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PROJECTED WOOD ENERGY IMPACT ON U.S. FOREST WOOD RESOURCES

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Abstract

The USDA Forest Service has developed long-term projections of wood energy use as part of a 1993 assessment of demand for and supply of resources from forest and range lands in the United States. To assess the impact of wood energy demand on timber resources, a market equilibrium model based on linear programming was developed to project residential, industrial, commercial, and utility wood energy use from various wood energy sources: roundwood from various land sources, primary wood products mill residue, other wood residue, and black liquor.

Baseline projections are driven by projected price of fossil fuels compared to price of wood fuels and the projected increase in total energy use in various end uses. Wood energy use is projected to increase from 2.67 quad in 1986 to 3.5 quad in 2030 and 3.7 quad in 2040. This is less than the DOE National Energy Strategy projection of 5.5 quad in 2030. Wood energy from forest sources (roundwood) is projected to increase from 3.1 billion (10^9) ft^3 in 1986 to 4.4 billion ft^3 in 2030 and 4.8 billion ft^3 in 2040 (88, 124 and 136 million m3, respectively). This zate of increase of roundwood use for fhel -0.8 percent per year - is virtually the same as the projected increase rate for roundwood for pulpwood. Pulpwood roundwood is projected to increase from 4.2 billion ft^3 in 1986 to 6.0 billion ft^3 in 2030 and 6.4 billion ft^3 in 2040 (119,170 and 183 million m^3, respectively).

Introduction

The Forest Service of the U.S. Department of Agriculture is directed under requirements of the Renewable Resources Planning Act (RPA) of 1978 to make periodic assessments of the current and long-range demand for and supply of renewable resources from forest and range lands in the United States. The Forest Service prepares major assessments each decade and is now completing a mid-decade update. The assessment update has been prepared in draft form (USDA Forest Service 1993). This paper discusses part of the assessment update. It focuses on a part of the timber situation-the analysis of demand for and supply of wood for energy. The results in this paper are an update of the projections prepared for the 1989 RPA Assessment (High and Skog 1990).

The model discussed in this paper, the National Wood Energy Model (NAWEM), projects how much of several types of wood energy will be used by 1) households, 2) pulp/paper/paperboard mills, 3) solid wood products mills, 4) other industries, 5) commercial buildings, and 6) electric utilities in response to projected changes in fossil fuel prices and wood energy supply.

Wood for energy can come from many sources. To assess timber demand, it is usefull to sort wood energy supply sources because many sources are not used for sawlogs, veneer logs, or pulpwood. As a result, much wood energy supply (nongrowing stock) may not compete with lumber, panels, and paper for wood input. Wood energy supply sources used to prepare this report include:

Roundwood, in the form of
- StickWood (primarily for residential use)
- Logging residue (wood that would be left on harvest sites if not used for fuel)
- Chips (made by whole tree harvesting and chipping)

Wood residue from primary wood products mills:
- (wood and bark from pulp and paper mills, sawmills, and panel mills)

Wood residue from secondary wood products mills
- construction waste, demolition waste, and discarded wood products (e.g. pallets)

Black pulping liquor from wood pulp mills

Roundwood, which by definition comes directly from timber, is further subdivided into categories traditionally used to assess timber supply: first, by hardwood and softwood species; second, byland source--timberland, other forest land, and nonforest land; and third, (on timberland only) by type of timber volume--growing stock and other. Timberland produces growing stock growth of 20 ft^3 per acre per year or more; other forest land produces less. The “other” category of timber volume includes, tops, branches, cull sections, and saplings. For simplicity, we group roundwood into four categories:

Growing stock volume
- Hardwood
- Softwood

Other sources
- Hardwood
- softwood

Methods Used to Project Wood Energy Use to 2040

Wood energy demand and supply have been projected through the year 2040 with the use of a computer model (NAWEM) that simulates economic markets, where supply of wood fuels from 15 sources is balanced against demand from six end users for three U.S. regions. The model is constructed using the Price Endogenous Linear Programming framework (PELPS) developed at the University of Wisconsin (Zhang, Buongiomo, and Ince, in preparation).

NAWEM determines the quantities and prices of wood fuels supplied, and quantities and prices of wood energy demanded in various end uses. The model interacts sequentially with other U.S. Forest Sewice models. It obtains input projections from, TAMM/ATLAS and NAPAP, and provides output projections for TAMM. Through several exchanges of projections, these models provide mutually consistent projections of supply and demand for timber, wood products, and wood energy for the U.S. forest sector. Figure 1 shows projections that are passed between models. TAMM and associated models project sawtimber, lumber and panel production, and end use (Adams and Haynes 1980); ATLAS projects timber growth, inventory and the distribution of timber removals. NAPAP projects pulpwood use; pulp, paper, and paperboard production; and paper and paperboard recycling (Ince, in press).

NAWEM is disaggregated into three independent regional models, North, South, and West. They are run simultaneously. Since transporting wood fuel for long distances is not economical, we assume there is no interregional trade in wood fuel supplies. The regions are shown in figure 2.

Structure of the Model

The model projects wood energy use by solving a series of annual linear programming problems, starting with the base year 1986. In each year, three sets of sector characteristics are specified: 1) a set of raw material (wood fuel) supply equations, 2) a set of technology conversion characteristics, and 3) a set of end-use demand equations. For each year, market equilibrium quantities and prices of wood energy commodities supplied and demanded are calculated by using linear programming to maximize consumer plus producer surplus (in terms of a graph of supply and demand curves, this is the area under demand curves above price plus area above supply curves below price). Between yearly estimates, projected values of exogenous variables are used to update supply equations, technology conversion factors, and demand equations.

Demand and supply equations are of the Cobb-Douglas form with the allowance for possible dynamic partial adjustment of demand or supply by including a lagged independent variable on the right-hand side of equations. This is to accommodate the possibility that demand and supply may be slow to respond to wood energy or fossil fuel price changes. That is, long-run price elasticity may be greater than short-run price elasticity.

Wood Energy Demand Equations

Demand equations are estimated for six end uses: Residential Households, the Pulp and Paper Industry, Other Forest Products Industry, Other industry, Commercial Buildings, and Electric Utilities. Demand is measured in Btus (joules) of energy content in the wood fuel before conversion to heat, steam, or electrical energy.

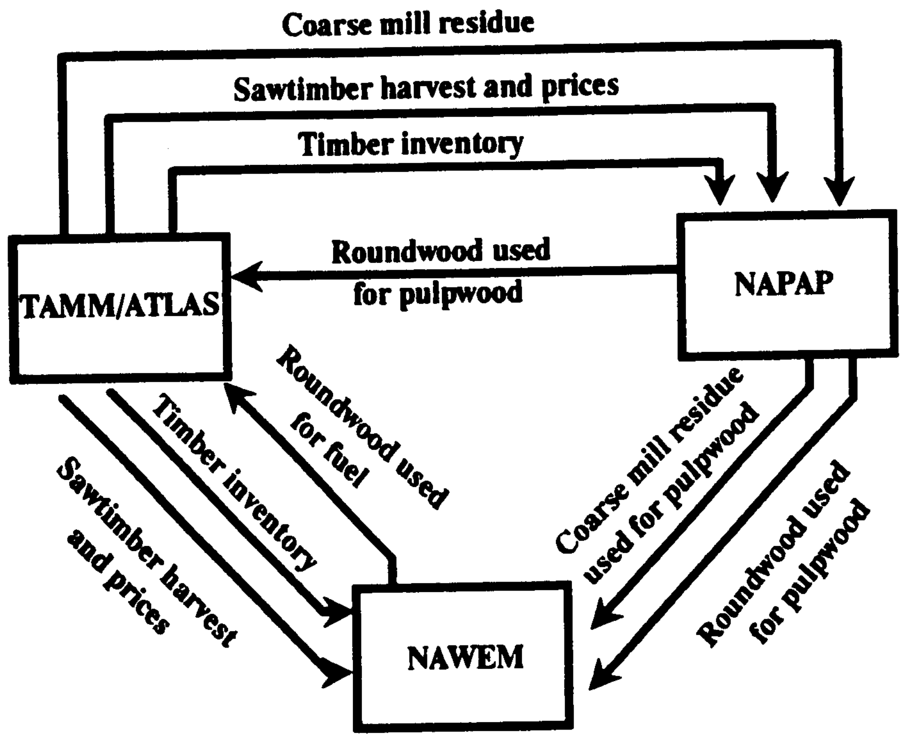

Figure 1.--Data passed between NAWEM, TAMM/ATLAS and NAPAP models

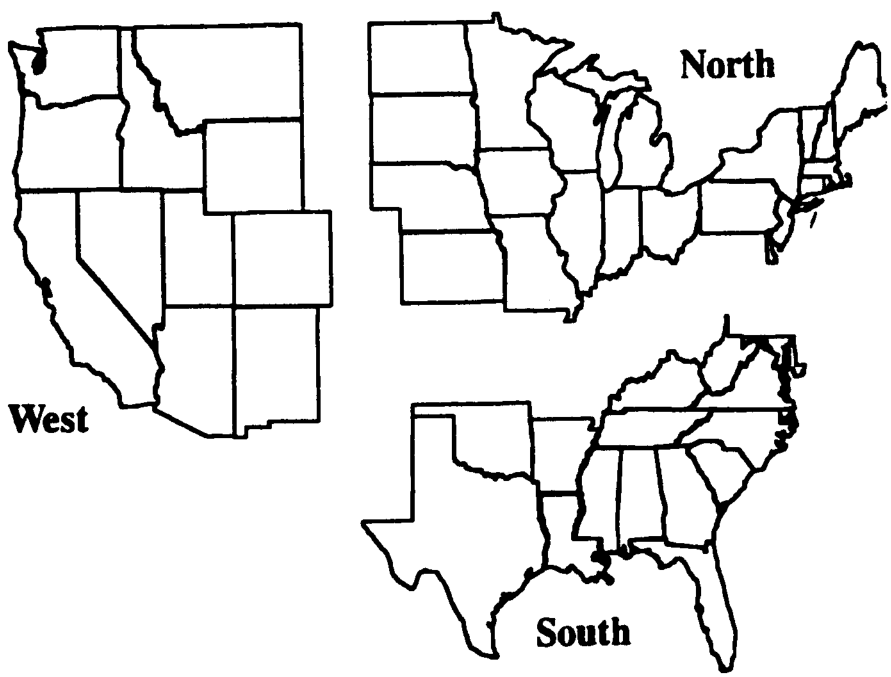

Figure 2.-National wood energy model regions

Demand equations for residential fuelwood use have elasticities estimated from a model using cross-sectional data on fuelwood use in 1980-81 (Skog 1989). The model shows how fuelwood demand per household responds to changes in prices of fuelwood and fossil fuels; household income; population density heating degree days; and percentage of land in forests. For our long-run projections, we assume heating degree days will remain at the long-inn average level and forest land area will remain at the current levels.

Results show that household demand response to fuel price change is slightly inelastic (less than 1) (table 1). Fuelwood use per household declines with increasing population density and increases with increasing income. Demand is adjusted for increasing efficiency of wood and fossil fhel burning between yearly estimates.

Wood energy use in the Pulp and Paper Industry is divided into two parts: use of black liquor, and use of wood and bark. Demand for black liquor for fuel is projected exogenously based on projections of paper and paperboard production from the NAPAP model. Demand for wood and bark for fuel is projected by NAWEM endogenously using estimated demand equations. The wood and bark demand shifters include wood fuel price, fossil fuel price, quantity of purchased fuel, and lagged wood and bark demand (Zhang 1992). Equation estimates indicate demand is determined primarily by previous period (lagged) demand and changes only slowly in response to changing prices and quantity of purchased fuel (table 2). As for household demand, demand equations are adjusted for expected increasing efficiency of wood and fossil fuel burning.

Demand equations for Other Forest Products Industry and Other Industry were estimated with a single equation using data for all industry (other than Pulp and Paper). Demand shifters include wood fuel price, and fossil fuel price, the level of industrial production, and lagged wood energy demand. Equation estimates indicate demand is determined largely by previous period demand, but to a lesser extent than that for Pulp and Paper (table 2). Changes in prices and production level have a greater short run influence on demand for Other Industry than for the Pulp and Paper Industry. That is, the impact of a given change in prices occurs more quickly for Other Industry.

Separate equations are used in NAWEM for Other Industry. Although the elasticities are the same as for Other Forest Products Industry, different shift variables are used to indicate the trend in the level of industrial production. Roundwood use in the industry is used as a shift variable for Other Forest Products, and the U.S. index of industrial production is used for Other Industry. Demand equations are adjusted between yearly estimates for expected increasing efficiency of wood burning and fossil fuel burning.

Demand equations for Commercial Buildings use shifters including wood and fossil fuel prices, amount of commercial floor space and lagged wood energy demand. Equation estimates suggest demand is more responsive to prices than the Pulp and Paper Industry but less responsive than Other Industry (table 2).

Demand equations for Electric Utilities use shifters including wood and fossil fuel prices, amount of power produced and lagged wood energy demand. Equation estimates suggest demand by Electric Utilities is about as responsive to price changes as demand for Commercial Buildings (table 2)

Note that the demand elasticities in table 2 are short run elasticities. They indicate the change in demand over one year in response to a change in prices or the indicator of production.

Table 1.--Residential fuelwood demand equation elasticities

Own price	Fossil fuel price	Number of households	Household income	Population density
-0.87	0.87	1.00	0.30	-0.55

Source: Skog 1989.

Table 2.-- Wood energy demand equation elasticities

End use	Demand elasticity with respect to: Own price	Fossil fuel price	Sector production indicator	Sector production indicator name	Lagged wood energy demand
North					
Pulp and paper	-.08	.08	.04	Purchased fuel	.96
Other Forest Products	-.39	.39	.19	Roundwood use	.81
Other Industry	-.39	.39	.19	Industry production	.81
Commercial Buildings	-.15	.15	.16	Floor space	.84
Electric Utilities	-.13	.13	.09	Power production	.91
South					
Pulp and paper	-.08	.08	.04	Purchased fuel	.96
Other Forest Products	-.39	.39	.19	Roundwood use	.81
Other Industry	-.39	.39	.19	Industry production	.81
Commercial Buildings	-.15	.15	.16	Floor space	.84
Electric Utilities	-.13	.13	.09	Power production	.91
West					
Pulp and paper	-.08	.08	.04	Purchased fuel	.96
Other Forest Products	-.39	.39	.19	Roundwood use	.81
Other Industry	-.39	.39	.19	Industry production	.81
Commercial Buildings	-.14	.14	.16	Floor space	.84
Electric Utilities	-.10	.10	.29	Power production	.71

sources: Zhang 1992.

Long run elasticity (response over several years) is calculated as:

$$E_{LR} = (E_{SR} / ((1 - E_{LD}))$$

where E_{LR} and E_{SR} are short run and long run elasticities, respectively, and E_{LD} is the elasticity with respect to lagged wood energy demand.

For example, the long run wood price elasticity for Pulp and Paper wood energy demand (excluding black liquor) is 2.0 (=.08/(1 - .96)). In the long run demand is highly responsive to prices of wood and fossil fbels. Long run elasticities are 1.4 to 2.1, except for Commercial Buildings and Electric Utilities in the West where elasticities are lower.

Technical Conversion Factors and Technology Improvement

Wood fuel supply quantities in cubic volume are converted to Btus of energy based on 8600 Btu/lb for both hardwood and softwood, and 30.4 lb/ft^3 for softwoods and 34.8 lb/ft^3 for hardwoods.

Projected technology improvements in the efficiency of converting wood to energy have an influence by shifting demand equations and thereby decreasing the amount of demand as efficiency increases. For residential fuelwood use, the improvement in efficiency is estimated to average about 0.9 percent per year, for Commercial Buildings, 0.7 percent per year; and for all industrial sectors, 0.6 percent per year.

Wood Fuel Supply Equations

Supply equations were prepared for 16 categories of wood fuel (tables 3 and 4). Preparation of these equations was more speculative than for wood fuel demand because data are very limited. Supply price is generally the price including delivery to a particular end user. Supply to alternate users may have extra transport costs added.

Sixteen supply sources were identified in an effort to distinguish among characteristics of various sources. The first six sources in table 3 are stickwood sources used only by Residential Households and are supplied by household harvesting or commercial vendor harvesting. Residential Households also use logging residue (in the form of stickwood) and coarse residue from primary wood products mills. Logging residue supply is wood taken for fuel in either combined harvesting operations when sawlogs, veneer logs, or pulpwood are removed, or subsequent to initial harvesting operations.

If black liquor is excluded, Pulp and Paper mills use the same wood fbel sources as Other Forest Products Industry mills: residue from primary wood products mills, logging residue, and other residue (which includes residue from secondary wood products mills).

Other industry, Commercial Buildings, and Electric Utilities are assumed to compete for the same sources as forest products plants but generally incur higher transportation costs. As the price of these residue sources increases we assume they will also use chips from whole tree harvesting. Unlike logging residue harvest, whole tree harvesting only takes wood for fuel. No other products are extracted.

Supply equations in table 3 are specified by several features:

-an elasticity with respect to delivered price,

-an elasticity with respect to the inventory or annual production of the wood source, and

-in some cases, an exogenously given upper limit of supply and reservation price from TAMM.

Table 3.--Wood fuel supply equation elasticities and/or use of an upper limti[a]

Supply equation	Demand elasticity with respect to: Own price	Inventory or production	Inventory or production variabie	Upper limit and(or reservation price source
Softwood growing stock	.85	1.00	SW GS inventory	---
Hardwood growing stock	.85	1.00	HW GS inventory	---
Other softwood roundwood	.90	1.00	SW GS inventory	---
Other hardwood roundwood	.90	1.00	HW GS inventory	---
Other forest roundwood	.95	1.00	GS inventory	---
Non-forest roundwood	.95	---	---	---
Logging residue	.95	1.00	Annual logging residue production	TAMM
Softwood coarse residue	1.00	1.00	SWC Residue	TAMM
Hardwood coarse residue	1.00	1.00	HWC Residue	TAMM
Softwood fine residue	1.00	1.00	SWF Residue	TAMM
Hardwood fine residue	1.00	1.00	HWF Residue	TAMM
Softwood bark	1.00	1.00	SW Bark	TAMM
Hardwood bark	1.00	1.00	HW Bark	TAMM
Other wood residue	1.00	---	---	---

Tabie 4.-Whole tree chip supply equation variabies, eiasticities and/or use of upper limit or reservation price.

Suppiy quation/region	Demand elasticity with respect to: Own price	Growing stock inventory	Sawlog price	Bond discount rate	Lagged wood supply	Upper limit projection source
Softwood chips						
North	.903	.250	-.009	---	.75	---
South	.909	.300	.110	---	.70	---
West	---	---	---	---	---	TAMM
Hardwood chips						
North	1.674	.590	.550	.78	.41	---
South	3.618	.350	.550	4.12	.65	---
West	---	---	---	---	---	TAMM

Source: Ince, in press.

[a] GS is growing stock volume. SWC, HWC, SWF, and HWF are softwood coarse, hardwood coarse, softwood fine, and hardwood fine residue, respectively.

The elasticities in table **3** with respect to delivered price are based on estimates of pulpwood supply equations for the Lake States (Adams 1975). These results suggest an elasticity of about 1. Price elasticities were set lower for growing stock than for nongrowing stock on the premise that owners would be less willing to sell growing stock for fuelwood because it may have an alternate market for pulpwood or other higher valued products.

Whole tree chip supply equations were developed based on pulpwood roundwood supply equations used in the NAPAP model (Ince, in press). We assume that pulpwood roundwood and whole tree chips would be supplied from the same inventory pool of timber and would be harvested by the same type of harvesting operators. This timber inventory pool includes both growing stock (used for pulpwood) and nongrowing stock (not used much for pulpwood). The NAPAP pulpwood supply equations were adjusted to include the estimated amount of nongrowing stock associated with the growing stock supplied for pulpwood. These adjusted supply equations are included in NAWEM as a some of both pulpwood roundwood supply and whole tree chip supply (table 4). In NAWEM, pulpwood demand from NAPAP (plus associated but unharvested nongrowing stock) is deducted from the supply. NAWEM solves for additional amounts of growing stock and nongrowing stock taken from the supply equations for fuel.

Assumptions and Limitations

The demand equations were constructed using historical data on the assumption that end users would alter wood energy demand in response to changing prices, industry production, and other factors in a manner similar to recent history. No provision was made for government intervention in markets beyond environmental restrictions, which are reflected in the historical data.

We assume, in these base case projections, that economical fuelwood supplies will be restricted to the 16 categories used in the model and that conditions would not develop to allow extensive development of plantations of fast-growing trees for fuel.

Projections of the amount of roundwood that comes from growing stock are strongly influenced by the assumed proportion of whole tree chips that are from growing stock. We assume that as whole tree harvesting expands, harvest methods and composition of harvested stands will decrease the proportion of whole tree chips that come from growing stock over the projection period.

External Inputs

Supply and demand equations are shifted over time by changes in independent variables such as timber inventory or industrial production. These independent variables, with the exception of price, are projected exogenously. Demand equations are shifted by variables which include average fossil fuel prices in various sectors, the industrial production price index, commercial floor space, and electric power production. These projections are from the National Energy Strategy (DOE 1991). Residential demand equations are shifted by additional variables including U.S. population, household income, and population per household (USDA Forest Service 1988). Selected supply equations are shifted by pulpwood roundwood use, pulpwood residue use, and purchased energy in the Pulp and Paper industry from the NAPAP model (Ince, in press). Supply functions are also shifted by hardwood and softwood growing stock inventory, primary mill wood residue production, sawtimber price, and harvest of sawtimber and pulpwood (determinants of logging residue). Except for pulpwood roundwood, these latter projections are from the TAMM model.

Projections of Wood Energy Use 1986 to 2040

Demand for Wood Energy

Overall, NAWEM projects total wood energy use to increase 39 percent between 1986 and 2040: from 2.66 quad in 1986, to 3.40 uad in 2030, and 3.70 quad in 2040 (table 5, figure 3) (1 quad equals 1.055x 10^{18}joules). In comparison, the National Energy Strategy base case projects higher total use of 5.5 quad by 2030 (DOE 1990). Both NAWEM and NES base case projections exclude use of biomass to make alcohol fuels. It appears the difference between the projections is due to the substantially different projection methods used. The NES projections of wood energy use given in two parts: electric power production (0.5 quad in 2030) and dispersed applications (5.0 quad in 2030). The dispersed applications projections are made using equations linking historical changes in aggregate wood energy use in three sectors (industrial, residential, commercial/utility) to historical changes in GNP, electricity prices, and world oil price. They do not account for projected changes in wood fuel price.

The NES projections for 2030 are probably to high because the projection equations were estimated on data over a period when price was low for residential fuelwood and mill residue was cheap and readily available for use by industry, commercial buildings, and utilities. Mill residue is now almost fully utilized for fuel or products and future increases in industrial/commercial/utility wood energy use must come from more expensive logging residue and whole tree chip sources. The NES projections are to high because they do not account for these projected changes in wood sources and the resultant extra increases in price of wood fuels.

NAWEM projects wood energy use will increase fastest for Other Industry (126 percent), Commercial Buildings (68 percent), and Electric Utilities (56 percent) over the projection period. But the proportion of total wood energy use in these sectors will still be low--7.6 percent in 2040. Residential use will increase 53 percent, Pulp and Paper 27 percent, and Pulp and Paper 2 percent. Pulp and Paper use will increase by 30 percent *in* the North and South, but will decline by 31 percent in the West due to constraints on timber harvest.

Wood energy use will increase the most over the projection period *in* the North, 54 percent, followed by the South, 38 percent, and the West, 15 percent. Two key reasons of the differences among regions are differences in projected average fossil fuel prices (each region has a different mix of fuels), and regional differences in the availability of various sources of wood supply.

Supply of Roundwood for Energy

The impact of wood energy use on forest wood resources is determined by the amount of wood fiel that comes in the form of roundwood from forests, either growing stock or nongrowing stock. Use of forest sources are lower to the extent that wood energy is produced from alternate sources, including wood mill residue, black pulping liquor, or waste wood products such as pallets. Although NAWEM projects roundwood and wood residue use for fuel, the following section focuses on roundwood use because of its important impact on forest wood use.

NAWEM projects roundwood use for energy to increase from 3.1 billion fi3 in 1986 (26 percent from growing stock) to 4.4 billion ft^3 in 2030 and 4.8 billion fi^3 in 2040 (22 percent growing stock) (table 6,

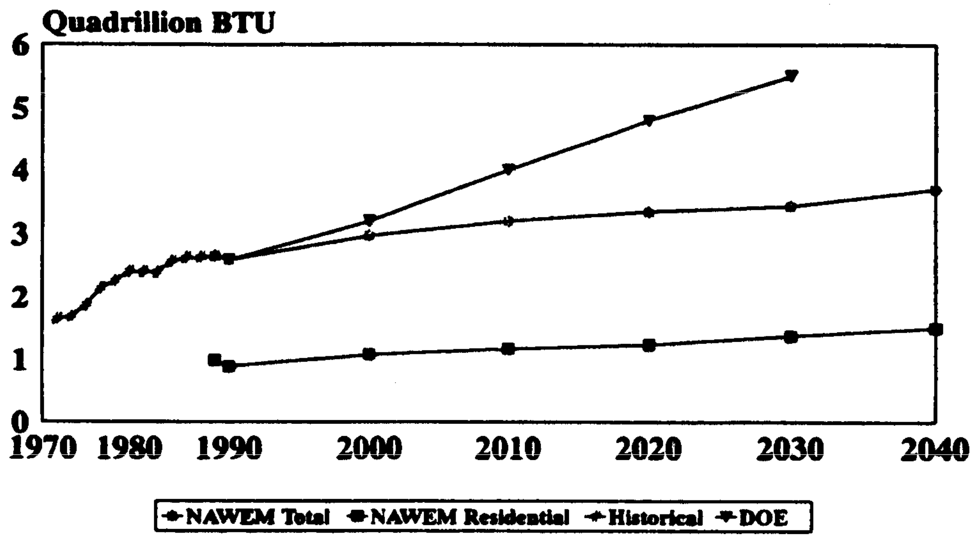

Figure 3.--U.S. Wood energy use, 1972-1986, with projections to 2040. Sources: Klass 1988, DOE 1991. (1 Btu = 1055 joules)

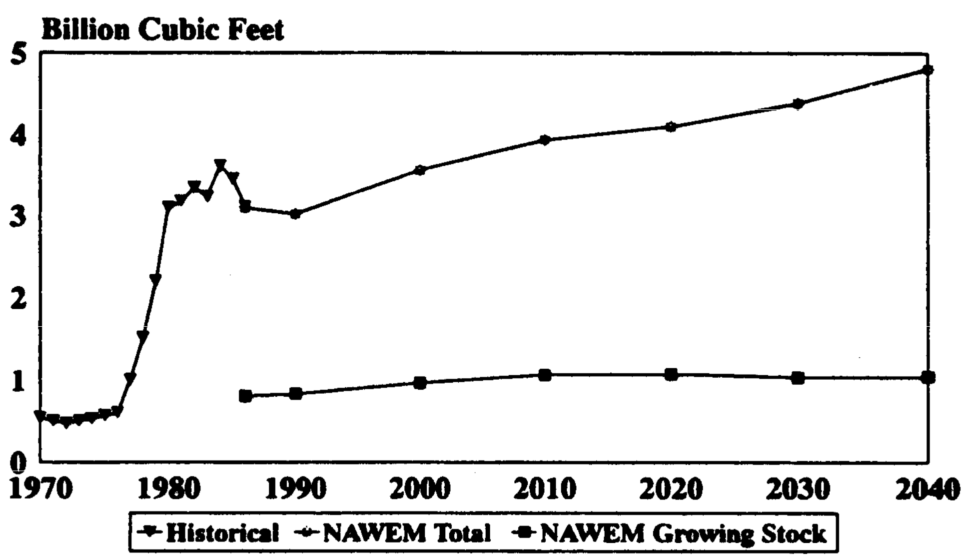

Figure 4.--U.S. Roundwood use for energy, 1970-1986, with projections to 2040. Source: USDA Forest Service 1990. (1 ft^3=0.028 m^3)

Table 5.--Wood energy demand in the U.S. in 1986, with projections to 2040

Region/ Year	Total	Residential	Pulp and Paper: Black Liquor	Pulp and Paper: Wood and Bark	Other Forest Products	Other Industry	Commercial	Utilities
			Quadrillion Btu[a]					
North								
1986	0.849	0.570	0.100	0.070	0.045	0.048	0.011	0.004
1990	0.807	0.529	0.107	0.068	0.045	0.044	0.011	0.004
2000	0.977	0.665	0.124	0.066	0.048	0.057	0.013	0.005
2010	1.067	0.724	0.127	0.069	0.053	0.072	0.015	0.006
2020	1.126	0.770	0.131	0.070	0.055	0.078	0.016	0.006
2030	1.218	0.856	0.116	0.073	0.056	0.092	0.018	0.006
2040	1.309	0.933	0.106	0.076	0.058	0.110	0.020	0.006
South								
1986	1.288	0.242	0.650	0.261	0.094	0.035	0.006	0.000
1990	1.292	0.215	0.694	0.252	0.092	0.032	0.006	0.000
2000	1.494	0.261	0.825	0.253	0.107	0.041	0.007	0.000
2010	1.611	0.285	0.867	0.273	0.125	0.053	0.008	0.000
2020	1.680	0.301	0.901	0.277	0.136	0.057	0.008	0.000
2030	1.666	0.331	0.815	0.293	0.152	0.067	0.009	0.000
2040	1.782	0.357	0.859	0.357	0.123	0.076	0.010	0.000
West								
1986	0.526	0.175	0.146	0.060	0.116	0.019	0.005	0.005
1990	0.500	0.150	0.161	0.060	0.102	0.018	0.004	0.005
2000	0.508	0.158	0.196	0.061	0.060	0.021	0.005	0.007
2010	0.525	0.166	0.200	0.064	0.055	0.027	0.006	0.008
2020	0.544	0.175	0.206	0.065	0.055	0.029	0.006	0.008
2030	0.558	0.197	0.184	0.067	0.061	0.033	0.006	0.008
2040	0.604	0.222	0.170	0.072	0.080	0.045	0.007	0.008
United States								
1986	2.663	0.987	0.897	0.391	0.255	0.102	0.022	0.009
1990	2.600	0.894	0.963	0.380	0.239	0.094	0.022	0.009
2000	2.979	1.084	1.144	0.381	0.215	0.119	0.025	0.011
2010	3.203	1.174	1.195	0.406	0.233	0.152	0.029	0.013
2020	3.350	1.245	1.239	0.412	0.247	0.164	0.030	0.014
2030	3.441	1.384	1.115	0.433	0.270	0.193	0.033	0.014
2040	3.695	1.512	1.135	0.505	0.261	0.231	0.037	0.014

[a] 1 Btu = 1005 Joules.

Table 6. -- Roundwood used for fuel in the U.S.in 1986 with projections to 2040 (excludes logging residue use)[a]

Year	Roundwood			Growing Stock		
	Total	HW	SW	Total	HW	SW
	Million cubic feet[b]					
North						
1986	1825	1705	121	241	223	18
1990	1748	1636	112	264	247	18
2000	2189	1952	236	326	268	58
2010	2441	2095	346	363	276	87
2020	2530	2209	322	371	295	76
2030	2674	2404	271	356	299	57
2040	2898	2668	230	377	332	45
South						
1986	739	682	57	329	286	43
1990	758	702	57	344	301	43
2000	800	743	57	365	323	42
2010	864	747	116	399	325	74
2020	875	773	102	384	319	65
2030	914	849	65	361	311	49
2040	998	926	73	354	299	55
West						
1986	531	192	340	228	86	142
1990	513	183	330	227	84	143
2000	575	200	375	272	95	177
2010	644	230	414	297	107	190
2020	708	254	455	315	113	203
2030	799	295	504	312	114	198
2040	914	302	612	314	119	195
United States						
1986	3096	2578	518	798	595	202
1990	3019	2521	498	835	632	203
2000	3563	2895	667	963	686	277
2010	3949	3072	877	1058	708	350
2020	4114	3235	878	1070	727	343
2030	4388	3548	840	1029	724	304
2040	4810	3896	914	1045	750	295

[a] HW is hardwood and SW is softwood.
[b] 1 $ft^3 = 0.0283\ m^3$

figure 4) (88, 136 and 124 million m^3, respectively). The increase is 55 percent over the projection period. NAWEM projections are consistent with the 1989 Forest Service fuelwood projections of 5.1 billion $f1^3$ by 2040 (High and Skog 1990). Our current projections are lower primarily because projected fossil fiel prices are now lower. In 1989 DOE projected world oil prices to increase to $61 (1990$/barrel) by 2030. Currently the National Energy Strategy projects world oil price to increase to $49 (1990$/barrel) by 2030. The rate of increase of roundwood use for fuel, 0.8 percent per year, is virtually the same as that the projected rate of increase of roundwood use for pulpwood. Pulpwood roundwood is projected to increase from 4.2 billion $f1^3$ in 1986 to 6.0 billion $!1^3$ in 2030 and 6.4 billion ft^3 in 2040 (119, 170 and 183 million m^3, respectively) (Ince, in press). This rate of increase in greater than for total roundwood harvest which is projected to increase from about 18 billion ft^3 and 25 billion 83 between 1990 and 2040, or 0.68 percent per year.

The proportion of roundwood used for fuel that is from growing stock is a critical factor in determining the impact of wood energy use on forest wood sources. Most timber products (sawlogs, veneer logs, and pulpwood) come predominantly from growing stock -70 percent or more. But only 26 percent of fuelwood comes from growing stock. If this proportion from growing stock declines to 22 percent as projected by NAWEM then the wood energy drain horn growing stock will increase about 31 percent through 2040, much less than 55 percent increase for all wood energy from roundwood, and less than the 40 percent increase for all roundwood harvested.

Conclusions

Wood energy use is projected to increase 39 percent, which is modest in comparison to the large increases in the 1970's and early 1980's. This is based on projected increases in fossil fuel prices from the National Energy Strategy, the aggregate increases in residential and industrial energy consumption, and the supply response, including price increases, from wood energy sources.

Roundwood use for fuelwood is projected to increase about 55 percent over the projection period, which is faster than for the projected use of wood residue and black liquor sources.

Roundwood use for fuelwood is projected to remain a significant facor in forest management and harvesting at about 75 percent the volume of roundwood used for pulpwood. But, unlike pulpwood roundwood, fuelwood roundwood is projected to use only 22 percent horn growing stock volume by 2040. Pulpwood roundwood is 74 percent from growing stock. Therefore, fuelwood use has a much lower impact on drain of growing stock than pulpwood.

These projections would be altered by changes in key assumptions; a change in the trend in fossil fuel prices; major advances in technology which reduces the cost to convert wood to energy, an increase in the proportion of fuelwood roundwood from growing stock; advances in reducing the cost of producing short rotation woody crops; and changes in government regulations or incentives such as those that would restrict harvesting to maintain ecosystem features or that would promote tree planting to sequester atmospheric carbon.

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