G. 2011. Estimates of biomass in logging residue and standing residual inventory following tree-harvest activity on timberland acres in the southern region. Res. Bull. SRS–169. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 25 p.

Daniels, J.M. 2008. United States trade in wood products, 1978–2005. Gen. Tech. Rep. PNW–GTR–738. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 124 p.

DOE. 2010a. Annual energy outlook 2010. Rep. No. DOE/EIA–0383(2010). Washington, DC: U.S. Department of Energy.

DOE. 2010b. Renewable fuels module. Rep. No. DOE/EIA–0554(2010). Washington, DC: U.S. Department of Energy. 170 p.

DOE. 2007. Energy and economic impacts of implementing both a 25-percent renewable portfolio standard and a 25-percent renewable fuel standard by 2025. Rep. No. SR/OIAF/2007–05. Washington, DC: U.S. Department of Energy. 70 p.

Faaij, A. 2007. Potential contribution of bioenergy to the world's future energy demand. IEA Bioenergy EXCO: 2007:02. 12 p. http://www2.bren.ucsb.edu/~writing/IEA.pdf. (Accessed 12 July 2011).

FAO. 2006. Global forest resources assessment 2005. FAO Forestry Pap. 147. Rome: Food and Agriculture Organization of the United Nations. 320 p.

Gurgel, A.; Reilly, J.M.; Paltsev, S. 2007. Potential land implications of a global biofuels industry. [Special Issue: Explorations in biofuels economics, policy, and history]. Journal of Agricultural & Food Industrial Organization. 5(3) (Spec. issue): 33 p.

Hartsough, B.; Spinelli, R.; Pottle, S.; Klepac, J. 2000. Fiber recovery with chain flail delimbing/debarking and chipping of hybrid poplar. Journal of Forest Engineering. 11(2): 59–68.

Hausman, J.A. 1978. Specification tests in econometrics. Econometrica. 46(6): 1251–71.

Haynes, R.W., (tech. coord.). 2003. An analysis of the timber situation in the United States: 1952 to 2060. Gen. Tech. Rep. PNW–GTR–560. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 254 p.

Hoogwijk, M.; Faaij, A.; Eickhout, B.; de Vries, B.; Turkenburg, W. 2005. Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios. Biomass and Bioenergy (Elsevier). 29(2005): 225–257.

Howard, J.L. 2007. U.S. timber production, trade, consumption, and price statistics 1965–2005. FPL–RP–637. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 91 p.

Howard, J.L.; Quevedo, E.; Kramp, A. 2009. Use of indexing to update U.S. annual timber harvest by state. FPL–RP–653. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 33 p.

IEA. 2011. Technology roadmap, biofuels for transport. Paris, France: International Energy Agency Renewable Energy Division. 52 p. www.iea.org.

IMF. 2010. World economic outlook database. Washington, DC: International Monetary Fund. http://www.imf.org/external/ns/cs.aspx?id=28. (Accessed 12 July 2011).

Ince, P.J.; Buongiorno, J. 2007. Globalization and world trade. In: Adams, D.M.; Haynes, R.W., eds. Resource and market projections for forest policy development: twenty-five years of experience with the U.S. RPA timber assessment. Dordrecht, The Netherlands: Springer. 589 p. Series: Managing forest ecosystems, Vol. 14: Chapter 13: 419–447.

Ince, P.J.; Kramp, A.D.; Skog, K.E.; Yoo, D.; Sample, V.A. 2011. Modeling future U.S. forest sector market and trade impacts of expansion in wood energy consumption. Journal of Forest Economics (Elsevier). 17(2011): 142–156.

Ince, P.; Schuler, A.; Spelter, H.; Luppold, W. 2007. Globalization and structural change in the U.S. forest sector: an evolving context for sustainable forest management. Gen. Tech. Rep. FPL–GTR–170. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 62 p.

Keegan, C.E., III; Niccolucci, M.J.; Fiedler, C.E.; Jones, J.G.; Regel, R.W. 2002. Harvest cost collection approaches and associated equations for restoration treatments on national forests. Forest Products Journal. 52(7/8): 96–99.

Luppold, W.G.; Bumgardner, M.S. 2007. Examination of lumber price trends for major hardwood species. Wood and Fiber Science. 39(3): 404–413.

Nakicenovic, N.; Swart, R., eds. 2000. Special report on emissions scenarios. Prepared for Intergovernmental Panel on Climate Change (IPCC). United Kingdom: Cambridge University Press. 570 p. http://www.ipcc.ch/ipccreports/sres/emission/index.htm. (Accessed 12 July 2011).

Openshaw, K. 2010. Can biomass power development? IIED Gatekeeper Series Rep. 144. London: International Institute for Environment and Development (IIED). 17 p.

Perlack, R.D.; Wright, L.L.; Turhollow, A.F.; Graham, R.L. [and others]. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. ORNL/TM-2005/66. Washington, DC: U.S. Department of Energy and U.S. Department of Agriculture, Forest Service. 7 p.

Poylakov, M.; Wear, D.N.; Huggett, R. 2010. Harvest choice and timber supply models for forest forecasting. Forest Science. 56(4): 344–355.

Prentiss & Carlisle. 2006. Timber Mart North price report. Wisconsin and Michigan ed. Vol. 12, No. 1–2. Bangor, ME: Prentiss & Carlisle.

Raunikar, R.; Buongiorno, J.; Turner, J.A.; Zhu, S. 2010. Global outlook for wood and forests with the bioenergy demand implied by scenarios of the Intergovernmental Panel on Climate Change. Forest Policy and Economics. 12(2010): 48–56.

RISI. 2007. International woodfiber report. San Francisco, CA: Resource Information Systems, Inc. Vol. 13(No. 04). (April, 2007). 6 p.

RISI. 2006. Log Lines, a log price reporting service. Mount Vernon, WA: Resource Information Systems, Inc. http://www.risiinfo.com/risi-store/do/product/detail/log-lines.html. (Accessed 12 July 2011).

Smith, W.B., tech. coord.; Miles, P.D., data coord.; Perry, C.H., map coord.; Pugh, S.A., data CD coord. 2009. Forest resources of the United States, 2007. Gen. Tech. Rep. WO–78. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 336 p.

Smith, W.B.; Miles, P.D.; Vissage, J.S.; Pugh, S.A. 2004. Forest resources of the United States, 2002. Gen. Tech. Rep. NC–241. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 137 p.

Soirinsuo, J. 2009. The long-term consumption of magazine paper in the United States. Why is consumption declining and how should it be projected? Cologne, Germany: Lambert Academic Publishing. 91 p.

Song, N.; Chang, S.J.; Aguilar, F.X. 2011. U.S. softwood lumber demand and supply estimation using cointegration in dynamic equations. Journal of Forest Economics. 17(2011): 19–33.

Spelter, H.N.; Toth, D. 2009. North America's wood pellet sector. Res. Pap. FPL–RP–656. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 21 p.

Timber Mart-South. 2006. Timber Mart-South market news quarterly. Vol. 31. Athens, GA: Timber Mart-South, Inc.

Turner, J.A.; Buongiorno, J.; Zhu, S. 2006. An economic model of international wood supply, forest stock and forest area change. Scandinavian Journal of Forest Research. 2006(21): 73–86.

USDA Forest Service. In preparation. Future scenarios: A technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. RMRS-GTR-XXX. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. XX p.

USDA Forest Service. 2010. Timber product output (TPO) reports. http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int1.php. (Accessed 12 July 2011) Washington, D.C.: USDA Forest Service.

Wear, David N. 2011. Forecasts of county-level land uses under three future scenarios: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. SRS-141. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 41 p.

Wear, David N.; Huggett, Robert; Li, Ruhong; Perryman, Benjamin; and Liu, Shan. In preparation. Regional forecasts of forest conditions under future scenarios : a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. SRS-xxx. Asheville, NC: Department of Agriculture Forest Service, Southern Research Station. xxx p. [Not cited in text]

Wear, David N.; Huggett, Robert; Li, Ruhong; Perryman, Benjamin; and Liu, Shan. In preparation. Forecasts of forest conditions under future scenarios : a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. SRS-xxx. Asheville, NC: Department of Agriculture Forest Service, Southern Research Station. xxx p. [Not cited in text]

Wongcharupan, M.; Ince, P.J. 2004. Analysis of U.S. printing and writing paper demand. Unpublished manuscript. On file with: P. Ince, Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726. 26 p.

Wongcharupan, M.; Ince, P.J. 2003. Error correction models and directed graphs of U.S. newsprint demand. In: Moffat, S.O., ed. Proceedings of the 2003 southern forest economics workers annual meeting; March 17–18, 2003; New Orleans, LA. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 47–55. 416 p. (Published on CD).

WWPA. 2006. Statistical yearbook of the western lumber industry. Portland, OR: Western Wood Products Association. 12 p.

Zhang, D.; Buongiorno, J.; Ince, P.J. 1993. PELPS III: a microcomputer price endogenous linear programming system for economic modeling, v. 1.0. Res. Pap. FPL–RP–526. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 43 p.

Zhu, S.; Buongiorno, J.; Turner, J.; Li, R. 2006. Calibrating and updating the Global Forest Products Model (GFPM version 2006). Staff Pap. Series No. 59. Madison, WI:

University of Wisconsin, Department of Forest Ecology and Management. 62 p.

Additional Data References

AF&PA. 2006–2007. Paper, paperboard, and wood pulp statistics. (Various eds.). Washington, DC: American Forest & Paper Association. 12 p. (monthly)

CPA. 2005. North American capacity report. Particleboard MDF hardboard. Leesburg, VA: Composite Panel Association.

DOC. New privately owned housing units started. Washington, DC: U.S. Department of Commerce, Bureau of the Census. http://www.census.gov/const/www/newresconstindex_excel.html. (Accessed 12 July 2011).

DOC. Real gross domestic product. Chained dollars. Table 1.1.6. Washington, DC: U.S. Department of Commerce, Bureau of Economic Analysis. http://www.bea.gov/national/nipaweb/SelectTable.asp?Selected=N. (Accessed 12 July 2011).

DOL. Producer price index database. Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics. http://www.bls.gov/ppi. (Accessed 12 July 2011).

FRA. 2005. Annual pulpwood statistics summary. Rep. 06-A-7. Rockville, MD: Forest Resources Association, Inc. 37 p.

Illinois Agricultural Statistics Service. Illinois timber prices. (Various issues). Urbana, IL: University of Illinois Extension. http://web.extension.uiuc.edu/forestry/il_timber_prices. (Accessed 12 July 2011).

MillsOnline. The center for paper business and industry studies. http://www.cpbis.gatech.edu/data/mills-online. (Accessed 12 July 2011).

Ohio State University. Ohio timber price report. Columbus, OH: Ohio State University. http://www.oardc.ohio-state.edu/ohiowood/timberarchive.htm. (Accessed 12 July 2011).

Pennsylvania State College. Published stumpage and mill price report data. Timber market report, Pennsylvania woodlands. University Park, PA: Pennsylvania State College of Agricultural Sciences, Cooperative Extension. http://www.sfr.psu.edu/TMR/TMR.htm. (Accessed 12 July 2011).

Random Lengths. 2007. Forest product market prices and statistics yearbook 2006. Vol. XLII. Eugene, OR: Random Lengths Publications, Inc.

RISI. 2003. North American lumber forecast. Boston, MA: Resource Information Systems, Inc. (Paperloop.com). (July 2003).

USITC. Interactive tariff and trade data web. Washington, DC: U.S. International Trade Commission. http://dataweb.usitc.gov/scripts/user_set.asp. (Accessed 12 July 2011).

WWPA. 2006. Statistical yearbook of the western lumber industry. Portland, OR: Western Wood Products Association.

Appendix A—Global Forest Products Model (GFPM) Formulation and Structure

This appendix contains an overview of the mathematical structure and formulation of the GFPM, adapted from a recent overview written by Zhu and others (2010). This overview describes formulas that are used in solving the global spatial market equilibrium problem each period (objective function, constraints, and manufacturing activities), formulas that control market dynamics or exogenous shifts from period to period (demand shifts, supply shifts, changes in forest area and forest stock, changes in manufacturing costs and inputs, and other exogenous changes), and methods for linear approximation and implementation of trade inertia constrains. Also included in this appendix are lists of commodities and countries represented in the GFPM structure.

Global Spatial Market Equilibrium

Objective Function

$$\max Z = \sum_i \sum_k \int_0^{D_{ik}} P_{ik}(D_{ik})dD_{ik} - \sum_i \sum_k \int_0^{S_{ik}} P_{ik}(S_{ik})dS_{ik} - \sum_i \sum_k \int_0^{Y_{ik}} m_{ik}(Y_{ik})dY_{ik} - \sum_i \sum_j \sum_k c_{ijk}T_{ijk} \quad \text{(A1)}$$

where

i,j	is	country,
k		product,
P		price in U.S. dollars of constant value,
D		final product demand,
S		raw material supply,
Y		quantity manufactured,
m		manufacturing cost,
T		quantity transported, and
c		cost of transportation, including tariff.

All variables refer to a specific year. In making predictions, the period between successive equilibria may be multiple years.

End Product Demand

$$D_{ik} = D^*_{ik}\left(\frac{P_{ik}}{P_{ik,-1}}\right)^{\delta_{ik}} \quad \text{(A2)}$$

where

D^*	is	current demand at last period's price,
P_{-1}		last period's price, and
δ		price elasticity of demand.

As shown in the section on market dynamics, below, D^* depends on last period's demand, and the growth of GDP in the country. In the base year, D^* is equal to the observed base-year consumption, and P_{-1} is equal to the observed base-year price.

Primary Product Supply

$$S_{ik} = S^*_{ik}\left(\frac{P_{ik}}{P_{ik,-1}}\right)^{\lambda_{ik}} \quad \text{(A3)}$$

where

S^* is current supply at last period's price and λ is price elasticity of supply.

As shown in the section on market dynamics, below, S^* depend on last period's supply, and on exogenous or endogenous supply shifters. In the base year, S^* is equal to the base-year supply, and P_{-1} is equal to the observed base-year price.

Total Wood Supply

$$S_i = S_{ir} + S_{in} + \theta_i S_{if} \quad \text{(A4)}$$

where

r	is	industrial roundwood,
n		other industrial roundwood,
f		fuelwood,
θ		fraction of fuelwood that comes from the forest.

Also, $S_i \le I_i$ where I_i is forest stock.

Material Balance Constraint

A material balance constraint is imposed to ensure that regional shipments and consumption of each commodity are in balance with supply and production:

$$\sum_j T_{jik} + S_{ik} + Y_{ik} - D_{ik} - \sum_n a_{ikn}Y_{in} - \sum_j T_{ijk} = 0 \qquad \forall i,k \quad \text{(A5)}$$

where a_{ikn} is input of product *k* per unit of product *n*.

In addition, byproducts that result from the production of a manufactured commodity satisfy the constraint

$$Y_{il} - b_{ikl}Y_{ik} = 0 \qquad \forall i,k,l$$

where b_{ikl} is the amount of byproduct *l* that can be recovered per unit of production of manufactured commodity *k*.

Trade Inertia Constraint

Trade inertia constraints limit the range of variability in trade flows from one period to the next, and for each commodity they are defined in terms of upper and lower bounds on transportation quantities

$$T^L_{ijk} \le T_{ijk} \le T^U_{ijk} \quad \text{(A6)}$$

where the superscripts *L* and *U* refer to a lower bound and upper bound, respectively. The upper and lower bounds on trade flows for each period are actually computed from a user-specified constraint on the periodic change in the trade flow quantity, specified as a decimal fraction (such as for example 0.05, which would set upper and lower bounds on the trade flow at 5% above and 5% below the trade flow in the previous period).

Prices

The shadow prices of the material balance constraints (Eq. (A5)) give the market-clearing prices for each commodity and country.

Manufacturing Cost

Manufacturing is represented by activity analysis, with input-output coefficients and a manufacturing cost. The manufacturing cost is the marginal cost of the inputs not recognized explicitly by the model (labor, energy, capital, etc.):

$$m = m^*_{ik}\left(\frac{Y_{ik}}{Y_{ik,-1}}\right)^{s_{ik}} \qquad \text{(A7)}$$

where

m^* is current manufacturing cost, at last period's output, and

s elasticity of manufacturing cost with respect to out put.

As shown in the next section, m^* depend on last period's quantity manufactured, and on the exogenous rate of change of manufacturing cost. In the base year, m^* is equal to the observed base-year manufacturing cost and $Y_{ik,-1}$ is equal to the observed base-year quantity manufactured.

Transport Cost

The transport cost for commodity *k* from country *i* to country *j* in any given year is

$$c_{ijk} = f_{ijk} + t^I_{jk}\left(f_{ijk} + P_{ik,-1}\right) \qquad \text{(A8)}$$

where

c is transport cost, per unit of volume,
f freight cost, per unit of volume,
t^I import ad-valorem tariff, and
P_{-1} last period's equilibrium export price predicted endogenously by the model. In the base year, P_{-1} is equal to the observed base-year price.

Market Dynamics

Unless otherwise indicated, variables refer to one country, one commodity, and one year. Rates of change refer to a multi-year period. All periodic exponential rates of change, r_p, are defined by the annual exponential rate of change, r_a, as

$$r_p = (1 + r_a)^p - 1 \text{ where } p \text{ is the length of a period, in years.} \qquad \text{(A9)}$$

All periodic linear changes, Δv_p are defined by the corresponding annual linear change, Δv_a, as:

$$\Delta v_p = p\Delta v_a \qquad \text{(A10)}$$

Shifts of Demand

$$D^* = D_{-1}(1 + \alpha_y g_y) \qquad \text{(A11)}$$

where

g_y is GDP periodic growth rate, and
α elasticity.

In the GFPM, the assumed growth rate for real GDP in each country is the only shifter of forest product demands, but in the USFPM we also added some other shifters of demands in the United States, such as projected housing starts as an additional shifter of softwood lumber and structural panel demands.

Shifts of Supply

Industrial roundwood and fuelwood:

$$S^* = S_{-1}(1 + \beta_I g_I + \beta_{y'} g_{y'}) \text{ for } k = r, n, f \qquad \text{(A12)}$$

Where

g_I is periodic rate of change of forest stock (endogenous, see below),
$g_{y'}$ periodic rate of change of GDP per capita, and
β elasticity.

Waste paper and other fiber pulp:

$$S^* = S_{-1}(1 + \beta_y g_y) \qquad \text{(A13)}$$

Changes in Forest Area and Forest Stock

$$A = (1 + g_a)A_{-1} \qquad \text{(A14)}$$

where

A is forest area, and
g_a periodic rate of forest area change based on the period length, p, Equation (A9) and the annual rate of forest area change, g_{aa}, defined by

$$g_{aa} = \alpha_0 + \alpha_1 y' + \alpha_2 y'^2 \text{ for } y' \le y'^*, \text{ else } g_{aa} = 0 \qquad \text{(A15)}$$

where, for each country, α_0 is calibrated so that in the base year the observed g_{aa} is equal to the g_{aa} predicted by Equation (A15) given the income per capita y'.

y' is income per capita, predicted from

$$y' = (1 + g_{y'})y'_{-1} \qquad \text{(A16)}$$

y'^* is defined by $g_{aa} = \alpha_0 + \alpha_1 y'^* + \alpha_2 y'^{*2} = 0$

$$\text{and } y'^* > -\alpha_1/2\alpha_2 \qquad \text{(A17)}$$

Forest stock evolves over time according to a growth-drain equation:

$$I = I_{-1} + G_{-1} - pS_{-1} \qquad \text{(A18)}$$

where

$G = (g_a + g_u + g_u^*)I$ is the periodic change of forest stock without harvest,

g_u periodic rate of forest growth on a given area, without harvest, and

g_u* adjustment of periodic rate of forest growth on a given area, without harvest.

The last is exogenous, for example to represent the effect of invasive species, or of climate change.

The periodic rate of forest growth, g_u, is based on the annual rate of forest growth, g_{ua}, defined by

$$g_{ua} = \gamma_0 (\frac{I}{A})^{\sigma} \tag{A19}$$

where σ is negative, so that g_{ua} decreases with stock per unit area. For each country, γ_0 is calibrated so that in the base year the observed g_{ua} is equal to the g_{ua} predicted by Equation (A19) given the stock per unit area, I/A.

The periodic rate of change of forest stock net of harvest, used in Equation (A12) is then

$$g_I = \frac{I - I_{-1}}{I_{-1}} \tag{A20}$$

Changes in Manufacturing Coefficients and Costs

The input-output coefficients a (in equation [A5]), may be changed exogenously over time, for example to reflect increasing use of recycled paper in paper manufacturing:

$$a = a_{-1} + \Delta a \tag{A21}$$

where Δa is an exogenously specified periodic change in the input-output coefficient.

Likewise, the manufacturing cost for any manufacturing activity (m in Equation (A7) may be adjusted exogenously over time:

$$m^* = m_{-1}(1 + g_m) \tag{A22}$$

where g_m is an exogenously specified periodic rate of change in manufacturing cost.

The current versions of the GFPM and USFPM incorporate adjustments in the material input coefficients (in Equation (A21) for forest product manufacturing processes. The adjustments are designed to gradually shift the wood and wood fiber input requirements toward the more technologically efficient levels, with target levels determined by those of the most efficient countries at present. In other words the model assumes that efficient technology will be adopted globally over the 50-year projection period such that eventually the production efficiencies in all countries will match the current efficiencies of the most efficient countries.

Changes in Freight Cost and Tariff

The freight cost and the import tariffs in Equation (A8) may be changed exogenously over time:

$$f = f_{-1} + \Delta f, \; t = t_{-1} + \Delta t \tag{A23}$$

where Δf and Δt are periodic changes in freight cost and tariff, respectively. This optional feature of the model was not actually applied in the current scenarios developed with the GFPM and USFPM (i.e., import tariffs and changes in freight costs were not applied in USFPM/GFPM) but this is a feature that could be activated in future applications of the model.

Changes in Trade Inertia Bounds

$$\begin{aligned} T^L &= T_{-1}(1-\varepsilon)^p \\ T^U &= T_{-1}(1+\varepsilon)^p \end{aligned} \tag{A24}$$

ε is absolute value of maximum annual relative change in trade flow (exogenous). This feature is applied in USFPM to "loosen" the trade inertia constraints in the projection period. As with the GFPM, the USFPM trade flows are highly constrained in the base period by very tight inertia constraints (e.g., not allowing more than 1% variation in trade flow quantities relative to the actual base-year trade flows), but this constraint is relaxed in the projection period (beyond 2010) by allowing up to 5% variation in trade flow quantities each period.

Linear Approximation of Demand, Supply, Manufacturing Cost

Supply and demand equations and manufacturing cost functions in the GFPM (and USFPM) are actually linear approximations of the equations specified by the elasticities. For example, considering a demand equation such as Equation (A2), and omitting the subscripts for region and product, the inverse demand equation in any given year is

$$P = P_{-1}(\frac{D}{D^*})^{1/\sigma} \tag{A25}$$

The linear approximation is then the following:

$$P = a + bD \text{ with } a = P_{-1} - bD^* \text{ and } b = \frac{P_{-1}}{\sigma D^*}$$

for D*>1, else $b = \frac{P_{-1}}{\sigma}$ (A26)

$b = 0$ if $\sigma = 0$. The same method of approximation is used for the supply equations, and the manufacturing cost equations. Linear approximation of the equations allows for more efficient solution of the mathematical optimization problem.

Implementation of Trade Inertia Bounds

To avoid infeasibilities due to inconsistent bounds, the inertia constraints (Equation (A6)) are implemented as

$$\begin{aligned} T_{ijk} + \Delta T_{ijk}^{L} &\geq T_{ijk}^{L} \\ T_{ijk} - \Delta T_{ijk}^{U} &\leq T_{ijk}^{U} \end{aligned} \qquad \text{(A27)}$$

where ΔT^L, ΔT^U is the amount by which trade falls short of the lower bound, or exceeds the upper bound. These two variables appear in the objective function:

$$\max Z = ... - \sum_{i,j,k} W(\Delta T_{ijk}^{L} + \Delta T_{ijk}^{U})... \qquad \text{(A28)}$$

where W is an arbitrarily large number.

GFPM Commodities and Countries

Table A1 lists the commodities represented in the GFPM (the USFPM has somewhat more detailed commodity structure as described previously), and Table A2 lists the countries that are represented in the GFPM. The reader is referred to GFPM documentation for additional information on the model structure (Buongiorno and others 2003; Zhu and others 2006; Zhu and others 2010).

Table A1—Commodities represented in the GFPM[a]

Code	Commodities	Units
80	Fuelwood and charcoal	$\times 10^3$ m^3
81	Industrial roundwood	$\times 10^3$ m^3
82	Other industrial roundwood	$\times 10^3$ m^3
83	Sawnwood	$\times 10^3$ m^3
84	Veneer and plywood	$\times 10^3$ m^3
85	Particleboard	$\times 10^3$ m^3
86	Fiberboard	$\times 10^3$ m^3
87	Mechanical wood pulp	$\times 10^3$ t
88	Chemical and semi-chemical wood pulp	$\times 10^3$ t
89	Other fiber pulp	$\times 10^3$ t
90	Waste paper	$\times 10^3$ t
91	Newsprint	$\times 10^3$ t
92	Printing and writing paper	$\times 10^3$ t
93	Other paper and paperboard	$\times 10^3$ t

[a]The listed commodities are default commodities in GFPM. It is possible to add or remove commodities (see Zhu and others 2008).

Table A2—Countries represented in GFPM[a]

Code	Country	Code	Country	Code	Country	Code	Country
	Africa		**North and Central America**		**Asia**		**Europe**
A0	Algeria	F0	Bahamas	I5	Afghanistan	N5	Albania
A1	Angola	F1	Barbados	I6	Bahrain	N6	Austria
A2	Benin	F2	Belize	I7	Bangladesh	N7	Belgium
A3	Botswana	F3	Canada	I8	Bhutan	N8	Bosnia and Herzegovina
A4	Burkina Faso	F4	Cayman Islands	I9	Brunei Darussalam	N9	Bulgaria
A5	Burundi	F5	Costa Rica	J0	Cambodia	O0	Croatia
A6	Cameroon	F6	Cuba	J1	China	O1	Czech Republic
A7	Cape Verde	F7	Dominica	J2	Cyprus	O2	Denmark
A8	Central African Republic	F8	Dominican Republic	J3	Hong Kong	O3	Finland
A9	Chad	F9	El Salvador	J4	India	O4	France
B0	Congo, Republic of	G0	Guatemala	J5	Indonesia	O5	Germany
B1	Côte d'Ivoire	G1	Haiti	J6	Iran, Islamic Republic of	O6	Greece
B2	Djibouti	G2	Honduras	J7	Iraq	O7	Hungary
B3	Egypt	G3	Jamaica	J8	Israel	O8	Iceland
B4	Equatorial Guinea	G4	Martinique	J9	Japan	O9	Ireland
B5	Ethiopia	G5	Mexico	K0	Jordan	P0	Italy
B6	Gabon	G6	Netherlands Antilles	K1	Korea, Democratic People's Republic	P1	Macedonia, The Former Yugoslav Republic of
B7	Gambia	G7	Nicaragua	K2	Korea, Republic of	P2	Malta
B8	Ghana	G8	Panama	K3	Kuwait	P3	Netherlands
B9	Guinea	G9	Saint Vincent/Grenadines	K4	Laos	P4	Norway
C0	Guinea-Bissau	H0	Trinidad and Tobago	K5	Lebanon	P5	Poland
C1	Kenya	H1	United States of America	K6	Macau	P6	Portugal
C2	Lesotho		**South America**	K7	Malaysia	P7	Romania
C3	Liberia	H2	Argentina	K8	Mongolia	P8	Slovakia
C4	Libyan Arab Jamahiriya	H3	Bolivia	K9	Myanmar	P9	Slovenia
C5	Madagascar	H4	Brazil	L0	Nepal	Q0	Spain
C6	Malawi	H5	Chile	L1	Oman	Q1	Sweden
C7	Mali	H6	Colombia	L2	Pakistan	Q2	Switzerland
C8	Mauritania	H7	Ecuador	L3	Philippines	Q3	United Kingdom
C9	Mauritius	H8	French Guiana	L4	Qatar	Q4	Serbia and Montenegro
D0	Morocco	H9	Guyana	L5	Saudi Arabia		**Former USSR**
D1	Mozambique	I0	Paraguay	L6	Singapore	Q5	Armenia
D2	Niger	I1	Peru	L7	Sri Lanka	Q6	Azerbaijan, Republic of
D3	Nigeria	I2	Suriname	L8	Syrian Arab Republic	Q7	Belarus
D4	Réunion	I3	Uruguay	L9	Thailand	Q8	Estonia
D5	Rwanda	I4	Venezuela, Republic of Bolivia	M0	Turkey	Q9	Georgia
D6	Sao Tome and Principe			M1	United Arab Emirates	R0	Kazakhstan
D7	Senegal			M2	Viet Nam	R1	Kyrgyzstan
D8	Sierra Leone			M3	Yemen	R2	Latvia
D9	Somalia				**Oceania**	R3	Lithuania
E0	South Africa			M4	Australia	R4	Moldova, Republic of
E1	Sudan			M5	Cook Islands	R5	Russian Federation
E2	Swaziland			M6	Fiji Islands	R6	Tajikistan
E3	Tanzania, United Republic of			M7	French Polynesia	R7	Turkmenistan
E4	Togo			M8	New Caledonia	R8	Ukraine
E5	Tunisia			M9	New Zealand	R9	Uzbekistan
E6	Uganda			N0	Papua New Guinea		
E7	Congo, Democratic Republic of			N1	Samoa	ZY	Dummy Region
E8	Zambia			N2	Solomon Islands	ZZ	World
E9	Zimbabwe			N3	Tonga		
				N4	Vanuatu		

[a]The listed countries are the default countries in GFPM. It is also possible to add or remove countries; see Zhu and others (2008).

Appendix B—USFPM/GFPM Projections of Global Fuelwood Demands

This appendix describes an approach to projecting global fuelwood demands for the 2010 RPA scenarios (described in the text as "option 3"). This approach is an extension of the approach used previously in the GFPM (Raunikar and others 2010). We have considered and explored different options for projecting global fuelwood demands in USFPM/GFPM. We believe the approach described here should come closer to representing fuelwood consumption levels implicit in the RPA scenarios because the scenarios were based on IPCC SRES scenarios and because this approach takes into account relevant regional land use projections as well as regional biomass energy projections provided by scenario in the IPCC SRES report and its supporting database (Nakicenovic and Swart 2000).

Projected Global Land Use and Biomass Energy Production by Macro Region

The IPCC SRES database provides projections of global land use for each of four major global regions (called "macro" regions). The four macro regions are OECD 90 (Organization for Economic Cooperation and Development) member states as of 1990, including chiefly countries of Western Europe, the United States, Canada, Japan, Australia, and New Zealand), ALM (Africa, Latin America, and Middle East including South America and Caribbean countries), REF (Central and Eastern Europe and newly independent states of the former Soviet Union), and ASIA (remaining countries of Asia, including China, India, and other south and east Asian countries but excluding the Middle East and Japan). Table B1 shows the countries within each SRES macro region.

The SRES land use projections include several categories of land use that produce biomass for energy, including non-forest biomass energy plantations (or "energy biomass" lands as described in the SRES report), agricultural cropland, and forest land. Furthermore, the SRES provides projected changes in land use and biomass energy production for each of the four macro regions, from which we can deduce relationships between projected land use and biomass energy production. Table B2 shows SRES projections of regional biomass energy plantation area for the three RPA scenarios, while Table B3 shows SRES projections of total biomass energy production by macro region for the three RPA scenarios.

In all three scenarios, projected regional expansion of biomass energy plantation area is directly correlated with projected regional expansion in primary biomass energy production. For example, the A1B scenario has largest regional expansion in the area of biomass energy plantations and also biomass energy production, while expansions of biomass energy plantation area and biomass energy production are both smaller in the A2 and B2 scenarios. It can be noted also that biomass energy plantation area only begins to expand by the year 2020 in all scenarios, coinciding with projected regional expansion in biomass energy production, while the regional areas of forest land and cropland remain relatively static throughout the projection period in all three scenarios. Figure B1 illustrates SRES projections of these categories of global land use for the three RPA scenarios. Therefore, we deduce that biomass energy plantations are an important element of biomass energy supply in the RPA scenarios according to SRES.

In addition to recognizing that biomass energy plantations are an important element of biomass energy supply in the RPA scenarios according to SRES, we have observed also that biomass energy plantations are an important element of future biomass supply according to other studies that have analyzed the potential for significant expansion in global biomass energy production (e.g., Gurgel and others 2007; Faaij 2007; Hoogwijk and others 2005). Fuelwood and other fuel feedstocks from forests are currently the largest global source of biomass used for energy via direct combustion, but significant future expansion in use of biomass for energy and biofuels would entail expansion in biomass supply from non-forest biomass energy plantations according to the SRES and other global studies.

Furthermore, the energy equivalent of global roundwood fuelwood consumption is well below the estimated global production of biomass energy, indicating clearly that other non-forest sources of biomass are already important contributors to biomass energy production. Those other sources of biomass energy include agricultural crops (e.g., corn or sugar cane used for ethanol production), cropland residues, and also various forms of wood residues used for energy. For example, in the year 2000, global consumption of roundwood fuelwood was 1,825,914,364 cubic meters according to the FAOSTAT global database. This is equivalent in energy to approximately 26 EJ, which is much less than the 43.1 EJ of global primary biomass energy production in 2000 (Table B3), and thus the remainder or approximately 17 EJ of biomass energy must be attributable to biomass other than roundwood fuelwood, specifically sources such as agricultural crops, cropland residues, and wood residues (biomass energy plantations are not yet a significant conventional source of biomass for energy).

Projecting Implicit Fuelwood Consumption by Macro Region for RPA Scenarios

Having concluded that biomass energy plantations, agricultural crops and biomass residues are important elements of global biomass energy supply along with fuelwood in the RPA scenarios, we apply a direct approach to projecting the expansion of fuelwood consumption for RPA scenarios. Specifically, we deduct estimated energy supply of biomass plantations, agricultural crops, and residues from the

Table B1—Countries within Special Report on Emissions Scenarios (SRES)[a] macro regions

		OECD90 Region		
		North America (NAM)		
Canada	Guam	Puerto Rico	United States of America	Virgin Islands
		Western Europe (WEU)		
Andorra	Austria	Azores	Belgium	Canary Islands
Channel Islands	Cyprus	Denmark	Faeroe Islands	Finland
France	Germany	Gibraltar	Greece	Greenland
Iceland	Ireland	Isle of Man	Italy	Liechtenstein
Luxembourg	Madeira	Malta	Monaco	Netherlands
Norway	Portugal	Spain	Sweden	Switzerland
Turkey				
		Pacific Organization for Economic Cooperation and Development (PAO)		
Australia	Japan	New Zealand		
		Asia Region		
		Centrally Planned Asia and China (CPA)		
Cambodia	China	Hong Kong	Korea (DPR)	Laos (PDR)
Mongolia	Viet Nam			
		South Asia (SAS)		
Afghanistan	Bangladesh	Bhutan	India	Maldives
Nepal	Pakistan	Sri Lanka		
		Other Pacific Asia (PAS)		
American Samoa	Brunei Darussalam	Fiji	French Polynesia	Gilbert-Kiribati
Indonesia	Malaysia	Myanmar	New Caledonia	Papua New Guinea
Philippines	Republic of Korea	Singapore	Solomon Islands	Taiwan, province of
China	Thailand	Tonga	Vanuatu	Western Samoa
		REF Region		
		Central and Eastern Europe (EEU)		
Albania	Bosnia and Herzegovina	Bulgaria	Croatia	Czech Republic
The Former Yugoslav Republic of Macedonia	Hungary	Poland	Romania	Slovak Republic
Slovenia	Yugoslavia			
		New independent states of the former Soviet Union		
Armenia	Azerbaijan	Belarus	Estonia	Georgia
Kazakhstan	Kyrgyzstan	Latvia	Lithuania	Republic of Moldova
Russian Federation	Tajikistan	Turkmenistan	Ukraine	Uzbekistan
		ALM Region		
		Middle East and North Africa		
Algeria	Bahrain	Egypt (Arab Republic)	Iraq	Iran (Islamic Republic)
Israel	Jordan	Kuwait	Lebanon	Libya/GSPLAJ[b]
Morocco	Oman	Qatar	Saudi Arabia	Sudan
Syria (Arab Republic)	Tunisia	United Arab Emirates	Yemen	
		Latin America and the Caribbean		
Antigua and Barbuda	Argentina	Bahamas	Barbados	Belize
Bermuda	Bolivia	Brazil	Chile	Colombia
Costa Rica	Cuba	Dominica	Dominican Republic	Ecuador
El Salvador	French Guyana	Grenada	Guadeloupe	Guatemala
Guyana	Haiti	Honduras	Jamaica	Martinique
Mexico	Netherlands	Antilles	Nicaragua	Panama
Paraguay	Peru	Saint Kitts and Nevis	Santa Lucia	Saint Vincent and the Grenadines
Suriname	Trinidad and Tobago	Uruguay	Venezuela	

Table B1—Countries within Special Report on Emissions Scenarios (SRES) macro regions—con.

		Sub-Saharan Africa		
Angola	Benin	Botswana	British Indian Ocean Territory	Burkina Faso
Burundi	Cameroon	Cape Verde	Central African Republic	Chad
Comoros	Cote d'Ivoire	Congo	Djibouti	Equatorial Guinea
Eritrea	Ethiopia	Gabon	Gambia	Ghana
Guinea	Guinea-Bissau	Kenya	Lesotho	Liberia
Madagascar	Malawi	Mali	Mauritania	Mauritius
Mozambique	Namibia	Niger	Nigeria	Reunion
Rwanda	Sao Tome and Principe	Senegal	Seychelles	Sierra Leone
Somalia	South Africa	Saint Helena	Swaziland	Tanzania
Togo	Uganda	Zaire	Zambia	Zimbabwe

[a]Nakicenovic and Swart (2000).

[b]Great Socialist People's Libyan Arab Jamahiriya.

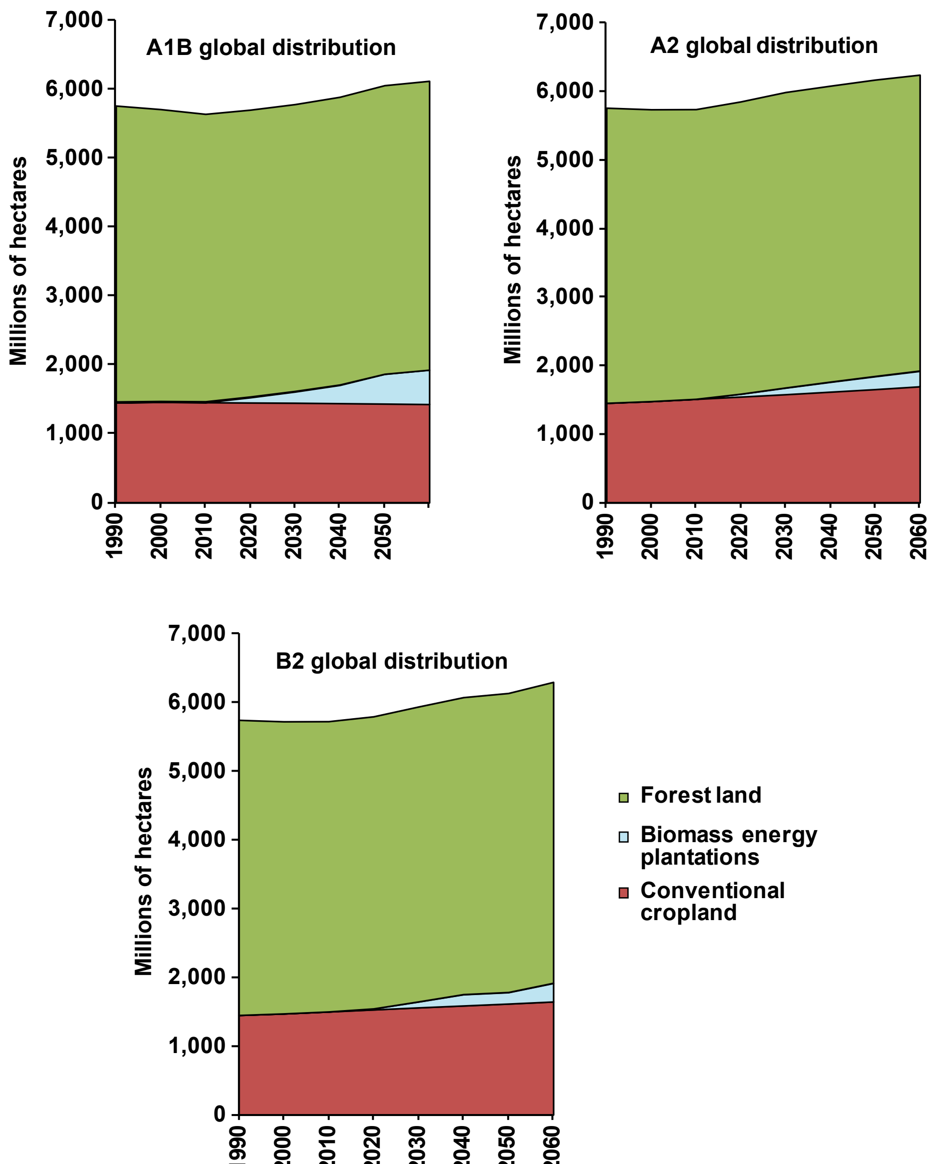

Figure B1—SRES projections of global land use for the three RPA scenarios of land that supply biomass, including forest land, cropland, and biomass energy plantations.

Table B2— Special Report on Emissions Scenarios (SRES)[a] projections of regional biomass energy plantation area ("energy biomass" land)

	Hectares ($\times 10^6$)						
World	2000	2010	2020	2030	2040	2050	2060
A1B (A1 AIM)	0.0	0.0	73.7	157.7	256.8	418.3	484.1
A2 (A2 ASF)	0.0	0.0	41.2	96.8	144.9	189.7	227.1
B2 (B2 Message)	0.0	0.0	14.4	86.3	164.6	167.0	271.3
OECD 90							
A1B (A1 AIM)	0.0	0.0	11.2	24.0	38.9	63.1	73.1
A2 (A2 ASF)	0.0	0.0	8.4	23.5	37.3	47.2	42.8
B2 (B2 Message)	0.0	0.0	2.6	11.1	17.5	21.7	26.9
REF							
A1B (A1 AIM)	0.0	0.0	3.0	6.1	10.1	16.5	19.1
A2 (A2 ASF)	0.0	0.0	0.0	0.1	0.5	0.8	8.1
B2 (B2 Message)	0.0	0.0	0.7	3.5	6.3	8.5	11.8
Asia							
A1B (A1 AIM)	0.0	0.0	17.1	37.0	60.6	99.1	114.7
A2 (A2 ASF)	0.0	0.0	20.6	44.7	58.2	71.6	72.8
B2 (B2 Message)	0.0	0.0	3.9	40.2	75.7	67.3	125.0
ALM							
A1B (A1 AIM)	0.0	0.0	42.5	90.5	147.2	239.5	277.3
A2 (A2 ASF)	0.0	0.0	12.2	28.5	49.0	70.1	103.4
B2 (B2 Message)	0.0	0.0	7.1	31.5	65.1	69.5	107.5

[a]Nakicenovic and Swart (2000).

projected total biomass energy production, yielding a remainder, which is the implicit consumption of fuelwood.

We start by computing projected production and consumption of biomass from biomass energy plantations based on SRES projections of regional biomass energy plantation area (Table B2) multiplied times conventional estimates of biomass energy plantation productivity by region. Estimates of biomass energy plantation productivity by global region are available in the literature, and we adopted estimates developed in the recent MIT study (Gurgel and others 2007) because the MIT study provided consistent estimates for all global regions and also estimated future gains in productivity. According to the MIT study (and similar estimates reported in other studies) the highest productivity levels for biomass energy plantations are found in Central and South America, where current productivity is estimated to be 15 metric tonnes per hectare per year, with a potential for doubling by the year 2100 (Gurgel and others 2007). Productivity rates for other global regions as reported in the MIT study were used to derive current and projected biomass plantation productivity levels for each of the four SRES macro regions, as shown in Table B4.

Multiplying biomass plantation productivity estimates (Table B4) by SRES projections of biomass energy plantation area (Table B2) gives corresponding estimates of regional biomass production from biomass energy plantations for each RPA scenario, which are shown in Table B5. The ALM region (Africa and Latin America) followed by Asia are the macro regions with the largest projected expansion in biomass output from biomass energy plantations, because those regions are projected to have the largest expansion in biomass energy plantations according to the SRES (Table B2) as well as highest estimated average regional productivity levels (Table B4). This result is also similar to findings of other global studies (e.g., Gurgel and others 2007, Hoogwijk and others, 2005)

After computing estimated regional biomass production from biomass energy plantations (Table B5), we computed estimates of other non-roundwood biomass consumption for energy, representing biomass from agricultural crops and crop residues plus other non-roundwood sources including mill residues. We estimated this cropland and residue biomass energy output of each region in the year 2000 by subtracting the energy equivalent of roundwood fuelwood consumption in 2000 from total biomass energy production in 2000 (Table B3). We then projected this cropland and residue biomass output based on SRES projections of cropland area, and results are shown in Table B6.

Next we computed global and regional projections of roundwood fuelwood consumption for the RPA scenarios based on the SRES projections of biomass energy production (Table B3) with deductions for the projected biomass consumption from biomass energy plantations (Table B5) and the projected biomass consumption from cropland and residues (Table B6). The roundwood fuelwood consumption estimates for the year 2000 were also calibrated to match precisely historical roundwood fuelwood consumption data by macro region as reported by FAOSTAT. Resulting preliminary global and regional roundwood fuelwood consumption estimates (in thousands of cubic meters per year) are shown in Table B7. Figure B2 shows preliminary projections of global biomass consumption for energy by RPA scenario based on our interpretation of SRES data and information. Projected global consumption of roundwood fuelwood from forests drives the wood energy demands in USFPM/GFPM. In USFPM, roundwood that can be used for energy includes conventional fuelwood, logging residues, and other roundwood such as pulpwood, which are sourced from timber harvest or SRWC, while mill residues can also be used for energy (compare Fig. 4).

We used the preliminary estimates of roundwood fuelwood consumption (Table B7) to derive preliminary expansion factors for fuelwood consumption by macro region for each RPA scenario (Table B8). However, we also computed unique growth rates for fuelwood consumption in each country based on the assumption that each country's targeted share of regional fuelwood consumption will match its projected share of regional GDP in 2060. This assumption is analogous to the fuelwood demand and GDP share assumptions applied previously in the GFPM (Raunikar and others 2010). Secondly, we also applied common regional elasticities of fuelwood demand with respect to the demand growth rates to calibrate the model solution.

Table B3—SRES[a] projections of total primary biomass energy production[b] by scenario, with projections adjusted to match B2 data in 2000

World	2000	2010	2020	2030	2040	2050	2060
A1B (A1 AIM)	43.10	45.60	69.50	93.37	135.86	200.80	254.54
A2 (A2 ASF)	43.10	45.60	52.22	71.87	91.63	111.40	131.80
B2 (B2 Message)	43.10	45.60	52.60	61.10	79.10	104.60	135.90
OECD 90							
A1B (A1 AIM)	6.80	6.10	10.20	15.50	22.64	35.20	43.34
A2 (A2 ASF)	6.80	6.10	8.43	14.82	21.22	27.61	27.51
B2 (B2 Message)	6.80	6.10	7.20	7.50	8.50	11.50	15.20
REF							
A1B (A1 AIM)	1.20	0.80	1.90	3.20	5.07	8.40	10.50
A2 (A2 ASF)	1.20	0.80	0.80	0.86	1.03	1.21	5.61
B2 (B2 Message)	1.20	0.80	0.80	1.60	2.40	3.90	5.90
Asia							
A1B (A1 AIM)	22.40	24.70	26.28	24.50	35.07	51.69	64.40
A2 (A2 ASF)	22.40	24.70	27.22	33.74	40.27	46.79	45.71
B2 (B2 Message)	22.40	24.70	28.00	32.20	40.60	53.70	68.40
ALM							
A1B (A1 AIM)	12.70	14.00	31.11	50.17	73.07	105.51	136.30
A2 (A2 ASF)	12.70	14.00	16.92	23.60	30.27	36.94	54.13
B2 (B2 Message)	12.70	14.00	16.60	19.80	27.60	35.50	46.40

[a]Nakicenovic and Swart (2000).
[b]Energy production measured in exajoules (EJ).

Table B4—Current and projected average productivity of biomass energy plantations by SRES[a] macro region (t/ha/y)

Region	2010	2020	2030	2040	2050	2060
OECD 90[b]	6.6	7.4	8.3	9.1	9.9	10.7
REF[c]	6.8	7.4	8.1	8.8	9.5	10.1
Asia[d]	10.2	11.3	12.3	13.3	14.3	15.3
ALM[e]	8.4	9.4	10.4	11.4	12.3	13.3

[a]Nakicenovic and Swart (2000).
[b]Average for USA, Europe, Canada, Japan, Australia, and New Zealand.
[c]Average for Former Soviet Union and Eastern Europe.
[d]Average for China, India, Indonesia, East Asia, and other.
[e]Average for Africa, Central and South America, Mexico, and the Middle East.

Final expansion factor targets for roundwood fuelwood consumption by global region are shown in Table B8. Final targets for roundwood fuelwood consumption in each country within each macro region were computed by multiplying the preliminary expansion factor for the region (Table B8) times the country's share of regional GDP in 2060, divided by the country's share of regional fuelwood consumption in 2006. The same formula was used to compute the U.S. wood fuel feedstock expansion factor. Compound growth rates for fuelwood demand in each country were computed on the basis of the expansion targets for each country. This procedure ensured that target expansion factors for fuelwood consumption in each country were calibrated to each country's regional share of GDP in 2060 (similar to previous GFPM approach) while also calibrated to the imputed regional shares of fuelwood consumption derived from SRES (Table B7).

The model solution for each scenario was then obtained by adjusting regional elasticities with respect to compound growth rates for demand, until the USFPM/GFPM projections of global fuelwood consumption matched the final targets for expansion in fuelwood consumption. In general, the target fuelwood consumption shares of individual countries within each region matched their regional GDP shares in 2060. However, projected supplies of wood within each country also influence projected equilibrium fuelwood consumption quantities of each country. Thus, each country has a unique equilibrium projection of expansion in fuelwood consumption, depending on its GDP share of regional GDP and depending on its inherent fuelwood supply capacity, while regionally and globally the expansion of fuelwood consumption is also driven by the overall expansion targets shown in Table B8.

This approach resulted in projected U.S. roundwood fuelwood consumption expanding more than the global average rate of expansion. This is partly because fuelwood expansion factors for the OECD90 region (which includes the United States) are higher than the worldwide expansion factors (Table B8). It is also because the U.S. share of roundwood fuelwood consumption in the OECD90 region was only 34% in 2006, but projected U.S. shares of regional GDP in 2060 are higher (42% in A1B, 44% in A2, and 49% in the B2 scenario). Thus, the U.S. share of regional fuelwood consumption must increase to match U.S. regional GDP shares in 2060. In addition, the United States has fairly

Table B5—Global and regional biomass production from biomass energy plantations[a] based on SRES[b] land use projections

Region	2000	2010	2020	2030	2040	2050	2060
World							
A1B (A1 AIM)	0	0	697,527	1,642,259	2,920,218	5,156,163	6,428,115
A2 (A2 ASF)	0	0	409,255	1,039,143	1,672,822	2,365,486	3,035,300
B2 (B2 Message)	0	0	135,927	940,088	1,960,368	2,116,181	3,758,080
OECD 90							
A1B (A1 AIM)	0	0	82,833	198,165	353,404	625,046	784,206
A2 (A2 ASF)	0	0	62,351	193,741	338,420	467,631	458,860
B2 (B2 Message)	0	0	19,645	91,892	159,207	215,173	289,017
REF							
A1B (A1 AIM)	0	0	22,223	49,669	88,236	155,821	192,929
A2 (A2 ASF)	0	0	0	897	3,986	7,126	82,402
B2 (B2 Message)	0	0	5,316	28,210	55,175	79,967	119,166
Asia							
A1B (A1 AIM)	0	0	192,910	454,814	806,022	1,419,983	1,759,926
A2 (A2 ASF)	0	0	231,891	548,860	773,337	1,025,312	1,117,791
B2 (B2 Message)	0	0	44,312	492,910	1,006,763	963,161	1,918,808
ALM							
A1B (A1 AIM)	0	0	399,561	939,612	1,672,556	2,955,312	3,691,054
A2 (A2 ASF)	0	0	115,014	295,645	557,079	865,416	1,376,247
B2 (B2 Message)	0	0	66,654	327,076	739,224	857,881	1,431,089

[a]Measured in (×10^3 t/y).
[b]Nakicenovic and Swart (2000).

Table B6—Global and regional cropland and residue biomass use for energy[a]

Region	2000	2010	2020	2030	2040	2050	2060
World							
A1B (A1 AIM)	875,725	954,125	951,349	949,322	945,413	941,521	937,156
A2 (A2 ASF)	875,725	985,150	1,006,816	1,029,312	1,053,631	1,077,951	1,104,917
B2 (B2 Message)	875,725	981,107	1,000,551	1,020,014	1,038,209	1,056,403	1,076,126
OECD 90							
A1B (A1 AIM)	257,439	210,701	209,840	209,360	207,505	205,667	203,021
A2 (A2 ASF)	257,439	216,774	220,563	224,565	229,242	233,918	239,503
B2 (B2 Message)	257,439	216,664	220,972	225,109	228,277	231,445	234,745
REF							
A1B (A1 AIM)	15,509	21,133	21,081	21,055	20,985	20,916	20,869
A2 (A2 ASF)	15,509	21,839	22,331	22,844	23,386	23,928	24,526
B2 (B2 Message)	15,509	21,739	22,171	22,625	23,049	23,473	23,940
Asia							
A1B (A1 AIM)	537,137	565,352	563,955	562,613	561,499	560,387	559,398
A2 (A2 ASF)	537,137	583,878	597,721	612,033	627,343	642,653	659,072
B2 (B2 Message)	537,137	580,538	591,767	603,095	614,897	626,699	639,438
ALM							
A1B (A1 AIM)	65,639	156,908	156,502	156,143	155,758	155,373	155,118
A2 (A2 ASF)	65,639	162,764	166,690	170,717	174,934	179,151	183,725
B2 (B2 Message)	65,639	161,791	165,071	168,342	171,534	174,725	178,259

[a]Measured in (×10^3 t/y).
[b]2000 data based on historical biomass consumption for energy production minus roundwood fuelwood consumption, and projections based on cropland area as projected by SRES (Nakicenovic and Swart 2000).

abundant wood supply, and in USFPM logging residues also contribute to roundwood fuelwood supply, which helps to support the higher expansion in U.S. fuelwood consumption relative to other countries and regions.

Total U.S. wood fuel feedstock consumption expands less rapidly than U.S. roundwood fuelwood consumption because roundwood is only a fraction of total U.S. wood fuel feedstock consumption (about 40% in the base year including bark). As explained previously, U.S. wood fuel feedstock consumption as modeled in USFPM includes both roundwood (e.g., harvested roundwood fuelwood and harvest residues that can be used as fuel) and also fuel

Table B7—Imputed global and regional roundwood fuelwood consumption estimates[a] for RPA scenarios[b]

World	2000	2010	2020	2030	2040	2050	2060
A1B (A1 AIM)	1,825,914	1,893,180	2,612,634	2,983,116	4,208,244	5,682,124	7,712,877
A2 (A2 ASF)	1,825,914	1,849,745	1,715,082	2,193,072	2,671,559	3,067,467	3,536,509
B2 (B2 Message)	1,825,914	1,855,405	2,133,559	1,582,373	1,403,096	2,965,152	2,855,246
OECD 90							
A1B (A1 AIM)	121,096	136,962	312,524	527,026	817,807	1,329,528	1,686,572
A2 (A2 ASF)	121,096	128,459	200,743	463,947	707,603	972,914	970,176
B2 (B2 Message)	121,096	128,614	172,971	87,276	59,412	189,056	343,052
REF							
A1B (A1 AIM)	63,260	27,063	73,914	127,580	206,158	347,375	444,456
A2 (A2 ASF)	63,260	26,074	25,386	27,519	34,903	42,215	247,271
B2 (B2 Message)	63,260	26,213	18,167	42,129	60,432	131,346	217,433
Asia							
A1B (A1 AIM)	834,161	957,525	801,623	310,249	569,016	888,002	1,313,461
A2 (A2 ASF)	834,161	931,588	765,805	764,068	890,425	978,283	748,832
B2 (B2 Message)	834,161	936,264	1,092,182	745,688	604,579	1,576,715	1,261,887
ALM							
A1B (A1 AIM)	807,397	771,675	1,424,532	2,018,472	2,614,796	3,116,068	4,266,635
A2 (A2 ASF)	807,397	763,476	803,981	1,017,864	1,118,360	1,153,191	1,649,071
B2 (B2 Message)	807,397	764,838	851,037	708,461	679,306	1,068,121	1,032,516

[a]Measured in ($\times 10^3$ m^3/y).
[b]Based on Food and Agriculture Organization (FAO) of United Nations statistical database (FAOSTAT) data for 2000 and projections based on Special Report on Emissions Scenarios (SRES· Nakicenovic and Swart 2000) biomass energy production with deductions for biomass production from energy plantations, agricultural crops, and residue.

residues (mill residues that are used as fuel). In fact about 60% of U.S. wood fuel feedstock consumption in 2006 was fuel residues (total U.S. wood fuel feedstock consumption was 113.3 million cubic meters in 2006, of which only about 45 million cubic meters was roundwood fuelwood and bark). On the other hand, in USFPM most of the projected increase in future U.S. wood fuel feedstock consumption comes from roundwood, because supplies of mill residues are limited by projected U.S. wood product production volumes. Thus, the target expansion factors in USFPM for total U.S. wood fuel feedstock consumption from 2006 to 2060 are 15.7× (or 5.2% per year) in the A1B scenario, 9.4× (or 4.2% per year) in the A2 scenario, and 3.7× (or 2.4% per year) in the B2 scenario. As explained above, those rates of expansion for U.S. fuel feedstock consumption and the target expansion factors for global roundwood fuelwood consumption by macro region (Table B8) are all aligned with the SRES projections of regional biomass energy production and regional land use by RPA scenario, including the SRES projections by scenario of regional land use for non-forest biomass energy plantations.

For the United States and for many other countries the resulting projections of expansion in wood energy consumption are prodigious in all RPA scenarios, but by far the highest in the A1B scenario, followed by the A2 scenario, and lowest in the B2 scenario. In the A1B scenario for example U.S. wood fuel feedstock consumption climbs to levels that dwarf U.S. consumption of wood for all other end uses (about five times higher by 2060 than all other wood uses) while in the B2 scenario U.S. wood fuel feedstock consumption climbs to a level only moderately higher than all other commercial uses. Figure B3 shows final projected rates of expansion in volumes of wood consumed for energy by RPA scenario from 2006 to 2060, according to USFPM/GFPM equilibrium results.

The A1B scenario has the highest projected global expansion of roundwood fuelwood consumption (4.5× from 2006 to 2060), while the A2 has the lowest global expansion of fuelwood consumption (2.2×). The projected global expansion rates for fuelwood are not exactly the same as expansion rates for biomass energy production as projected by SRES (Table 22) because of the adjustment for the output of biomass energy plantations and the added requirement that each country's regional share of fuelwood consumption match its regional GDP share in 2060. Thus, as shown in Figure B3, the counter-factual assumptions of the RPA scenarios and USFPM/GFPM projections provide a wide range of perspectives on potential expansion in U.S. and global demand for wood energy, while taking into account SRES projections of regional biomass energy production and regional land use, and specifically taking into account SRES projections of non-forest biomass energy plantations for each RPA scenario.

Mathematical Summary

Mathematically, our "option 3" approach to projecting global fuelwood consumption in USFPM/GFPM can be summarized as follows:

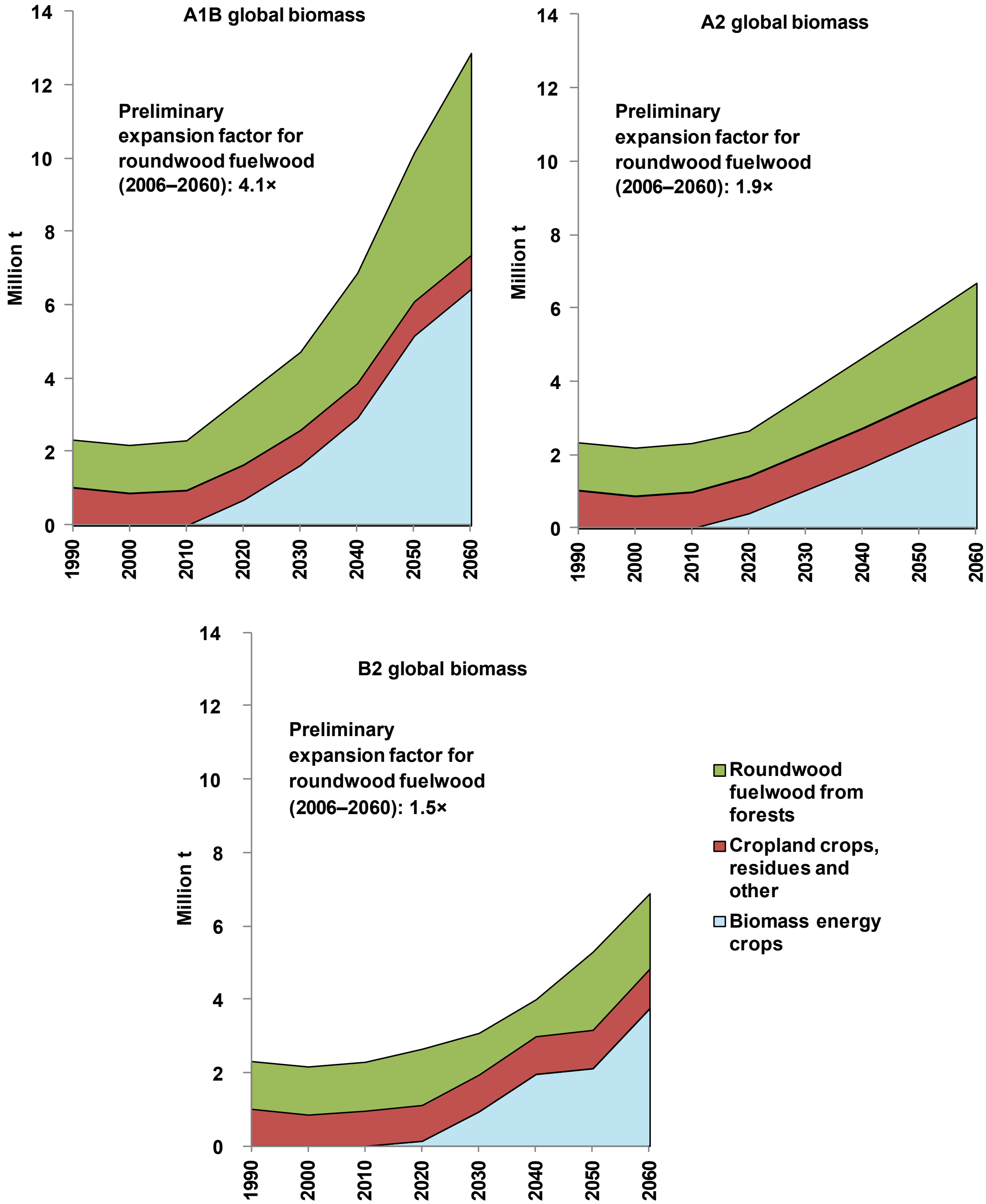

Figure B2—Preliminary projections of global biomass consumption for energy (millions of metric tons per year) by source for three RPA scenarios, based on interpretation of SRES land use projections and other information.

We used FAOSTAT data (the same data used conventionally in the GFPM) to determine initial roundwood fuelwood consumption in the base year (2006) for each country (i) in each macro region (j), and we denote the base-year demand quantity as $d_{ij,\,06}$. Applying the conventional GFPM approach in USFPM/GFPM, we specify roundwood fuelwood demand of each country (d_{ij}) with a common global price elasticity (-0.5 for all countries), and we apply long-term fuelwood demand growth rates (g_i) that are unique to each country. We also apply common regional elasticities (e_j) to the growth rates for all countries within each macro region (j). Over time, from year (t) to year (t+1), the global demand for fuelwood is thus shifted according to the following formula (B1):

Table B8—Preliminary expansion factors and final expansion factor targets[a] for global and regional roundwood fuelwood consumption for RPA scenarios (2006–2060)

	Preliminary	Final targets
World		
A1B (A1 AIM)	4.1×	4.5×
A2 (A2 ASF)	1.9×	2.2×
B2 (B2 Message)	1.5×	2.6×
OECD 90		
A1B (A1 AIM)	12.8×	14.0×
A2 (A2 ASF)	7.4×	8.1×
B2 (B2 Message)	2.6×	3.0×
REF		
A1B (A1 AIM)	7.5×	7.5×
A2 (A2 ASF)	4.2×	4.2×
B2 (B2 Message)	3.7×	3.7×
Asia		
A1B (A1 AIM)	1.7×	1.7×
A2 (A2 ASF)	0.9×	0.9×
B2 (B2 Message)	1.6×	1.6×
ALM		
A1B (A1 AIM)	4.8×	4.8×
A2 (A2 ASF)	1.8×	1.8×
B2 (B2 Message)	3.4×	3.4×

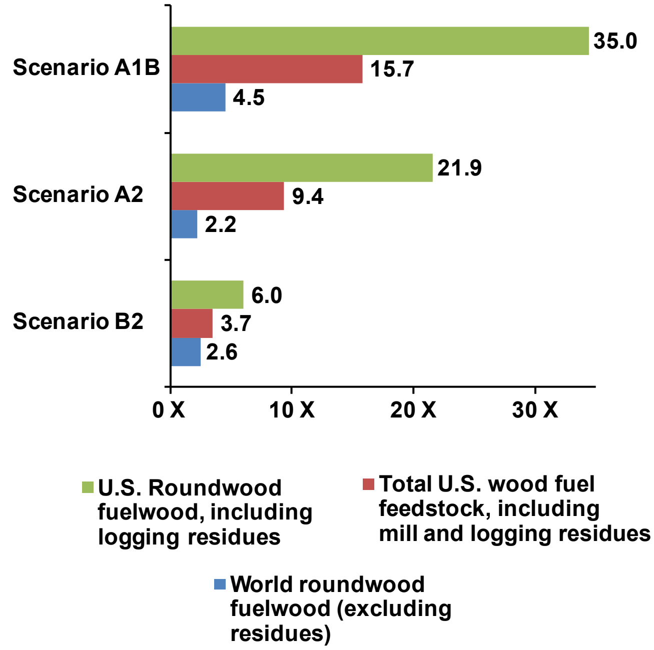

Figure B3—Projected expansion from 2006 to 2060 in volumes of wood consumed for energy by RPA scenario, including U.S. roundwood fuelwood consumption, total U.S. wood fuel feedstock consumption, and world roundwood fuelwood consumption.

$$\sum_j \sum_i d_{ij,\ t+1} = \sum_j e_j \sum_i (1+g_i) \cdot d_{ij,\ t} \qquad \text{(B1)}$$

The specified growth rates for fuelwood consumption in each country (g_i) are compound rates of growth that precisely match targeted expansion factors for fuelwood consumption of each country for each RPA scenario. The target expansion factors (F_i) for each country are computed according to the following formula (B2):

$$F_i = \frac{\dfrac{GDP^j_{i\,60}}{\sum_i GDP^j_{i\,60}}}{\dfrac{d_{ij,06}}{\sum_i d_{ij,06}}} \times F_j \qquad \text{(B2)}$$

Where $GDP^j_{i\,60}$ is the GDP of country *i* in macro region *j* in the year 2060, $\Sigma GDP^j_{i\,60}$ is the sum of GDP for all countries within macro region *j* (so the numerator in the term above is the GDP share of country *i* in region *j* in 2060), and the denominator in the term above is the fuelwood consumption share of country *i* in region *j* in 2006, and F*j* is the final target expansion factor for fuelwood consumption in region *j* for the given scenario (Table B8).

Thus, in each macro region, the target expansion of fuelwood consumption for each country is based on the target expansion for the region adjusted by a ratio of that country's share of regional GDP in 2060 to that country's share of regional fuelwood consumption in 2006. This approach ensures that the targeted expansion of fuelwood consumption for each country converges toward its share of regional GDP in 2060, while the aggregate expansion of fuelwood consumption for all countries within a given macro region (*j*) matches appropriate expansion factor for each region (Table B8). The fuelwood demand growth rates for each country (g_i) are simply compound growth rates that correspond precisely to that country's expansion factor (F_i), computed as F_i to the power of (1/54)-1, where 54 is the number of years from 2006 to 2060.

Operationally, when running USFPM/GFPM to generate results for the RPA scenarios, we used only the regional elasticity factors (e_j) for each of the four macro regions as adjustment parameters to raise or lower the equilibrium consumption of fuelwood until we obtained model projections that closely matched the targeted global and regional expansion factors for fuelwood consumption (Table B8). Thus we ensured that the projected expansion of fuelwood consumption for the RPA scenarios, both globally and by macro region, took into account the IPCC SRES projections of biomass energy production by macro region for each scenario (Table B3), and also took into account the IPCC SRES projections of biomass energy plantation area by macro region (Table B2), corresponding biomass output from energy plantations (Table B5), and biomass output from cropland (Table B6) based on IPCC SRES cropland area projections. We believe that this approach ensures that the

USFPM/GFPM projections of global and regional fuelwood consumption are linked closely to the full array of biomass energy information as presented in the IPCC SRES for the selected RPA scenarios.

USDA

United States Department of Agriculture

Forest Service

Forest Products Laboratory

Research Paper FPL-RP-662

September 2011