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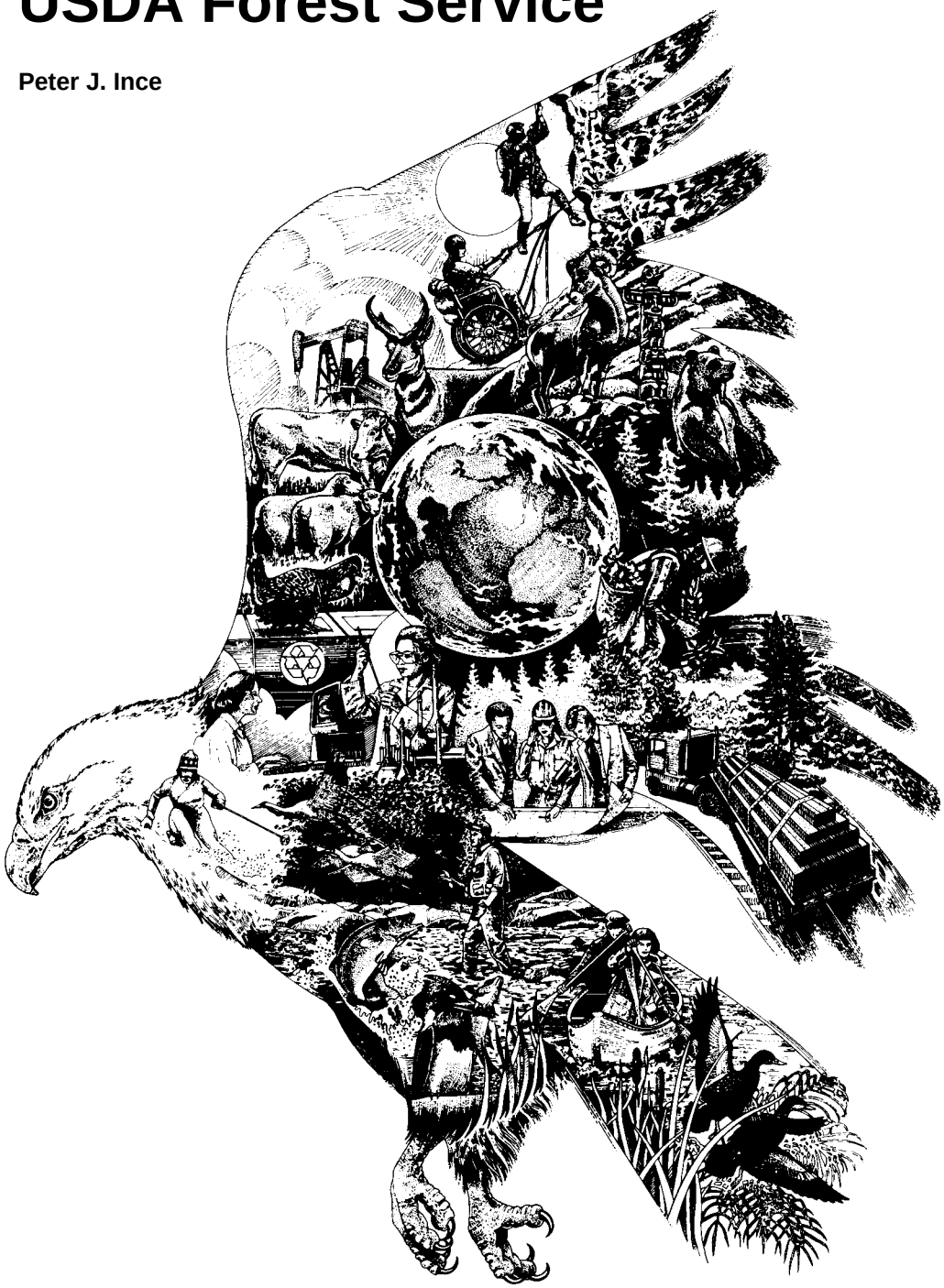
Recycling and Long-Range Timber Outlook

Background Research Report
1993 RPA Assessment Update
USDA Forest Service

Peter J. Ince



Abstract

This research report presents an economic analysis of the U.S. and Canadian pulp and paper sector, and addresses the issue of paper recycling and its projected impact on the long-range timber outlook. The report describes the structure, data, and assumptions of a comprehensive economic model developed to simulate competitive future evolution of technology and markets for all products and fiber inputs of the U.S. and Canadian pulp and paper sector. The model was linked by iterative solution to the USDA Forest Service TAMM/ATLAS model, which encompasses the lumber and plywood sectors, timber stumpage markets, and timber growth and inventory. Thus, results are based on a comprehensive economic assessment of future trends in paper recycling and future impacts on timber markets throughout the forest and forest product sectors of the United States. Projections extend five decades into the future, to the year 2040. The results lead to the conclusion that rapid increases will occur in U.S. paper recycling rates in the 1990s, followed by more gradual increases in subsequent decades. Increased recycling will expand fiber supply and extend timber resources in the United States. Pulpwood prices are projected to remain relatively stable in the decades ahead, while pulp, paper, and paperboard production in the United States is projected to increase substantially. The U.S. balance of trade in pulp, paper, and paperboard commodities is projected to swing strongly in favor of U.S. exports. However, contrary to earlier findings based on the 1989 RPA Assessment, results indicate that the United States still faces serious timber supply problems for softwood sawtimber despite projected increases in recycling rates. National Forest timber harvest levels are projected to decline to levels much lower than those predicted in the 1989 Assessment. Other adjustments since the 1989 Assessment include higher demand for softwood lumber and plywood in the United States, lower Canadian lumber production, lower private industrial sawtimber harvests in the U.S. West, increased imports of softwood lumber, and reduced softwood log exports from the Pacific Northwest. The net economic impact of the adjustments is that softwood sawtimber prices in the United States are projected to increase substantially in the future. Consequently, earlier conclusions that increased recycling could stabilize softwood sawtimber prices are no longer warranted.

The NAPAP Model data and projections presented in this report were derived from the 3/5/93 NAPAP Model data set, with exogenous timber supply projections from TAMM/ATLAS run LR123. The TAMM/ATLAS projections presented in this report were obtained from the draft TAMM/ATLAS run for the 1993 RPA Update, which incorporated pulpwood projections from the NAPAP Model run dated March 5, 1993.

Keywords: RPA, NAPAP, economics, paper

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Disclaimer

Projections shown in this report are the result of long-range economic modeling based on supply and demand theory. The projections are intended only to provide a professional opinion about directional trends of the future. The projections should not be viewed as official endorsement of specific outcomes or events, and they do not represent outcomes that are certain to occur in the future. Ongoing changes in markets and technology will certainly render these projections obsolete, and reasonable variation in data and assumptions can lead to a wide range of projected future outcomes apart from the projections shown in this report. The data and projections are presented here solely for the purpose of explaining the assumptions and detailed analysis of paper recycling and long-range timber outlook that was developed for the Forest Service 1993 RPA Assessment Update.

Contents

	Page
Emergence of the Issue	1
Landfill Crisis and Solid Waste Management Dilemma	1
Relevance to RPA Assessment	5
Questions Addressed in This Report	7
Previous Studies	7
RPA Assessment Studies	8
Definition of Issue	9
Objectives of 1993 Update	10
Methods and Approach	10
NAPAP Model	11
Development of NAPAP Model	12
Previous Pulp and Paper Sector Models	14
Methodology of NAPAP Model	15
Long-range Projections by NAPAP Model	17
NAPAP Model Structure and Data Base	18
Regional Structure	18
Product Categories, Processes, and Base-year Capacity	19
Process Data	19
Pulpwood Supply	46
Linkage to TAMM/ATLAS Model	48
Recovered Paper Supply	50
Maximum Feasible Recovery Constraints	51
U.S. and Canadian Domestic Product Demand	51
Export Demand	55
U.S. Import Supply	58
Energy and Labor Input Supply	58
Transportation Costs, Exchange Rates, and Ad-valorum Import Taxes	59
Capacity Change, Capital Costs, and Capacity Depreciation Assumptions	60
NAPAP Study Results	61
Projected Consumption (Demand) for Paper and Paperboard	61
Projected Production and Technological Trends	61
U.S. Trade Flow Projections	83
Projected Paper Recycling Rates	83
Projected Supply and Price Trends	90
Projected Lumber, Plywood, and OSB Production	96
Projected Timber Trends	97
Projected Employment Trends of Pulp and Paper Sector	102
Conclusions	102
Implications of Results	102
Alternative Scenarios	104
References	105
Additional Sources of Information	108
Glossary	109

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Emergence of the Issue

The issue of recycling and long-range timber outlook has two basic elements. First, the issue concerns paper recycling—specifically, what is the future of paper recycling? Second, the issue concerns the use and adequacy of forest resources— what is the future of supply and demand for virgin timber and recycled wood fiber resources in North America? Assuming that competitive markets will determine the allocation of resources in North America, the two elements merge into a single economic issue: what will be the market allocation of resources in the forest products sector in the future, considering both the short-run allocation of wood and fiber resources and the long-run allocation of technological and capital resources? Although this issue is singular when framed in the context of resource economics, it is necessary to note how both elements of the issue have emerged separately in recent years as a result of their significant externalities and potential government policy dimensions. Government policies designed for broader social benefits in the 1990s, related to recycling and use of forest resources, could alter the allocation of resources that would otherwise be obtained optimally only among market participants. Thus, potential for change in government policies is an important part of the issue.

Landfill Crisis and Solid Waste Management Dilemma

In industrialized countries of North America, Europe, and East Asia, the latter half of the 20th century has been characterized by sustained economic growth, rapid expansion of consumer goods markets, and increased urbanization. In the United States for example, a growing and more urbanized economy has consumed paper and paperboard products in steadily increasing volumes, rising from 22 million tonnes annually in 1949 to over 75 million tonnes in 1990 (API 1960–1992). Although some organized means of trash collection and disposal was provided in industrialized countries throughout this period, the approach to waste management evolved. In some instances, waste disposal created significant environmental and economic problems. To a greater or lesser extent, depending on degree of urbanization and waste management techniques, the same problems are now recognized throughout the industrialized and commercially developed regions of the world.

Since the mid-1980s, there has been a significant and continuous upward shift in paper recycling rates in the United States. While paper recycling may be extolled as a means of conserving forest resources, concern about forest resources is not the real economic reason for the shift in paper recycling. The shift upward in recycling is primarily a response by the paper industry to increased supplies of paper being recovered for recycling. Recovery of paper for recycling has been increased substantially in recent years as a result of widespread expansion of paper collection and sorting programs (e.g., community-based curbside collection, sorting, and office wastepaper collection). Such programs themselves have been directly or indirectly a response to long-term environmental, economic, and human health problems associated with landfills, waste incineration, and solid waste management. In economic terms, the expansion of collection and sorting programs has led to cheaper and more abundant supplies of recovered paper, and this market phenomenon has provided the economic incentive for industrial expansion of paper recycling. Thus, while paper recycling technology and concern about forest resources have coexisted in North America for many decades, the landfill crisis and solid waste management dilemma actually precipitated the departure from historical trends in paper recycling.

In North America, particularly the United States and Canada, the approach to municipal solid waste (MSW) disposal followed an evolutionary path that gradually led to the current landfill crisis and solid waste management dilemma. Several decades ago, it was not uncommon for trash to be discarded in local "dumps." Dumps were usually in rural or remote locations, often managed rather minimally by local governments. Trash would be dumped and commonly burned at such sites. In some locations, trash was also used as a fill material for landscaping or land recovery projects. In part in response to growing concerns about air quality associated with open incineration and nuisance concerns associated with open dumps, the practice of landfilling became increasingly the more common approach (burying trash in layers, with intervening layers of soil). It has been estimated that throughout the 1960s and 1970s, roughly 90 percent of MSW generated in the United States was landfilled (Franklin Associates 1988). By the early 1970s, approximately 300 to 400 new municipal landfills were being built in the United States each year ((NSWMA 1992). However, as environmental, economic, and human health problems associated with landfilling became more widely appreciated, installation of new landfills declined dramatically to less than half their previous number by the late 1980s (NSWMA 1992).

In 1978, approximately 20,000 MSW landfills were operating in the United States, but more than 14,000 were closed in subsequent years due to environmental risks, operating costs, or limits on capacity. By 1990, only about 6,000 MSW landfills were in operation (Denison and Ruston 1990). More than half of the United States are now projected to have less than 10 years of remaining landfill capacity (NSWMA 1992). In the meantime, trash volumes have increased to 178 million tonnes per year in the United States (EPA 1992), roughly doubling over a 30-year period (NSWMA 1992).

The volumes of MSW generated in the United States have been projected to increase substantially in the years ahead (Fig. 1). A recent report by the U.S. Environmental Protection Agency (EPA) projected that the amount of MSW generated will reach 202 million metric tonnes by the year 2000, without additional source reduction (EPA 1992). It was estimated that in 1990, 37.5 percent (by weight) of all MSW generated in the United States was paper and paperboard (Fig. 2). Paper and paperboard is by far the largest single component of MSW. These circumstances led to the present solid waste management dilemma: what to do about increasing volumes of garbage, including substantial volumes of wastepaper, against a backdrop of limited landfill space and availability.

Current systems for MSW disposal in the United States are based on three principal approaches: landfilling, recycling, and incineration. While waste volumes have increased, recycling and incineration have increased proportionately faster than landfilling in recent years. In 1992, the EPA

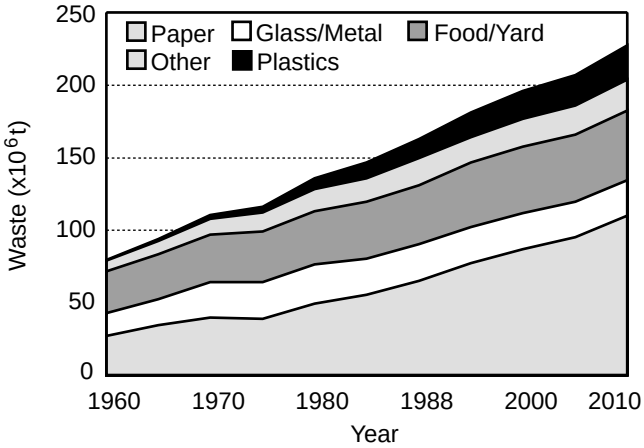

Figure 1—Historical and projected trends in waste materials generated annually in MSW (Source: EPA 1992).

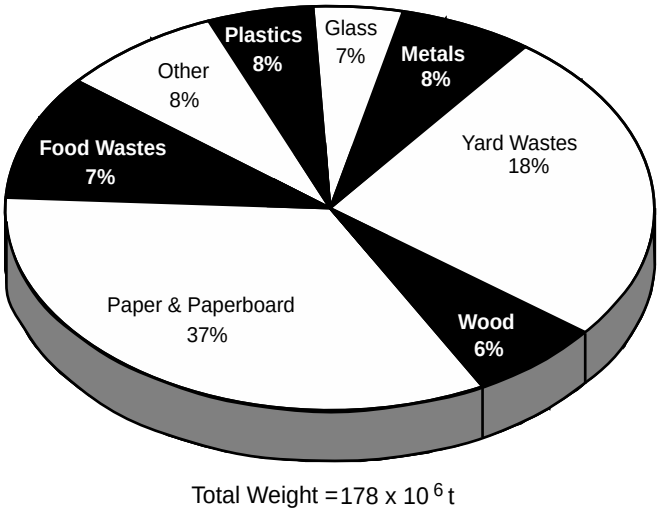

Figure 2—Estimated proportions of materials generated in MSW, 1990 (Source: EPA 1992).

estimated that 17 percent of MSW was recovered for recycling or composting, 16 percent was incinerated, and 67 percent was landfilled or otherwise disposed of (EPA 1992). The percentages vary by type of waste material (e.g., higher proportions of wastepaper are recycled—roughly one-third). Landfilling remains the primary disposal mechanism despite the fact that landfill space and availability are declining. Recognizing environmental, economic, and human health problems associated with each option, the EPA recommended a hierarchy for evaluating components of integrated waste management programs. The EPA hierarchy placed source reduction (simply reducing consumption and disposal of materials) at the top of the hierarchy along with recycling (including composting), while waste combustion and landfilling were placed lower in the hierarchy (EPA 1989). To understand this hierarchy and potential policy choices, it is necessary to understand the root environmental, economic, and human health problems associated with each disposal option.

Although landfilling was once viewed as a benign and efficient option for waste disposal, that perspective has now substantially changed, from both a scientific and technical standpoint and an economic and public perspective. Basic problems associated with landfills are groundwater contamination by landfill leachate and landfill gas emissions. Surveys have shown that MSW landfill leachate generally contains concentrations of toxic and carcinogenic substances that greatly exceed human health exposure standards (EPA 1988; OTA 1989). Contaminants in MSW landfill leachate with concentrations well above exposure standards run the gamut from inorganics such as lead, mercury, cadmium, and zinc, to organics such as benzene, phenol, and tetrachloroethylene, and a complex array of other toxic and carcinogenic compounds. Contamination of groundwater by landfill leachate and surface water by landfill runoff represents a serious hazard in the United States where virtually all municipal and rural drinking water comes from groundwater wells or surface water sources. When groundwater or surface water sources become contaminated, switching to alternative sources of potable water can be very expensive for individuals and local communities. Gas emissions include carbon dioxide and methane (hazardous as toxic and explosive) from decomposition of organic materials, along with other carcinogenic compounds such as benzene, vinyl chloride, and methylene chloride, some of which are associated with degradation of plastics. While severity and risk of these problems can vary significantly depending on materials placed in landfills, local climate (rainfall and temperature), soil conditions, elevation of the water table, and proximity to local population, such problems are in fact being encountered in all regions of North America where landfills have been sited in recent decades.

In some cases, problems have stemmed from poor landfill management practices of the past that may not be characteristic or even legally acceptable today, but public perception of problems has led to widespread local public opposition to siting of new landfills in general. Optimal landfill design has improved such that problems of groundwater contamination and gas emissions may be technically limited or ameliorated to some extent (via installation of less permeable clay substrates and plastic liners to contain leachate and vents to disperse gases). However, such improvements and their long-term management harbor uncertainties and can be quite costly. In 1989, only 1 percent of landfills were estimated to have plastic liners to control landfill leachate (OTA 1989), and only about one in twenty had a leachate collection system (Denison and Ruston 1990). In the long term, even the best liner and leachate collection systems will ultimately fail due to natural deterioration. Thus, problems will continue to surface with older existing and abandoned landfills, requiring in many cases substantial remedial expenditures by various branches of government.

In the United States, cleanup costs for particularly hazardous sites are borne in part by Federal funding via the so-called Superfund administered by EPA, while local communities and states bear costs of cleaning up other less hazardous sites. Billions of dollars have been spent in recent years on remediation and cleanup of abandoned landfills, dumps, and other waste disposal sites. By 1988, more than 20 percent of toxic waste sites on the Superfund National Priority List were MSW landfills (249 of 1,177 Superfund NPL sites), and 8 of the 20 worst Superfund NPL sites were MSW landfills (Denison and Ruston 1990). Many communities now face very substantial remedial costs to clean up or rectify contamination problems associated with locally abandoned landfills, or costs to enhance the quality of existing waste management and disposal systems. Such costs can place very heavy financial burdens on local governments, which must also provide education, police protection, and other local community services. Thus, the landfill crisis has also contributed to a crisis of community welfare and stability in many localities.

In addition to substantial cleanup costs, landfills are associated with price effects on private real estate located within their vicinity. In general, landfills impose negative price effects on local real estate values, particularly the value of residential housing, or people are willing to pay higher prices for residential sites that are not affected by the nuisance problems of landfills. One empirical study based on a sample of home values in Minnesota found that location of residential housing in proximity to a landfill depressed home values by 12 percent for homes located near the landfill boundary and by 6 percent for homes located at a distance of about 1.6 km from the landfill (Nelson and others 1992). Nuisance problems associated with landfills can include noise of equipment operation, flies and other insects, traffic congestion, operation of the landfill at odd hours of the day or night, odors and drifting debris, and general appearance of the site. Beyond about 3.2 to 4 km from the landfill, adverse effects on property values were negligible.

Widespread recognition of environmental, economic, and human health problems led to the decline in siting of new landfills in the 1980s and to siting of landfills in more remote locations (often in neighboring states). As the local availability of new landfills began to decline or landfills were located in more remote locations, fees increased substantially for disposal of garbage in landfills. Such fees, called landfill tipping fees, increased the most in the more densely urbanized North and East, but also to a lesser degree in the South and West. Between 1982 and 1990, tipping fees (measured in constant 1986 dollars) increased 386 percent in the North (nearly 500 percent in New England), 221 percent in the South, and 210 percent in the West (NSWMA 1992). Rapidly escalating tipping fees, along with concern about the economic, environmental, and health problems of landfills, prompted many local and state governments and other institutions to initiate programs for collection and sorting of materials for recycling, to divert material from landfills and extend the life of existing landfills. From the perspective of the mid-1980s, recycling programs appeared to offer a potentially lucrative option to escalating landfill tipping fees

or disposal costs. Materials could be collected, sorted, and sold, instead of landfilled at a cost. In reality, by 1990, most municipal collection programs ("recycling" programs) did not actually pay for themselves by sales of recyclables, but did afford substantial benefits by avoidance of disposal costs. The collection programs have proliferated rapidly in recent years to the extent that they have created an unprecedented sustained glut in the markets for certain recyclables, such as recovered paper.

Between 1983 and 1991, 25 states enacted laws mandating that their local communities make provisions for recycling (i.e., collection of recyclables) or otherwise provide their citizens with the opportunity to recycle (Alig 1992). The number of communities with active collection programs soared from less than 1,000 in the late 1980s to more than 4,000 by 1992. In the meantime, countless businesses, establishments, and other institutions also established recycling programs. Since paper and paperboard has generally represented the largest single component of MSW (Fig. 2), it was natural that paper recovery became a major focus of the new collection and sorting programs. Ironically, by vastly increasing the collection of recyclable paper, the collection programs created a glut in markets for recovered paper as growing demand could not match the rapidly increasing supply. The glut in recovered paper markets, with prices significantly depressed for old newspapers (ONP) and old corrugated containers (OCC), has been most acute in the Northeast and upper Midwest in recent years. It can be noted that paper recycling does not wholly eliminate landfill burdens, as paper recycling mills generate sludge—a residual by-product consisting of broken fibers and residual material (such as clays and pigments) from the paper, which in turn must be landfilled or disposed of by other means such as incineration or land spreading. However, collection programs have generally achieved the purpose of diverting significant quantities of materials from local landfills. Paper collection and recycling continue to grow at a rapid pace in the United States.

In the face of the market glut created by increased collection, some states have enacted laws aimed at further "stimulating" demand for recyclables, such as minimum mandatory recycled content laws for newsprint, which were passed by 12 states between 1989 and 1992. Such laws generally require newspaper publishers to certify that the newsprint in newspapers contains a certain minimum percentage of recycled fiber (usually around 40 percent), with a graduated timetable for implementation of the law (usually by around the year 2000). Voluntary agreements by publishers to use recycled newsprint exist in 13 other states. Similar state laws for telephone directories have been passed by a few states, but so far no other paper products have been thus regulated (Alig 1992). Consideration has been given to such regulation at the Federal level (most notably in bills submitted recently for reauthorization of the Resource Conservation and Recovery Act of 1972, and in proposals by various public interest groups) but no Federal action has been taken thus far.

In the meantime, the sustained glut in recovered paper markets (with prices having been depressed for several years) has provided economic incentive for substantial investment in recycling capacity by the pulp and paper industry. Between 1989 and 1992, over 100 major projects were announced in the pulp and paper industry for expansion of existing capacity or siting of new mills for the use of recycled fiber (API 1991a). Although the capital investment and construction process was prudently gradual in response to the market conditions (recovered paper prices have historically been rather volatile, and new paper mills represent large capital investments), it is now clear that the pulp and paper sector is in the midst of a major upturn in recycling rates. As illustrated subsequently in this report, it is anticipated that the industry response will gradually eliminate the market glut and push recovered paper prices to significantly higher levels, perhaps obviating the intent of mandatory recycled content laws.

In addition to recycling, incineration and other options are alternatives to landfilling. Wood or wood fiber alone is a fairly clean combustion fuel, with insignificant quantities of sulfur compared with coal for example, but with moderately low combustion heat value (approximately half to two-thirds that of low grade coal on a dry weight basis). In the United States, incineration of wastepaper occurs primarily in MSW incineration facilities. Two types of facilities are common: the so-called "mass burn" facilities and refuse-derived fuel (RDF) facilities. The mass-burn facilities consume primarily unsorted MSW, which may contain substantial quantities of wastepaper. The RDF facilities operate with a presorting or classification system that separates the more highly combustible components of MSW (e.g., wastepaper, plastics, and organics) for fuel. By 1990, approximately 160 large waste combustion facilities were operating nationwide (Denison and Ruston 1990). Most of the large facilities recovered some usable heat energy, such as electrical energy or low pressure steam for heating municipal buildings, while some facilities served only as trash incinerators. In general, the primary function of all such facilities has been to reduce the volume of waste (via conversion of bulky quantities of MSW into more compact volumes of ash, which can be one-quarter to one-third by weight of the input waste (Denison and Ruston 1990). Characteristic problems associated with MSW incineration include adverse impacts on air quality and the need for ash disposal (generally via landfilling).

The MSW waste incinerators emit a range of air pollutants that pose human health risks, including heavy metals, acidic gases, and toxic organic compounds such as dioxins and furans (Denison and Ruston 1990). Waste incinerator ash generally contains high levels of toxic metals and organic compounds, which are more readily dispersed through the environment in more concentrated amounts than in MSW (i.e., contaminants are more readily leached from the ash in a landfill, and more readily inhaled or ingested by humans in the form of fly ash). Consequently, widespread public opposition to siting of large waste incineration facilities has

appeared, akin to public oppostion to siting of new landfills. Depending on the type of waste material being incinerated and the type of combustion process, the capital cost of ensuring compliance with air quality standards can be very high; devices such as flue gas scrubbers, precipitators, and baghouses are required to reduce air emissions and fly ash particulates. Such equipment requirements lead to significant economies of scale, where only very large facilities are economical. Such facilities generally require enormous capital investments, generally in the range of hundreds of millions of dollars each (Denison and Ruston 1990). The primary source of revenue at MSW incineration facilities are payments received for accepting garbage (tipping fee revenues), while revenues from sale of energy generally cover only a small fraction of costs. A higher degree of fuel presorting can help remove the more hazardous materials prior to combustion, but sorting can be costly and may approach the cost of sorting required for recycling. Thus, waste incineration can remain economical in the future only to the extent that MSW or RDF have low or negative values (i.e., if payment is received for accepting such materials). If prices for sorted recovered paper increase substantially in the future, use of recovered paper as fuel may become highly uneconomical. However, use of certain categories of nonrecyclable wastepaper (i.e., wastepaper that has no higher value because of contaminants, low fiber quality, etc.) may remain a viable option. This report includes projections of recovered paper prices and further discussion of the economic potential for wastepaper incineration versus recycling.

Composting and various other uses are other alternatives to landfilling and conventional paper recycling. In many communities, MSW or sorted organic material from MSW is composted, producing a relatively inert soil amendment or mulching material. Composting can be applied to wastepaper. The MSW is composted most efficiently in composting facilities, which commonly feature a large composting vessel or digester that can reduce organic material to acceptable compost in a matter of weeks or days. An economic drawback to the composting option for wastepaper is the relatively low potential value of the end product, at most having the value of a gardening soil or mulching material. As with incineration, composting will remain economically viable only as long as the input waste materials have little or no value, or if payment is received for accepting such materials. To the extent that prices for recovered paper increase in the future with increased recycling, only the disposal of low-value nonrecyclable wastepaper via composting will remain economical. Other utilization options that have been applied commercially to wastepaper include cellulose insulation, molded pulp products, animal bedding, paper mulch, packaging cushioning material, and wallboard panels (API 1991b). Actual use of recovered paper for molded pulp products (egg cartons, containers), cellulose insulation, and other uses is estimated to have nearly doubled between 1986 and 1991, but the total quantity is still estimated to be only around 1 million metric tonnes per year. Generally, such products have low value, either because the recovered paper is used as a substitute for low-value materials (e.g., animal bedding straw, garden mulch) or it competes against materials with better-perceived product performance (e.g., insulating materials such as foam or fiber glass, or plastics used in lightweight containers). One example of an exception to this rule is composite plasterboard wall panels, introduced recently as a substitute for conventional gypsum wallboard. The new panels are a composite of recycled fiber (from old newspapers) and gypsum, and are reputed to have advantages of lighter weight and better nail-holding performance. Thus, recycling paper into higher value composite products might represent an economically viable alternative for use of recovered paper, even if recovered paper prices increase in the future.

In summary, to understand the issue of recycling and the long-range timber market outlook, it is essential to understand the landfill crisis and solid waste management dilemma. Management of solid waste is a growing concern of industrialized nations throughout the world. In the United States, the concern is manifested by efforts to find alternatives to landfilling as the principal means of waste disposal and to extend the life of existing landfills. Concern is prompted by serious environmental, economic, and human health problems associated with landfills, principally groundwater contamination and gas emissions, and their high remedial costs. Awareness of problems has led to a significant decline in siting of new landfills, shortages of local landfill capacity, and escalating landfill tipping fees. Principal alternatives to landfilling include source reduction, sorting and collection of material for recycling, waste incineration, and composting. Preferred options, according to EPA, include source reduction, recycling, and composting. Landfilling and incineration are least preferred. Each option has its drawbacks. Collection and sorting for recycling face challenges due to the glut in markets for recyclables, created ironically by increased collection and sorting nationwide. Incineration faces environmental and economic problems associated primarily with air emissions and ash disposal, and economics may limit the competitiveness of waste-to-energy versus recycling if the value of recovered paper increases in the years ahead. Likewise, composting produces a product with relatively low value. Potential exists for stronger government policies related to waste reduction, recycling, and increased collection of materials for recycling. This analysis may provide the basis for examining potential impacts of such policies in the context of projected evolution of markets and technology.

Relevance to RPA Assessment

The Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA), the National Forest Management Act of 1976 (NFMA), and the Forest and Rangeland Renewable Resources Research Act of 1978 require the USDA Forest

Service to develop comprehensive long-range assessments of supply and demand for timber and other forest resources in the United States. A new RPA Assessment report is provided every 10 years, with interim updates every 5 years. The decennial Assessment reports and their interim updates include detailed analyses of the prospective timber supply and demand situation in the United States. The reports include long-range projections of timber market trends (regional supply, demand, and prices), forest product demand, domestic production, and technological changes in major forest product sectors of the U.S. economy (including the pulp and paper sector). The RPA Assessment reports have been prepared since the 1970s. The timber analysis component of the RPA Assessment follows a much longer tradition of Federal timber outlook studies, dating back to the late 19th century (for bibliography of such studies, see the preface to Forest Resource Report 23, USDA Forest Service, 1982). The most recent RPA Assessment report was completed in 1989 (USDA Forest Service 1989a), accompanied by publication of a more detailed long-range analysis of the timber situation in the United States (Haynes 1990). The next scheduled report is the 1993 RPA Assessment Update, which will assess key forest resource issues that have surfaced in recent years. The RPA Assessment and interim updates provide a factual and analytical basis for the RPA Program of the Forest Service, a program of recommended agency activities that is revised and submitted to Congress every 5 years under the provisions of RPA. Forestry professionals in both the public and private sectors also frequently use the long-range RPA timber analysis and projections as benchmarks for discussion of forest policy and timber supply and demand issues.

Looking at data and projections from the most recent timber analysis (Haynes 1990), it is apparent that demand for timber has grown substantially in recent decades and is expected to grow substantially in the future. Figure 3 shows historical data on timber consumption in the United States by timber product category since 1952, along with 1989 RPA Base projections to the year 2040. The pulpwood share of total timber consumption has grown in recent decades, and has been projected to grow substantially in the decades ahead. However, the 1989 RPA Base projections assumed a very conservative trend in paper recycling rates. Figure 4 shows historical data on timber demand from U.S. forest lands, with imports and exports, along with 1989 RPA Base projections to the year 2040. Of approximately 500 million m^3 of commercial timber supplied annually from timberland in the late 1980s, approximately one-fourth was pulpwood supplied directly to pulp mills. In addition, by the late 1980s, timber coming directly from the forest represented only about 60 percent of pulpwood input to pulp mills; around 40 percent of pulpwood was obtained indirectly as wood residues (wood chips) from sawmills and veneer mills. Therefore, total pulpwood consumption, including timber harvest and mill residues, amounted to over 200 million m^3 annually by the late 1980s, or over 40 percent of the timber

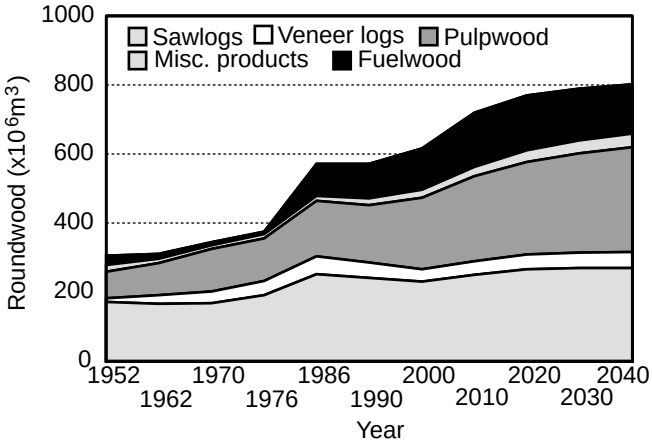

Figure 3—U.S. roundwood consumption, specified years 1952–1986, with 1989 RPA Base projections of demand to 2040.

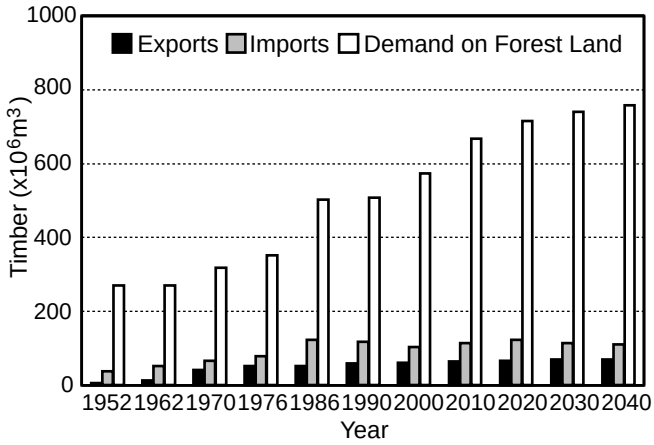

Figure 4—U.S. timber demand, specified years 1952–1986, with 1989 RPA Base projections of demand to 2040.

supplied from U.S. timberlands. In the 1989 RPA Base case, this percentage was projected to grow to over 50 percent in the decades ahead. Thus, in the 1989 RPA Assessment report, projected growth in pulpwood consumption was a major element in projections of substantially increased timber consumption in the United States.

Although net annual growth and inventory of timber growing stock have been steadily increasing in recent decades, and although timber supply is expected to increase in the future, the 1989 RPA Assessment Base projections showed that overall growth in timber demand would generally exceed growth in timber supply. This resulted in projected increases in timber prices, particularly increases in softwood timber stumpage prices in the U.S. West and U.S. South (Haynes 1990). This general assessment of the future, that timber prices would increase substantially over the long term, was not dissimilar to conclusions of other recent timber analysis

studies (e.g., USDA Forest Service 1982, 1988). Furthermore, forest policy developments of the past few years related to mandatory preservation of habitat for endangered species (most notably actions taken on Federal lands in the Pacific Northwest to preserve old-growth forest habitat for the Northern spotted owl, effectively constraining timber supply) have given greater weight to a conclusion that timber prices will rise substantially in the future. Adding future constraints on timber supply, such as preservation of old-growth forests, resulted in greater timber scarcity and even higher projected timber price trends when extrapolated from the 1989 RPA Assessment Base (see Schallau and Goetzl 1992). However, such conclusions were based on a timber supply and demand scenario that assumed very low future paper recycling rates. The 1989 RPA Base, for example, assumed no increase in paper recycling rates nationwide between the years 1986 and 2000, and only very small increases thereafter. In reality, the United States in the short period since the mid-1980s has experienced the most dramatic increase in paper recycling rates since World War II.

Questions Addressed in This Report

The methodology and analysis presented in this report were designed to address specific questions related to the issue of recycling and the long-range timber outlook. As we have stated, the fundamental question was what will be the market allocation of resources in the forest products sector in the future, considering both the short-run allocation of wood and fiber resources and the long-run allocation of technological and capital resources? To answer that question, the methodology and analysis answered the following questions: what will be the likely competitive evolution of technology in the pulp and paper sector of North America, considering simultaneously the evolution of product demand and trade, pulpwood markets, and recovered paper markets, and what will be the future competititve evolution of paper recycling in North America? With linkage to a comprehensive economic model of timber growth, inventory, and the solid-wood product sector (i.e., the Forest Service TAMM/ATLAS model, which includes lumber and plywood sectors), the analysis also answered the question of what will be the likely trends in sawtimber markets, lumber production, plywood production, timber harvest, and timber inventory levels in the United States.

In addition, the analysis looked at the overall question of whether projected trends present an “acceptable” or “impaired” future, in terms of resource conditions and resource use. Thus, the analysis provided specific answers to the following policy-related questions (discussed in the Conclusions):

- Will increased paper recycling extend timber resources?
- Will paper recycling eliminate future U.S. timber supply problems?
- What aspects of the future timber supply and demand situation will remain problematic?
- What are the implications for forest management?
- Will increased paper recovery (for recycling and export) either eliminate or reduce the disposal burden associated with wastepaper?
- Will paper recycling be offset by alternative disposal options such as wastepaper incineration?
- Will increased recycling and economic growth in the pulp and paper sector contribute to increased regional employment in pulp and paper mills or to a better balance of trade?
- What are the implications for forestry research and forest products research, associated with projected trends in recycling and timber markets?
- Considering paper recycling and policy options, what alternative future scenarios are possible, and how would policy changes affect the projected trends?

Previous Studies

Much public attention has been brought to bear in recent years on the separate issues of waste management and the long-range timber market outlook, but most published studies have not focused on their relationship as a single issue. Studies focused primarily on solid waste management have been sponsored by state and local governments, Federal agencies, and environmental public interest groups. Studies focused more narrowly on paper recycling have been sponsored by the pulp and paper industry, states, and consultants or advisors to policymakers at the Federal level. Studies focused on timber issues have been sponsored more commonly by the forest products industry, USDA Forest Service, and various public interest groups. Few studies have synthesized trends in recycling and long-range timber markets (or recycling and long-range materials policy in general).

Recycling has become a top issue on state legislative agendas because of public concern over problems such as solid waste management and environmental pollution, and to a lesser extent energy conservation and resource management. The National Conference of State Legislatures, for example, sponsored a report that examined different approaches to developing recycling markets and industries (Thurner and Ashley 1990). The report noted that in recent years state recycling efforts have encouraged the collection of recyclable materials, but have largely ignored the market demand for such materials; consequently, state efforts have not always been successful and have sometimes produced gluts of recyclable materials. Likewise, the United States

Conference of Mayors has focused primarily on resource recovery and options to landfilling, sponsoring work such as an annual report on the status of energy and materials recovery facilities in the United States (see National Resource Recovery Association 1990). Similar data on waste combustion facilities are also compiled (but not published) by the U.S. Department of Energy. Public interest groups, such as the Environmental Defense Fund, have sponsored in-depth studies that evaluate economic and environmental aspects of choices that must be made by state and local governments in developing recycling programs and waste incineration facilities (Denison and Ruston 1990). In addition, Federal agencies such as the EPA and the Office of Technology Assessment have sponsored major studies that have provided substantial data on the status of waste management and waste materials generated in the United States (see, for example, EPA 1988, 1989, 1990; OTA 1989). In general, such studies have provided useful information about the current landfill crisis and solid waste management dilemma. However, such studies generally have not examined future consequences or expected outcomes of the current dilemma from a national perspective. Thus, the focus of most broad studies has been on the dimension and character of waste management problems from a static perspective, rather than on dynamic factors, such as the likely evolution of competitive markets or technology in response to the solid waste management dilemma.

On the other hand, studies focused more narrowly on paper recycling have generally emphasized the dynamic character of markets or the development of recycling as a market response to the solid waste management dilemma. Perhaps the classic example is the 1982 report for the Solid Waste Council of the Paper Industry (Franklin and others 1982). This study heavily relied on historical industry data from the American Paper Institute (API). It discussed in great detail the historical evolution of paper recycling, recovered paper exports, and other uses of wastepaper such as energy recovery. Among the conclusions were the predictions that recovery and utilization rates would likely increase faster in the 1980s and 1990s than they did in the 1970s, that waste-to-energy facilities would expand with increased collection programs in response to emerging solid waste problems, and that increased utilization could eventually have significant impacts on prices for recovered paper if supply limits were reached. A similarly detailed study, describing current trends and the outlook for newspaper recycling, was recently prepared for the Canadian government (Hatch Associates 1989). In 1990, the API sponsored a study by Franklin Associates to develop projections of paper recycling levels to the year 1995 (Franklin Associates 1990). This report provided the basis for a view that recyclable paper recovery rates would reach 40 percent by 1995. Subsequently, the API announced their national goal of 40 percent paper recovery for recycling by 1995. A more recent study by Franklin Associates examined supply and demand for office wastepaper, with projections to 1995 (Franklin Associates 1991). The report was sponsored by the National Office Paper Recycling Project, managed by the United States Conference of Mayors with principal support from a number of leading paper companies. The report concluded that both recovery and demand for office wastepaper were likely to more than double between 1990 and 1995. Among various multi-client studies of recycling trends are those of Resource Information Systems, Inc., which have projected that paper recycling will continue to expand in the 1990s, and that paper recovery rates in the United States are likely to exceed the 1995 industry goal of 40 percent and reach a level of 55 percent by the year 2005 (Young 1991).

Despite rapid acceleration in paper recycling rates and growing concerns about the adequacy of timber resources, few studies have sought to synthesize projections of paper recycling and timber markets. This is not unexpected given that trends in recycling have emerged from the landfill crisis and solid waste management dilemma rather than from concern about future adequacy of forest resources. However, given public awareness that paper recycling can extend forest resources, and awareness that timber resource adequacy is related to preservation issues, it is surprising that the two elements have not been linked in past studies. Awareness of broader dimensions of recycling policies related to materials was reflected clearly in a report by William Kovacs, former Chief Counsel, U.S. House of Representatives, Subcommittee on Transportation and Commerce, describing the history, challenges, and opportunities of solid waste management and recycling (Kovacs 1988). The title of this report, “The Coming Era of Conservation and Industrial Utilization of Recyclable Materials,” as well as its contents, certainly reflected awareness that the nation stood on the brink of a new era in materials policy. However, although the Kovacs report became a landmark for discussion of recycling policy options, it is noteworthy that the report did not actually examine broad consequences of new recycling policies, except by pointing to the likelihood that such policies could substantially alter waste disposal and recycling patterns in the United States. For example, little consideration was given to the question of how increased paper recycling or increased incineration would affect the future of forestry or forest product markets in the United States. It is precisely that analysis of the forestry and forest product market implications of recycling that this study provides, thus increasing the understanding of how new recycling policies will affect society on a broader level.

RPA Assessment Studies

Various approaches lend themselves to analysis of long-range issues in resource economics and agricultural economics. In recent decades, techniques have evolved from investigation of temporal resource conditions and simple trend extrapolation toward development of more sophisticated mathematical or computer models that simulate

dynamic responses or behavioral adjustments over time. Recent experiences in resource economics have provided important lessons on application of modeling techniques. For example, gloomy forecasts of energy shortages in the early 1970s and optimistic forecasts of agricultural commodity export demands in the late 1970s both proved to be incorrect by the 1980s, for similar reasons. In both cases, analyses depended primarily on trend extrapolation and failed to account for significant behavioral adjustments, which tended to offset earlier trends. Projections of energy shortages based on supply constraints in the early 1970s failed to consider the rapid evolution of more energy-efficient technology and development of new energy sources. Projections of booming U.S. agricultural exports made in the late 1970s, based on the historical position of the United States in satisfying growing world food needs, failed to appreciate the widespread application of improved agricultural techniques worldwide, particularly in developing countries. The adaptiveness of competitive free markets coupled with technological change has contributed to a remarkable ability to adjust and capitalize on changing resource conditions. One important conclusion is warranted: Assuming that competitive free markets will prevail in North America, analysis of future resource conditions must take into account mechanisms by which markets adjust to resource conditions and, in turn, the effects of such adjustments on resource markets. Thus, accurate analysis requires appropriate economic modeling techniques.

Definition of Issue

The 1993 RPA Assessment Update was intended to reflect analysis of important issues currently related to long-range forest resource trends, particularly issues that have continued to be important since the 1989 Assessment. Certainly, trends in paper recycling have remained an important issue given the significant upward trend in paper recycling. Figure 5 shows the historical trend in the U.S. recyclable paper utilization rate since 1970 (API 1991). The recyclable paper utilization rate is the ratio of the tonnage of recyclable paper used as fiber input in domestic paper and paperboard mills to total tonnage of paper and paperboard produced. Figure 6 shows the historical trend in U.S. recyclable paper recovery rate for the same period (API 1960–1992). The recyclable paper recovery rate is the ratio of the tonnage of recyclable paper recovered for both domestic use and for export to the total tonnage of paper and paperboard consumed in the U.S. economy. Note that a substantial historical upturn in recycling rates occurred, beginning in the mid-1980s (Figs. 5 and 6). Also note that by 1992, U.S. recycling rates actually reached levels that were not forecast to occur until the year 2040, according to the 1989 RPA Base projections. Thus, the Forest Service recognized that scenarios such as the 1989 RPA Base should not be viewed in isolation from alternative scenarios that show more realistic trends in paper recycling.

Consequently, in the 1989 RPA Assessment report (USDA Forest Service 1989a), in the supporting timber analysis

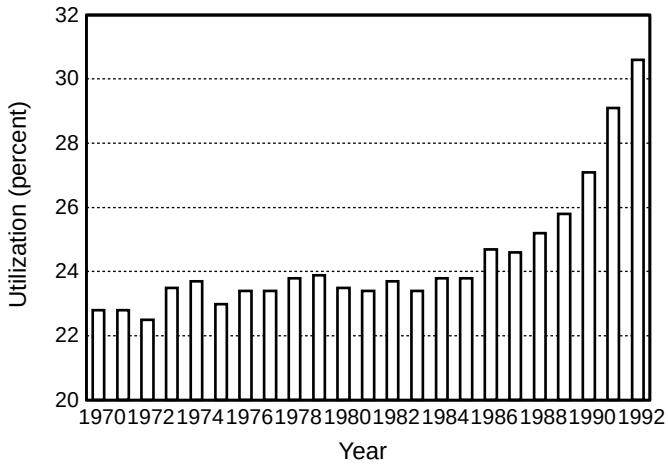

Figure 5—Historical trend of U.S. recyclable paper utilization rate (API 1991). Estimate for 1992.

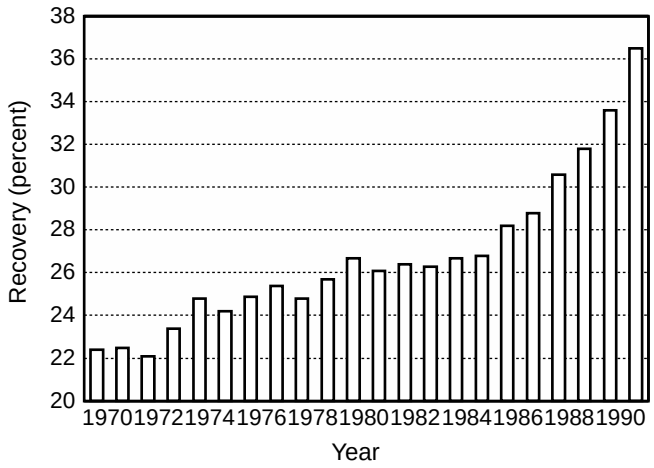

Figure 6—Historical trend of U.S. recyclable paper recovery rate (API 1991).

report (Haynes 1990), and in subsequent reports (Ince 1990, Adams and Haynes 1991), alternative scenarios examined projected impacts on timber markets of increased paper recycling. Generally, such scenarios showed that increased recycling would extend timber supplies and would tend to mitigate projected timber supply shortages and timber price increases to some extent. Thus, one of the more significant conclusions of the 1989 RPA Assessment and subsequent studies was that likely increases in paper recycling could have significant impacts on U.S. timber supply and demand in the decades ahead. For that reason, in 1990 the Forest Service identified recycling and its impact on the long-range timber market outlook as a key issue requiring further in-depth analysis for the 1993 RPA Assessment Update.

As stated previously, assuming that competitive free markets prevail, the future of paper recycling and the long-range timber market outlook devolve to a singular economic issue: what will be the market allocation of resources in the forest products sector in the future, considering both the short run

allocation of wood and fiber resources and the long run allocation of technological and capital resources? Allocation refers essentially to the choice of the competitive free market, the balance between supply and demand. Of course, as discussed earlier in the case of recycling and timber resources, this allocation may be strongly influenced by government policies, which may affect supply or demand. Thus, the issue is defined as an economic issue of resource allocation in competitive markets, although the impact of policy on those markets is also part of the issue and the analysis.

Objectives of 1993 Update

This study was focused on the objective of assessing timber resource implications of expected trends in paper recycling and timber markets. Projections show the expected impact of paper recycling on future markets for pulpwood and recovered paper, and the effects of recycling on timber markets in general and other sectors of the forest products industry. The results provide a basis for comparing the economics of recycling with incineration, composting, and other options in waste reduction, on the basis of projected prices for recovered paper. The results also show the extent to which paper recycling and export of recovered paper will affect overall waste disposal volumes in the future. Finally, the analysis can be extended to show how policy options in recycling, such as source reduction, mandatory minimum recycled content, and increased collection, are likely to change the competitive market evolution of paper recycling technology, and how such policies may affect future timber supply and demand.

Meeting the objectives of this study required certain research tasks, which had their own preliminary objectives. One preliminary objective was to develop a comprehensive economic forecasting model of the entire North American pulp and paper sector. An economic model was needed to simulate the competitive market allocation of resources throughout the pulp and paper sector, to determine the evolution of regional market equilibria and trade flows and the competitive evolution of production technology in the long run, including evolution of technology for using recycled fiber and virgin wood fiber in all paper and paperboard products.

A second preliminary objective was to link the model of the pulp and paper sector to other Forest Service RPA Assessment models, and to project future recycling rates and timber market trends. The pulp and paper model projects annual market equilibria of the pulp and paper sector, and change in production capacity from year to year depending on market conditions. Solutions obtained by the pulp and paper model were linked by iteration with solutions obtained by other Forest Service RPA Assessment models, including the TAMM/ATLAS model, which determines future timber inventory and growth, and future market equilibria in lumber, plywood, and other forest product sectors. Thus, a comprehensive assessment of the entire forest product sector was provided.

Methods and Approach

As in past RPA Assessment studies, the approach of this study was to start with basic assumptions about future economic growth and future population growth in the United States, and to develop a detailed forest product sector model to provide projections based on those assumptions. In this case, an economic model of the entire North American pulp and paper sector was developed. Modeling methods were based on established principles of economic theory, with application of econometrics, regional market modeling techniques, and capital investment theory applied to technology forecasting. Intrinsic assumptions included the assumption that competitive free markets will prevail as a primary mechanism by which wood and fiber resources will be allocated in the forest product sector, and that competitive economics will determine the allocation of capital and technological resources over time. Model constraints and shifts in fiber supply were introduced to simulate introduction of government policies related to recycling.

This study proceeded from a set of basic assumptions about future population and economic growth in the United States, the same growth assumptions that applied in all economic models and supporting studies of the 1993 RPA Assessment Update. These growth assumptions are nearly identical to those used in the 1989 RPA Assessment and related studies (USDA Forest Service 1989b). The RPA growth assumptions were used in our study for years after 1993; actual growth data and near-term growth projections were used up to 1993.

For the 1993 RPA Assessment Update, only one set of basic population growth assumptions was used. Growth in population and the economy has stimulated domestic demand for paper and paperboard products. In the past 50 years, the U.S. population increased by more than 100 million. Projections of the Bureau of Census indicate that population is likely to continue to grow during the next 50 years, but at a gradually declining rate. The population growth assumptions were based on Bureau of Census "middle series" projections with a high immigration assumption (750,000 per year). The high immigration assumption accounts for trends in both legal and illegal immigration. The overall net annual growth rate for U.S. population is projected to gradually decline from around 1 percent in the late 1980s to 0.3 percent by the year 2040. The decline in the rate of population growth reflects Bureau of Census assumptions about fertility rates, which have fluctuated widely in recent decades but generally have fallen sharply since the 1950s. The projections are based on an assumed fertility rate

of 1.9, a level close to current birth expectations of females of child-bearing age. The current fertility rate is actually below 1.9, and it is at a level that may lead to approximately zero population growth in the early part of the 21st century. However, immigration amounts to a significant part of U.S. population growth.

The age distribution of the population is another relevant factor in considering future product demands. Bureau of Census projections by age classes indicate a substantial increase during most of the 50-year projection period in the number and proportion of people in the middle-age classes, which have the highest income levels and largest demands for goods and services. It can be noted that the population growth assumptions are somewhat higher than the 1979 RPA Assessment assumptions (population is projected to be roughly 8 percent higher by the year 2030 than the medium level assumptions of the 1979 RPA Assessment) mainly due to the higher immigration assumption. Figure 7 illustrates the basic assumption for net annual growth in U.S. population that was applied in this study. The population is projected to reach 327 million by the year 2040 under these assumptions; the population was estimated to be 254.8 million in 1991.

Likewise, for the 1993 RPA Assessment Update, only one set of basic economic growth assumptions was used. The U.S. demand for paper and paperboard products has been closely associated with historical changes in real gross national product (GNP; expressed in constant dollars), as well as increases in population. Figure 8 illustrates the basic assumptions for annual growth in per capita real GNP. The economic growth assumptions indicate rising affluence of the U.S. population, with a roughly threefold increase in per capita real GNP assumed between the years 1986 and 2040. Annual changes in real GNP since 1929 have fluctuated widely in a range from -19 percent to +19 percent; the decade with the highest sustained growth was the 1960s, when the change in real GNP averaged 4.2 percent per year. Fluctuations in annual GNP growth have reflected factors such as differences in rates of change in the labor force, rates of unemployment, hours worked per year, and productivity. Fluctuations are likely to continue to occur. Projections of GNP growth were obtained from Wharton Econometric Forecasting Associates (WEFA; see USDA Forest Service 1989b). The WEFA projections have business cycles with economic downturns occurring in 1990, 1998, and 2003. After 2003, no attempt was made to project business cycles and economic growth occurs smoothly throughout the remainder of the projection period. In constant dollars, the projected rates of GNP growth lead to a greater than fourfold increase in U.S. GNP between 1986 and 2040. Projections assume that services will account for an increasing share of GNP, although manufacturing and construction activities are expected to increase in absolute terms as well with large increases in the quantities of physical goods produced in the U.S. economy.

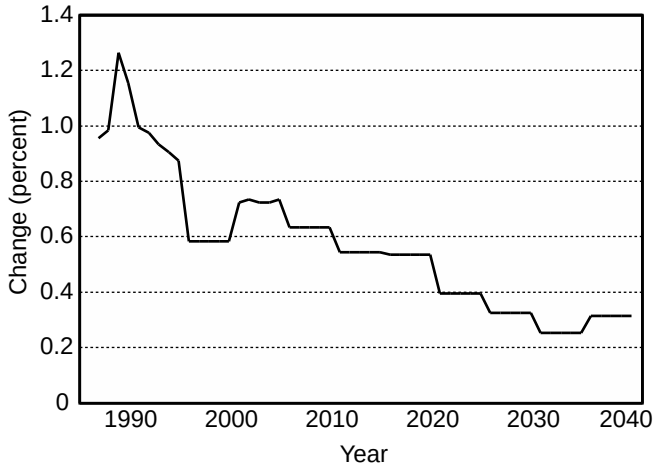

Figure 7—Projections of net annual growth in U.S. population.

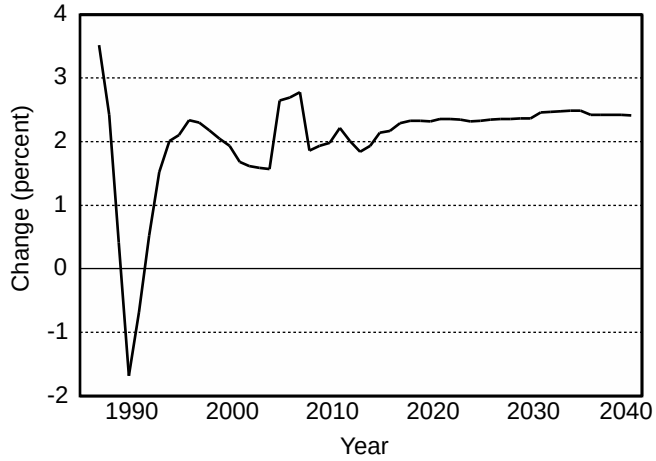

Figure 8—Projections of U.S. annual growth in real GNP per capita.

NAPAP Model

A spatial equilibrium and dynamic process economic model of the North American pulp and paper sector was developed and applied in this study. The model is known as the North American Pulp and Paper (NAPAP) Model (Ince and others 1993). It was developed to project future technological changes, production, capacity, imports and exports, and related market equilibria for the United States and Canadian pulp and paper sector. It incorporates basic RPA assumptions of economic growth and population growth, and includes five North American production or supply regions (Canada East and West, U.S. North, South, and West) and two North American demand regions (United States and Canada). The model combines regional information on supply and demand, manufacturing processes, and transportation costs to compute future market equilibria year to year, using a price-endogenous linear programming system. The model

determines annual growth in production capacity among different processes and regions as a function of their relative profitability and market conditions. It projects evolution of manufacturing processes, regional markets, and trade for 13 principal grades of paper and paperboard, and 5 grades of wood pulp (including market pulp grades). It projects the regional supply and demand equilibria of pulpwood inputs and recovered paper inputs (recycled wastepaper). The model is also a trade model, providing a capability to simulate trade flows and impacts of trade restrictions and exchange rates between the United States and Canada. The model also accounts for United States and Canadian trade with outside trading regions including Atlantic, Pacific, Latin American, and other trade regions.

Development of NAPAP Model

Development of the NAPAP Model was guided by practical observation and economic theory. In the North American pulp and paper sector, and in competitive market sectors generally, technological change and evolution of prices, production, capacity, and trade all occur simultaneously with some interrelationship. This general observation is well supported (see, for example, Landau and Rosenberg 1986, Rosenberg 1982, 1976, Gold 1977, Mansfield 1968, Schmookler 1966), and it is reflected by experience in the pulp and paper sector (see Berard 1977, Strange 1977, Guthrie 1972). Economic theory and models seek to explain how such phenomena are interrelated in an optimizing process under competitive free market conditions.

The RPA required the USDA Forest Service to make periodic assessments of long-term supply and demand, equilibria for forest resources (i.e., to project the competitive market balance between supply, demand, and prices for forest resources). The Forest Service had many decades of experience in making periodic assessments of the timber situation in the United States prior to the RPA, but it was not until the early 1980s that such assessments included projections of equilibrium prices, as well as projections of timber production and consumption (USDA Forest Service 1982). Initially, this was done only for softwood sawtimber, lumber and plywood, using an economic model called the Timber Assessment Market Model (TAMM) (Adams and Haynes 1980). A similar supply and demand model was not available for pulpwood or the complex pulp and paper sector. Thus, in planning model development in the early 1980s in consultation with interested parties in industry and universities, the Forest Service recognized that a model of the North American pulp and paper sector should be developed with specific characteristics, including the capability to project competitive market equilibria within that sector (Gilless and Buongiorno 1987).

In more detail, the specified characteristics of the model included the following:

- The model should reflect the regional character of the industry, especially of the forest resources on which it depends, while recognizing the international setting in which the industry competes.
- The key role played by competitive markets and prices should be recognized, and prices should be endogenous, reflecting the balance between demand and supply forces within and outside the industry.
- The model should represent the technical processes of pulp and paper making in enough detail to explain how they are selected under different economic conditions and how they evolve over time in relation to competitive markets.
- Projected regional shifts of manufacturing capacity should be the result of projected supply and demand conditions in North America and abroad, especially with regard to availability of pulpwood and other fiber raw materials.
- Finally, the model should be designed in a way that it could be linked with TAMM to reflect the interrelationships between the solid-wood products (lumber and plywood) and pulp and paper sectors.

The initial attempt to meet those specifications led to development of a model of the North American pulp and paper industry known as PAPYRUS (Gilless and Buongiorno 1987), which was developed at the University of Wisconsin–Madison, Department of Forestry. PAPYRUS evolved out of earlier models discussed in Buongiorno (1981), Buongiorno and Gilless (1983, 1984), and Gilless (1983). The work was supported by the FPL. PAPYRUS was the first comprehensive economic model of the pulp and paper sector to be developed for the Forest Service with capability to project evolution of regional market equilibria and prices.

Development of PAPYRUS was a truly landmark accomplishment for the Forest Service, not so much for its application (which became limited) as for the methodology development that it embodied. The Forest Service never successfully linked PAPYRUS to the TAMM model, and in some ways the structure of PAPYRUS did not meet all of the Forest Service specifications. Production capacity was allocated among different product grades and regions as a dynamic process, but the evolution of production capacity by process was not simulated in PAPYRUS. Also, PAPYRUS had a somewhat more detailed regional structure and less detailed product grade structure than needed in Forest Service technology assessment studies.

Accompanying (and actually preceding) development of PAPYRUS, Gilless and Buongiorno (1985) developed the general computerized economic modeling technique known as the Price Endogenous Linear Programming System (PELPS). This work was supported also by the FPL. The

PAPYRUS model was a first-generation application of PELPS methodology. Gilless and Buongiorno separately published and presented PELPS as a general system for economic modeling based on regional market modeling theory (Gilless and Buongiorno 1985). Thus, by the mid-1980s, the FPL had supported development of a general methodology for economic modelling of large industrial sectors, with demonstrated application of the technique in the PAPYRUS model and earlier models of the pulp and paper sector.

In anticipation of the 1989 RPA Assessment report, the Forest Service recognized that further analysis would be needed to project significant technological changes taking place or likely to occur in the pulp and paper sector, such as increased use of hardwood in kraft linerboard in the South and increased use of recycled fiber in various product grades. In 1985, FPL researchers were detailed to develop projections of those technological changes, and it was decided to develop an improved economic model for that purpose based on PELPS methodology. The result was the so-called FPL Pulpwood Model (unpublished), which was used to provide economic projections of the pulp and paper sector for the 1989 RPA Assessment (USDA Forest Service 1989).

The FPL Pulpwood Model was a second-generation application of PELPS (following PAPYRUS). The structure of the FPL Pulpwood Model was much less detailed in regional specification (only three U.S. production regions, one production region for Canada, and a single "North American" demand region), but much more detailed in product grade specification than PAPYRUS. Whereas PAPYRUS recognized only three categories of final products—including newsprint, paper (other than newsprint), and paperboard—the FPL Pulpwood Model recognized eight categories of final products, four of paper and four of paperboard (matching the most aggregate product grade categories recognized by the U.S. and Canadian industry trade associations).

More importantly, the FPL Pulpwood Model introduced a technique for modeling technological change that had not been employed in PAPYRUS or earlier models. In developing the FPL Pulpwood Model, it was recognized that production capacity in the pulp and paper sector tended to be fixed not only by location but also by process (e.g., mills could not be "changed" from one type of process to another without considerable expense, just as they could not easily be moved from one location to another). Also, it was recognized that evolution of technology and competitive economic behavior within the pulp and paper sector were interrelated. Therefore, the FPL Pulpwood Model was designed to simulate technological change by allocating growth in capacity over time among competing production processes, as a function of their relative profitability and changing market conditions. Capacity growth each year was allocated to the most efficient among competing processes, with constraints on overall capacity growth by product grade (see Ince and others 1987). Development of the FPL Pulpwood Model was accompanied by development at the University of Wisconsin of an improved microcomputer version of the PELPS system, known as PELPS II (Calmels and others 1990).

The approach to modeling technological change in the FPL Pulpwood Model (and in PELPS II) was significantly different than the technique of PAPYRUS, in which technological substitution of one process for another occurred instantaneously without any reference to production capacity by process. Whereas PAPYRUS only simulated allocation of production capacity over time among competing regions and product grades, the FPL Pulpwood Model also simulated the allocation of production capacity among competing processes, showing how they would evolve in capacity over time.

The FPL Pulpwood Model was used by the Forest Service to develop long-range projections of pulpwood markets and technological changes in the pulp and paper sector for the 1989 RPA Assessment (USDA Forest Service 1989; see also Haynes 1990). One of the more significant findings was that production processes based on hardwood fiber and recycled fiber would gradually obtain a larger share of production capacity in North America. These trends were ongoing in the pulp and paper sector, and the model gave a precise projection of the trends into the future. Projections derived from the FPL Pulpwood Model and Forest Service TAMM model in 1990 showed that paper recycling could accelerate in the 1990s, with significant impacts on future timber prices and timber consumption patterns in North America. For example, instead of rising real timber prices in the South in the decades ahead, as projected previously, the results showed that timber prices in the South would be relatively stable (Ince 1990).

Because of the significance of those findings in the context of the 1989 RPA Assessment, the Forest Service decided to further investigate the issue of timber market impacts of recycling, and to report results in the 1993 RPA Assessment Update. In addition, the Forest Service and Forestry Canada (ministry of forestry of the Federal government of Canada) launched a cooperative research effort to develop a more comprehensive model of the North American pulp and paper sector, using the PELPS methodology. The result of the cooperative research effort was an entirely new model, the North American Pulp and Paper Model (NAPAP Model). Development of the NAPAP Model was accompanied by development of an improved microcomputer version of PELPS, known as PELPS III (Zhang and others 1992a). The NAPAP Model itself is described in more detail in a separate report (Ince and others 1993).

In summary, the NAPAP Model is a third-generation application of the PELPS methodology. As such, it is an extension of research that was initiated by the Forest Service and University of Wisconsin in the early 1980s. The NAPAP Model provides a completely reestimated data set, a more thorough representation of the industry structure in North

America, and additional methodological improvements (see Ince and others 1993). It includes all of the principal pulp, paper, and paperboard grades produced in the United States and Canada. The NAPAP Model meets all of the original Forest Service specifications for an economic model of the pulp and paper sector. From a broader perspective, the model represents a tool that can serve many potential applications in the United States and Canada, ranging from technology forecasting to assessment of resource, technology, trade, or environmental policy impacts.

Previous Pulp and Paper Sector Models

Prior to the recent modeling experience (development of PELPS, PAPYRUS, FPL Pulpwood Model, and NAPAP Model), there were few published examples of large or comprehensive economic forecasting models of the pulp and paper sector, and none published in North America for the purpose of investigating long-range trends in pulpwood markets (see Gilless and Buongiorno 1987). General economists seldom dealt with the pulp and paper sector as a whole, and specialized forest economists concentrated on modeling the solid wood sector (lumber and plywood). In general, earlier attempts to comprehend the overall dynamic behavior of the North American pulp and paper sector either took a more general approach than economic modelling (such as synoptic books on the industry structure by Guthrie (1972) or Strange (1977) or they involved models intended to examine issues other than timber supply and demand, such as energy consumption in the 1970s.

From a forestry perspective, the focus on lumber and plywood may have made sense at times in the past. Compared with prices for pulpwood, higher prices have always been paid for larger diameter sawtimber (used for lumber or plywood). Only in recent decades did pulpwood consumption grow to such proportions that many foresters in North America began to view pulpwood and sawtimber as equally important elements in the forest economy. Also, in recent decades technological developments in forest products have increased the ability of industry to substitute smaller "pulpwood-quality" logs for larger diameter logs in products such as oriented strandboard, which substitutes for softwood plywood, and in "small-log" lumber and plywood mills geared to utilize smaller diameter timber. In addition, with the advent of timber supply and demand models that simulated dynamics of changing timber growth and inventory, it became apparent that trends in pulpwood consumption could have a large bearing on the long-run timber supply and demand situation in North America (Adams and Haynes 1980).

One example of a comprehensive model of resource use and competitive behavior in the pulp and paper sector was the model developed for analysis of energy use by the National Center for Analysis of Energy Systems at Brookhaven National Laboratory (Pilati and others 1980). The model was designed to project future regional energy consumption patterns in the U.S. pulp and paper sector. The Brookhaven model was a "process model" based on linear programming, described as "a regional dynamic mathematical programming model." The model determined annually the selection of investments and process options of the industry that minimized total discounted costs. It considered the energy requirements and costs of processing of three sources of fiber into various pulps and the processing of these pulps into seven different paper and paperboard products. Regional demands for paper products were specified exogenously over a 25-year time horizon. The model was validated for a base year (1975) and examples were provided to show how the model could be used for making energy demand projections, technology assessments, or energy policy studies.

In some respects, the Brookhaven model was similar to the NAPAP Model and may be viewed to some extent as a forerunner of the NAPAP approach. The Brookhaven model was based on dynamic regional optimization with linear programming. It selected the optimal allocation of capacity growth among competing processes (as an annual optimizing investment decision, using cost-minimizing criteria), and it projected simultaneously the evolution of production technology and input requirements over time. In other respects, the Brookhaven model was quite different than the NAPAP Model. It was not a regional market model (it did not solve for the supply and demand equilibria or prices in any markets, and it did not determine how the evolution of production technology would affect markets or vice versa.

Another example of research in modeling the energy sector was provided by the ETA-MACRO model (Manne 1981). ETA-MACRO was designed to estimate the extent of two-way linkages between the energy sector and the balance of the economy. It represented a merger between ETA (a process analysis model for energy technology assessment) and a macroeconomic growth model providing for substitution among capital, labor, and energy inputs. The model simulated a market economy over time. Supplies, demands, and prices were matched through a dynamic nonlinear programming model. In the model, the higher that energy prices rose, the greater were the future amounts of energy that became available and the greater were the inducements for consumers to conserve energy. Although this type of model is not reproduced per se, the NAPAP Model does incorporate some important features that provide similar capabilities, particularly in simulating how technological substitution will affect supply in fiber markets and vice versa.

As discussed by Gilless and Buongiorno (1987), the original development of PELPS and the earlier PAPYRUS model were significantly influenced by the extensive earlier modeling work done for the energy sector by Manne (1979) and Kennedy (1974). Also, many of the same techniques were considered in an earlier model of the entire forest sector (Haynes and others 1978). The PELPS methodology (and hence the NAPAP Model) drew three basic concepts from these earlier works: spatial equilibrium modeling,

price-endogenous linear programming, and technology forecasting based on recursive programming. Other earlier studies, described by Gilless and Buongiorno (1987), for the most part were examples of single-equation or multiple-equation econometric models, designed to develop predictions based on historical relationships, rather than a comprehensive behavioral modeling approach.

In addition, in the past decade a number of comprehensive "forest sector" models or forest resource supply and demand analyses have been developed. Such models or analyses serve to project markets of industry sectors that rely on forest resources within large geographic regions. Recent examples include the forest sector model developed for Sweden (Lonner 1991) and the wood supply and demand analysis developed for the United Kingdom (Whiteman 1991). In the 1980s, a highly generalized global forest sector model was developed by the Forest Sector Project at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria, with research contributions from numerous forest sector modeling specialists around the world (Kallio and others 1987). The IIASA global forest sector model was a spatial equilibrium model, which primarily used recursive programming.

Generally, recent forest sector models, such as the IIASA model, have represented production technology and commodities at relatively aggregate or generalized levels. However, the mathematical formulation of the IIASA global forest sector model was similar to that of the PAPYRUS model, and hence similar to that of the NAPAP Model (Kallio and others 1987). In essence, when the NAPAP Model is linked to a model of the North American timber and wood product sector (such as TAMM; Adams and Haynes 1980) the result is a comprehensive North American forest sector model, providing a very detailed simulation of how forest sector technology and markets will evolve in North America.

Methodology of NAPAP Model

The NAPAP Model is an application of spatial equilibrium modeling methods, based on price-endogenous linear programming, using PELPS III (see Zhang and others 1993). The model represents technological options as economic choices via activity analysis, with production capacity modeled for many different production processes. Recursive programming is used to provide for adjustment in capacity and shifts in supply and demand from year to year.

Nobel Laureate Paul Samuelson (1952) described a spatial equilibrium model as one for which

> . . we are given at each of two or more localities a domestic demand and supply curve for a given product (e.g. wheat) in terms of its market price at that locality. We are also given constant transport costs (shipping, insurance, duties, etc.) for carrying one unit of the product between any two of the specified localities.

From this information, we wish to know

> What then will be the final competitive equilibrium of prices in all the markets, of amounts supplied and demanded at each place, and of exports and imports?

Thus, spatial equilibrium models simulate interregional economies by finding the balance of supply, demand, and trade that results in a competitive market equilibrium among various regions.

Samuelson (1952) showed that the spatial equilibrium for an economic sector was the solution to a mathematical programming problem. He called the corresponding objective function (to be maximized) the "net social payoff" of the sector. This payoff is the sum of producer and consumer surplus for each region in a sector, minus transportation costs between and within regions.

Iterative procedures to solve this maximization problem were developed by Fox (1953), Judge and Wallace (1958), Tramel and Seale (1959), Schrader and King (1962), and Yaron (1967). A quadratic programming solution was used by Takayama and Judge (1964a) for the special case of linear supply and demand curves.

A linear programming formulation of the spatial equilibrium problem (price-endogenous linear programming) was developed by Duloy and Norton (1975). Variants have been used to model a number of agricultural and natural resource sectors (Kennedy 1974; McCarl and Spreen 1980). The NAPAP Model is based on price-endogenous linear programming, using the generalized PELPS (price-endogenous linear programming system (Gilless and Buongiorno 1985). The NAPAP Model utilizes the most recent version of this system, PELPS III (Zhang and others 1993). The system is a general microcomputer system for modeling economic sectors percent. It is the successor of PELPS (Gilless and Buongiorno 1985), PELPS II (Calmels and others 1989), and PELPS II PLUS (Zhang and others1990).

It is worth noting that maximizing Samuelson's net social payoff has no normative implications beyond that of identifying the regional market equilibria for a sector described in terms of regional supply and demand curves, and transportation costs between and within these regions. The real justification for its use, other than efficiency in calculating an equilibrium, is therefore that

> . . . its behavioral implications are consistent with theoretical economic behavior of the sectoral participants. Thus a model with this objective function can be used to simulate producer response to policy (McCarl and Spreen 1980).

This ability to simulate producer and consumer responses to changes in the economic environment is important when modeling long-range evolution of technology and market conditions. In the long run, where economic conditions and technological change may occur, the historical data base and

conventional econometric approach are not fully adequate. Historical data reflect only historical technological trends and historical conditions, whereas the behavioral model reflects an understanding of the interrelationship between technological change and economic conditions over time (see Landau and Rosenberg 1986; Gold 1977; Rosenberg 1976, 1982).

Takayama and Judge (1964b, 1970, 1971) introduced an extension of this concept by representing manufacturing activities in a spatial equilibrium model with activity analysis. Thus, they conceptualized the idea of finding the competitive equilibrium not only among regions but also among various manufacturing processes, which were separately described in terms of inputs required per unit of output, unit cost of manufacturing net of inputs, and regional manufacturing capacities.

PELPS incorporated spatial equilibrium modeling concepts and provided a general framework for constructing spatial equilibrium models with production choices determined by activity analysis (Gilless and Buongiorno 1985), but the original version of PELPS (and also the PAPYRUS model) did not incorporate separate capacity constraints for competing processes. Nevertheless, it was observed that production capacity at pulp and paper mills in North America was highly differentiated by type of manufacturing process as well as by product grade (mainly by type of pulping process or by distinction between recycled-fiber and virgin-fiber processes; see Guthrie 1972 or Strange 1977). Different types of processes required different combinations of material, energy, labor, and capital inputs, and conversion of capacity from one process to another generally required capital investment. Thus, it was recognized that the evolution of production capacity by process would be modeled more appropriately as a long-run behavioral phenomenon rather than a short-run phenomenon, while existing process capacity acted as a short-run constraint on economic substitution among production inputs.

Given that existing processes in the pulp and paper sector constrain production in the short run, it was logical to model capacity constraints by process and capacity growth by process over time (as well as by region) using the spatial equilibrium framework. In effect, the NAPAP Model was designed to address issues beyond the original spatial equilibrium problem considered by Samuelson (1952). The NAPAP Model finds the competitive production equilibria among regional manufacturing processes in the short run, and it forecasts the competitive evolution of capacity by process in the long run. Thus, the NAPAP Model is described more aptly as a "techno-spatial equilibrium model," or one that solves the technology forecasting problem as well as the classical spatial and production equilibrium problem.

The earlier FPL Pulpwood Model was the first application of PELPS in which the activity analysis suggested by Takayama and Judge was fully extended to deal with the problem of finding the competitive equilibrium among competing manufacturing processes, with capacity constraints and capacity growth simulated separately for each manufacturing process within various commodity categories. Subsequently PELPS was modified to fully reflect that extension and other improvements (see PELPS II; Calmels and others 1990). The NAPAP Model likewise incorporated the fully extended activity analysis, and a further update of PELPS was developed accordingly (see Zhang et al. 1993). Thus, the NAPAP Model applied the activity analysis approach conceptualized originally by Takayama and Judge (Zhang et al. 1993). The adaptability of the classical spatial equilibrium framework to the problem of technology forecasting was a major consideration in the decision to use this approach. This technique has been validated as an accurate technology forecasting technique (Zhang 1992).

Dividing a multiyear spatial equilibrium problem into a sequence of problems, one for each year, is known as "recursive programming." Originally developed by Day (1973), the concept was applied to model agricultural and industrial sectors (Abe 1973; Nelson 1973). Recursive programming combines the theory of short-run optimization (finding the market equilibrium via maximization of consumer and producer surplus) with long-run imperfect foresight. Long-run decisions, such as capacity expansion decisions in the pulp and paper sector, are made without perfect foresight (i.e., there is generally a lack of perfect knowledge about future market conditions). Given an understanding of imperfect foresight, it can be deduced that capacity expansion decisions in the pulp and paper sector are made primarily in reference to current market conditions. Thus, in the NAPAP Model (as well as previous PELPS-based models) it has been assumed that projected capacity expansion for the next year is always made in reference to market conditions in the current year (e.g., current prices). Prices are computed endogenously for each year in solving the supply and demand equilibria.

A single linear program could have been used to calculate a multiyear (intertemporal) equilibrium for the pulp and paper sector. However, this would have assumed perfect foresight on the part of decision makers. Therefore, such a model would have been unrealistic, inasmuch as long-run decisions are inevitably based on temporal information. The recursive approach reduces the size of the linear program that otherwise must be solved, breaking up the multiyear problem into a sequence of smaller problems, one for each year. This also affords a model that includes more detail on the pulp and paper sector—detail that enhances the usefulness of the model in examining implications of policy recommendations and other exogenous changes related to the pulp and paper sector.

In summary, the NAPAP Model can be conceived as simulating the rational economic behavior of suboptimizing decision makers who must rely on temporal economic data to make long-run decisions, in a generally competitive free

market environment. Reflecting the reality of decision-making in the North American pulp and paper sector, the model simulates the behavior of decision makers who face an economic environment each year that has been determined in part by their past decisions (e.g., decisions on past capacity expansion), and in part by prevailing economic conditions also shaped by exogenous forces (such as government policies, which have increased supplies of recovered paper in recent years). The realism of recursive programming was a major consideration in the decision to use this methodology in simulating pulp and paper sector behavior and responses to change.

Long-Range Projections by NAPAP Model

The NAPAP Model has two elements or computational phases: a linear program that describes the pulp and paper sector in a given year, and a set of recursive relationships that update the data in the linear program to reflect changes in the economic environment from year to year. The NAPAP Model makes multiyear forecasts iteratively. The market and production equilibrium for the base year (1986) is found by solving the linear program with relevant data describing the pulp and paper sector in 1986. Recursive relationships are used to update the linear program to account for changes in the industry's economic environment between 1986 and 1987. The updated (1987) linear program is then solved to obtain the market and production equilibrium for 1987. This iterative process of solution and update is repeated over the forecast period, which extends to the year 2040, providing a forecast of annual market equilibria over the entire period.

The linear program data describe the pulp and paper sector in sufficient detail to solve the techno-spatial equilibrium problem for all principal commodities of the pulp and paper sector in North America (United States and Canada). Included in the linear program data are estimates of regional supply functions for manufacturing inputs; regional demand functions for commodity outputs; technological coefficients describing production possibilities in terms of inputs per unit of product output in various production processes for each commodity; other (net) manufacturing costs by process; transportation costs for various commodities and regions; regional production capacities for the various processes; regional constraints on recovery of paper for recycling; import and export ad-valorum taxes; and monetary exchange rate assumptions (for United States and Canada). As discussed previously, the objective function of the linear program is maximization of consumer plus producer surplus (the net social payoff for the pulp and paper sector; Samuelson 1952). Its solution approximates the spatial market and production equilibrium of the sector in a given year. The quantities supplied, transported, manufactured, and demanded match consumer willingness to pay and producer marginal costs of procurement, production, and delivery. The solution prices and quantities of commodities demanded and supplied correspond to market equilibrium prices and quantities, under the assumption of competitive economic behavior (Samuelson 1952).

The recursive relationships used to update the linear program from year to year reflect exogenous changes in the economic environment of the pulp and paper sector, and also changes influenced by previous market equilibria (e.g., changes in technology and capacity expansion). Changes to the linear program data include shifts in product demand curves, shifts in input supply curves or input prices, changes in import and export ad-valorum taxes, changes in monetary exchange rates (between United States and Canada), introduction and availability of new (future) production processes at specified points in time, and changes in regional manufacturing capacities of various processes determined endogenously by capacity growth and depreciation formulas.

The model includes other static elements. Manufacturing cost of a commodity using a specific process and in a specific region is the sum of the net production cost and the shipping cost within the region. The transportation cost of a commodity between two regions is defined as the freight cost, to which may be added any import ad-valorem taxes. In each region, the amount of a commodity received, supplied, and manufactured must be equal to the sum of the quantity used in the manufacturing of other commodities in the same region and of the amount demanded and shipped to other regions (material balancing constraint). Thus, the inflow of a commodity must balance the outflow for each region. In each region, the production of a commodity by each process is limited by the existing manufacturing capacity for that process in the specified region. In addition, several categories of recycling constraints can be introduced in the NAPAP Model, including constraints on recycling capacity, product demand, and recovered paper supply. For the supply of recovered paper, an upper bound and a lower bound on the supply may be imposed to reflect maximum and minimum recovery rates. Maximum recovery rates by region are specified in the NAPAP Model to reflect maximum feasible recovery of paper for recycling, as limited by collection programs and infrastructure in North America. Minimum recovery rates may also be specified, but are not included in the NAPAP Model data set. Demand and capacity constraints are specified to reflect reaction to government policies, such as policies that require minimum recycled content in newsprint. In the 1993 Assessment base scenario, such constraints are applied only to capacity in the historical and near-term projection period.

Dynamic elements of the model include the following. Demand functions are updated between periods to reflect changes in up to three demand-shift variables (independent variables such as population and per capita GNP, derived from the RPA Base assumptions). Supply functions are updated between periods to reflect changes in up to three supply-shift variables (such as projected timber inventory and sawtimber prices from the TAMM model, which are

used to shift pulpwood supply, and projected tipping fees and paper consumption levels, which are used to shift recovered paper supply). Because all prices and costs in the NAPAP Model are expressed in a common currency (1986 U.S. dollars), any changes in the value of a region's currency can change these prices and costs. The U.S.–Canada exchange rate adjustments are made for each year from 1986 to 1992, according to historical data. Exchange rates are then held constant for the remainder of the projection period. Manufacturing costs are updated annually to reflect projected changes in wage rates and energy costs. Transportation costs are updated annually to reflect projected changes in ad valorum import tariffs. The NAPAP Model assumes full implementation of the U.S.–Canada Free Trade Agreement with a graduated phase-out of all U.S.–Canada import tariffs between 1987 and 1993. Changes in capacity from one period to the next are determined endogenously by the NAPAP Model, or they can be imposed exogenously by the user. The user also specifies rates of depreciation or retirement for existing capacity.

Changes in capacity are computed by a "*q*-theory" of capacity expansion, based on the *q*-theory of capital investment pioneered by Nobel Laureate James Tobin (1969):

> The rate of investment—the speed at which investors wish to increase capital stock—should be related, if to anything, to *q*, the value of capital relative to its replacement cost.

Following Tobin's *q* theory, the change in capacity for each production process is determined as an increasing function of the *q* ratio, the shadow price (marginal profitability) of current capacity to the cost of new capacity. Empirical results with data of the U.S. pulp and paper industry suggest that gross change in capacity of the pulp and paper sector is a function of the current *q* ratio, the *q* ratio lagged one period, and the gross change in capacity lagged one period (Zhang and Buongiorno 1992a).

The interaction between demand functions and product supply determines the equilibrium solution for product markets each year. The model also includes an endogenous solution of the regional supply and demand equilibrium for pulpwood and wastepaper, with regional demand determined by raw material requirements of production processes and the simultaneous equilibrium solution for paper and paperboard production. Capacity growth by process is determined by the Tobin *q* model. As markets and production capacity evolve from year to year, and as new production processes are introduced, the regions and processes that experience the most capacity growth are projected to change. Over time, the model shows how recovered paper and pulpwood markets are expected to respond to shifting demand and changing technology, and in turn how technology is expected to evolve in response to market conditions (i.e., supply, demand, and prices for fiber inputs and pulp, paper, and paperboard products).

NAPAP Model Structure and Data Base

The NAPAP Model includes regional supply functions for pulpwood and recovered paper, and a highly detailed representation of production capacity and supply for all principal grades of market pulp, paper, and paperboard, in five North American production regions. It also includes demand functions for all end products, with separate demand functions for U.S. domestic demand, Canadian domestic demand, and demand from various trading regions for export from the United States and Canada. Regional production capacity for each product is divided among one or more competing processes (such as recycled-fiber and virgin-fiber processes, or chemical pulping and mechanical pulping processes). The processes in the model include all current principal manufacturing processes, plus processes expected to become available for production at assumed future dates in the model. The aggregate product supply function is defined each year by the production capacity among the various processes and the production costs of each process among the various regions, combined with overseas import supply.

Empirical data for econometric estimates and technical assumptions in the NAPAP Model were obtained from many sources. Principal sources included the American Paper Institute (API), the Canadian Pulp and Paper Association (CPPA), the U.S. Commerce Department, Statistics Canada, Forestry Canada, and USDA Forest Service. In developing the data base we obtained substantial advice from experts in industry and from trade associations and industry research organizations, including API, CPPA, Pulp and Paper Research Institute of Canada (PAPRICAN), USDA Forest Service, Forest Products Laboratory (FPL), and Technical Association of the Pulp and Paper Industry (TAPPI).

Regional Structure

On the demand side, functions representing eight demand regions were included in the NAPAP Model (Table 1) for 14 categories of final products. On the supply side, functions representing pulpwood and recovered paper supply were included for five North American supply regions (Table 1). Price-responsive supply functions were included for hardwood and softwood pulpwood (roundwood and residues) and for four principal grades of recovered paper. Supply functions with predetermined prices (assuming price-taking behavior) were specified in each supply region for purchased fuel, purchased electric power, and labor wage rates.

Trade with regions outside of the United States and Canada was represented in the NAPAP Model by including export demand functions and import supply functions for principal trading regions (Table 1). Export demand functions for regions outside of the United States and Canada were included for all products that were exported recently in significant quantities from these countries. Import supply functions were included for all products that were imported

Table 1—Regional structure of NAPAP Model

Demand Regions
Canada
United States
Demand from Canada
Pacific
Atlantic
Demand from United States
Latin American
European
Pacific Rim
Other
Supply/Production Regions
Canada East
Canada West
U.S. North
U.S. South
U.S. West
Supply to United States
Latin American
European
Pacific Rim
Other

in significant quantities to the U.S. market (imports to Canada from regions other than the United States were very small, and are not represented in the model).

Product Categories, Processes, and Base-Year Capacity

The NAPAP Model data include input requirements and production capacity by process for 18 categories of products (Table 2). The product categories were selected to encompass virtually all primary products of the North American pulp and paper sector. Fourteen product categories were end products, which meet North American product demands and export demands in the NAPAP Model. The intermediate products meet export demands and input requirements for production of end products in North America. Some products were also specified as imported to North America (chiefly to the United States). Table 2 also lists categories of production inputs recognized by the NAPAP Model, including categories of fiber inputs.

Product categories were formed on the basis of different end uses and manufacturing technologies. The products correspond generally to the principal commodity categories or product "grades" recognized by leading industry trade associations in the United States and Canada (API and CPPA). Primary end-uses for products of the North American pulp and paper sector include packaging (chiefly for paperboard categories, specialty and industrial packaging, and kraft packaging), communication (i.e., for the first five paper categories), sanitary purposes (tissue & sanitary products), construction uses (construction paper and board, and other), and miscellaneous industrial uses (for some uses of specialty packaging and industrial paper products). Dissolving pulp is used to produce polymer fibers and various other cellulose-based products.

Table 2—NAPAP product and production categories

End Products
Paper[a]
Newsprint (4)
Coated free sheet (2)
Uncoated free sheet (4)
Coated groundwood (2)
Uncoated groundwood (2)
Tissue & sanitary (4)
Specialty packaging & industrial (1)
Kraft packaging (3)
Paperboard
Linerboard (3)
Corrugating medium (3)
Solid bleached board (1)
Recycled board (1)
Other
Construction paper and board, and other (1)
Dissolving pulp (1)
Intermediate Products[b]
Softwood chemical market pulp
Hardwood chemical market pulp
Mechanical market pulp
Market pulp from recycled fiber
Production Inputs
Softwood pulpwood roundwood
Softwood pulpwood residue
Hardwood pulpwood roundwood
Hardwood pulpwood residue
Old newspaper (ONP)
Old corrugated container (OCC)
Mixed recovered paper
Pulp substitutes and high grade deinking
Purchased fuel
Purchased electric power
Mill labor
Administrative labor
Other costs (e.g., capital, chemicals, materials, overhead)

[a]Number of different manufacturing processes is shown in parentheses.
[b]One manufacturing process for each product.

Process Data

From one to four manufacturing processes were specified for each product in the base year, 1986. Additional processes ("new" processes) were also specified in the model to appear at dates after 1986, simulating commercialization of very likely new or future technology. Likely future developments and new processes in pulp, paper, and related technologies were surveyed and described in more detail in a separate unpublished report (see Ince 1992). For each process, technical coefficients were estimated that included wood fiber, energy, chemical, labor, capital, and other material inputs per tonne of product output. Thus, each process in the NAPAP Model was defined individually by data that described the allowable range of fiber inputs (i.e., pulpwood, recovered paper, or market pulp inputs required per tonne of product output), purchased fuel energy input, electrical energy input, labor input, and other manufacturing costs (including capital costs, chemicals, etc.). In addition, the data include estimated regional production capacity for each

process in 1986, the base year of the NAPAP Model. The model projects evolution of production capacity by process and region over time.

The following sections describe NAPAP Model process data and input assumptions separately for each product category. Fiber inputs are shown in tonnes of fiber input per tonne of product output with the following moisture content conventions: pulpwood inputs are expressed in cubic meters of solid wood equivalent, market pulp inputs are in "air-dry" tonnes (at 10 percent moisture content, total weight basis), and recovered paper inputs are in "tonnes as purchased" (generally at ambient moisture content of around 15 percent). Many processes were defined with an allowable range of fiber inputs, which permits the process to accept more than one combination or "mix" of fiber inputs. This feature of the model simulates technological substitution possibilities and shows the maximum ranges of hardwood, softwood, or recycled fiber inputs allowed for each process (generally the allowable types of fiber inputs in each process are limited because of inherent fiber quality requirements of products, such as requirements for product strength, printability, opacity, smoothness, and sanitary considerations).

Regional differences in data for each process were estimated to account for differences in regional heat energy requirements and wood density. Higher energy inputs in the U.S. North and Canada were associated with operation in colder climates. Pulpwood and recovered paper input requirements take into account pulp yield and fiber recovery factors. Substantial differences exist in wood density (specific gravity) for pulpwood consumed in different regions, which account for differences in wood volume input requirements by region. Wage rates and energy price data varied by region. Capital costs and chemical costs were also adjusted by small amounts for Canada.

Newsprint

This commodity category includes the newsprint grade recognized by the API in the United States and the newsprint grade recognized by the CPPA in Canada. It includes both newsprint produced from recycled fiber and newsprint produced from virgin fiber. It is used chiefly in printing daily newspapers. Newspapers account for three-fourths of newsprint consumed in North America. Smaller quantities are used by government printers, and by commercial printers for uses such as newspaper inserts and advertising pamphlets. Newsprint is made largely from mechanical wood pulp with some chemical wood pulp and recycled fiber. This commodity category excludes uncoated groundwood printing and writing paper (such as directory paper). Production capacity for newsprint in 1986 was 9,885,000 tonnes in Canada (Source: CPPA) and 5,276,000 tonnes in the United States (Source: API). In 1986, there were generally four types of manufacturing processes for producing newsprint in North America, as identified by review of mill listings and technical literature of the pulp and paper industry. For the purpose of the NAPAP Model, the four processes were characterized as follows:

Process 1: Based on integrated mechanical and chemical pulping facilities. On average, Process 1 used a furnish mix of approximately 75 percent mechanical pulp and 25 percent chemical pulp. The mechanical pulp was mostly stone groundwood. The chemical pulp was mostly sulfite pulp in Canada and bleached kraft in the United States.

Process 2: Based on integrated mechanical pulping facilities, with no integrated chemical pulping. Process 2 used mostly thermomechanical pulp (TMP), with about 10 percent bleached chemical pulp. Generally, mills had to mix the TMP with about 10 percent bleached kraft market pulp to produce newsprint.

Process 3: Based entirely on secondary (recycled) fiber, using primarily old newspapers (ONP).

Process 4: Based on integrated mechanical pulping facilities in Canada, using 100 percent TMP or chemi-thermomechanical pulp (CTMP), with no chemical pulp furnish. Process 4 was confined to Canada in 1986 (TMP mills in the United States used 10 percent bleached chemical pulp, as indicated by Process 2).

In many cases, newsprint mills used more than one process. For example, some newsprint mills used a combination of 50 percent TMP and 50 percent recycled fiber in 1986. The newsprint industry in North America was examined in detail, using industry directories and other published sources of information (Post's and Lockwood's directories, and company profiles). Mill data were used to infer regional distribution of production capacity by process for newsprint in 1986, using capacity data published by API and CPPA as the measure of overall capacity by region. Newsprint base-year capacity data are shown in Table 3.

In addition to newsprint manufacturing processes that existed in 1986, two newsprint processes were introduced in the NAPAP Model to simulate new process technologies that

Table 3—Regional distribution of newsprint production capacity by process in North America, 1986

	Distribution ($\times 10^3$ t/year)				
Region	Process 1	Process 2	Process 3	Process 4	Total
U.S. North	275	—	349	—	624
U.S. South	1,514	1,336	119	—	2,969
U.S. West	168	1,010	505	—	1,683
Canada East	4,410	1,764	98	1,764	8,036
Canada West	980	—	—	784	1,764

will become commercially available after 1986. Technological developments will be facilitated by continued expansion of twin-wire forming technology (enabling better utilization of lower quality fiber), improved methods for removing in recycled fiber contaminants, improved bleaching technologies, further development of improved mechanical pulping methods, improved pressing and drying technology, improved printability, advances in biological effluent treatment systems, environmental responses, and market demand for products that contain substantial fractions of recycled fiber. The two new manufacturing processes for newsprint were defined as follows:

Process 5: This new process represents the North American application of flotation deinking technology to produce newsprint from recycled fiber, with 30 percent of fiber furnished from coated mixed paper, such as old magazines (and 70 percent of fiber furnished from ONP). Process 5 affords somewhat higher efficiency than the conventional recycled newsprint process (Process 3). This type of process actually began to be introduced in North America around 1988, and it is introduced in the NAPAP Model data base at that point in time.

Process 6: This new process represents anticipated North American development of a newsprint process utilizing advanced pressing technology (such as press drying, impulse drying, or related technology) and 100 percent mechanical pulp (TMP or CTMP). The technology has been demonstrated in laboratory studies and represents a likely future advance in newsprint technology. The technology affords process cost savings and a higher proportion of hardwood fiber in newsprint. In the NAPAP Model data base, it is assumed that Process 6 becomes available for commercial adoption in the year 2000.

Table 4 summarizes NAPAP Model base-level fiber input assumptions for the six newsprint manufacturing processes. Fillers and coatings are assumed to constitute less than 1 percent of the final product by weight.

Table 5 summarizes NAPAP Model base-level input coefficients and costs by region for the six newsprint manufacturing processes.

Coated Free Sheet

This commodity category includes the coated free sheet category recognized by API in the United States and a small portion of the book, fine & miscellaneous fine paper category recognized by CPPA in Canada. Included are heavily clay-coated woodfree papers containing generally less than 10 percent mechanical pulp. Coated free sheet is used primarily for high quality printing paper, mainly by commercial printers. Primary end-uses include annual reports, specialty catalogs, advertising or promotional materials, and magazines. Most of the product is made with a glossy finish (about two-thirds) while some is produced with dull finish (about one-third) and small amounts are produced with matte or embossed finishes. Production capacity in 1986 was 2,676,000 tonnes in the United States (API) and 140,000 tonnes in Canada (estimated as a small fraction of capacity for Book, Fine & Miscellaneous Fine Papers as reported by CPPA). In 1986, there were generally two types of manufacturing processes for producing coated free sheet in North America, as identified by review of mill listings and technical literature of the pulp and paper industry. For the purpose of the NAPAP Model, the two processes were characterized as follows:

Table 4—Base-level fiber input assumptions for newsprint manufacturing processes in the NAPAP Model

	Fiber input (percent)					
Fiber source	Process 1	Process 2	Process 3	Process 4	Process 5	Process 6
Integrated pulp						
Groundwood	75	—	—	—	—	—
Bleached chemical	25	—	—	—	—	—
TMP/CTMP	—	90	—	100	—	100
Market pulp						
Softwood chemical	—	10	—	—	—	—
Recycled fiber						
Old newspapers	—	—	100	—	70	—
Mixed paper	—	—	—	—	30	—
Maximum softwood fiber[a]						
Groundwood	100	—	—	—	—	—
Bleached chemical	100	—	—	—	—	—
TMP/CTMP	—	100	—	100	—	100
Maximum hardwood fiber[a]						
Groundwood	10	—	—	—	—	—
Bleached chemical	20	—	—	—	—	—
TMP/CTMP	—	10	—	10	—	30

[a]Maximum amount allowed in pulp.

Table 5—Base-level input coefficients and costs for newsprint manufacturing processes by region, per tonne of finished product output

Region and output	Process 1	Process 2	Process 3	Process 4	Process 5	Process 6
U.S. North						
Softwood pulpwood (m^3)	2.70–2.31					1.82–1.28
Hardwood pulpwood (m^3)	0–0.37					0–0.60
Old newspapers (t)			1.40		0.88	
Mixed papers (t)					0.38	
Purchased fuel (x10 GJ)	1.00		0.72		0.72	0.30
Electricity (MWh)	1.50		1.00		0.90	1.60
Labor (h)	0.46		0.13		0.13	0.30
Administrative labor (h)	0.09		0.03		0.03	0.05
Other mfg. costs (1986$)	153.35		172.93		186.93	179.93
U.S. South						
Softwood chem. mkt. pulp (t)		0.11				2.23–1.57
Softwood pulpwood (m^3)	2.73–2.36	2.02–1.81				0–0.51
Hardwood pulpwood (m^3)	0–0.29	0–0.15				0–0.51
Old newspapers (t)			1.40		0.88	
Mixed papers (t)					0.38	
Purchased fuel (x10 GJ)	0.90	0.30	0.72		0.72	0.20
Electricity (MWh)	1.50	2.50	1.00		0.90	1.60
Mill labor (h)	0.46	0.25	0.03		0.03	0.05
Administrative labor (h)	0.09	0.05	0.03		0.03	0.05
Other mfg. costs (1986$)	153.35	153.93	172.93		186.93	179.93
U.S. West						
Softwood chem. mkt pulp (t)		0.11				2.90–2.03
Softwood pulpwood (m^3)	3.27–3.05	2.62–2.35				2.90–2.03
Hardwood pulpwood (m^3)	0–0.46	0–0.24				0–0.82
Old newspapers (t)			1.40		0.88	
Mixed papers (t)					0.38	
Purchased fuel (x10 GJ)	0.90	0.30	0.62		0.72	0.20
Electricity (MWh)	1.50	2.50	1.00		0.90	1.60
Labor (h)	0.46	0.25	0.13		0.13	0.30
Administrative labor (h)	0.09	0.04	0.03		0.03	0.05
Other mfg. costs (1986$)	53.35	153.93	172.93		186.92	179.93
Canada East						
Softwood chem. mkt. pulp (t)		0.11				
Softwood pulpwood (m^3)	3.45–2.97	2.53–2.28		2.81–2.53		2.82–1.97
Hardwood pulpwood (m^3)	0–0.47	0–0.25		0–0.28		0–0.82
Old newspapers (t)			1.40		0.88	
Mixed papers (t)					0.38	
Purchased fuel (x10 GJ)	1.05	0.40	0.86	0.41	0.82	0.40
Electricity (MWh)	1.50	2.50	1.00	2.60	0.90	1.60
Mill labor (h)	0.49	0.30	0.15	0.31	0.15	0.30
Administrative labor (h)	0.10	0.06	0.03	0.06	0.03	0.06
Other mfg. costs (1986$)	162.89	206.32	183.04	173.82	187.00	180.00
Canada West						
Softwood chem. mkt pulp (t)		0.11				
Softwood pulpwood (m^3)	3.45–2.90	2.53–2.28		2.81–2.53		2.82–1.97
Hardwood pulpwood (m^3)	0–0.47	0–0.25		0–0.28		0–0.82
Old newspapers (t)			1.40		0.88	
Mixed papers (t)					0.38	
Purchased fuel (x10 GJ)	1.00	0.30	0.86	0.41	0.72	0.30
Electricity (MWh)	1.50	2.50	1.00	2.60	0.90	1.60
Labor (h)	0.49	0.30	0.15	0.31	0.15	0.30
Administrative labor (h)	0.10	0.06	0.03	0.06	0.03	0.06
Other mfg. costs (1986$)	163.37	206.58	183.30	174.08	187.00	180.00

Process 1: Based on integrated chemical pulping facilities, using mainly bleached kraft pulp or kraft blend. A small amount of secondary (recycled) fiber and other chemical pulp was also used. Secondary fiber was entirely pulp substitutes and high grade deinking.

Process 2: Primarily based on market pulp, using mainly bleached chemical pulp. A small amount of secondary (recycled) fiber was used in some mills. Secondary fiber was entirely pulp substitutes and high grade deinking.

The coated free sheet industry in North America was examined in detail, using industry directories and other published sources of information (Post's and Lockwood's directories, and company profiles). Mill data were used to infer regional distribution of production capacity by process for coated free sheet, using capacity data published by API as the measure of overall capacity by region. Base-year capacity data are shown in Table 6.

In addition to the coated free sheet processes that existed in 1986, another coated free sheet process was introduced in the NAPAP Model to simulate new process technology becoming commercially available after 1986. Future commercial development of the new process will be facilitated by ongoing technical improvements in recycled fiber recovery and contaminant removal, improved bleaching technologies, environmental concerns, and market demand for products that contain substantial fractions of recycled fiber. The new manufacturing process for coated free sheet was defined as follows:

Process 3: This new process represents the introduction of a process based on 100 percent recycled fiber in North America. Similar processes already exist overseas. The process includes deinking technology to use 100 percent high grade deinking or pulp substitutes. Alternatively, the process would be capable of using 100 percent bleached market pulp.

Table 7 summarizes NAPAP Model base-level fiber input assumptions for the three coated free sheet manufacturing processes. Fillers and coatings are assumed to comprise 25 percent of the final product by weight.

Table 6—Regional distribution of coated free sheet production capacity by process in North America, 1986

	Distribution ($\times 10^3$ t)		
Region	Process 1	Process 2	Total
U.S. North	1,497	582	2,079
U.S. South	449	—	449
U.S. West	104	43	147
Canada East	—	140	140
Canada West	—		0

Table 8 summarizes NAPAP Model base-level input coefficients and costs by region for the three coated free sheet manufacturing processes.

Uncoated Free Sheet

This commodity category includes the uncoated free sheet, cotton fiber, thin paper, and solid bleached bristol grades recognized by API in the United States, and the uncoated woodfree portion of the book, fine & miscellaneous fine papers category recognized by CPPA in Canada. Ordinarily, bristols are recognized as a separate commodity grade, as specified by API, but for consistency in the NAPAP model the bristols are included in the uncoated free sheet commodity category. Major uses for uncoated free sheet are for office papers (bond, forms, copy paper, tablet, and envelopes) and printing papers (offset, cover, and text), while bristols include bleached tabulating index, tag, file folder, coated cover bristols, and uncoated bristols. Bristols were <10 percent of total production in the NAPAP uncoated free sheet category. Production capacity in 1986 was 11,411,000 tonnes in the United States (API; including uncoated free sheet, cotton fiber, thin papers, and solid bleached bristols) and >893,000 tonnes in Canada (estimated as a large fraction of capacity for book, fine & miscellaneous fine papers as reported by CPPA). In 1986, there were generally four distinct types of manufacturing processes for producing uncoated free sheet in North America, as identified by review of mill listings and technical literature of the pulp and paper industry. For the purpose of the NAPAP Model, the four processes were characterized as follows:

Process 1: Based on integrated chemical pulping facilities, using mainly bleached sulfite pulp or sulfite blend.

Table 7—Base-level fiber input assumptions for coated free sheet manufacturing processes in the NAPAP Model

	Fiber input (percent)		
Fiber source	Process 1	Process 2	Process 3
Integrated pulp[a]	100	—	—
Market pulp			
Softwood chemical	—	30	33
Hardwood chemical	—	60	67
Recycled fiber			
Pulp subs. & high grade	—	10[b]	(or 100)[c]
Max. softwood fiber[a,d]	40[e]	—	—
Max. hardwood fiber[a,d]	80	—	—

[a]Bleached chemical.
[b]Maximum.
[c]Either 33 percent softwood chemical plus 67 percent hardwood chemical pulps or 100 percent pulp substitutes and high-grade deinking.
[d]Maximum amount allowed in pulp.
[e]70 percent in U.S. West.

Table 8—Base-level input coefficients and costs for coated free sheet manufacturing processes by region, per tonne of finished product output

Region and output	Process 1[a]	Process 2	Process 3
U.S. NORTH			
Softwood chem. mkt. pulp (t)		0.27–0.24	0–0.27
Hardwood chem. mkt. pulp (t)		0.53–0.48	0–0.53
Softwood pulpwood (m^3)	1.30–0.65 (or 1.17)		
Hardwood pulpwood (m^3)	1.85–2.48 (or 1.67)		
Pulp subs. & high grade (t)	(+0.09)	0–0.09	1.05–0
Purchased fuel (x10 GJ)	1.13	0.74	0.90
Electricity (MWh)	1.20	1.00	1.10
Labor (h)	0.28	0.19	0.28
Administrative labor (h)	0.11	0.11	0.11
Other mfg. costs (1986$)	274.63	185.08	185.00
U.S. SOUTH			
Softwood chem. mkt. pulp (t)			0–0.27
Hardwood chem. mkt. pulp (t)			0–0.53
Softwood pulpwood (m^3)	1.32–0.65 (or 1.19)		
Hardwood pulpwood (m^3)	1.49–1.98 (or 1.34)		
Pulp subs. & high grade (t)	(+0.09)		1.05–0
Purchased fuel (x10 GJ)	1.03		0.80
Electricity (MWh)	1.20		1.10
Labor (h)	0.28		0.28
Administrative labor (h)	0.11		0.11
Other mfg. costs (1986$)	274.63		185.00
U.S. WEST			
Softwood chem. mkt. pulp (t)		0.27–0.24	0–0.27
Hardwood chem. mkt. pulp (t)		0.53–0.48	0–0.53
Softwood pulpwood (m^3)	2.98–0.86 (or 1.54)		
Hardwood pulpwood (m^3)	1.18–3.15 (or 2.13)		
Pulp subs. & high grade (t)	(+0.09)	0–0.09	1.05–0
Purchased fuel (x10 GJ)	1.03	0.64	0.80
Electricity (MWh)	1.20	1.00	1.10
Labor (h)	0.28	0.19	0.28
Administrative labor (h)	0.11	0.11	0.11
Other mfg. costs (1986$)	274.63	185.08	185.00
CANADA EAST			
Softwood chem. mkt. pulp (t)		0.27–0.24	0–0.27
Hardwood chem. mkt. pulp (t)		0.53–0.48	0–0.53
Pulp subs. & high grade (t)		0–0.09	1.05–0
Purchased fuel (x10 GJ)		0.84	1.00
Electricity (MWh)		1.00	1.10
Labor (h)		0.19	0.28
Administrative labor (h)		0.11	0.11
Other mfg. costs (1986$)		203.38	185.00
CANADA WEST			
Softwood chem. mkt. pulp (t)		0.27–0.24	0–0.27
Hardwood chem. mkt. pulp (t)		0.53–0.48	0–0.53
Pulp subs. & high grade (t)		0–0.09	1.05–0
Purchased fuel (x10 GJ)		0.74	0.90
Electricity (MWh)		1.00	.10
Labor (h)		0.19	0.28
Administrative labor (h)		0.11	0.11
Other mfg. costs (1986$)		203.45	185.00

Table 9—Regional distribution of uncoated free sheet production capacity by process in North America, 1986

	Distribution ($\times 10^3$ t)				
Region	Process 1	Process 2	Process 3	Process 4	Total
U.S. North	922	1,573	2,170	760	5,425
U.S. South	—	4,425	282	—	4,707
U.S.West	—	881	166	230	1,277
Canada East	—	372	34	64	779
Canada West	—	—	114	—	114

Process 2: Based on integrated chemical pulping facilities, using mainly bleached kraft pulp or kraft blend.

Process 3: Primarily based on market pulp, at nonintegrated paper mills (without pulping facilities); small fractions of other nonwood pulps, including flax pulp and rag pulp, used in some mills.

Process 4: Primarily based on secondary (recycled) fiber, using pulp substitutes or high grade deinking grades of recovered paper.

In many cases, a single mill used more than one process. The uncoated free sheet industry in North America was examined in detail, using industry directories and other published sources of information (Post's and Lockwood's directories, and company profiles). Mill data were used to infer regional distribution of production capacity by process for uncoated free sheet in 1986, using capacity data published by API and CPPA as the measure of overall capacity by region. Uncoated free sheet base-year capacity data are shown in Table 9.

In addition to the uncoated free sheet manufacturing processes that existed in 1986, another uncoated free sheet process was introduced in the NAPAP Model to simulate likely new technology becoming commercially available after 1986. Future commercial development of the new process will be facilitated by ongoing technical improvements in recycled fiber recovery and contaminant removal, improved bleaching technologies, further development of improved mechanical pulping methods, advances in biological effluent treatment systems, environmental concerns, and market demand for products that contain recycled fiber. The new manufacturing process for uncoated free sheet was defined as follows:

Process 5: Represents introduction of larger fractions of recycled fiber or mechanical pulp as partial substitutes for bleached chemical market pulp in nonintegrated paper mills (as in Process 3). It is assumed that up to 20 percent of the bleached chemical market pulp can be replaced by market pulp made from recycled fiber or by bleached mechanical market pulp (such as bleached chemithermomechanical pulp (BCTMP)). Conventionally, little BCTMP or recycled market pulp are used in uncoated free sheet in North America, but the technical and commercial feasibility of such a process has been demonstrated.

Table 10 summarizes NAPAP Model base-level fiber input assumptions for the three uncoated free sheet manufacturing processes. Fillers and coatings are assumed to constitute 9 percent of the final product by weight.

Table 11 summarizes NAPAP Model base-level input coefficients and costs by region for the three uncoated free sheet manufacturing processes.

Coated Groundwood Paper

This commodity category includes the coated groundwood grade recognized by API in the United States, and a small portion of the groundwood printing & specialty grade category recognized by CPPA in Canada. Primary end-uses include magazines (more than 60 percent of market), catalogs, directories, newspaper inserts, books, brochures, and other commercial printing. Coated groundwood papers contain technically no less than 10 percent mechanical pulp (but usually contain much higher percent ages of mechanical pulp) with the balance being mostly chemical pulp and

Table 10—Base-level fiber input assumptions for uncoated free sheet manufacturing processes in the NAPAP Model

	Fiber input (percent)				
Fiber source	Process 1	Process 2	Process 3	Process 4	Process 5
Integrated pulp					
Bleached sulfite	100	—	—	—	—
Bleached kraft	—	100	—	—	—
Market pulp					
Softwood chemical	—	—	50	—	40
Hardwood chemical	—	—	50	—	40
Mechanical (BCTMP)	—	—	—	—	20
Recycled fiber					
Pulp subs. & high grade	—	—	—	100	—
Max. hardwood fiber[a]					
Bleached kraft	—	65	—	—	—
Bleached sulfite	65	—	—	—	—
Max. softwood fiber[a]					
Bleached kraft	—	75	—	—	—
Bleached sulfite	75[b]	—	—	—	—

[a]Maximum amount allowed in pulp.
[b]90 percent in U.S. West.

Table 11—Base-level input coefficients and costs for uncoated free sheet manufacturing processes per tonne of finished product

Region and output	Process 1	Process 2	Process 3	Process 4	Process 5
U.S. NORTH					
Softwood chem. mkt. pulp (t)			0.48		0.39
Hardwood chem. mkt. pulp (t)			0.48		0.39
Mechanical market pulp (t)					0.19
Softwood pulpwood (m^3)	3.15–1.47	3.02–1.41			
Hardwood pulpwood (m^3)	1.01–2.61	0.96–2.49			
Pulp subs. & high grade (t)				1.20	
Purchased fuel (x10 GJ)	1.50	1.39	0.90	0.80	0.80
Electricity (MWh)	1.20	1.00	0.80	1.10	0.80
Labor (h)	0.25	0.21	0.19	0.42	0.17
Administrative labor (h)	0.12	0.11	0.11	0.13	0.10
Other mfg. costs (1986$)	271.60	253.35	210.37	280.15	183.03
U.S. SOUTH					
Softwood chem. mkt. pulp (t)			0.48		0.39
Hardwood chem. mkt. pulp (t)			0.48		0.39
Mechanical market pulp (t)					0.19
Softwood pulpwood (m^3)		3.06–1.43			
Hardwood pulpwood (m^3)		0.77–2.00			
Purchased fuel (x10 GJ)		1.29	0.80		0.80
Electricity (MWh)		1.00	0.80		0.80
Labor (h)		0.21	0.19		0.17
Administrative labor (h)		0.11	0.11		0.10
Other mfg. costs (1986$)		253.35	210.37		83.03
U.S. WEST					
Softwood chem. mkt. pulp (t)			0.48		0.39
Hardwood chem. mkt. pulp (t)			0.48		0.39
Mechanical market pulp (t)					0.19
Softwood pulpwood (m^3)		4.74–1.85			
Hardwood pulpwood (m^3		0.49–3.17			
Pulp subs. & high grade (t)				1.20	
Purchased fuel (x10 GJ)		1.29	0.80	0.80	0.80
Electricity (MWh)		1.00	0.80	1.10	0.80
Labor (h)		0.21	0.19	0.42	0.17
Administrative labor (h)		0.11	0.11	0.13	0.10
Other mfg. costs (1986$)		253.35	210.37	280.15	183.03
CANADA EAST					
Softwood chem. mkt. pulp (t)			0.48		0.39
Hardwood chem. mkt. pulp (t)			0.48		0.39
Mechanical market pulp (t)					0.19
Softwood pulpwood (m^3)	4.03–1.89	3.86–1.81			
Hardwood pulpwood (m^3)	1.33–3.47	1.28–3.33			
Pulp subs. & high grade (t)				1.20	
Purchased fuel (x10 GJ)	1.60	1.49	1.00	1.00	0.90
Electricity (MWh)	1.20	1.00	0.80	1.10	0.80
Labor (h)	0.32	0.30	0.19	0.34	0.17
Administrative labor (h)	0.15	0.15	0.11	0.10	0.10
Other mfg. costs (1986$)	272.89	268.95	195.59	295.29	211.17
CANADA WEST					
Softwood chem. mkt. pulp (t)			0.48		0.39
Hardwood chem. mkt. pulp (t)			0.48		0.39
Mechanical market pulp (t)					0.19
Softwood pulpwood (m^3)		3.86–1.81			
Hardwood pulpwood (m^3)		1.28–3.33			
Pulp subs. & high grade (t)					
Purchased fuel (x10 GJ)		1.39	0.90		0.80
Electricity (MWh)		1.00	0.80		0.80
Labor (h)		0.30	0.19		0.17
Administrative labor (h)		0.15	0.11		0.10
Other mfg. costs (1986$)		269.34	195.68		211.19

fillers. In addition, as much as one-third of the weight of coated groundwood paper can be coatings (mainly clay coatings), particularly in the so-called lightweight coated (LWC) subgrades. Production capacity in 1986 was 3,425,000 tonnes in the United States (API) and approximately 215,000 tonnes in Canada (estimated, based on a fraction of the groundwood printing & specialty grade; CPPA). In 1986, there were generally two types of manufacturing processes for producing coated groundwood in North America, as identified by review of mill listings and technical literature of the pulp and paper industry. For the purpose of the NAPAP Model, the two processes were characterized as follows:

Process 1: Based on integrated mechanical and chemical pulping facilities. The mechanical and chemical pulps were produced on site and blended in the coated groundwood product.

Process 2: Primarily based on integrated mechanical pulping facilities. The mechanical pulp was produced on site and blended with fiber from other sources, either market pulp or secondary fiber (pulp substitutes and high grade deinking grades of recovered paper.)

The coated groundwood industry in North America was examined in detail, using industry directories and other published sources of information (Post's and Lockwood's directories, and company profiles). Mill data were used to infer regional distribution of production capacity by process for coated groundwood in 1986, using capacity data published by API and CPPA as the measure of overall capacity by region. Coated groundwood base-year capacity data are shown in Table 12.

In addition to North American coated groundwood manufacturing processes that existed in 1986, a coated groundwood process was introduced in the NAPAP Model to simulate new process technology becoming available after 1986. Future commercial development of the new process will be facilitated by ongoing technical improvements in recycled fiber recovery and contaminant removal, improved bleaching technologies, environmental concerns, and market demand for products that contain recycled fiber. The new manufacturing process for coated groundwood was defined as follows:

Table 12—Regional distribution of coated groundwood production capacity by process in North America, 1986

	Distribution ($\times 10^3$ t)		
Region	Process 1	Process 2	Total
U.S. North	1,014	1,774	2,788
U.S. South	408	143	551
U.S. West	86	—	86
Canada East	40	175	215
Canada West	—	—	0

Process 3: Represents commercial introduction of a 100-percent recycled fiber process for coated groundwood; the process would be based on flotation deinking technology and would have the ability to use a high proportion of mixed recovered paper (such as old magazines, which would provide roughly two-thirds of fiber in finished product), along with high grade deinking and pulp substitutes. This type of process has been commercialized already overseas.

Table 13 summarizes NAPAP Model base-level fiber input assumptions for the three coated groundwood manufacturing processes. Fillers and coatings are assumed to constitute 36 percent of the final product by weight.

Table 14 summarizes NAPAP Model base-level input coefficients and costs by region for the three coated groundwood manufacturing processes.

Uncoated Groundwood Paper

This commodity category includes the uncoated groundwood grade recognized by API in the United States, and most of the groundwood printing & specialty grade category recognized by CPPA in Canada. Primary end-uses include Sunday magazines, newspaper inserts, catalogs, directories, and forms. Uncoated groundwood papers contain technically no less than 10 percent mechanical pulp (but usually contain much higher percent ages of mechanical pulp) with the balance being mostly chemical pulp, fillers, and some recycled fiber. Production capacity in 1986 was 1,532,000 tonnes in the United States (API), and an estimated 1,346,000 tonnes in Canada (estimated by Forestry

Table 13—Base-level fiber input assumptions for coated groundwood manufacturing processes in the NAPAP Model

	Fiber input (percent)		
Fiber source	Process 1	Process 2	Process 3
Integrated pulp			
Bleached chemical	58	—	—
Groundwood/TMP[a]	42	42	—
Market pulp			
Softwood chemical	—	48	—
Hardwood chemical	—	8	—
Recycled fiber			
Pulp subs. & high grade	—	2[b]	32–100
Mixed paper			68–0
Max. softwood fiber[c]			
Bleached chemical	95	—	—
Groundwood/TMP	100	100	—
Max. hardwood fiber[c]			
Bleached chemical	15	—	—
Groundwood/TMP	10	10	—

[a]TMP is thermomechanical pulp.
[b]Maximum.
[c]Maximum amount allowed in pulp.

Table 14—Base-level input coefficients and costs for coated groundwood paper manufacturing processes per tonne of finished product

Region and output	Process 1	Process 2[a]	Process 3
U.S. North			
Softwood chem. mkt. pulp (t)		0.36 (or 0.34)	
Hardwood chem. mkt. pulp (t)		0.06 (or 0.06)	
Softwood pulpwood (m^3)	2.17–1.95	0.60–0.54 (or 0.58)	
Hardwood pulpwood (m^3)	0.08–0.30	0–0.06	
Mixed papers (t)			0.62–0
Pulp subs. & high grade (t)		(+0.02)	0.30–0.85
Purchased fuel (x10 GJ)	0.89	0.79	0.80
Electricity (MWh)	1.20	1.00	1.00
Labor (h)	0.39	0.25	0.32
Administrative labor (h)	0.07	0.08	0.07
Other mfg. costs (1986$)	332.53	279.87	346.28
U.S. South			
Softwood chem. mkt. pulp (t)		0.36 (or 0.34)	
Hardwood chem. mkt. pulp (t)		0.06 (or 0.06)	
Softwood pulpwood (m^3)	2.21–98	0.61–0.54 (or 0.60)	
Hardwood pulpwood (m^3)	0.06–0.24	0–0.05	
Mixed papers (t)			0.62–0
Pulp subs. & high grade (t)		(+0.02)	0.30–0.85
Purchased fuel (x10 GJ)	0.79	0.69	0.80
Electricity (MWh)	1.20	1.00	1.00
Labor (h)	0.39	0.25	0.32
Administrative labor (h)	0.07	0.08	0.07
Other mfg. costs (1986$)	332.53	279.87	346.28
U.S. West			
Softwood chem. mkt. pulp (t)		0.36 (or 0.34)	
Hardwood chem. mkt. pulp (t)		0.06 (or 0.06)	
Softwood pulpwood (m^3)		0.79–0.71 (or 0.78)	
Hardwood pulpwood (m^3)		0–0.07	
Mixed papers (t)			0.62–0
Pulp subs. & high grade (t)		(+0.02)	0.30–0.85
Purchased fuel (x10 GJ)		0.69	0.80
Electricity (MWh)		1.00	1.00
Labor (h)		0.25	0.32
Administrative labor (h)		0.08	0.07
Other mfg. costs (1986$)		279.87	346.28
Canada East			
Softwood chem. mkt. pulp (t)		0.36 (or 0.34)	
Hardwood chem. mkt. pulp (t)		0.06 (or 0.06)	
Softwood pulpwood (m^3)	3.00–2.69	0.83–0.74 (or 0.81)	
Hardwood pulpwood (m^3)	0.12–0.43	0–0.08	
Mixed papers (t)			0.62–0
Pulp subs. & high grade (t)		(+0.02)	0.30–0.85
Purchased fuel (x10 GJ)	0.99	0.88	0.90
Electricity (MWh)	1.20	1.00	1.00
Labor (h)	0.39	0.25	0.32
Administrative labor (h)	0.07	0.08	0.07
Other mfg. costs (1986$)	349.65	297.63	360.00
Canada West			
Mixed papers (t)			0.62–0
Pulp subs. & high grade (t)			0.30–0.85
Purchased Fuel (x10 GJ)			0.80
Electricity (MWh)			1.00
Labor (h)			0.32
Administrative labor (h)			0.07
Other mfg. costs (1986$)			360.00

[a]Data in parentheses show feasible input combinations. See Table 8 (footnote) for explanation.

Canada). In 1986, there were generally two types of manufacturing processes for producing uncoated groundwood in North America, as identified by review of mill listings and technical literature of the pulp and paper industry. For the purpose of the NAPAP Model, the two processes were characterized as follows:

Process 1: Based on integrated mechanical and chemical pulping facilities. The mechanical and chemical pulps were produced on site and blended in the uncoated groundwood product.

Process 2: Primarily based on integrated mechanical pulping facilities. The mechanical pulp was produced on site and blended with fiber from other sources, either market pulp or secondary fiber (pulp substitutes or high grade deinking grades of recyclable paper.)

The uncoated groundwood industry in North America was examined in detail, using industry directories and other published sources of information (Post's and Lockwood's directories, and company profiles). Mill data were used to infer regional distribution of production capacity by process for uncoated groundwood in 1986, using capacity data published by API and CPPA as the measure of overall capacity by region. Uncoated groundwood base-year capacity data are shown in Table 15.

In addition to North American uncoated groundwood manufacturing processes that existed in 1986, another uncoated groundwood process was introduced in the NAPAP Model to simulate new process technology becoming available after 1986. Future commercial development of the new process will be facilitated by ongoing technical improvements in recycled fiber recovery and contaminant removal, improved sheet printability with developments such as "soft calendering," improved bleaching technologies, environmental concerns, and market demand for products that contain recycled fiber. The new manufacturing process for uncoated groundwood was defined as follows:

Process 3: Represents commercial introduction of a 100-percent recycled fiber process for uncoated groundwood; the process would be based on flotation deinking technology and would have the ability to use a high proportion of mixed recovered paper (such as old magazines, which would provide roughly two-thirds of fiber in finished product), along with high-grade deinking and pulp substitutes.

Table 16 summarizes NAPAP Model base-level fiber input assumptions for the three uncoated groundwood manufacturing processes. Fillers and coatings are assumed to constitute 9 percent of the final product by weight.

Table 17 summarizes NAPAP Model base-level input coefficients and costs by region for the three uncoated groundwood manufacturing processes.

Table 15—Regional distribution of uncoated groundwood production capacity by process in North America, 1986

	Distribution ($\times 10^3$ t)		
Region	Process 1	Process 2	Total
U.S. North	214	975	1,189
U.S. South	50	13	163
U.S. West	—	180	180
Canada East	572	567	1,139
Canada West	207	—	207

Table 16—Base-level fiber input assumptions for uncoated groundwood manufacturing processes in the NAPAP Model

	Fiber input (percent)		
Fiber source	Process 1	Process 2	Process 3
Integrated pulp			
Bleached chemical	35	—	—
Groundwood/TMP	65	58	—
Market pulp			
Softwood chemical	—	30	—
Hardwood chemical	—	5	—
Recycled fiber			
Pulp subs. & high grade	—	7[a]	31–100
Mixed paper			69–0
Max. softwood fiber allowed in pulp			
Bleached chemical	95	—	—
Groundwood/TMP	100	100	—
Max. hardwood fiber allowed in pulp			
Bleached chemical	15	—	—
Groundwood/TMP	10	10	—

[a]Maximum.

Tissue & Sanitary Paper

In the NAPAP Model, this commodity category includes the tissue grade recognized by API in the United States, and the sanitary paper grade recognized by CPPA in Canada. This commodity category excludes the tissue special papers grade recognized by CPPA in Canada (tissue special papers are included in the specialty packaging & industrial category). Almost all tissue products are used for sanitary purposes. Products include bathroom tissue, facial tissue, paper toweling, napkins, basestock for sanitary products, absorbent wadding, and sanitary wipes. A very small fraction (around 2 percent in the United States) is used for other purposes, including wrapping and miscellaneous tissue products. A variety of fiber sources are used to make tissue products, including recycled fiber, chemical pulp, and mechanical pulp. Production capacity in 1986 was 4,975,000 tonnes in the United States (API) and 486,000 tonnes in Canada (CPPA). Four types of processes were generally used to produce tissue in 1986, as identified in mill directories and technical literature of the pulp and paper industry. For the purpose of the NAPAP model, the four processes were characterized as follows:

Table 17–Base-level input coefficients and costs for uncoated groundwood paper manufacturing processes per tonne of finished product

Region and output	Process 1	Process 2[a]	Process 3
U.S. NORTH			
Softwood chem. mkt. pulp (t)		0.30 (or 0.28)	
Hardwood chem. mkt. pulp (t)		0.05 (or 0.05)	
Softwood pulpwood (m^3)	2.65–2.38	1.17–1.06 (or 1.16)	
Hardwood pulpwood (m^3)	0.06–0.33	0–0.11	
Mixed papers (t)			0.89–0
Pulp subs. & high grade (t)		(+0.08)	0.40–1.13
Purchased fuel (x10 GJ)	1.09	0.89	0.80
Electricity (MWh)	1.70	1.40	1.00
Labor (h)	0.40	0.28	0.29
Administrative labor (h)	0.11	0.10	0.10
Other mfg. costs (1986$)	263.23	205.49	287.15
U.S. SOUTH			
Softwood chem. mkt. pulp (t)		0.30 (or 0.28)	
Hardwood chem. mkt. pulp (t)		0.05 (or 0.05)	
Softwood pulpwood (m^3)	2.69–2.42	1.20–1.08 (or 1.18)	
Hardwood pulpwood (m^3)	0.06–0.26	0–0.09	
Mixed papers (t)			0.89–0
Pulp subs. & high grade (t)		(+0.08)	0.40–1.13
Purchased fuel (x10 GJ)	0.99	0.79	0.80
Electricity (MWh)	1.70	1.40	1.00
Labor (h)	0.40	0.28	0.29
Administrative labor (h)	0.11	0.10	0.10
Other mfg. costs (1986$)	263.23	205.49	287.15
U.S. WEST			
Softwood chem. mkt. pulp (t)		0.30 (or 0.28)	
Hardwood chem. mkt. pulp (t)		0.05 (or 0.05)	
Softwood pulpwood (m^3)		1.55–1.39 (or 1.52)	
Hardwood pulpwood (m^3)		0–0.14	
Mixed papers (t)			0.89–0
Pulp subs. & high grade (t)		(+0.08)	0.40–1.13
Purchased fuel (x10 GJ)		0.79	0.80
Electricity (MWh)		1.40	1.00
Labor (h)		0.28	0.29
Administrative labor (h)		0.10	0.10
Other mfg. costs (1986$)		205.49	287.15
CANADA EAST			
Softwood chem. mkt. pulp (t)		0.30 (or 0.28)	
Hardwood chem. mkt. pulp (t)		0.05 (or 0.05)	
Softwood pulpwood (m^3)	3.39–3.06	1.50–1.36 (or 1.47)	
Hardwood pulpwood (m^3)	0.08–0.44	0–0.14	
Mixed papers (t)			0.89–0
Pulp subs. & high grade (t)		(+0.08)	0.40–1.13
Purchased fuel (x10 GJ)	1.19	0.99	0.90
Electricity (MWh)	1.70	1.40	1.00
Labor (h)	0.40	0.28	0.29
Administrative labor (h)	0.11	0.10	0.10
Other mfg. costs (1986$)	272.59	216.62	295.00
CANADA WEST			
Softwood pulpwood (m^3)	3.39–3.06		
Hardwood pulpwood (m^3)	0.08–0.44		
Mixed papers (t)			0.89–0
Pulp subs. & high grade (t)			0.40–1.13
Purchased fuel (GJ)	1.09		0.80
Electricity (MWh)	1.70		1.00
Labor (h)	0.40		0.29
Administrative labor (h)	0.11		0.10
Other mfg. costs (1986$)	272.94		295.00

[a]Data in parentheses show feasible input combinations.

Process 1: Based on a combination of market pulp and some recycled fiber; found in tissue mills without integrated pulping facilities. Information on actual fiber furnish was sketchy for those mills. We assumed that most fiber furnish was market pulp, and that recycled fiber could make up 30 percent of fiber furnish. This process existed only in the United States and Eastern Canada in 1986.

Process 2: Based exclusively on recycled fiber; found in tissue mills without any integrated pulping facilities and where the reported consumption of recycled fiber usually matched the mill production of tissue paper. This process existed only in the United States and Eastern Canada in 1986.

Process 3: Based primarily on integrated chemical pulping facilities, with some recycled fiber input (assumed to be 25 percent of fiber furnish at most); represented by tissue mills in which reported production of chemical pulp was not significantly less than reported production of tissue products. This process existed only in the United States in 1986.

Process 4: Based primarily on integrated mechanical pulping facilities. Other pulps or recycled fiber were blended with the mechanical pulp in some mills, but additional fiber furnish information by mill was sketchy. This process existed only in Canada and the U.S. West in 1986.

The tissue & sanitary paper industry in North America was examined in detail, using industry directories and other published sources of information (Post's and Lockwood's directories, and company profiles). Mill data were used to infer regional distribution of production capacity by process for tissue & sanitary paper in 1986, using capacity data published by API and CPPA as the measure of overall capacity by region. Tissue & sanitary base-year capacity data are shown in Table 18.

In addition to the tissue & sanitary manufacturing processes that existed in 1986, two processes were introduced in the NAPAP Model to simulate new process technologies becoming commercially available after 1986. Future commercial development of the new processes will be facilitated by ongoing technical improvements in recycled fiber recovery and contaminant removal, improved bleaching technologies, further development of improved mechanical pulping methods and bleached mechanical pulps that can displace chemical pulps, advances in biological effluent treatment systems, environmental concerns, and market demand for products that contain substantial fractions of recycled fiber. The two new manufacturing processes for tissue & sanitary paper were defined as follows:

Process 5: Represents the introduction of a 100 percent recycled fiber process that can use mixed paper for up to half the fiber input. The process would use higher grade pulp substitutes and high grade deinking gades for the remainder of fiber input. In 1986, some North American tissue mills used recycled fiber exclusively, but generally mixed paper accounted for only a small fraction of fiber input. This process simulates the evolution of technology that will incorporate higher proportions of lower grade recycled fiber (mixed paper) in response to increased demand for recycled products and likely changes in consumer preferences. Such technology is already used to produce tissue paper in regions outside of North America.

Process 6: Represents the introduction of bleached mechanical market pulp (e.g., BCTMP) for up to half the fiber input in nonintegrated tissue mills.

Table 19 summarizes NAPAP Model base-level fiber input assumptions for tissue & sanitary manufacturing processes. Fillers and coatings are assumed to constitute less than 1 percent of the final product by weight in tissue & sanitary products.

Table 20 summarizes NAPAP Model base-level input coefficients and costs by region for the tissue & sanitary manufacturing processes.

Table 18—Regional distribution of tissue & sanitary paper production capacity by process in North America, 1986

	Distribution ($\times 10^3$ t)				
Region	Process 1	Process 2	Process 3	Process 4	Total
U.S. North	1,044	1,044	587	—	2,676
U.S. South	331	402	764	—	1,497
U.S.West	305	24	433	40	802
Canada East	267	102	—	34	403
Canada West	83	—	—	—	83

Specialty Packaging & Industrial Paper

This NAPAP commodity category includes the bleached packaging and industrial converting, specialty packaging, and special industrial grades recognized by API in the United States (within the packaging & industrial converting category defined by API); specialty packaging and industrial also includes the tissue special papers grade recognized by CPPA in Canada. The construction paper and board grades are included in a separate category. As defined here, specialty packaging & industrial papers are products that serve a wide variety of end-uses in industrial and packaging applications; for example, paper and board commodities of various weights and furnishes used as protective packaging for food and other consumer products, such as bakery bags,

Table 19—Base-level fiber input assumptions for tissue & sanitary paper manufacturing processes in the NAPAP Model

	Fiber input (percent)					
Fiber source	Process 1	Process 2	Process 3	Process 4	Process 5	Process 6
Integrated pulp						
Bleached chemical	—	—	75–100	—	—	—
Groundwood/TMP	—	—	—	90–100	—	—
Market pulp						
Softwood chemical	50	—	—	—	—	25
Hardwood chemical	20	—	—	—	—	25
Mech. mkt. pulp (BCTMP)	—	—	—	—	—	50
Recycled fiber						
Old newspapers (ONP)	—	10	—	—	—	—
Old corrugated (OCC)	—	15	—	—	—	—
Mixed paper	—	15	—	—	52–0	—
Pulp subs. & high grade	30	60	25–0	10–0	48–100	—
Max. softwood fiber in pulp						
Bleached chemical	—	—	50[a]	—	—	—
Groundwood/TMP	—	—	—	100	10	—
Max. hardwood fiber in pulp						
Bleached chemical	—	—	60	—	—	—
Groundwood/TMP	—	—	—	10	—	—

[a]100 percent in U.S. West and Canada.

fast food and frozen food wraps, glassine paper, and greaseproof paper. The category also includes specialty paper and board products designed for specialized end-uses and generally manufactured to exact customer specifications, such as abrasive paper, electrical insulation paper, and filter paper. In 1986, production capacity in this general category was 2,273,000 tonnes in the United States (API) and 23,000 tonnes in Canada (CPPA). The functional requirements of various products in this category are so different that many specialized processes are required. Because of the wide variety of processes and because of the relatively small overall production capacity in this category (approximately 2 percent of North American paper and paperboard capacity), we decided to develop a simplified representation of technology for this product category in the NAPAP Model. Therefore, a single generic "process" is defined for specialty packaging & industrial paper. This process represents a generic composite of the various processes used in specialty packaging & industrial paper mills in 1986.

Process 1: Production is based primarily on integrated pulping facilities (mostly kraft pulp in the United States and mechanical pulp in Canada).

Table 21 shows the regional distribution of specialty packaging & industrial paper production capacity in 1986 based on capacity data published by API and CPPA.

Some improvements in energy efficiency and labor productivity were anticipated to occur over time for all processes in the model, but entirely new or future processes for specialty packaging & industrial paper were not included in the base-level data of the NAPAP Model. Table 22 summarizes NAPAP Model base-level fiber input assumptions for the one specialty packaging & industrial manufacturing process included in the model. Fillers and coatings are assumed to constitute 5 percent of the final product by weight in specialty packaging & industrial products.

Table 23 summarizes NAPAP Model base-level input coefficients and costs by region for the specialty packaging & industrial manufacturing process.

Kraft Packaging & Industrial Paper

Kraft packaging includes the unbleached kraft paper grade recognized by API in the United States (within the packaging & industrial converting category) and also the kraft papers grade category (multiwall sack and other kraft papers) recognized by CPPA in Canada. The unbleached kraft grade in the United States contains more than 80 percent unbleached kraft pulp. Specialty packaging & special industrial grades are not included in this category. As defined here, kraft packaging paper includes products such as kraft wrapping paper, shipping sack, grocers sack, and other brown bag or converting paper. Production capacity for kraft packaging paper in 1986 was 3,254,000 tonnes in the United States (API) and 579,000 tonnes in Canada (CPPA). In North America, there were essentially three distinct production processes for kraft packaging paper in 1986:

Process 1: Based entirely on integrated chemical pulping facilities, primarily unbleached kraft, with some bleached kraft, semibleached kraft, and sulfite or semichemical pulping facilities. Except for mill broke and cuttings, no recycled fiber was used in this process. This was the dominant process in North America in 1986, used in about 20 mills in the United States and Canada.

Process 2: Also based on integrated chemical pulping facilities, primarily unbleached kraft, with some semichemical pulping; in addition, the process used some secondary fiber (primarily OCC). Recycled fiber was approximately 10 to 25 percent of the fiber furnish. This process existed in only a few mills in the United States in 1986.

Process 3: Based entirely on secondary (recycled) fiber, primarily OCC. This process existed in only a couple of mills in the United States in 1986.

Table 24 shows the regional distribution of kraft packaging paper production capacity in 1986 based on capacity data published by API and CPPA.

Some improvements in energy efficiency and labor productivity were anticipated to occur over time for all processes in the model, but entirely new or future processes for kraft packaging paper were not included in the base-level data of the NAPAP Model. Table 25 summarizes NAPAP Model base-level fiber input assumptions for the three kraft packaging manufacturing processes included in the model. Fillers and coatings are assumed to constitute less than 1 percent of the final product by weight in specialty packaging & industrial products.

Table 26 summarizes NAPAP Model base-level input coefficients and costs by region for the kraft packaging manufacturing processes.

Linerboard

In the NAPAP Model, this commodity category includes all unbleached kraft paperboard and the linerboard fraction of recycled paperboard (approximately 5 percent of recycled paperboard capacity) as recognized by API in the United States. It also includes the kraft linerboard and recycled linerboard grades recognized by CPPA in Canada, and any unbleached kraft paperboard in the boxboard category recognized by CPPA in Canada. In the United States, approximately 93 percent of unbleached kraft paperboard was actually used as linerboard, as the surface facing material in corrugated boxes or containers, while the remaining 7 percent was used for folding paperboard backing (folding cartons and beverage containers) and paperboard backing (such as file folders). The NAPAP Model linerboard category excludes solid bleached paperboard (3 percent of which was actually used as linerboard according to API; in the NAPAP Model, this paperboard is included in the solid bleached board commodity category). As such, the linerboard commodity category in the NAPAP Model refers generally to unbleached paperboard used primarily as linerboard. It is combined with corrugating medium when converted into corrugated boxboard and containers. It is used also for folding cartons, containers, and other folders. As defined here, linerboard capacity in 1986 was 17,355,000 tonnes in the United States (API) and 1,373,000 tonnes in Canada (estimates based on data from CPPA). In 1986, the production processes for manufacturing linerboard in North America were as follows:

Process 1: Based on integrated unbleached kraft pulping facilities, using pre-1980 papermaking technology (i.e., without wide-nip or high-impulse press sections and related mill improvements, which first became common in the 1980s). Because of technological limitations of the papermaking process in achieving adequate product performance (i.e., strength), fiber furnish was primarily limited to long-fiber softwood pulpwood, with less than 10 percent hardwood or secondary (recycled) fiber input.

Process 2: Also based on integrated unbleached kraft pulping facilities, but used modernized papermaking technology (i.e., specifically wide-nip or high-impulse press sections and related mill improvements undertaken at many linerboard mills beginning around 1980). Fiber furnish was primarily softwood pulpwood, but the process was capable of utilizing up to 30 percent hardwood fiber or secondary (recycled) fiber input, mainly OCC. The process was also capable of using slightly higher yield kraft pulp than did Process 1 and of increased mill throughput (15 to 20 percent higher than that of Process 1) with correspondingly lower capital costs. Process 2 also afforded energy savings relative to Process 1, as a result of better water removal in the press prior to sheet drying.

Process 3: Based exclusively on secondary (recycled) fiber. The process used mostly OCC and a small amount of pulp substitutes to produce recycled linerboard (also known as testliner).

The linerboard industry in North America was examined in detail, using industry directories and other published sources of information (Post's and Lockwood's directories, company profiles, and publications describing application of new press technology in linerboard mills). Data were available on which mills had installed wide-nip or high-impulse press sections by 1986. The mill data were used to infer the regional distribution of production capacity by process, as shown in Table 27 (the capacity data were calibrated to industry capacity data reported by API and CPPA).

In addition to linerboard manufacturing processes that existed in 1986, two processes were introduced in the NAPAP Model to simulate new technologies being adopted commercially after 1986. New linerboard technology will reflect adjustments to recently revised shipping rules for corrugated boxes, with emphasis on compressive strength rather than basis weight and burst test. Changes in shipping rules will facilitate greater use of short-fiber furnish (i.e., hardwood fiber) and recycled fiber as substitutes for long-fiber softwood (which was needed to meet burst test under the old shipping rules). Improved pressing and drying

Table 20—Base-level input coefficients and costs for tissue & sanitary paper manufacturing processes per tonne of finished product

Region and output	Process 1	Process 2	Process 3	Process 4	Process 5	Process 6
U.S. North						
Softwood chem. mkt. pulp (t)	0.53					0.27
Hardwood chem. mkt. pulp (t)	0.21					0.27
Mechanical mkt. pulp (t)						0.53
Softwood pulpwood (m^3)			2.42–1.94 (or 1.70)			
Hardwood pulpwood (m^3)			0.62–2.78 (or 1.14)			
Old newspapers (t)		0.14				
Old corrugated (t)		0.20				
Mixed papers (t)		0.21			0.70–0	
Pulp subs. & high grade (t)	0.40	0.79	(+33)		0.66–1.32	
Purchased fuel (×10 GJ)	1.00	1.04	1.36		0.90	0.90
Electricity (MWh)	0.40	0.70	0.80		0.70	0.40
Labor (h)	0.82	1.00	1.16		0.75	0.75
Administrative labor (h)	0.42	0.47	0.45		0.42	0.42
Other mfg. costs (1986$)	193.57	283.42	306.25		331.42	276.57
U.S. South						
Softwood chem. mkt. pulp (t)	0.53					0.27
Hardwood chem. mkt. pulp (t)	0.21					0.27
Mechanical mkt. pulp (t)						0.53
Softwood pulpwood (m^3)			2.46–1.96 (or 1.72)			
Hardwood pulpwood (m^3)			1.30–2.22 (or 0.91)			
Old newspapers (t)		0.14				
Old corrugated (t)		0.20				
Mixed papers (t)		0.21			0.70–0	
Pulp subs. & high grade (t)	0.40	0.79	(+0.33)		0.66–1.32	
Purchased fuel (×10 GJ)	0.90	0.94	1.26		0.90	0.90
Electricity (MWh)	0.40	0.70	0.80		0.70	0.40
Labor (h)	0.82	1.00	1.16		0.75	0.75
Administrative labor (h)	0.42	0.47	0.45		0.42	0.42
Other mfg. costs (1986$)	193.57	283.42	306.25		331.42	276.57
U.S. West						
Softwood chem. mkt. pulp (t)	0.53					0.27
Hardwood chem. mkt. pulp (t)	0.21					0.27
Mechanical mkt. pulp (t)						0.53
Softwood pulpwood (m^3)			5.41–2.55 (or 2.23)	3.75–3.37 (or 2.63)		
Hardwood pulpwood (m^3)			0–3.53 (or 1.44)	0–0.24		0.27
Mixed papers (t)					0.70–0	
Old newspapers (t)		0.14				
Old corrugated (t)		0.20			0.70–0	
Mixed papers (t)		0.21				
Pulp subs. & high grade (t)	0.40	0.79	(+0.33)	(+0.13)	0.66–1.32	
Purchased fuel (×10 GJ)	0.90	0.94	1.26	0.81	0.90	0.90
Electricity (MWh)	0.40	0.70	0.80	2.70	0.70	0.40
Labor (h)	0.82	1.00	1.16	0.90	0.75	0.75
Administrative labor (h)	0.42	0.47	0.45	0.48	0.41	0.42
Other mfg. costs (1986$)	193.57	283.42	306.25	296.44	331.42	276.57

Table 20—Base-level input coefficients and costs for tissue & sanitary paper manufacturing processes per tonne of finished product—con.

Region and output	Process 1	Process 2	Process 3	Process 4	Process 5	Process 6
CANADA EAST						
Softwood chem. mkt. pulp (t)	0.53					0.27
Hardwood chem. mkt. pulp (t)	0.21					0.27
Mechanical market pulp (t)						0.53
Softwood pulpwood (m^3)				3.64–3.28 (or 2.56)		
Hardwood pulpwood (m^3)				0–0.25		
Old newspapers (t)		0.14				
Old corrugated (t)		0.20				
Mixed papers (t)		0.21			0.70–0	
Pulp subs. & high grade (t)	0.40	0.79		(+0.13)	0.66–1.32	
Purchased fuel (×10 GJ)	1.10	1.14		1.01	1.00	1.00
Electricity (MWh)	0.40	0.70		2.70	0.70	0.40
Labor (h)	0.82	1.00		0.90	0.75	0.75
Administrative labor (h)	0.42	0.47		0.48	0.42	0.42
Other mfg. costs (1986$)	198.83	293.22		306.49	340.00	285.00
CANADA WEST						
Softwood chem. mkt. pulp (t)						0.27
Hardwood chem. mkt. pulp (t)						0.27
Mechanical market pulp (t)						0.53
Softwood pulpwood (m^3)				3.64–3.28 (or 2.56)		
Hardwood pulpwood (m^3)				0–0.25		
Old newspapers (t)						
Old corrugated (t)						
Mixed papers (t)					0–0.7	
Pulp subs. & high grade (t)				(+0.13)	0.66–1.32	
Purchased fuel (×10 GJ)				0.91	0.90	0.90
Electricity (MWh)				2.70	0.70	0.40
Labor (h)				0.90	0.75	0.75
Administrative labor (h)				0.48	0.42	0.42
Other mfg. costs (1986$)				306.49	340.00	285.00

Table 21—Regional distribution of specialty packaging & industrial paper production capacity in North America, 1986

Region	Total ($\times 10^3$ t)
U.S. North	1,124
U.S. South	846
U.S. West	303
Canada East	23
Canada West	—

Table 22—Base-level fiber input assumptions for specialty packaging & industrial paper manufacturing process in the NAPAP Model

Fiber source	Fiber input (percent)
Integrated pulp[a]	93–100
Recycled fiber	
Mixed paper	2–0
Pulp subs. & high grade	5–0
Max. softwood fiber [a,b]	80
Max. hardwood fiber [a,b]	25

[a]Chemical and mechanical pulp.
[b]Maximum amount allowed in pulp.

Table 23—Base-level input coefficients and costs for specialty packaging & industrial paper manufacturing processes per tonne of finished product

U.S. NORTH	
Softwood pulpwood (m^3)	2.87–2.69 (or.2.67)
Hardwood pulpwood (m^3)	0.68–0.85 (or 0.63)
Mixed papers (t)	(or 0.03)
Pulp subs. & high grade (t)	(+0.06)
Purchased fuel (×10 GJ)	1.42
Electricity (MWh)	1.50
Labor (h)	0.43
Administrative labor (h)	0.13
Other mfg. costs (1986$)	268.58
U.S. SOUTH	
Softwood pulpwood (m^3)	3.44–2.73 (or 2.70)
Hardwood pulpwood (m^3)	0.14–0.68 (or 0.51)
Mixed papers (t)	(or 0.03)
Pulp subs. & high grade (t)	(+0.06)
Purchased fuel (×10 GJ)	1.32
Electricity (MWh)	1.50
Labor (h)	0.43
Administrative labor (h)	0.13
Other mfg. costs (1986$)	268.58
U.S. WEST	
Softwood pulpwood (m^3)	4.47–3.54 (or 3.51)
Hardwood pulpwood (m^3)	0.22–1.09 (or 0.81)
Mixed papers (t)	(or 0.03)
Pulp subs. & high grade (t)	(+0.06)
Purchased fuel (×10 GJ)	1.32
Electricity (MWh)	1.50
Labor (h)	0.43
Administrative labor (h)	0.13
Other mfg. costs (1986$)	268.58
CANADA EAST	
Softwood pulpwood (m^3)	3.67–3.45 (or 3.42)
Hardwood pulpwood (m^3)	0.92–1.14 (or 0.86)
Mixed papers (t)	(or 0.03)
Pulp subs. & high grade (t)	(+0.06)
Purchased fuel (×10 GJ)	1.52
Electricity (MWh)	1.50
Labor (h)	0.43
Administrative labor (h)	0.13
Other mfg. costs (1986$)	281.20

Table 24—Regional distribution of kraft packaging paper production capacity in North America, 1986

	Distribution ($\times 10^3$ t)			
Region	Process 1	Process 2	Process 3	Total
U.S. North	—	157	13	170
U.S. South	1,182	982	28	2,192
U.S. West	588	304	-—	892
Canada East	208	—	—	208
Canada West	371	—	—	371

Table 25—Base-level fiber input assumptions for kraft packaging paper manufacturing processes in the NAPAP Model

	Fiber input (percent)		
Fiber source	Process 1	Process 2	Process 3
Integrated pulp[a]	100	75–100	—
Recycled fiber			
Old corrugated (OCC)	—	25–0	85
Mixed paper	—	—	10
Pulp subs. & high grade	—	—	5
Max. softwood fiber allowed in pulp[a]	100	100	—
Max. hardwood fiber allowed in pulp[a]	5	5	—

[a]Unbleached chemical.

Table 26—Base-level input coefficients and costs for unbleached kraft paper manufacturing processes per tonne of finished product

Region and output	Process 1	Process 2	Process 3
U.S. North			
Softwood pulpwood (m^3)		3.97–3.78 (or 2.99)	
Hardwood pulpwood (m^3)		0–0.18	
Old corrugated (OCC) (t)		(+0.31)	1.06
Mixed papers (t)			0.14
Pulp subs. & high grade (t)			0.07
Purchased fuel (×10 GJ)		1.16	1.03
Electricity (MWh)		1.00	0.50
Labor (h)		0.40	0.30
Administrative labor (h)		0.09	0.15
Other mfg. costs (1986$)		140.21	107.06
U.S. South			
Softwood pulpwood (m^3)	4.04–3.84	4.04–3.84 (or 3.03)	
Hardwood pulpwood (m^3)	0–0.15	0–0.15	
Old corrugated (OCC) (t)		(+0.31)	1.06
Mixed papers (t)			0.14
Pulp subs. & high grade (t)			0.07
Purchased fuel (×10 GJ)	1.16	1.06	0.93
Electricity (MWh)	1.00	1.00	0.50
Labor (h)	0.43	0.40	0.30
Administrative labor (h)	0.09	0.09	0.15
Other mfg. costs (1986$)	134.29	140.21	107.06
U.S. West			
Softwood pulpwood (m^3)	5.25–4.98	5.25–4.98 (or 3.93)	
Hardwood pulpwood (m^3)	0–0.24	0–0.24	
Old corrugated (OCC) (t)		(+0.31)	
Purchased fuel (×10 GJ)	1.16	1.06	
Electricity (MWh)	1.00	1.00	
Labor (h)	0.43	0.40	
Administrative labor (h)	0.09	0.09	
Other mfg. costs (1986$)	134.29	140.21	
Canada East			
Softwood pulpwood (m^3)	5.09–4.84		
Hardwood pulpwood (m^3)	0–0.25		
Purchased fuel (×10 GJ)	1.36		
Electricity (MWh)	1.00		
Labor (h)	0.43		
Administrative labor (h)	0.09		
Other mfg. costs (1986$)	139.25		
Canada West			
Softwood pulpwood (m^3)	5.09–4.84		
Hardwood pulpwood (m^3)	0–0.25		
Purchased fuel (×10 GJ)	1.26		
Electricity (MWh)	1.00		
Labor (h)	0.43		
Administrative labor (h)	0.09		
Other mfg. costs (1986$)	139.36		

Table 27—Regional distribution of linerboard production capacity in North America, 1986

	Distribution ($\times 10^3$ t)			
Region	Process 1	Process 2	Process 3	Total
U.S. North	—	—	276	276
U.S. South	8,454	5,636	68	14,158
U.S. West	568	2,272	81	2,921
Canada East	259	412	290	961
Canada West	371	—	—	371

technology enables production of high-performance linerboard with hardwood and recycled fiber furnish. Environmental concerns and market demand for products that contain substantial fractions of recycled fiber will also promote greater use of recycled fiber in linerboard. Within a decade, it is likely also that unbleached high-yield mechanical pulp in linerboard will be used commercially as a substitute for conventional unbleached kraft (this potential has been demonstrated in laboratory studies, facilitated also by improved pressing and drying techniques). The two new manufacturing processes for linerboard in the NAPAP Model were defined as follows:

Process 4: Represents the commercial application of more advanced pressing and drying technology in North America, using techniques known as impulse drying or press drying. Under the new shipping rules for corrugated containers, the process will be capable of using hardwood pulp as a substitute for softwood kraft.

Process 5: Represents the commercial application of a process based on high-yield mechanical or chemimechanical pulp, such as unbleached CTMP, neutral-sulfite chemimechanical pulp (NSCM), or chemimechanical pulp (CMP) along with advanced pressing and drying technology.

Table 28 summarizes NAPAP Model base-level fiber input assumptions for the five linerboard manufacturing processes. Fillers and coatings are assumed to constitute approximately 1 percent of the final product by weight in linerboard.

Table 29 summarizes NAPAP Model base-level input coefficients and costs by region for the five linerboard manufacturing processes.

Corrugating Medium

In the NAPAP Model, this commodity category includes semichemical paperboard and the corrugating medium portion of recycled paperboard grades recognized by API in the United States. The corrugating medium portion of recycled paperboard represented about 18 percent of total recycled paperboard capacity in 1986. For Canada, corrugating medium includes the semichemical corrugating medium

Table 28—Base-level fiber input assumptions for linerboard manufacturing processes in the NAPAP Model

	Fiber input (percent)				
Fiber source	Process 1	Process 2	Process 3	Process 4	Process 5
Integrated pulp					
Unbleached kraft	95–100	70 –100	—	50–100	
Unbleached mechanical	—	—	—	—	70 –100
Recycled fiber					
Old corrugated (OCC)	5 –0	0 –30	90	—	—
Pulp subs. & high grade	—	—	10	0–50	0 –30
Max. softwood fiber[a]					
Unbleached kraft	100	100	—	100	—
Unbleached mechanical	—	—	—	—	100
Max. hardwood fiber[a]					
Unbleached kraft	5	30	—	50	—
Unbleached mechanical	—	—	—	—	50

[a]Maximum amount allowed in pulp.

and recycled corrugating medium grade categories recognized by CPPA. As defined here, corrugating medium refers exclusively to unbleached paperboard manufactured for use as corrugated fluting material (corrugated core material in corrugated boxes and containers). It is combined with linerboard when converted into corrugated boxboard and containers. In the United States, virtually all semichemical paperboard and all the corrugating medium portion of recycled paperboard are used for that purpose. Production capacity in 1986 was 6,488,000 tonnes in the United States (API) and 729,000 tonnes in Canada (estimated by Forestry Canada). In North America, there were three distinct production process used for manufacturing corrugating medium in 1986. For the purpose of the NAPAP Model, the processes were defined as follows:

Process 1: Based on integrated semichemical pulping facilities, along with some secondary (recycled) fiber input. Generally, around one-third of the fiber furnish was recycled fiber (mostly OCC, with small amounts of mixed papers and pulp substitutes).

Process 2: Based almost exclusively on integrated semichemical pulping facilities, with little or no secondary (recycled) fiber furnish. This process was similar to Process 1, except that mills in Process 2 were not equipped for large amounts of secondary (recycled) fiber input. Less than 10 percent of fiber furnish was secondary fiber (mostly OCC).

Process 3: Based exclusively on secondary (recycled) fiber. OCC was the primary fiber furnish.

The corrugating medium industry in North America was examined in detail, using industry directories and other published sources of information (Post's and Lockwood's directories, and company profiles). The mill data were used to infer the regional distribution of production capacity by process. Table 30 summarizes the estimated regional production capacity for corrugating medium in 1986 (U.S. data calibrated to industry capacity data reported by API; estimates for Canada provided by Forestry Canada).

In addition to corrugating medium manufacturing processes that existed in 1986, another process was introduced in the NAPAP Model to simulate new technology being adopted commercially after 1986. We assumed that there would be relatively modest changes in technology for manufacturing corrugating in the decades ahead, but increased capability to use high-yield mechanical or chemimechanical pulp. In 1986, North American technology for manufacturing corrugating medium was quite efficient in wood and fiber use, based primarily on high yield semichemical pulp and recycled fiber. However, we anticipate that ongoing and future technological developments in corrugating medium will include use of improved pressing and drying technology, and displacement of conventional semichemical pulp with even higher yield mechanical or chemimechanical pulps such as CMP or NSCMP. In addition, there will be increased capability to utilize lower quality recycled fiber in corrugating medium. The new manufacturing process for corrugating medium in the NAPAP Model is Process 4.

Process 4: Represents commercial adoption of advanced pressing and drying technology for corrugating medium (wide-nip or high-impulse press equipment, and later impulse drying or press drying technology). The process will utilize primarily CMP such as NSCMP, with a pulp yield around 90 percent. Up to one-third of fiber input may be provided by lower quality grades of recovered paper, such as mixed recovered paper.

Table 29—Base-level input coefficients and costs for linerboard manufacturing processes by region, per tonne of finished product output

Region and output	Process 1	Process 2	Process 3	Process 4	Process 5
U.S. North					
Softwood pulpwood (m^3)				3.43–1.71 (or 0.85)	2.28–1.14 (or 0.80)
Hardwood pulpwood (m^3)				0–1.63 (or 0.82)	0–1.09 (or 0.76)
Old corrugated (OCC) (t)			1.11	(+0.62)	(+0.37)
Pulp subs. & high grade (t)			0.12		
Purchased fuel (×10 GJ)			0.93	0.05	0.15
Electricity (MWh)			0.49	0.75	0.80
Labor (h)			0.13	0.18	0.15
Administrative labor (h)			0.05	0.05	0.05
Other mfg. costs (1986$)			77.56	100.49	92.02
U.S. South					
Softwood pulpwood (m^3)	3.86–3.66 (or 3.57)	3.60–2.52 (or 2.44)		3.48–1.74 (or 0.87)	2.32–1.16 (or 0.81)
Hardwood pulpwood (m^3)	0–0.14 (or 0.07)	0.07–0.81 (or 0.33)		0–1.31 (or 0.65)	0–0.87 (or 0.61)
Old corrugated (OCC)(t)	(+0.06)	(+0.25)	1.11	(+0.62)	(+0.37)
Pulp subs. & high grade (t)			0.12		
Purchased fuel (×10 GJ)	0.36	0.25	0.93	0.05	0.15
Electricity (MWh)	0.83	0.75	0.49	0.75	0.80
Labor (h)	0.20	0.18	0.13	0.18	0.15
Administrative labor (h)	0.06	0.05	0.05	0.05	0.05
Other mfg. costs (1986$)	93.02	81.01	77.56	100.49	92.02
U.S. West					
Softwood pulpwood (m^3)	5.02–4.77 (or 4.64)	4.66–3.27 (or 3.73)		4.51–2.26 (or 1.13)	3.01–1.51 (or 1.05)
Hardwood pulpwood (m^3)	0–0.23 (or 0.11)	0–1.29		0–2.08 (or 1.04)	0–1.03 (or 0.97)
Old corrugated (OCC) (t)	(+0.06)	(+0.25)	1.11	(+0.62)	(+0.37)
Pulp subs. & high grade (t)			0.12		
Purchased fuel (×10 GJ)	0.36	0.25	0.93	0.05	0.15
Electricity (MWh)	0.83	0.75	0.49	0.75	0.80
Labor (h)	0.20	0.18	0.13	0.18	0.15
Administrative labor (h)	0.06	0.05	0.05	0.05	0.05
Other mfg. costs (1986$)	93.02	81.01	77.56	100.49	92.02
Canada East					
Softwood pulpwood (m^3)	4.86–4.61 (or 4.50)	4.53–3.17 (or 2.70)		4.38–2.19 (or 1.09)	2.91–1.46 (or 1.02)
Hardwood pulpwood (m^3)	0–0.25 (or 0.11)	0–1.36 (or 0.47)		0–2.24 (or 1.12)	0–1.48 (or 1.05)
Old corrugated (OCC) (t)	(+0.06)	(+0.37)	1.11	(+0.62)	(+0.37)
Pulp subs. & high grade (t)			0.12		
Purchased fuel (×10 GJ)	0.56	0.45	1.12	0.15	0.25
Electricity (MWh)	0.80	0.80	0.50	0.75	0.80
Labor (h)	0.25	0.23	0.13	0.18	0.15
Administrative labor (h)	0.09	0.08	0.05	0.05	0.05
Other mfg. costs (1986$)	122.79	110.48	117.03	127.22	117.07
Canada West					
Softwood pulpwood (m^3)	4.86–4.61 (or 4.50)	4.53–3.17 (or 2.70)		4.38–2.19 (or 1.09)	2.91–1.46 (or 1.02)
Hardwood pulpwood (m^3)	0–0.25 (or 0.11)	0–1.36 (or 0.47)		0–2.24 (or 0.12)	0–1.48 (or 1.05)
Old corrugated (OCC) (t)	(+0.06)	(+0.37)	1.11	(+0.62)	(+0.37)
Pulp subs. & high grade (t)			0.12		
Purchased fuel (×10 GJ)	0.46	0.35	1.02	0.05	0.15
Electricity (MWh)	0.80	0.80	0.50	0.75	0.80
Labor (h)	0.25	0.23	0.13	0.18	0.15
Administrative labor (h)	0.09	0.08	0.05	0.05	0.05
Other mfg. costs (1986$)	122.91	110.52	121.53	127.00	116.74

Table 30—Regional distribution of corrugating medium production capacity in North America

Region	Distribution ($\times 10^3$ t)			
	Process 1	Process 2	Process 3	Total
U.S. North	1,325	442	1,026	2,793
U.S. South	1,533	1,022	60	2,615
U.S. West	292	438	350	1,080
Canada East	309	239	107	655
Canada West	24	—	50	74

Table 31 summarizes NAPAP Model base-level fiber input assumptions for the four corrugating medium manufacturing processes. Fillers and coatings are assumed to constitute a negligible fraction of the final product by weight in corrugating medium.

Table 32 summarizes NAPAP Model base-level input coefficients and costs by region for the four corrugating medium manufacturing processes.

Solid Bleached Board

In the NAPAP Model, this commodity category includes the solid bleached packaging paperboard grade recognized by API in the United States and the solid bleached boxboard category recognized by CPPA in Canada. Solid bleached board includes folding paperboards used for conversion into folding cartons, such as cartons for ice cream, frozen foods, butter, and bakery products; paperboards used for conversion into milk cartons, paper plates, food trays, cups, and food packaging; and other solid bleached linerboard and packaging paperboards. Thus solid bleached paperboard refers generally to bleached (white) paperboard used primarily in food packaging or food service products. Production capacity of solid bleached board in 1986 was 4,160,000 tonnes in the United States (API) and 73,000 tonnes in Canada (CPPA). In North America, essentially only one production process was used for solid bleached board in 1986. For the purpose of the NAPAP Model, the process was defined as follows:

> **Process 1:** Based almost entirely on integrated bleached kraft pulping facilities. Almost all of the fiber furnish (more than 97 percent) was bleached kraft pulp, with only a very small fraction derived from TMP or secondary fiber (OCC). Solid bleached board was generally limited by the market to use of virgin bleached kraft pulp because of the general food contact applications and sanitary requirements of the product.

The solid bleached board industry in North America was examined in detail, using industry directories and other published sources of information (Post's and Lockwood's directories, and company profiles). Table 33 summarizes the estimated regional production capacity for solid bleached board in 1986 (based on capacity data reported by API and CPPA).

Table 31—Base-level fiber input assumptions for corrugating medium manufacturing processes in the NAPAP Model

Fiber source	Fiber input (percent)			
	Process 1	Process 2	Process 3	Process 4
Integrated pulp				
Semichemical pulp	67–100	90–100	—	—
Mechanical pulp (CMP)	—	—	—	67–100
Recycled fiber				
Old corrugated (OCC)	33–0	10–0	95	—
Mixed paper	—	—	5	33–0
Max. softwood fiber[a]				
Semichemical pulp	95	95	—	—
Mechanical pulp (CMP)	—	—	—	100
Max. hardwood fiber[a]				
Semichemical pulp	95	95	—	—
Mechanical pulp (CMP)	—	—	—	100

[a]Maximum amount allowed in pulp.

In addition to the conventional solid bleached board manufacturing process that existed in 1986, another process was introduced in the NAPAP Model to simulate new technology being adopted commercially after 1986. It was assumed that technology would be commercially developed to use some high-yield mechanical or chemimechanical pulp, such as bleached CTMP, in solid bleached board (in the range of 10 to 50 percent of total fiber furnish, as suggested by research studies, or around 30 percent on average). The technology would be facilitated by improved multiply sheet forming techniques (e.g., using the mechanical pulp furnish as filler in multiply paperboard). In addition, efforts to replace chlorine-based bleaching technology because of trace dioxin contamination may also tend to favor use of mechanical pulps (which are generally bleached without chlorine) in solid bleached paperboard. The new manufacturing process for solid bleached board in the NAPAP Model was therefore defined as follows:

> **Process 4:** Represents commercial adoption of technology that will incorporate up to 30 percent mechanical pulp (e.g., CTMP), using multiply forming and other techniques.

Table 34 summarizes NAPAP Model base-level fiber input assumptions for the solid bleached board manufacturing processes included in the model. Fillers and coatings were assumed to constitute 8 percent of the final product by weight in solid bleached board.

Table 32—Base-level input coefficients and costs for corrugating medium manufacturing processes by region, per tonne of finished product output

Region and output	Process 1	Process 2	Process 3	Process 4
U.S. North				
Softwood pulpwood (m^3)	2.31–0.12 (or 0.08)	2.31–0.12 (or 0.10)		2.30–0
Hardwood pulpwood (m^3)	0.11–2.21 (or 1.49)	0.11–2.21 (or 1.98)		0–2.20 (or 1.48)
Old corrugated (OCC) (t)	(+0.41)	(+0.12)	1.18	
Mixed papers (t)			0.06	(+0.43)
Purchased fuel (×10 GJ)	0.86	0.90	0.92	0.15
Electricity (MWh)	0.62	0.75	0.55	1.00
Labor (h)	0.24	0.24	0.16	0.15
Administrative labor (h)	0.04	0.04	0.05	0.04
Other mfg. costs (1986$)	88.79	90.27	62.28	89.02
U.S. South				
Softwood pulpwood (m^3)	2.35–0.12 (or 0.08)	2.35–0.12 (or 0.11)		2.33–0
Hardwood pulpwood (m^3)	0.10–1.77 (or 1.19)	0.10–1.77 (or 1.59)		0–1.76 (or 1.18)
Old corrugated (OCC) (t)	(+0.41)	(+0.12)	1.18	
Mixed papers (t)			0.06	(+0.43)
Purchased fuel (×10 GJ)	0.76	0.80	0.82	0.15
Electricity (MWh)	0.62	0.75	0.55	1.00
Labor (h)	0.24	0.24	0.16	0.15
Administrative labor (h)	0.04	0.04	0.05	0.04
Other mfg. costs (1986$)	88.79	90.27	62.28	89.02
U.S. West				
Softwood pulpwood (m^3)	3.21–0.16 (or 2.15)	3.05–0.16 (or 2.89)		3.03–0 (or 2.14)
Hardwood pulpwood (m^3)	0–2.81 (or 0.09)	0.15–2.8 (or 0.13)		0–2.79
Old corrugated (OCC) (t)	(+0.41)	(+0.12)	1.18	
Mixed papers (t)			0.06	(+0.43)
Purchased fuel (×10 GJ)	0.76	0.80	0.82	0.15
Electricity (MWh)	0.62	0.75	0.55	1.00
Labor (h)	0.24	0.24	0.16	0.15
Administrative labor (h)	0.04	0.04	0.05	0.04
Other mfg. costs (1986$)	88.79	90.27	62.28	89.02
Canada East				
Softwood pulpwood (m^3)	2.95–0.17 (or 0.11)	2.95–0.17 (or 0.14)		2.94–0 (or 2.02)
Hardwood pulpwood (m^3)	0.17–2.95 (or 1.97)	0.17–2.95 (or 2.67)		0–3.01
Old corrugated (OCC) (t)	(+0.41)	(+ 0.12)	1.18	
Mixed papers (t)			0.06	(+0.43)
Purchased fuel (×10 GJ)	0.96	1.00	1.02	0.25
Electricity (MWh)	0.62	0.75	0.55	1.00
Labor (h)	0.24	0.24	0.16	0.15
Administrative labor (h)	0.04	0.04	0.05	0.04
Other mfg. costs (1986$)	91.01	92.31	64.15	95.00
Canada West				
Softwood pulpwood (m^3)	2.95–0.17 (or 0.11)			2.94–0 (or 2.02)
Hardwood pulpwood (m^3)	0.17–2.95 (or 1.97)			0–3.01
Old corrugated (OCC) (t)	(+0.41)	1.18		
Mixed papers (t)			0.06	(+0.43)
Purchased fuel (×10 GJ)	0.86		0.92	0.15
Electricity (MWh)	0.62		0.55	1.00
Labor (h)	0.24		0.16	0.15
Administrative labor (h)	0.04		0.05	0.04
Other mfg. costs (1986$)	91.14		64.58	95.00

Table 33—Regional distribution of solid bleached board production capacity in North America, 1986

Region	Total ($\times 10^3$ t)
U.S. North	21
U.S. South	3,678
U.S. West	461
Canada East	73
Canada West	—

Table 34—Base-level fiber input assumptions for solid bleached board manufacturing process in the NAPAP Model

	Fiber input (percent)	
Fiber source	Process 1	Process 2
Integrated pulp		
Bleached kraft pulp	98–100	70
Mechanical pulp (CTMP)		30
Recycled fiber		
Old corrugated (OCC)	2–0	
Max. softwood fiber[a]		
Bleached kraft pulp	75[b]	75
Mechanical pulp (CTMP)		100
Max. hardwood fiber[a]		
Bleached kraft pulp	67	67
Mechanical pulp (CTMP)		100

[a]Maximum amount allowed in pulp.
[b]100 percent in U.S. West.

Table 35 summarizes NAPAP Model base-level input coefficients and costs by region for the solid bleached board manufacturing process.

Recycled Board

This commodity category includes about two-thirds of the recycled paperboard grade recognized by API in the United States. For the purpose of the NAPAP Model, this category excludes the linerboard and corrugating medium products within the API recycled paperboard grade (linerboard and corrugating medium are included in separate commodity categories in the NAPAP Model, as explained previously). Recycled board also includes the recycled paperboard portions of the folding boxboard and other boxboard grade categories recognized by CPPA in Canada. As defined here, the recycled board category includes paperboard products that are made entirely from secondary (recycled) fiber and that include folding boxboard, container chip and filler board, set-up board, gypsum wallboard facing, and other recycled paperboard products, such as file folders, tablet backs, tubes, and can and drum stock. As defined here, recycled board production capacity in 1986 was 6,328,000 tonnes in the United States (API) and upwards of 502,000 tonnes in Canada (estimated by Forestry Canada based on

Table 35—Base-level input coefficients and costs for solid bleached board manufacturing processes by region, per tonne of finished product output

Region and output	Process 1	Process 2
U.S. North		
Softwood pulpwood (m^3)	2.75–1.21 (or 2.70–1.18)	2.57–0.85
Hardwood pulpwood (m^3)	0.88–2.35 (or 0.85–2.30)	0.61–2.25
Old corrugated (OCC) (t)	(+ 0.02)	
Purchased fuel ($\times$10 GJ)	0.98	0.70
Electricity (MWh)	1.23	1.50
Labor (h)	0.44	0.35
Administrative labor (h)	0.06	0.05
Other mfg. costs (1986$)	224.56	221.88
U.S. South		
Softwood pulpwood (m^3)	2.80–1.22 (or 2.75–1.21)	2.60–0.86
Hardwood pulpwood (m^3)	0.70–1.88 (or 0.68–1.85)	0.49–1.80
Old corrugated (OCC) (t)	(+0.02)	
Purchased fuel ($\times$10 GJ)	0.88	0.60
Electricity (MWh)	1.23	1.50
Labor (h)	0.44	0.35
Administrative labor (h)	0.06	0.05
Other mfg. costs (1986$)	224.56	221.88
U.S. West		
Softwood pulpwood (m^3)	4.82–1.60 (or 3.55–1.57)	3.37–1.12
Hardwood pulpwood (m^3)	0–2.99 (or 1.09–2.93)	0.78–2.86
Old corrugated (OCC) (t)	(+0.02)	
Purchased fuel ($\times$10 GJ)	0.88	0.60
Electricity (MWh)	1.23	1.50
Labor (h)	0.44	0.35
Administrative labor (h)	0.06	0.05
Other mfg. costs (1986$)	224.56	221.88
Canada East		
Softwood pulpwood (m^3)	3.53–1.56 (or 3.45–1.53)	3.27–1.08
Hardwood pulpwood (m^3)	1.17–3.14 (or 1.14–3.08)	0.84–3.08
Old corrugated (OCC) (t)	(+0.02)	
Purchased fuel ($\times$10 GJ)	1.08	0.80
Electricity (MWh)	1.23	1.50
Labor (h)	0.44	0.35
Administrative labor (h)	0.06	0.05
Other mfg. costs (1986$)	251.45	245.00
Canada West		
Softwood pulpwood (m^3)		3.27–1.08
Hardwood pulpwood (m^3)		0.84–3.08
Old corrugated (OCC) (t)		
Purchased fuel ($\times$10 GJ)		0.70
Electricity (MWh)		1.50
Labor (h)		0.35
Administrative labor (h)		0.05
Other mfg. costs (1986$)		245.00

Table 36—Regional distribution of recycled board production capacity in North America, 1986

Region	Total ($\times 10^3$ t)
U.S. North	3,682
U.S. South	1,714
U.S. West	932
Canada East	445
Canada West	57

information from CPPA). In 1986, there was essentially only one production process for recycled board in North America in terms of fiber inputs since all fiber input was recycled fiber. For the purpose of the NAPAP Model, the process was defined as follows:

> **Process 1:** Based exclusively on secondary (recycled) fiber, with no integrated pulping facilities and no market pulp input. Fiber furnish included various grades of recovered paper, including ONP, OCC, mixed papers, pulp substitutes, and some high-grade deinking grades of recovered paper.

The recycled board industry in North America was examined in detail, using industry directories and other published sources of information (Post's and Lockwood's directories, and company profiles). Table 36 summarizes the estimated regional production capacity for recycled board in 1986 (based on capacity data reported by API and CPPA).

Some improvements in energy efficiency and labor productivity were anticipated to occur over time for all processes in the model, but entirely new or future processes for recycled board were not included in the base-level data of the NAPAP Model. Fiber input data for recycled board were developed separately for each region of the NAPAP Model, based on unpublished fiber furnish survey data from API and CPPA. Table 37 summarizes NAPAP Model base-level input coefficients and costs by region for the recycled board manufacturing process.

Construction Paper & Board

The NAPAP commodity category of construction paper & board (and other) includes four product categories recognized by the U.S. Department of Commerce in 1986, wet machine board, insulating board, construction paper, and hardboard products. It also includes the building & other commodity category recognized by CPPA in Canada. Generally, construction paper & board (and other) includes products such as sheathing paper and felt (including roofing felt), binders board, shoe board, automotive board, furniture backing, insulating board, acoustical tile, standard and tempered hardboard, and laminated and coated hardboard. Regional production capacity data for the United States were not directly available from the U.S. Department of Commerce for products in this category, but were estimated based on Commerce Department data and other sources. The data

Table 37—Base-level input coefficients and costs for recycled board manufacturing process by region, per tonne of finished product output

Region and output	Process 1
U.S. North	
Old newspapers (ONP) (t)	0.19
Old corrugated (OCC) (t)	0.57
Mixed papers (t)	0.18
Pulp subs. & high grade (t)	0.13
Purchased fuel ($\times$10 GJ)	0.81
Electricity (MWh)	0.49
Labor (h)	0.46
Administrative labor (h)	0.06
Other mfg. costs (1986$)	87.80
U.S. South	
Old newspapers (ONP) (t)	0.15
Old corrugated (OCC) (t)	0.58
Mixed papers (t)	0.26
Pulp subs. & high grade (t)	0.10
Purchased fuel ($\times$10 GJ)	0.81
Electricity (MWh)	0.49
Labor (h)	0.46
Administrative labor (h)	0.06
Other mfg. costs (1986$)	87.80
U.S. West	
Old newspapers (ONP) (t)	0.11
Old corrugated (OCC) (t)	0.83
Mixed papers (t)	0.09
Pulp subs. & high grade (t)	0.06
Purchased fuel ($\times$10 GJ)	0.81
Electricity (MWh)	0.49
Labor (h)	0.46
Administrative labor (h)	0.06
Other mfg. costs (1986$)	87.80
Canada East	
Old newspapers (ONP) (t)	0.19
Old corrugated (OCC) (t)	0.57
Mixed papers (t)	0.18
Pulp subs. & high grade (t)	0.13
Purchased fuel ($\times$10 GJ)	0.81
Electricity (MWh)	0.49
Labor (h)	0.46
Administrative labor (h)	0.06
Other mfg. costs (1986$)	90.68
Canada West	
Old newspapers (ONP) (t)	0.19
Old corrugated (OCC) (t)	0.57
Mixed papers (t)	0.18
Pulp subs. & high grade (t)	0.13
Purchased fuel ($\times$10 GJ)	0.71
Electricity (MWh)	0.49
Labor (h)	0.46
Administrative labor (h)	0.06
Other mfg. costs (1986$)	91.82

on shipments from U.S. producers in 1986 showed approximately 2,400,000 tonnes of product shipments in this commodity category (of which more than 1,400,000 tonnes were classified as hardboard products (U.S. Department of Commerce 1987). The API reported that regional production capacity in 1986 for the API grades known as construction paper, wet machine board, and insulating board was 1,948,000 tonnes. The extent to which the API grades overlapped with the Commerce Department "hardboard" category was not clear, although the API data apparently excluded some hardboard products. Estimated 1986 production capacity for construction paper & board (and other) was 2,700,000 tonnes in the United States and 646,000 tonnes in Canada.

Products in the category of construction paper & board (and other) were made by various processes, primarily based on exploded/defibrated pulping or recycled fiber. Many of the major products were produced using only exploded/defibrated pulping, while others were made from recycled fiber or a mix of fiber inputs. (The API reported that in the United States more than 800,000 tonnes of recovered paper were consumed in construction paper and board manufacture in 1986.) The uniformly lower value of such fiber inputs and the significant variation among products by end-use in this category (with varying fiber input requirements) would make it unrealistic to characterize processes as competing substantially on the basis of fiber inputs or process differentiation. Also, data on the construction paper and board industry were quite limited, and the industry accounted for only a small share of overall North American wood fiber consumption. Therefore, for the purpose of the NAPAP Model, a single generic "process" was defined to represent the manufacturing technology for construction paper & board (and other). This generic process (Process 1) represented a composite of exploded/defibrated pulping and recycled fiber processes used in construction paper & board (and other) mills in 1986:

> **Process 1:** Represents a composite of various processes, primarily based on integrated exploded/defibrated pulping facilities or recycled fiber.

Table 38 shows the estimated regional distribution of production capacity for construction paper & board (and other) in the United States and Canada.

Some improvements in energy efficiency and labor productivity were anticipated to occur over time for all processes in the model, but entirely new or future processes for construction paper & board were not included in the base-level data of the NAPAP Model. Table 39 summarizes NAPAP Model base-level fiber input assumptions for the one construction paper & board manufacturing process included in the model. Fillers and coatings are assumed to constitute 5 percent on average of the final product by weight.

Table 40 summarizes NAPAP Model base-level input coefficients and costs by region for construction paper & board (and other).

Table 38—Regional distribution of production capacity for construction paper & board (and other) in North America, 1986

Region	Total ($\times 10^3$ t)
U.S. North	1,110
U.S. South	1,460
U.S. West	130
Canada East	472
Canada West	174

Table 39—Base-level fiber input assumptions for construction paper & board (and other) in the NAPAP Model

Fiber source	Fiber input (percent)
Integrated pulp[a]	60–100
Recycled fiber	
Old newspapers (ONP)	11–0
Old corrugated (OCC)	10–0
Mixed paper	16–0
Pulp subs. & high grade	3–0
Max. softwood fiber[a,b]	100
Max. hardwood fiber[a,b]	100

[a]Exploded/defibrated pulp.
[b]Maximum amount allowed in pulp.

Market Pulp

In the NAPAP Model, market pulp includes five commodity categories:

- Softwood chemical market pulp
- Hardwood chemical market pulp
- Mechanical market pulp
- Market pulp from recycled fiber
- Dissolving & special alpha pulp

The first four commodity categories are paper-grade market pulps, i.e., bleached market pulps used primarily in making paper or paperboard products. They are intermediate products in the NAPAP Model, providing fiber inputs to various paper or paperboard manufacturing processes. The market pulp commodity categories can be partially substituted for one another, and in the NAPAP Model they can be partially substituted in some cases. They generally serve different end-uses; in the NAPAP Model, they are used in different proportions in various paper and paperboard manufacturing processes. The last category, dissolving & special alpha pulp, is a separate end-product in the NAPAP Model. This kind of pulp is used to make synthetic cellulose products (such as rayon and celluloid) and a variety of fiber products that use purified cellulose fiber (such as filters and specialized wadding).

Table 40—Base-level input coefficients and costs for construction paper & board manufacturing process by region, per tonne of finished product output

Region and output	Process
U.S. North	
Softwood pulpwood (m^3)	2.03–0 (or 1.22–0)
Hardwood pulpwood (m^3)	0–1.93 (or 0–1.16)
Old newspapers (ONP) (t)	(or 0.12)
Old corrugated (OCC) (t)	(or 0.11)
Mixed papers (t)	(or 0.19)
Pulp subs. & high grade (t)	(+0.03)
Purchased fuel (×10 GJ)	1.22
Electricity (MWh)	0.70
Labor (h)	0.20
Administrative labor (h)	0.05
Other mfg. costs (1986$)	85.40
U.S. South	
Softwood pulpwood (m^3)	2.07–0 (or 1.23–0)
Hardwood pulpwood (m^3)	0–1.55 (or 0–0.93)
Old newspapers (ONP) (t)	(or 0.12)
Old corrugated (OCC) (t)	(or 0.11)
Mixed papers (t)	(or 0.19)
Pulp subs. & high grade (t)	(+0.03)
Purchased fuel (×10 GJ)	1.22
Electricity (MWh)	0.70
Labor (h)	0.20
Administrative labor (h)	0.05
Other mfg. costs (1986$)	85.40
U.S. West	
Softwood pulpwood (m^3)	2.67–0 (or 1.61–0)
Hardwood pulpwood (m^3)	0–2.47 (or 0–1.48)
Old newspapers (ONP) (t)	(or 0.12)
Old corrugated (OCC) (t)	(or 0.11)
Mixed papers (t)	(or 0.19)
Pulp subs. & high grade (t)	(+0.03)
Purchased fuel (×10 GJ)	1.22
Electricity (MWh)	0.70
Labor (h)	0.20
Administrative labor (h)	0.05
Other mfg. costs (1986$)	85.40
Canada East	
Softwood pulpwood (m^3)	2.61–0 (or 1.56–0)
Hardwood pulpwood (m^3)	0–2.61 (or 0–1.56)
Old newspapers (ONP) (t)	(or 0.12)
Old corrugated (OCC) (t)	(or 0.11)
Mixed papers (t)	(or 0.19)
Pulp Subs. & high grade (t)	(+ 0.03)
Purchased fuel (×10 GJ)	1.22
Electricity (MWh)	0.70
Labor (h)	0.20
Administrative labor (h)	0.05
Other mfg. costs (1986$)	87.82
Canada West	
Softwood pulpwood (m^3)	2.61–0 (or 1.56–0)
Hardwood pulpwood (m^3)	0–2.61 (or 0–1.56)
Old newspapers (ONP) (t)	(or 0.12)
Old corrugated (OCC) (t)	(or 0.11)
Mixed papers (t)	(or 0.19)
Pulp Subs. & High grade (t)	(+ 0.03)
Purchased fuel (×10 GJ)	1.22
Electricity (MWh)	0.70
Labor (h)	0.20
Administrative labor (h)	0.05
Other mfg. costs (1986$)	87.90

The softwood and hardwood chemical paper-grade pulps are primarily bleached kraft pulps. Production capacity for all chemical paper-grade pulps in 1986 was 7,151,000 tonnes in Canada (CPPA) and 6,027,000 tonnes in the United States (API). Production capacity for mechanical market pulp in 1986 was 589,000 tonnes in Canada (CPPA) and less than 13,000 tonnes in the United States (API). Production capacity for market pulp from recycled fiber was approximately 214,000 tonnes in the United States and approximately 33,000 tonnes in Canada (estimates based on data in Lockwood's Directory). Production capacity for dissolving and special alpha pulps in 1986 was 1,268,000 tonnes in the United States and 245,000 tonnes in Canada (API, CPPA).

In 1986, the five categories of market pulps were produced by processes that were characterized in the NAPAP Model as follows:

Softwood chemical market pulp: Represents a generic composite of bleached chemical pulping facilities, primarily bleached kraft and bleached sulfite, with softwood pulpwood as the raw material. Also included were all softwood chemical market pulps based on semibleached and unbleached processes (a very small share of capacity in relation to the bleached chemical market pulp).

Hardwood chemical market pulp: Represents primarily bleached kraft pulping facilities, with hardwood pulpwood as the raw material. Also included were hardwood chemical market pulps based on semibleached and unbleached processes (a small share of capacity in relation to the bleached kraft market pulp).

Mechanical market pulp: Represents mechanical pulping facilities producing market pulp, primarily bleached CTMP. The process produced a paper-grade market pulp that could be substituted to some extent for bleached chemical market pulp in printing and writing paper, solid bleached board, and tissue. The process for mechanical market pulp existed mainly in Canada in 1986.

Market pulp from recycled fiber: Based entirely on recycled fiber. In 1986, the process existed in only a few mills in the United States and one mill in Canada. It produced a paper-grade market pulp based on fiber from pulp substitutes and high-grade deinking grades of recovered paper.

Dissolving & special alpha pulp: Based on low-yield chemical pulping facilities, including both sulfite and kraft pulping facilities. Pulping processes varied to some extent, so this process represents a generic composite of existing dissolving & special alpha pulp mill technology in North America.

Table 41—Regional market pulp production capacity of the United States and Canada in 1986

Region	Regional production capacity by commodity ($\times 10^3$ t)				
	Softwood chemical pulp	Hardwood chemical pulp	Bleached mechanical pulp	Recycled fiber market pulp	Dissolving & special alpha pulp
U.S. North	—	563	7	72	—
U.S. South	3,058	1,605	5	95	655
U.S. West	739	61	—	47	615
Canada East	2,886	1,170	377	33	110
Canada West	4,531	—	212	—	135

Table 42—Base-level fiber input assumptions for linerboard manufacturing processes in the NAPAP Model

Fiber source	Fiber input (percent)				
	Softwood chemical pulp	Hardwood chemical pulp	Bleached mechanical pulp	Recycled fiber market pulp	Dissolving & special alpha pulp
Pulpwood	100	100	100	—	100
Recycled fiber[a]	—	—	—	100	—
Max. softwood fiber[b]	100	10	100	—	100
Max. hardwood fiber[b]	10	100	10	—	40

[a]Pulp substitutes and high-grade deinking.
[b]Maximum amount allowed in pulp.

The market pulp industry in North America was examined in detail, using industry directories and other published sources of information (Post's and Lockwood's directories, and company profiles). The mill data were used to infer the regional capacity distribution by commodity category for market pulp, as shown in Table 41 (based on national capacity data for the industry reported by API and CPPA, with regional distribution inferred from mill listings and other sources).

Some improvements in energy efficiency and labor productivity were anticipated to occur over time for all processes in the model, but entirely new commodities or future processes for market pulp were not included in the base-level data of the NAPAP Model. Table 42 summarizes NAPAP Model base-level fiber input assumptions for the market pulp commodities and manufacturing processes.

Table 43 summarizes NAPAP Model base-level input coefficients and costs by region for the market pulp manufacturing processes.

Pulpwood Supply

For the NAPAP Model, long-range supply functions were provided for each pulpwood category in each North American supply region (softwood roundwood, softwood residues, hardwood roundwood, hardwood residues; U.S. North, South, and West, and Canada East and West). Price and quantity units for pulpwood in the NAPAP Model were 1986 U.S. dollars and cubic meters. A more detailed discussion of estimation procedures, mathematical formulation of supply functions, data, and assumptions will be reported in a research paper on the NAPAP Model (Ince and others, in preparation).

Estimates of roundwood pulpwood stumpage supply functions (hardwood and softwood roundwood) for the U.S. North and U.S. South were provided by Professor Darius Adams (University of Montana; formerly of the University of Washington). Historical U.S. pulpwood consumption quantity data by region, 1950–1989, were obtained by Ingram, Durbak, and Ince (in preparation). Historical pulpwood price data were estimated by Adams. Although pulpwood supply quantity includes supply for exports as well as domestic consumption, the domestic pulpwood consumption data were used as a proxy for historical data on total pulpwood supply quantity by region (because data on U.S. pulpwood exports by region were unavailable). Stumpage supply functions were converted to delivered pulpwood supply functions for the NAPAP Model by assuming that a constant "log and haul" cost was associated with delivery of pulpwood to mills. This simplifying assumption implies that the ratio of delivered pulpwood supply elasticity to stumpage supply elasticity equals the ratio of delivered price to stumpage price at the equilibrium quantity; thus, estimates of

Table 43—Base-level input coefficients and costs for market pulp manufacturing processes by region, per air-dry tonne of finished product output

Region and output	Dissolving pulp	Softwood chemical	Hardwood chemical	Mechanical (BCTMP)	Market pulp from recycled fibers
U.S. North					
Softwood pulpwood (m^3)			0.42–0 .00	2.12–2.00	
Hardwood pulpwood (m^3)			3.58–3.98	0–0.20	
Pulp subs. & high grade (t)					1.25
Purchased fuel (×10 GJ)			1.08	0.62	0.96
Electricity (MWh)			0.70	2.50	0.50
Labor (h)			0.19	0.06	0.11
Administrative labor (h)			0.06	0.03	0.05
Other mfg. costs (1986$)			260.08	191.18	153.65
U.S. South					
Softwood pulpwood (m^3)	4.96–2.97	4.23–3.80	0.42–0.00	2.16–1.94	
Hardwood pulpwood (m^3)	0–1.50	0–0.32	2.86–3.18	0–0.16	
Pulp subs. & high grade (t)					1.25
Purchased fuel (×10 GJ)	0.90	5.00	5.00	0.52	0.96
Electricity (MWh)	0.70	0.15	0.15	2.50	0.50
Labor (h)	0.40	0.19	0.19	0.06	0.11
Administrative labor (h)	0.09	0.06	0.06	0.03	0.05
Other mfg. costs (1986$)	222.62	290.24	264.34	195.44	157.91
U.S. West					
Softwood pulpwood (m^3)	6.45–3.86	5.49–4.94	0.55–0.00		
Hardwood pulpwood (m^3)	0–2.37	0–0.51	4.55–5.05		
Pulp subs. & high grade (t)					1.25
Purchased fuel (×10 GJ)	0.90	5.30	5.30		0.96
Electricity (MWh)	0.70	0.70	0.70		0.50
Labor (h)	0.40	0.19	0.19		0.11
Administrative labor (h)	0.09	0.05	0.05		0.05
Other mfg. costs (1986$)	222.62	294.71	268.81		162.38
Canada East					
Softwood pulpwood (m^3)	6.25–3.75	5.31–4.78	0.53–0.00	2.72–2.45	
Hardwood pulpwood (m^3)	0–2.50	0–0.53	4.78–5.31	0–0.28	
Pulp subs. & high grade (t)					1.25
Purchased fuel (×10 GJ)	1.09	6.70	6.70	0.71	0.96
Electricity (MWh)	0.70	0.32	0.32	2.50	0.50
Labor (h)	0.40	0.24	0.24	0.06	0.11
Administrative labor (h)	0.09	0.08	0.08	0.03	0.05
Other mfg. costs (1986$)	232.44	293.44	267.08	186.92	143.05
Canada West					
Softwood pulpwood (m^3)	6.25–3.75	5.31–4.78		2.72–2.45	
Hardwood pulpwood (m^3)	0–2.50	0–0.53		0–0.28	
Pulp subs. & high grade (t)					
Purchased fuel (× 10 GJ)	1.00	1.08		0.61	
Electricity (MWh)	0.70	0.41		2.50	
Labor (h)	0.40	0.22		0.06	
Administrative labor (h)	0.09	0.08		0.03	
Other mfg. costs (1986$)	233.88	296.83		188.22	

delivered pulpwood price elasticities were derived from stumpage supply functions estimated by Adams. In addition, the price elasticity for hardwood pulpwood in the South was gradually reduced to 1.0 in the period between 2005 and 2015, to simulate a supply response to projected declines in hardwood timber inventory in the South (as projected by the Forest Service TAMM/ATLAS model). The hardwood roundwood pulpwood price elasticity was reduced from 2.98 to 2.3 in 2005, 1.5 in 2010, and 1.0 in 2015.

In the pulpwood stumpage supply equations estimated by Adams, pulpwood supply was related to regional timber inventory (timber growing stock volume), sawtimber stumpage price, and the discount rate (a determinant of timberland investment). Since the delivered pulpwood supply curves were derived by shifting stumpage supply curves only in the price dimension and not in any other dimension, the delivered pulpwood supply equations have the same elasticities with respect to exogenous shifter variables as the stumpage supply equations. Long-range projections of the first two shifters were obtained from the Forest Service TAMM/ATLAS model (which projects timber growth and inventory, stumpage markets, and outputs of the solid wood product sector). The exogenous projections were obtained from TAMM/ATLAS run number LR123 (dated January 29, 1993). The discount rate projection was obtained exogenously from the basic RPA assumptions.

Delivered pulpwood supply equations for residues in the United States (North, South, and West) and roundwood pulpwood supply in the West were all specified in a more simplified manner for the NAPAP Model. The "L-shaped" supply curves were specified (defining supply functions that are flat in the price dimension, with a vertical upper bound on supply). The flat portion of the supply curve represents a "reservation price" for the commodity (a price that must be paid to cover ordinary procurement and delivery costs), while the vertical portion of the supply curve represents an absolute upper bound on the supply of the commodity. Illustrative examples and discussion of techniques for specifying such functions are provided in the PELPS III manual (Zhang and others, in preparation). Upper bounds for residues and roundwood in the West were specified for the base period (1986) as equivalent to the base-year production quantity in each case.

Both the reservation price and upper bound were projected to change over time in the NAPAP Model, to reflect exogenous changes in supply. It was assumed that projected log and haul cost is an appropriate shifter of the reservation price for residues generally and for roundwood in the West. The idea was that all the residue material (including residue material such as chips, sawmill slabs, and edgings) must be initially logged as sawtimber and hauled to a mill (such as a sawmill or plywood mill), and therefore this cost establishes a minimum price that must be paid for the material. The vertical portion of the supply curves, or upper bounds on supply, were assumed to be equivalent to a certain fraction of regional sawmill and plywood mill residue output (a variable projected by the TAMM/ATLAS model). Similar concepts were used to specify delivered roundwood pulpwood supply equations for the U.S. West (i.e., L-shaped supply curves), except that the upper bound was regarded as determined by a regional timber harvest (largely influenced in the West by government timber policies on public lands). The projected changes in upper bounds on supply thus reflect projected limits on the physical quantities of mill residues available for pulpwood and projected limits on the quantity of roundwood available in the West (as determined by projected timber harvest in the West).

Canadian pulpwood roundwood supply functions for the NAPAP Model were estimated by the Economics and Policy Directorate of Forestry Canada (Ottawa, Ontario). For Canada, historical timber inventory data comparable to national data were not available, although it was known that Canadian inventories of timber are quite large and less dynamic than U.S. timber inventories. Delivered pulpwood supply in Canada was believed to be related primarily to labor costs, timber stumpage prices, and U.S./Canada exchange rates. Thus, delivered roundwood pulpwood supply functions included the shifter variables of labor costs, overall stumpage prices in Canada, and exchange rates. Delivered pulpwood residue supply functions included the shifter variables of regional lumber production and exchange rates. Canadian regional lumber production volumes projected by the TAMM/ATLAS model were used to shift residue pulpwood supply functions. Growth rates for other Canadian pulpwood supply shifter variables were projected exogenously by Forestry Canada.

Tables 44 and 45 summarize the pulpwood supply function elasticities, along with base-period prices and quantities. Base-period pulpwood supply quantity data were approximated based on data published by the U.S. Department of Commerce, API, Statistics Canada, and Forestry Canada. Base-period pulpwood price data were approximated based on USDA Forest Service data and other sources.

Linkage to TAMM/ATLAS Model

Linkage between the NAPAP Model and the USDA Forest Service TAMM/ATLAS system was established by obtaining convergent timber supply and demand equilibria through iterative solutions of the NAPAP and TAMM models. Revised timber projections from one model were used as data input for the other model on each iteration, until convergent solutions were obtained. Pulpwood market projections from the NAPAP Model were used as data input to the TAMM model. The pulpwood projections included regional supply quantities of pulpwood roundwood and residues, hardwoood and softwood, and projected pulpwood prices. In turn, timber projections from the TAMM model were used as data input to the NAPAP Model. These included projected timber inventory, sawtimber prices, lumber production and residue output by region, which were used to shift pulpwood supply functions in the NAPAP Model.

Table 44—Pulpwood supply function elasticities for U.S. North, South, and West, with base-period (1986) price and quantity assumptions used in NAPAP Model[a]

Region and pulpwood	Elasticities				Partial adjustment parameter (Lag, t-1)	Base-period supply quantity ($\times 10^3$ m^3)	Base-period supply price (1986$)
	Delivered price	Timber inventory[b]	Sawtimber stumpage price[b]	Discount rate			
U.S. North							
Softwood roundwood	0.71	0.249	-0.0086	—	0.751	12,394	35.00
Softwood residue	*	—	—	—	—	2,222	25.00
Hardwood roundwood	1.32	0.589	0.55	0.78	0.411	15,984	26.80
Hardwood residue	*	—	—	—	—	3,251	20.00
U.S. South							
Softwood roundwood	0.79	0.295	0.11	—	0.705	59,686	29.25
Softwood residue	*	—	—	—	—	26,352	15.00
Hardwood roundwood	2.98	0.354	0.55	4.12	0.646	24,448	23.05
Hardwood residue	*	—	—	—	—	11,359	15.00
U.S. West							
Softwood roundwood	*	—	—	—	—	7,761	25.00
Softwood residue	*	—	—	—	—	22,966	25.00
Hardwood roundwood	*	—	—	—	—	1,347	25.00
Hardwood residue	*	—	—	—	—	724	20.00

[a]Southern hardwood roundwood price elasticity of supply was adjusted downward (to 2.3 in the year 2005, 1.5 in 2010, and 1.0 in 2015) to simulate expected response of declining elasticity of supply resulting from projected declines in Southern hardwood timber inventories that occur around the year 2010.

[b]Softwood or hardwood. * denotes horizontal supply curve, with upper bound (L-shaped supply curve).

Table 45—Pulpwood supply function elasticities for Canada, with base-period (1986) price and quantity assumptions used in NAPAP Model

Region and pulpwood	Elasticities				Base-period supply quantity ($\times 10^3$ m^3)	Base-period supply price (1986$)
	Delivered price	Labor cost	Timber stumpage price	Lumber production		
Canada East						
Softwood roundwood	0.16	-0.290	-0.02	—	30,324	26.62
Softwood residue	1.00	—	—	1.00	19,806	28.52
Hardwood roundwood	0.16	-0.290	-0.02	—	6,892	15.83
Hardwood residue	1.00	—	—	1.00	2,201	18.97
Canada West						
Softwood roundwood	0.33	-0.20	-0.27	—	8,973	19.59
Softwood residue	0.10	—	—	1.00	26,858	17.11
Hardwood roundwood	0.16	-0.20	-0.27	—	861	12.84

The concept of iterative solutions is simply the concept of running one model to obtain projections, then running the other model based on projections from the first, repeating the process several times. This iterative process was crucial to obtaining results that were consistent between both models and that linked the NAPAP Model and TAMM/ATLAS results to a comprehensive analysis of overall timber stumpage supply and demand, and timber growth and inventory in North America.

The TAMM/ATLAS model also required projections of pulpwood consumption from the NAPAP Model in greater regional detail, since the TAMM/ATLAS regional structure is more detailed than that of the NAPAP Model. TAMM/ATLAS regions of the United States are subregions of the three U.S. supply regions recognized by the NAPAP Model. Historical trends in pulpwood consumption by TAMM/ATLAS subregion were used to allocate projected U.S. pulpwood consumption quantities of the NAPAP Model (North, South, and West) to the TAMM/ATLAS subregions. The NAPAP Model also provided projected equilibrium prices for pulpwood residues, which were needed to determine profit margins for solid wood product manufacturing activities simulated in the TAMM/ATLAS model.

Recovered Paper Supply

For the NAPAP Model, long-range supply functions were estimated for each recovered paper commodity in each North American supply region. Supply functions for the United States were estimated at the Forest Products Laboratory; supply functions for Canada were estimated at the Economics and Policy Directorate of Forestry Canada, Ottawa. The four recovered paper commodities included old newspapers (ONP), old corrugated containers (OCC), mixed papers, and pulp substitutes & high grade deinking. All four of the recovered paper commodities are fiber input commodities in North America, and they are also exported in significant quantities (as export demand commodities) from the United States to Latin America, Europe, the Pacific Rim, and other regions. Price and quantity units for recovered paper in the NAPAP Model were 1986 U.S. dollars and metric tonnes "as purchased" (this is equivalent to tonnage as reported by the leading industry trade associations and government agencies; recovered paper tonnages reported "as purchased" are generally assumed to have an ambient moisture content of around 15 percent on a total weight basis). The estimation procedures, mathematical formulations of supply functions, data, and assumptions will be reported in detail in the NAPAP Model monograph report (Ince and others, in preparation).

As discussed previously, supplies of recovered paper in the United States have increased substantially in recent years due to increased collection efforts aimed at diverting materials away from landfills and into recycling. A primary economic incentive for increased collection has been rising landfill tipping fees (fees charged for disposal of waste materials in landfills). Annual surveys of tipping fees conducted by the National Solid Waste Management Association (NSWMA) during the 1980s show clearly that landfill tipping fees have increased the most in northern and eastern regions of the country where the glut in recovered paper markets has been the most pronounced (as reflected by depressed prices for recovered paper). Thus, rising tipping fees appear to have been a causal factor in the expansion of collection programs and increased supply of recovered paper in recent years. Therefore, in estimating regional recovered paper supply functions for the United States, regional landfill tipping fees were used as a primary shifter variable for recovered paper supply. Future growth in tipping fees was projected through the 1990s by extrapolation of regional growth rates observed in the period from 1981 to 1991. A relatively modest long-run real tipping fee growth of 4 percent per year was assumed in the 21st century. Although 4 percent per year is a much more moderate rate of increase than the average real increase in tipping fees observed over the past decade, it is reasonable to assume that tipping fees will increase at the more moderate pace in the long run. This is because higher tipping fees should provide incentive for siting new landfill capacity using improved but more costly landfill technology. Although the environmental and health problems of landfills are never likely to be "solved" in the ultimate sense, the more modest increase in tipping fees over the long run is expected. An additional shifter variable for recovered paper supply in the United States was regional consumption of parent commodities from which recovered paper commodities are obtained. As the consumption of the parent commodities changes over time, recovery and supply of recovered paper commodities are likely to change proportionately. Paper and paperboard parent commodity consumption is projected by the NAPAP Model.

Finally, it was found that to accurately simulate the recovered paper glut of recent years (i.e., the depressed prices for recovered paper commodities), it was necessary to shift U.S. recovered paper supply functions by additional amounts that can be attributed to increased collection efforts (beyond what would be predicted by historical relationships to tipping fees alone). It may be assumed that the additional increase in collection reflects awareness or anticipation of broader externalities associated with waste disposal (e.g., human health effects, effects on local property values) that are not entirely represented by the increase in landfill tipping fees alone. Or, it may simply reflect a "bandwagon" phenomenon (a broad public and institutional desire to collaborate in recycling programs for environmental or political reasons that are not entirely explained by the increase in tipping fees).

For Canada, domestic recovered paper supply functions were developed using three shifter variables for each commodity. These shifter variables generally included consumption of the end products from which recovered paper commodities were obtained, time, and the Canada/U.S. exchange rate. For pulp substitutes & high grade deinking, price of chemical

grade market pulp (a substitute product) was used instead of time as a shifter variable. Canadian domestic supply of recovered paper is much smaller than U.S. supply. The NAPAP Model allows for transportation of recovered paper commodities from the U.S. supply regions to Canada, and a substantial share of Canadian recovered paper inputs were projected to be obtained from the United States.

Table 46 summarizes recovered paper supply function elasticities for the United States and Canada, along with base-period prices and quantities. Base-period supply quantity data for the United States were obtained from API (using regional consumption plus exports as a proxy for regional supply). Base-period delivered price data were obtained by adding estimated within-region transportation costs to wastepaper prices reported in the Official Board Markets price reporter. Quantity and price estimates for Canada were provided by Forestry Canada.

Maximum Feasible Recovery Constraints

Recovered paper commodities are obtained from many different sources, including preconsumer and postconsumer sources, but all recovered paper commodities are derived ultimately from recognized categories of paper or paperboard commodities (called parent commodities). For example, ONP is recovered from sources that range from households (via curbside collection) to newspaper publishers (in returns of overissue copies), but ultimately all ONP is derived from one parent commodity, newsprint. Therefore, newsprint consumption levels and recovery infrastructure limit the maximum feasible supply of ONP.

For the purpose of the NAPAP Model, it was assumed that ONP is derived only from newsprint; OCC is derived from linerboard and corrugating medium (used to make corrugated containers); mixed papers are derived from coated groundwood, uncoated groundwood, specialty packaging & industrial, kraft packaging & industrial, and solid bleached board; and pulp substitutes and high grade deinking are derived from coated free sheet, uncoated free sheet, tissue & sanitary, kraft packaging & industrial, solid bleached board, and construction paper & board. Maximum feasible recovery ratios and patterns of recovery vary substantially among these commodities. For example, whereas ONP is recovered largely from postconsumer sources (i.e., discarded newspapers), most pulp substitutes are recovered as fractional by-products from converting operations (e.g., cutting and trim waste from paper converting operations), and thus there are substantial differences in maximum feasible recovery ratios. Some paper and paperboard products are largely unrecoverable for recycling due to sewage disposal (e.g., tissue & sanitary) or long-term use and storage (e.g., printing & writing paper used for books). Even where most of the parent commodity is available for recovery, maximum potential recovery is less than 100 percent due to geographic dispersal of products in distribution, limitations on collection and sorting infrastructure, and disposal of products in waste streams.

For the NAPAP Model, maximum feasible recovery rates were applied as upper limits or constraints on supplies of recovered paper commodities. Table 47 reports the maximum feasible recovery rates. The U.S. data were based in part on estimates by Franklin Associates (1990) and by Jaakko Poyry Consulting (1992). Canadian data were estimated by Forestry Canada. In the NAPAP Model, the maximum feasible recovery rates limit the possible supply of each category of recovered paper throughout the projection period. For example, the maximum quantity of OCC that can be supplied from U.S. supply regions cannot exceed 75 percent of U.S. linerboard and corrugating medium consumption (see Table 47 for percentages for the various commodities in the U.S. and Canada). As consumption of the parent commodities are projected to increase over time in the NAPAP Model, the supply of recovered paper for recycling can increase, but it cannot exceed the specified maximum feasible recovery rates. Although it is possible to change maximum feasible recovery rates over time in the NAPAP Model, such changes were not programmed into the base data set. Thus, the recovery rate constraints (Table 47) were applied throughout the projection period in the base scenario.

U.S. and Canadian Domestic Product Demand

The U.S. and Canadian domestic demand functions were provided in the NAPAP Model for each of 13 principal categories of paper and paperboard commodities, and also for dissolving & special alpha pulp. Price and quantity units for paper and paperboard commodities were 1986 U.S. dollars and metric tonnes of paper or paperboard at finished product weight (generally assumed to be at 5 percent moisture content, total weight basis). Price and quantity units for pulp were 1986 U.S. dollars and metric tonnes at air-dry weight (generally assumed to be 15 percent moisture content, total weight basis). The estimation procedures, mathematical formulation of demand functions, data, and assumptions will be reported in detail in a forthcoming research paper (Ince and others, in preparation).

Estimates of U.S. domestic demand functions for paper, board, and dissolving pulp were provided by Dr. Hsien Chi Lu (Louisiana State University; formerly graduate student at University of Wisconsin–Madison) and Professor Joseph Buongiorno (University of Wisconsin–Madison), working in cooperation with the Forest Products Laboratory. The underlying theory of factor demand, the estimation procedures, and the econometric results were described in an unpublished research note (Lu and others 1991). It was recognized that most commodities are actually demanded by various secondary or converting industries, which utilize the commodities as inputs to make consumer products or to provide consumer services, rather than being demanded directly by consumers or households. Since various consumer products and consumer services are provided using paper and board commodities as primary inputs, the demands for the NAPAP product commodities are actually demands for input factors. According to the theory of input factor

Table 46—Recovered paper supply function elasticities, with base-period (1986) price and quantity assumptions used in the NAPAP Model

Region and paper supply	Elasticities: Delivered price	Elasticities: Landfill tipping fees	Elasticities: Parent commodity consumption	Time (year)	Base-period supply quantity ($\times 10^3$ t)	Base-period supply price (1986$)
U.S. North						
Old newspapers (ONP)	0.109	0.093	1.00		1,552	39.23
Old corrugated (OCC)	0.076	0.191	1.00		4,013	53.79
Mixed papers	0.140	0.136	1.00		1,282	20.58
High grade deinking & pulp substitutes	0.220	0.062	1.00		2,863	176.25
U.S. South						
Old newspapers (ONP)	0.185	0.589	1.00		848	38.39
Old corrugated (OCC)	0.118	0.304	1.00		3,317	56.22
Mixed papers	0.093	0.176	1.00		748	16.35
High grade deinking & pulp substitutes	0.578	0.062	1.00		1,211	177.60
U.S. West						
Old newspapers (ONP)	0.331	0.188	1.00		1,155	45.00
Old corrugated (OCC)	0.070	0.098	1.00		2,078	60.00
Mixed papers	0.524	0.226	1.00		442	20.00
High grade deinking & pulp substitutes	0.667	0.062	1.00		647	188.99
Canada East						
Old newspapers (ONP)	0.080		1.430	0.07	121	60.06
Old corrugated (OCC)	0.470		0.630	0.05	413	69.35
Mixed papers	0.080		0.500	0.02	126	60.00
High grade deinking & pulp substitutes	0.390		0.900	1.17	149	154.13
Canada West						
Old newspapers (ONP)	0.080		1.430	0.07	40	49.16
Old corrugated (OCC)	0.470		0.630	0.05	137	58.45
Mixed papers	0.080		0.500	0.02	42	55.00
High grade deinking & pulp substitutes	0.390		0.900	1.17	49	143.23

demand, the optimal factor demand is affected by price of the input factor, along with the production level and price of the final products. Since a broad array of final consumer products and consumer services is derived from use of paper and paperboard in the U.S. economy (e.g., ranging from advertising in newspapers and magazines to delivery of goods in paperboard packaging and provision of health care services using sanitary paper products), it was appropriate to assume that the relationship between factor demand and final product production level and prices could be approximated by the relationship between factor demand and per-capita gross national product (GNP) and population (as proxies for the consumption level and prices of the many goods and services derived from use of paper and paperboard commodities throughout the economy). Thus, for the United States, demand functions for the thirteen paper and board products and special alpha & dissolving pulp were estimated as functions of price along with the independent variables of U.S. population and U.S. per-capita GNP. As discussed earlier, the RPA basic assumptions for U.S. population and GNP (or gross domestic product (GDP)) trends were used to project population and per-capita GNP into the future.

For the United States, historical data for demand quantities were obtained from the API (1960–1992; consumption data were approximated by “new supply” data—production plus imports minus exports). Price data were derived from the U.S. Department of Commerce Current Industry Report series on Pulp, Paper, and Board (U.S. Department of Commerce 1990), and earlier data were derived by applying

Table 47—Maximum feasible recovery constraints on supply of recovered paper commodities in the NAPAP Model[a]

Supply region	Recovered paper commodity	Parent commodity	Maximum feasible recovery of recovered paper commodity from parent commodity (percent)
U.S. (North, South, West)	ONP	Newsprint	65
	OCC	Linerboard	75
		Corrugating medium	75
	Mixed papers	Coated groundwood	50
		Uncoated groundwood	50
		Specialty pkg. & industrial	50
		Kraft pkg. & industrial	50
		Solid bleached board	50
	Pulp substitutes & high grade deinking	Coated free sheet	60
		Uncoated free sheet	60
		Kraft pkg. & industrial	10
		Solid bleached board	10
Canada (East, West)	ONP	Newsprint	45
	OCC	Linerboard	60
		Corrugating medium	60
	Mixed papers	Coated groundwood	24
		Uncoated groundwood	24
		Specialty pkg. & industrial	9
	Pulp substitutes & high grade deinking	Coated free sheet	24
		Uncoated free sheet	24
		Tissue & sanitary	5
		Kraft pkg. & industrial	9
		Solid bleached board	20 (Canada East only)
		Construction paper & board	7

[a]U.S. data based in part on estimates by Franklin Associates (1990) and Jaakko Poyry Consulting (1992).

the historical producer price indexes published by the Bureau of Labor Statistics (BLS), U.S. Department of Labor, for the period 1960–1980. The BLS wholesale producer price indexes of 1960–1989 were used also to convert prices to constant U.S. dollars. Historical population data were obtained from the Bureau of the Census (U.S. Department of Commerce 1990). The GNP data and deflators were obtained from the Bureau of Economic Analysis, U.S. Department of Commerce (1960–1989).

In addition, U.S. demand functions were adjusted so that demand trends would correspond to aggregate demand trends. An aggregate demand function was estimated for all paper and paperboard commodities combined (along with dissolving & special alpha pulp). It was found that the aggregate demand function was more stable and provided more reasonable long-range projections than demand functions estimated separately for individual commodities. Therefore, the individual growth elasticities were adjusted proportionately such that the sum of individual demand projections matched projections obtained with the aggregate demand function (for details, see Lu and others 1991). Additional adjustments were imposed to provide overall per-capita consumption levels that were deemed reasonable in light of per-capita consumption trends of recent decades (specifically, an additional 0.6 percent per year negative shift on demand growth was imposed for all commodities beyond the year 2000). Table 48 summarizes adjusted demand function elasticities for the United States, along with base-period demand quantities and prices. In all cases, base-period prices were set within the bounds of price data reported in industry references for the year 1986 (e.g., see Miller Freeman 1992). In some cases, elasticities were adjusted (generally downward) to obtain more accurate projections over the historical period (1986–1992), or to reflect anticipated long-run substitution of other products or services for products and services provided with paper and paperboard (such as advertising in electronic media substituting for advertising in print media, or use of plastics in food packaging). Table 48 notes which adjustments were made to the estimated elasticities.

Table 48—Product demand function elasticities for the United States, with base-period (1986) price and quantity data used in NAPAP Model[a]

Product	Elasticities			Base period demand quantity ($\times 10^3$ t)	Base period demand price (1986$)
	Commodity price	U.S. per capita GNP	U.S. population		
Newsprint	-0.54	0.50 * (0.57)	0.35	11,813	472.00
Coated free sheet	-1.16	0.28	1.00 * (2.02)	2,675	955.00
Uncoated free sheet	-1.05	0.50 (0.58)	0.45	11,229	825.00
Coated groundwood	-0.54	0.38	1.00 * (1.50)	3,402	730.00
Uncoated groundwood	-0.53	0.28	1.80 * (2.04)	2,813	620.00
Tissue & sanitary	-0.26	0.48	0.92	4,676	1,015.00
Specialty pkg. & industrial	-1.18	0.21	2.25	1,847	700.00
Kraft pkg. & industrial	-1.01	0.36	-5.0 * (1.08)	2,865	460.00
Linerboard	-0.31	0.50 * (0.60)	0.30 * (0.31)	14,485	325.00
Corrugating medium	-0.18	0.50 * (0.52)	0.30 * 0.74)	6,101	290.00
Solid bleached board	-0.33	0.33 * (0.42)	0.66 * (1.14)	3,308	550.00
Recycled board	-0.40	0.50	0.62	5,619	300.00
Construction paper & board	-0.58	-0.26	1.31	1,674	275.00
Dissolving & special alpha pulp	-0.26	-0.73	1.0 * (3.81)	686	600.00

[a]Elasticities were generally derived from econometric analysis of demand over the historical period from 1960 to 1989. In some cases (noted by asterisk) elasticities were adjusted downward to provide more accurate projections in the period from 1986–1992, to account for anticipated future reduction in demand, via product substitution (i.e., advertising in electronic media substituting for advertising in print media). Unadjusted elasticities based on historical relationships are shown in parentheses in cases where elasticities were adjusted. In addition, a -0.6-percent annual adjustment in demand growth for all commodities was imposed beyond the year 2000, to provide a reasonable growth trend in aggregate per capita paper and board consumption.

Table 49—Product demand function elasticities for Canada, with base-period (1986) price and quantity data used in the NAPAP Model

Product	Elasticities		Base-period demand quantity ($\times 10^3$ t)	Base-period demand price (1986$)
	Commodity price	Canadian GDP		
Newsprint sheet	-0.20	0.50	252	1,080.00
Uncoated free sheet	-0.20	0.50	657	865.00
Coated groundwood	-0.20	0.60	263	730.00
Uncoated groundwood	-0.20	0.60	212	620.00
Tissue & sanitary	-0.60	0.40	385	1,043.00
Specialty pkg. & industrial	-0.60	-0.10	27	650.00
Kraft pkg. & industrial	-0.60	-0.20	324	475.00
Linerboard	-0.70	0.80	913	325.00
Corrugating medium	-0.70	0.80	422	280.00
Solid bleached board	-0.70	-0.10	262	550.00
Recycled board	-0.70	-0.10	612	400.00
Construction paper & board	-0.70	0.20	126	275.00
Dissolving & special alpha pulp	-1.40	-0.10	55	600.00

Estimates of demand functions for Canada were provided by the Economics and Policy Directorate of Forestry Canada, Ottawa. Canadian domestic demand functions were specified as functions of price along with shifter variables of Canadian GDP and Canada/U.S. exchange rate. Projections of Canadian GDP and exchange rates were provided by Forestry Canada (in this study, all exchange rates were held constant at 1992 levels for the entire projection period). Table 49 summarizes the demand function elasticities for Canada, along with base-period demand quantities and prices.

Export Demand

The U.S. and Canadian export demand functions were provided in the NAPAP Model for commodities exported from the United States or Canada to other regions. Trade flows between the United States and Canada are simulated endogenously by the NAPAP Model (in relation to domestic demand functions discussed previously and comparative advantage of production in the two countries). Therefore, export demand functions were needed only for exports to regions outside the United States and Canada. Export demands were estimated separately for the United States and Canada. Price and quantity units were 1986 U.S. dollars, and metric tonnes at finished product weight for paper and paperboard, metric tonnes at air-dry weight for pulp, metric tonnes as purchased for recovered paper, and cubic meters for pulpwood. The export demand functions are described in detail in a research paper on the NAPAP Model (Ince and others, in preparation).

Export demand functions for the United States were developed at the Forest Products Laboratory to simulate demand for U.S. product exports to four trading regions: Latin America, Europe, Pacific Rim, and other world demand (outside the United States and Canada). Export demand functions were estimated only for significant export commodities (i.e., those exported to the trading regions in significant quantities in recent decades, or for which significant exports were expected in the near future). Commodities with less significant export flows were added to the principal commodities to balance overall trade flows in the base year.

The independent variables used in U.S. export demand equations depended on the type of export commodity. For fiber raw material commodities, including pulpwood, woodpulp, and recovered paper exports, the independent variables were intended to reflect overseas demand for fiber inputs in overseas production of paper and paperboard. Therefore, the primary shifter variable was paper and paperboard production of a primary importing country within the trading region (such as Japan for the Pacific Rim). For all export demand regions, the long-range growth factor for foreign paper and paperboard production was assumed to be 2 percent per year.

For U.S. exports of paper and paperboard commodities, the primary independent variable was the historical trend in total U.S. paper and paperboard exports. Total U.S. paper and paperboard exports have shown a declining average annual growth rate in recent decades (from nearly 12-percent annual growth in the 1960s to 6-percent in the 1970s and 2.7-percent in the 1980s). It was assumed that this rate of growth would continue to follow the historical trend, until a projected 1-percent annual growth factor is reached in the year 2000, at which point the growth factor was held constant at that rate. Depending on elasticities estimated with respect to the growth factor, U.S. exports of individual commodities to certain regions were projected to be somewhat higher than the growth factor itself (e.g., with an estimated elasticity of 3.09, the export demand growth would be 3.09 percent per year after 2000). In addition, a 1-percent per year negative shift was imposed on export demand for linerboard to provide a more modest long-range growth in linerboard exports. The declining underlying trend in total export growth reflects a view that a growing share of world demand will be satisfied by production in countries other than the United States. Historically, the percentage of total world paper and paperboard production produced in the United States actually declined from around 37 percent in 1970 to around 31 percent in 1990 (based on comparison of data published by API and Food and Agriculture Organization (FAO)). Others have noted that North America (the United States and Canada) currently has a declining share of world paper and paperboard production capacity, expected to decline from 37 percent in 1991 to 35.5 percent in 1994 (Slinn 1992). As stated in a recent report by FAO (1986) on the outlook for pulp and paper, “the developed world may continue significant net exports to the developing world but the developing world may also continue to increase production faster than consumption, thus diminishing its dependence on imports.” Other shifter variables were introduced in some U.S. export demand functions and, in some cases, a partial adjustment parameter was also used. Table 50 summarizes export demand function elasticities for the United States, along with base-period demand quantities and prices.

Export demand functions for Canada were estimated by the Economics and Policy Directorate of Forestry Canada. For Canada, export demand functions were specified for only two trading regions, Pacific Rim and Europe, which together account for all Canadian exports outside of exports to the United States. Growth shifter variables for Canadian export demand functions were real GDP of Japan (for Pacific Rim export demand) and real GDP of the United Kingdom (for European export demand). Table 51 summarizes export demand functions for Canada, along with base-period export demand quantities and prices.

Table 50—Export demand function elasticities for the United States by export demand region, with base-period (1986) price and quantity data used in NAPAP Model

Demand from U.S. and product	Elasticities: Commodity price	Elasticities: Total U.S. paper & paperboard export	Elasticities: Other		Partial adjustment parameter	Base-period demand quantity ($\times 10^3$ t)	Base-period demand price (1986$)
LATIN AMERICAN DEMAND							
Newsprint	-1.00	1.00	—	—	—	78.4	542
Coated free sheet	-1.00	2.00	—	—	—	10.5	955
Uncoated free sheet	-1.00	2.00	—	—	—	20.4[a]	825
Coated groundwood	-1.00	2.00	—	—	—	0.8	780
Uncoated groundwood	-1.00	2.00	—	—	—	3.8	670
Linerboard	-0.33	0.72	Per-capita GDP of Costa Rica 1.02	—	-0.04	606.8[b]	350
Solid bleached board	-1.00	1.00	—	—	—	53.1[c]	625
Dissolving & special alpha pulp	-0.35	—	Per-capita GDP of Mexico -1.24	Export price of U.S. vs. Norway -0.47	—	49.1	615
Softwood chemical market pulp	-0.14	—	Paper & board production in Venezuela 0.12	—	0.37	210.9	640
Hardwood chemical market pulp	-0.40	—	Paper & board production in Mexico -0.05	—	0.38	160.1	610
Old newspapers (ONP)	-0.44	—	1.42	—	—	197.6	60
Old corrugated (OCC)	-1.45	—	Per-capita GDP of Mexico 0.50	—	—	190.6	75
Mixed recovered paper	-1.56	—	Per-capita GDP of Venezuela 0.50	—	0.33	47.5	45
Pulp substitutes & high grade deinking	-2.57	—	Per-capita GDP of Mexico 0.67	—	—	170.3	180
EUROPEAN DEMAND							
Linerboard	-0.60	1.01	Per-capita paper & board production in U.S. vs. Brazil 1.24	—	—	662.8[b]	350
Solid bleached board	-0.69	1.00	—	—	—	59.6[c]	625
Dissolving & special alpha pulp	-0.15	—	U.S./Canada exchange rate 1.33	Export price of U.S. vs Norway -0.20	—	258.6	615
Softwood chemical market pulp	-0.12	—	Paper & board production in Italy 0.10	—	0.68	1,058.9	640
Hardwood chemical market pulp	-0.20	—	Paper & board production in Germany 0.10	—	—	464.8	610
Old corrugated (OCC)	-0.42	—	Paper & board production in U.K. 0.50	—	0.49	178.0	75
Mixed recovered paper	-0.22	—	0.50	—	—	77.7	45
Pulp substitutes & high grade deinking	-1.03	—	Paper & board production in Italy 0.50	—	0.70	62.8	180

Table 50—Export demand function elasticities for the United States by export demand region, with base-period (1986) price and quantity data used in NAPAP Model—con.

Demand from U.S. and product	Elasticities: Commodity price	Elasticities: Total U.S. paper & paperboard export	Elasticities: Other		Partial adjustment parameter	Base-period demand quantity ($\times 10^3$ t)	Base-period demand price (1986$)
PACIFIC RIM DEMAND							
Newsprint	-0.96	3.09	—	—	—	272.0	542
Coated free sheet	-0.96	3.09	—	—	—	3.5	955
Uncoated free sheet	-0.96	3.09	—	—	—	23.0[a]	825
Coated groundwood	-0.96	3.09	—	—	—	0.8	780
Uncoated groundwood	-0.96	3.09	—	—	—	11.2	670
Linerboard	-1.20	1.33	—	—	0.46	882.3[b]	350
Solid bleached board	-0.37	1.00	—	—	—	290.3[c]	625
			Per-capita GNP in Japan	U.S./S. Africa exchange rate			
Dissolving & special alpha pulp	-0.26	0.20	0.41	0.27	—	318.9	555
			Paper & board production in Japan				
Softwood chemical market pulp	-0.18	—	0.59	—	0.47	666.0	640
Hardwood chemical market pulp	-0.37	—	0.65	—	0.55	593.4	610
Softwood pulpwood	-0.30	—	0.28	—	—	3461.7[d]	39.20[d]
Hardwood pulpwood	-0.30	—	0.28	—	—	496.7[d]	43.70[d]
			Paper & board production in Korea				
Old newspapers (ONP)	-0.20	—	1.21	—	—	485.1	60
Old corrugated (OCC)	-0.50	—	1.18	—	—	895.4	75
Mixed recovered paper	-2.54	—	0.29	—	—	477.9	45
Pulp substitutes & high grade deinking	-0.38	—	0.50	—	0.30	412.1	180
OTHER DEMAND							
			Per-capita paper & board production in US vs Sweden				
Linerboard	-0.28	1.22	2.15	—	0.25	220.6[b]	350
Solid bleached board	-0.63	1.00	—	—	—	53.3[c]	625
			World paper & board production				
Softwood chemical market pulp	-0.26	—	1.22	—	—	79.0	640

[a]Includes small quantities of tissue & sanitary paper.

[b]Includes small quantities of kraft packaging & industrial, specialty packaging & industrial, corrugating medium, recycled board, and construction paper & board.

[c]Includes small quantities of kraft packaging & industrial paper.

[d]Pulpwood quantities in 1000 m^3. Pulpwood prices in \$1986/m^3. Conversion factors: 2.051 m^3 per metric ton softwood; 1.795 m^3 per metric ton hardwood. In this case, pulpwood refers to wood chips.

Table 51—Export demand function elasticities for Canada by export demand region, with base-period (1986) price and quantity data used in NAPAP Model

Demand from Canada and product	Elasticities: Commodity price	Elasticities: Other	Base period demand quantity ($\times 10^3$ t)	Base period demand price (1986$)
PACIFIC DEMAND		GDP of Japan		
Newsprint	-4.13	0.09	657	520
Kraft pkg. & industrial	-1.30	2.60	82	466
Linerboard	-1.30	2.60	122	307
Corrugating medium	-1.30	2.60	32	48
Dissolving & special alpha pulp	-0.20	1.50	68	543
Softwood chemical market pulp	-0.37	1.25	1,398	623
Hardwood chemical market pulp	-0.37	1.25	125	626
Mechanical market pulp	-0.37	1.25	162	415
Softwood pulpwood (residue)	-1.00	1.70	1,295[a]	26[a]
ATLANTIC DEMAND		GDP of U.K.		
Newsprint	-1.03	0.10	930	520
Kraft pkg. & industrial	-1.30	2.60	65	482
Linerboard	-1.30	2.60	137	403
Corrugating medium	-1.30	2.60	83	405
Dissolving & special alpha pulp	-0.20	1.00	87	566
Softwood chemical market pulp	-0.75	0.91	1,892	638
Hardwood chemical market pulp	-0.75	0.91	247	611
Mechanical market pulp	-0.75	0.91	19	403
Softwood pulpwood (roundwood)	-1.00	1.00	312[a]	22[a]

[a]Pulpwood quantities in 1000 m^3. Pulpwood prices in $1986 per cubic meter.

NOTE: A revised set of U.S. export demand equations were developed for the NAPAP Model since the draft results were developed for this report. The revised equations are not included in this report, but they may be introduced in the final draft. The revised U.S. export demand equations have a much more parsimonious structure. They are based only on export relationships to Atlantic region and Pacific region GDP trends (similar to the Canadian export demand equations). Projections derived from the revised U.S. export demand equations are similar in aggregate quantity to the projections shown subsequently in this report.

U.S. Import Supply

For the NAPAP Model, long-range supply functions were provided for pulp and paper commodities that are imported in significant quantities into the United States from regions other than Canada. Those commodities include various grades of printing and writing paper and market pulp, imported from Latin America, Europe, Pacific Rim, and other regions. Import supply functions were provided separately for each principal commodity and supply region. Estimates were developed at the Forest Products Laboratory. Supply shifter variables in all cases were measures of production in the source regions (such as total production of bleached sulphate pulp in Latin America, used as the shifter for supply of chemical market pulp from Latin America). Table 52 summarizes the import supply function elasticities by import supply region and commodity. Price and quantity units were 1986 U.S. dollars, and metric tonnes at finished product weight for paper and paperboard, metric tonnes at air-dry weight for pulp. The estimation procedures, mathematical formulation of import supply functions, data, and assumptions will be reported in detail in the NAPAP Model monograph report (Ince and others, in preparation).

Energy and Labor Input Supply

Supplies of energy and labor inputs were represented in the NAPAP Model by horizontal supply curves. This assumes that the pulp and paper sector exhibits price-taking behavior in energy and labor markets (i.e., the pulp and paper sector in North America, although quite large, accounts for a small fraction of total North American labor and energy demands, and therefore changes in labor and energy inputs of the pulp and paper sector alone have negligible impacts on overall market prices for labor or energy in North America). However, changes in regional labor costs (wage rates) and

Table 52—Import supply function elasticities for the United States by import supply region, along with base-period (1986) price and quantity data used in the NAPAP Model

Supply and product	Elasticities: Commodity price	Elasticities: Other[a]		Partial adjustment parameter	Base period supply quantity ($\times 10^3$ t)	Base period supply price (1986$)
FROM LATIN AMERICA		Printing & writing paper, Brazil				
Uncoated Free Sheet	0.059	3.111	—	—	81.5	609
		Bleached sulphate pulp, Latin America				
Softwood chemical market pulp	0.220	3.574	—	—	33.1	401
Hardwood chemical market pulp	0.624	0.194	—	0.53	157.3	400
FROM EUROPE		GDP deflator[b]	Printing & writing paper[b]			
Coated Free Sheet	0.418	0.682	1.280	—	244.3	887
		Printing & writing paper, Europe				
Uncoated Free Sheet	0.500	0.761	—	0.49	166.2	787
		GDP deflator[b]	Printing & writing paper			
Coated Groundwood	0.418	0.682	1.280	—	97.3	956
		Printing & writing paper, Europe				
Uncoated Groundwood	0.500	1.087	—	0.71	428.5	583
		Bleached sulphate pulp, Europe				
Softwood chemical market pulp	0.744	1.024	—	0.54	62.4	490
Hardwood chemical market pulp	0.744	1.024	—	0.54	14.5	424
FROM PACIFIC RIM		Printing & writing paper, Japan & Korea				
Coated Free Sheet	0.946	0.849	—	—	27.4	1,065
FROM SOUTH AFRICA		Dissolving pulp				
Dissolving & special alpha pulp	0.683	0.220	—	—	110.7	415

[a]Other kinds of production noted.
[b]In 10 countries.

energy prices can be incorporated into the NAPAP Model data base. Changes in actual labor costs and energy prices for the period 1986 to 1991 were introduced, based in part on survey data from the Forest Sector Advisory Council (FSAC) of Canada. Beyond the year 1991, real prices of labor and energy inputs, as well as quantities of the inputs required by various production processes, remain unchanged in the base scenario. An implicit simplifying assumption in the base scenario is that future changes in real labor and energy prices will be fairly moderate, and any increases will be offset by proportionate increases in labor and energy productivity among the various production processes. Labor and energy input prices were expressed in 1986 U.S. dollars. Labor inputs were measured in total hours paid (including fringe benefits and paid leave). Purchased fuel inputs were measured in gigajoules (x10). Electrical energy inputs were measured in megawatt-hours (MW/h). Base-period (1986) prices of labor and energy inputs are summarized in Table 53.

Transportation Costs, Exchange Rates, and Ad-valorum Import Taxes

A full representation of commodity transportation costs, adjustments due to historical fluctuation in U.S./Canada currency exchange rates, and ad-valorum import taxes were included in the NAPAP Model data base. Transportation costs were applied to all simulated shipments of input commodities from one supply region to another (or to another manufacturing region) and to all shipments of product commodities from manufacturing regions to demand regions. Supply prices for fiber input commodities in supply regions (i.e., pulpwood and recovered paper supply prices) represented prices delivered to mills in the supply region. Therefore, the delivered prices of fiber inputs included the transportation costs for delivery to destinations within each supply region. Interregional transportation costs for fiber inputs were specified as net transportation costs (i.e., intraregional shipping costs were deducted, leaving

Table 53—NAPAP Model base-period (1986) labor and energy input prices by region

Region and labor/energy supply	Input price (1986 U.S. dollars)
U.S. North	
Purchased fuel (×10 GJ)	25.87
Electricity (MW/h)	48.40
Labor (h)	14.70
Administrative labor (h)	18.50
U.S. South	
Purchased fuel (×10 GJ)	27.06
Electricity (MWh)	40.10
Labor (h)	16.51
Administrative labor (h)	20.14
U.S. West	
Purchased fuel (×10 GJ)	27.07
Electricity (MWh)	32.16
Labor (h)	19.62
Administrative labor (h)	22.51
Canada East	
Purchased fuel (×10 GJ)	21.70
Electricity (MWh)	20.61
Labor (h)	15.77
Administrative labor (h)	18.36
Canada West	
Purchased fuel (×10 GJ)	20.20
Electricity (MWh)	23.13
Labor (h)	18.35
Administrative labor (h)	21.49

only the net additional transportation cost to move commodities from one supply region to another). Transportation costs for intermediate and final products (e.g., pulp, paper, and paperboard) were specified as total shipping costs (not net costs). Table 54 summarizes the transportation cost data for the NAPAP Model. Transportation costs for the United States were estimated and compiled by Zhang of the University of Wisconsin–Madison (Zhang and Ince 1991). Transportation costs for Canada were estimated by the Economics and Policy Directorate of Forestry Canada, Ottawa.

Although all prices in the NAPAP Model were expressed in constant 1986 U.S. dollars, adjustments in Canadian supply and demand functions were necessary to account for the effects of actual fluctuations in U.S./Canada monetary exchange rates during the historical period from 1986 to 1992. The Canadian/U.S. dollar exchange rate assumption in the NAPAP Model was set at 1.3895 in the base year (1986) and adjusted as follows in subsequent years: 1.3260 in 1987, 1.2307 in 1988, 1.1840 in 1989, 1.1668 in 1990, 1.1460 in 1991, and 1.1905 in 1992 (data reflect actual exchange rates as reported in the Federal Reserve Bulletin). After 1992, the U.S./Canada exchange rate was assumed to remain constant for the remainder of the projection period in the base scenario (a simplifying assumption, which can be adjusted for alternate scenarios).

Finally, full implementation of the U.S./Canada Free Trade Agreement, insofar as it affects pulp and paper commodities, was incorporated into the NAPAP Model data base. In particular, various U.S. and Canadian import ad-valorum taxes on pulp and paper commodities shipped between the two countries were included in the base-period (1986). However, in accordance with the Free Trade Agreement provisions, all such tariffs were incrementally eliminated between 1987 and 1993. Thus, in the NAPAP Model, there is a programmed phase-out of all import ad-valorum taxes on pulp and paper commodities between the United States and Canada, with phase-out completed by 1993. No additional tariffs are assumed to be imposed in the future in the base scenario. [The complete schedule of import tariffs for all pulp and paper commodities and annual tariff reductions for both the United States and Canada are tabulated in the 1992 *Pulp & Paper North American Factbook* (Miller Freeman 1992.) The same data were used in the NAPAP Model.]

Capacity Change, Capital Costs, and Capacity Depreciation Assumptions

Projected change in capacity for each production process was computed by the NAPAP Model using methods based on Tobin's *q* theory of investment behavior. The methods described in Zhang and Buongiorno (1992a) were employed in PELPS III (Zhang and others, in preparation). The methods were validated by producing accurate simulations of historical capacity trends in the North American pulp and paper sector, using historical models that covered the period from 1970 to 1990 (Zhang and Buongiorno 1992b).

The *q* theory of investment behavior was pioneered by Nobel Laureate James Tobin (1969). Following Tobin's *q* theory, gross change in production capacity was specified as an increasing function of the *q* ratio, the shadow price of current capacity to the cost of new capacity. Empirical results with data of the U.S. pulp and paper industry suggested that the relative gross change in capacity each year was accurately represented as a function of the current *q* ratio, the *q* ratio lagged 1 year, and the relative gross change in capacity lagged 1year (Zhang and Buongiorno 1992a), with coefficients of 0.20, -0.11, and 0.54, respectively. The same formula was used in the NAPAP model to compute change in capacity for each production process. The numerator in the *q* ratio (shadow price) measures profitability of marginally adding additional capacity. The unique shadow price of each production process in each region was computed as part of the linear programming solution obtained each year by the NAPAP Model. As market conditions were projected by the model to change over time, the shadow price (i.e., profitability of new capacity) for each production process was also projected to change, and hence capacity growth for each production process changed in relation to projected market

conditions. The denominator in the *q* ratio (the cost of new capacity) was estimated for each production process, based on estimated capital costs of new capacity, expressed on an annual average basis (per tonne of product output). Table 55 summarizes the estimated costs of new capacity for each process in the NAPAP Model. Cost estimates reflected differences in facility and equipment requirements of various processes, estimated scale of production facilities, and differences in capital costs between the United States and Canada.

In addition to gross capacity change computed by the Tobin *q* formula, a capacity "depreciation" or retirement factor was also used in the NAPAP Model. Capacity was assumed to be retired at a fixed rate each year for each production process. The retirement rate was specified at 2 to 6 percent per year, depending on whether the process was a relatively new or old technology (the higher rate was specified for older processes). Each year the net change in capacity for each process was computed as the gross change (based on Tobin *q* formula) minus capacity retired at the specified annual rate. Thus, in the NAPAP Model, capacity growth occurred for production processes that were projected to be relatively profitable (i.e., with relatively high shadow prices) and for which the gross change in capacity computed by the Tobin *q* formula exceeded the annual capacity retirement. Capacity of any production process that was relatively unprofitable was gradually retired. In summary, the projected evolution of capacity for each production process (and the evolution of technology in general) was simulated as a competitive economic process, influenced by projected market conditions; in turn, projected market conditions were influenced by the competitive evolution of technology.

NAPAP Study Results

Projections for the pulp and paper sector of the United States and Canada were provided by the NAPAP Model from the base year 1986 to the year 2040. This section of the report illustrates many key result with charts that show long-range projections of NAPAP Model variables plotted over time. Many charts include actual historical data showing the historical trends for the same variables in recent decades. The NAPAP projections over the recent historical period, 1986–1992, serve as additional validation of the modeling methods, to the extent that results match recent historical trends. All results were obtained through an iterative solution process, linking NAPAP and TAMM/ATLAS models. As noted on some charts, some results include projections from the TAMM/ATLAS model.

Projected Consumption (Demand) for Paper and Paperboard

The NAPAP Model projected consumption (demand quantity) of principal commodities in the United States and Canada. Figure 9 illustrates projected consumption of paper and board for the United States, along with the historical trend of recent decades. The projected trend is generally in line with the historical trend. Figure 10 illustrates projected total consumption of paper and board for both the United States and Canada. Canadian and U.S. paper and board consumption were projected to grow continuously in the decades ahead, with Canadian consumption remaining generally less than 10 percent of the total.

Whereas total U.S. paper and board consumption was projected to increase by more than 70 percent in the next 50 years, per capita consumption of paper and paperboard was projected to increase by roughly one-third, from around 315 kg in 1990 to around 410 kg in 2040. Historically, per capita paper and board consumption in the United States has increased, from around 150 kg in 1950 and approximately 250 kg in 1970 (API 1960–1992). Thus, projections indicate a modest decline in the growth of per capita paper and paperboard consumption. Historically, U.S. growth in per capita consumption did decline from around 2.8 percent per year in the 1950s and 1960s to around 1 percent per year in the 1970s and 1980s. In fact, per capita consumption has been on a relative plateau since 1986 (gaining only 1.4 percent in the 5-year period from 1986 to 1991 (API 1960–1992).

Figures 11 to 22 illustrate projected U.S. consumption of the principal paper and paperboard commodities; Figure 23 illustrates projected U.S. consumption of dissolving & special alpha pulp. All charts include actual historical trends in the data series from 1960 to 1990, for comparison to projected trends. For the most part, projections indicate a continuation of historical growth trends. Note that the NAPAP Model provides fairly close tracking of historical trends in the period from 1986 to 1992. Notable declines in consumption were projected only for construction paper & board and dissolving & special alpha pulp.

Projected Production and Technological Trends

Figures 24 to 85 illustrate production and technological trends for newsprint, printing & writing paper, tissue & sanitary paper, specialty packaging & industrial paper, paperboard, construction paper & board, and market pulp.

Newsprint

The U.S. share of total newsprint production was projected to gradually increase. (Fig. 24). Historically, the U.S. share has been increasing, rising from 23 percent in 1965 to 33 percent in 1980 and 40 percent in 1990 (Miller Freeman 1992). Canadian newsprint production has actually declined since 1988, while U.S. newsprint production has increased (Miller Freeman 1992). Projections indicated that the U.S. share should reach two-thirds of the total by 2040.

Table 54—NAPAP Model real transportation costs by commodity between source and destination regions[a]

Commodity and source region	Transportation cost ($1986/t) by destination region												
	Canada	U.S.	Pacific	Atlantic	Latin America	Europe	Pacific Rim	Canada East	Canada West	U.S. North	U.S. South	U.S. West	Other
Newsprint													
Canada East	22	47	108	93	—	—	—	—	—	—	—	—	—
Canada West	34	53	93	107	—	—	—	—	—	—	—	—	—
U.S. North	63	23	—	—	90	—	90	—	—	—	—	—	—
U.S. South	94	28	—	—	90	—	90	—	—	—	—	—	—
U.S. West	60	45	—	—	—	—	90	—	—	—	—	—	—
Coated free sheet paper													
Canada East	21	73	—	—	—	—	—	—	—	—	—	—	—
Canada West	42	73	—	—	—	—	—	—	—	—	—	—	—
U.S. North	161	42	—	—	90	—	90	—	—	—	—	—	—
U.S. South	154	33	—	—	90	—	90	—	—	—	—	—	—
U.S. West	140	40	—	—	90	—	90	—	—	—	—	—	—
Europe	—	93	—	—	—	—	—	—	—	—	—	—	—
Pacific Rim	—	93	—	—	—	—	—	—	—	—	—	—	—
Uncoated free sheet paper													
Canada East	21	61	—	—	—	—	—	—	—	—	—	—	—
Canada West	42	61	—	—	—	—	—	—	—	—	—	—	—
U.S. North	107	33	—	—	90	—	90	—	—	—	—	—	—
U.S. South	154	34	—	—	90	—	90	—	—	—	—	—	—
U.S. West	146	40	—	—	90	—	90	—	—	—	—	—	—
Latin America	—	90	—	—	—	—	—	—	—	—	—	—	—
Europe	—	93	—	—	—	—	—	—	—	—	—	—	—
Coated groundwood paper													
Canada East	26	71	—	—	—	—	—	—	—	—	—	—	—
Canada West	60	75	—	—	—	—	—	—	—	—	—	—	—
U.S. North	112	42	—	—	90	—	90	—	—	—	—	—	—
U.S. South	106	33	—	—	90	—	90	—	—	—	—	—	—
U.S. West	92	40	—	—	90	—	90	—	—	—	—	—	—
Latin America	—	—	—	—	—	—	—	—	—	—	—	—	—
Europe	—	93	—	—	—	—	—	—	—	—	—	—	—
Uncoated groundwood paper													
Canada East	26	49	—	—	—	—	—	—	—	—	—	—	—
Canada West	60	53	—	—	—	—	—	—	—	—	—	—	—
U.S. North	61	44	—	—	90	—	90	—	—	—	—	—	—
U.S. South	85	28	—	—	90	—	90	—	—	—	—	—	—
U.S. West	53	38	—	—	90	—	90	—	—	—	—	—	—
Latin America	—	—	—	—	—	—	—	—	—	—	—	—	—
Europe	—	93	—	—	—	—	—	—	—	—	—	—	—

Tissue and sanitary paper													
Canada East	57	85	—	—	—	—	—	—	—	—	—	—	—
Canada West	83	90	—	—	—	—	—	—	—	—	—	—	—
U.S. North	168	63	—	—	—	—	—	—	—	—	—	—	—
U.S. South	168	63	—	—	—	—	—	—	—	—	—	—	—
U.S. West	168	65	—	—	—	—	—	—	—	—	—	—	—
Specialty packaging & industrial													
Canada East	26	70	—	—	—	—	—	—	—	—	—	—	—
Canada West	41	75	—	—	—	—	—	—	—	—	—	—	—
U.S. North	77	49	—	—	—	—	—	—	—	—	—	—	—
U.S. South	47	47	—	—	—	—	—	—	—	—	—	—	—
U.S. West	100	70	—	—	—	—	—	—	—	—	—	—	—
Kraft packaging & industrial													
Canada East	26	55	—	—	—	—	—	—	—	—	—	—	—
Canada West	41	60	72	86	—	—	—	—	—	—	—	—	—
U.S. North	121	49	—	—	—	—	—	—	—	—	—	—	—
U.S. South	91	47	—	—	—	—	—	—	—	—	—	—	—
U.S. West	144	70	—	—	—	—	—	—	—	—	—	—	—
Linerboard													
Canada East	26	44	—	72	—	—	—	—	—	—	—	—	—
Canada West	33	54	72	86	—	—	—	—	—	—	—	—	—
U.S. North	85	34	—	—	90	90	90	—	—	—	—	—	90
U.S. South	97	33	—	—	90	90	90	—	—	—	—	—	90
U.S. West	78	35	—	—	90	90	90	—	—	—	—	—	90
Corrugating medium													
Canada East	26	46	86	72	—	—	—	—	—	—	—	—	—
Canada West	33	56	—	—	—	—	—	—	—	—	—	—	—
U.S. North	75	34	—	—	—	—	—	—	—	—	—	—	—
U.S. South	87	33	—	—	—	—	—	—	—	—	—	—	—
U.S. West	68	35	—	—	—	—	—	—	—	—	—	—	—
Solid bleached board													
Canada East	26	44	—	—	—	—	—	—	—	—	—	—	—
Canada West	33	54	—	—	—	—	—	—	—	—	—	—	—
U.S. North	100	34	—	—	100	100	100	—	—	—	—	—	—
U.S. South	112	33	—	—	100	100	100	—	—	—	—	—	100
U.S. West	92	35	—	—	100	100	100	—	—	—	—	—	100
Recycled board													
Canada East	26	44	—	—	—	—	—	—	—	—	—	—	—
Canada West	33	54	—	—	—	—	—	—	—	—	—	—	—
U.S. North	101	34	—	—	—	—	—	—	—	—	—	—	—
U.S. South	113	33	—	—	—	—	—	—	—	—	—	—	—
U.S. West	93	35	—	—	—	—	—	—	—	—	—	—	—

Table 54—NAPAP Model real transportation costs by commodity between source and destination regions[a]—con.

Commodity and source region	Transportation cost ($1986/t) by destination region												
	Canada	U.S.	Pacific	Atlantic	Latin America	Europe	Pacific Rim	Canada East	Canada West	U.S. North	U.S. South	U.S. West	Other
Construction paper & board and other													
Canada East	17	80	—	—	—	—	—	—	—	—	—	—	—
Canada West	30	85	—	—	—	—	—	—	—	—	—	—	—
U.S. North	134	57	—	—	—	—	—	—	—	—	—	—	—
U.S. South	99	49	—	—	—	—	—	—	—	—	—	—	—
U.S. West	99	49	—	—	—	—	—	—	—	—	—	—	—
Dissolving & special alpha pulp													
Canada East	22	60	86	72	—	—	—	—	—	—	—	—	—
Canada West	40	65	40	40	—	—	—	—	—	—	—	—	—
U.S. North	—	—	—	—	—	—	—	—	—	—	—	—	—
U.S. South	78	39	—	—	60	60	—	—	—	—	—	—	—
U.S. West	58	55	—	—	60	70	40	—	—	—	—	—	—
Other to U.S.	—	60	—	—	—	—	—	—	—	—	—	—	—
Softwood chemical market pulp													
Canada East	—	—	66	52	—	—	—	—	20	12	15	20	—
Canada West	—	—	49	64	—	—	—	20	—	20	20	12	—
U.S. North	—	—	—	—	—	—	—	—	—	—	—	—	—
U.S. South	—	—	—	—	60	60	70	—	—	19	—	37	60
U.S. West	—	—	—	—	70	70	60	—	—	20	25	—	60
Latin America	—	—	—	—	—	—	—	—	—	30	30	30	—
Europe	—	—	—	—	—	—	—	—	—	30	30	—	—
Hardwood chemical market pulp													
Canada East	—	—	66	52	—	—	—	—	20	12	15	20	—
Canada West	—	—	—	—	—	—	—	20	—	20	20	12	—
U.S. North	—	—	—	—	60	60	70	—	—	—	31	55	—
U.S. South	—	—	—	—	60	60	70	—	—	19	—	37	—
U.S. West	—	—	—	—	70	—	—	—	—	20	25	—	—
Latin America	—	—	—	—	—	—	—	—	—	30	30	30	—
Europe	—	—	—	—	—	—	—	—	—	30	30	—	—
Mechanical market pulp													
Canada East	—	—	66	52	—	—	—	—	20	12	15	20	—
Canada West	—	—	49	—	—	—	—	20	—	20	20	12	—
U.S. North	—	—	—	—	—	—	—	—	—	—	31	55	—
U.S. South	—	—	—	—	—	—	—	—	—	19	—	37	—

Market pulp from recycled fiber													
Canada East	—	—	—	—	—	—	—	—	20	40	50	50	—
Canada West	—	—	—	—	—	—	—	20	—	50	50	40	—
U.S. North	—	—	—	—	—	—	—	—	—	—	31	55	—
U.S. South	—	—	—	—	—	—	—	—	—	19	—	37	—
U.S. West	—	—	—	—	—	—	—	—	—	20	25	—	—
Softwood pulpwood[b]													
Canada East	—	—	31	12	—	—	—	—	—	—	—	—	—
Canada West	—	—	13	15	—	—	—	—	—	—	—	—	—
U.S. West	—	—	—	—	—	—	12	—	—	—	—	—	—
Hardwood pulpwood[b]													
U.S. South	—	—	—	—	—	—	15	—	—	—	—	—	—
Old newspapers (ONP)													
Canada East	—	—	—	—	—	—	—	—	83	10	20	25	—
Canada West	—	—	—	—	—	—	—	14	—	20	20	15	—
U.S. North	—	—	—	—	25	—	30	12	15	—	12	15	—
U.S. South	—	—	—	—	25	—	25	13	15	12	—	15	—
U.S. West	—	—	—	—	25	—	25	16	12	15	15	—	—
Old corrugated containers (OCC)[b]													
Canada East	—	—	—	—	—	—	—	—	83	10	20	25	—
Canada West	—	—	—	—	—	—	—	14	—	20	20	15	—
U.S. North	—	—	—	—	25	25	25	12	15	—	12	15	—
U.S. South	—	—	—	—	25	25	25	13	15	12	—	15	—
U.S. West	—	—	—	—	25	25	25	16	12	15	15	—	—
Mixed papers[b]													
Canada East	—	—	—	—	—	—	—	—	83	10	20	25	—
Canada West	—	—	—	—	—	—	—	14	—	20	20	15	—
U.S. North	—	—	—	—	25	25	25	12	15	—	12	15	—
U.S. South	—	—	—	—	25	25	25	13	15	12	—	15	—
U.S. West	—	—	—	—	25	25	25	16	12	15	15	—	—
Pulp substitutes & high grade deinking[b]													
Canada East	—	—	—	—	—	—	—	—	83	10	20	25	—
Canada West	—	—	—	—	—	—	—	14	—	20	20	15	—
U.S. North	—	25[c]	—	—	—	—	—	12	15	—	12	15	—
U.S. South	—	25[c]	—	—	—	—	—	13	15	12	—	15	—
U.S. West	—	25[c]	—	—	—	—	—	16	12	15	15	—	—

[a]Transportation costs for fiber inputs, pulpwood, and recovered paper are only net transportation costs (after deducting cost of delivery within supply region of origin); all costs are $1986 /t, except for pulpwood transportation costs, which are $1986/m^3.

[b]Net transport costs from supply regions. [c]From Latin America, Europe, and Pacific.

Table 55—Estimated costs of new capacity for production processes per tonne of product output[a]

Product and process[b]	Cost ($1986/t)
Newsprint—U.S.	
Process (1) 75% GWD+25% CHEM	212.00
Process (2) 90% TMP+10% CHEM	165.00
Process (3) 100% ONP	164.50
Process (5) 70% ONP+30% MIXED	155.00
Process (6) PRESS+100% TMP	165.00
Coated free sheet paper—U.S.	
Process (1) 90% CHEM+10% REC	275.00
Process (2) 90% MKT+10% REC	180.00
Process (3) 100% REC	300.00
Uncoated free sheet paper—U.S.	
Process (1) 100% SULPHITE	350.00
Process (2) 100% KRAFT	240.00
Process (3) 100% MKT PULP	160.00
Process (4) 100% REC	210.00
Process (5) 20% MECH/REC+80% CHEM	100.00
Coated groundwood paper—U.S.	
Process (1) 58% CHEM+42% MECH	240.00
Process (2) 56% MKT+MECH+2% REC	210.50
Process (3) 100% REC	240.00
Uncoated groundwood paper—U.S.	
Process (1) 35% CHEM+65% MECH	210.00
Process (2) 58% MECH+35% MKT+7% REC	165.00
Process (3) 100% REC	200.00
Tissue and sanitary paper— U.S.	
Process (1) 70% MKT+30% REC	185.00
Process (2) 100% REC	225.00
Process (3) 75% CHEM+25% REC	255.00
Process (4) 90% MECH+10% REC	210.00
Process (5) 50% MIX+50% ONP	225.00
Process (6) 50% BCTMP+50% MKT	185.00
Specialty packaging & industrial paper—U.S.	
Process (1)	260.00
Kraft pkg. & industrial converting paper—U.S.	
Process (1) 100% CHEM	120.00
Process (2) 75% CHEM+25% REC	125.00
Process (3) 100% REC	85.00
Linerboard—U.S.	
Process (1) 95% KRAFT+5% OCC	110.00
Process (2) 70% KRAFT+30% OCC	88.00
Process (3) 100% REC	85.00
Process (4) 50% KRAFT+50% OCC	75.00
Process (5) 70% MECH+30% OCC	60.00
Corrugating medium—U.S.	
Process (1) 67% SCHEM+33% OCC	96.00
Process (2) 90% SCHEM+10% OCC	98.00
Process (3) 100 REC	55.00
Process (4) 67% MECH+33% MIX	60.00
Solid bleached board—U.S.	
Process (1) 100% KRAFT	246.30
Process (2) 70% KRAFT+30% MECH	190.00
Recycled board—U.S.	
Process (1)	78.00
Construction paper and board, and other —U.S.	
Process (1)	67.00
Market pulp processes—U.S.	
Dissolving & special alpha pulp	240.00
Softwood chemical market pulp	230.00
Hardwood chemical market pulp	220.00
Mechanical market pulp (BCTMP)	118.00
Market pulp from recycled fiber	120.00

Product and process[b]	Cost ($1986/t)
Newsprint—Canada	
Process (1) 75% GWD+25% CHEM	222.60
Process (2) 90% TMP+10% CHEM	173.25
Process (3) 100% ONP	172.73
Process (4) 100% TMP/CTMP	173.25
Process (5) 70% ONP+30% MIXED	165.00
Process (6) PRESS+100% TMP	175.00
Coated free sheet paper—Canada	
Process (2) 90% MKT+10% REC	189.00
Process (3) 100% REC	315.00
Uncoated free sheet paper - Canada	
Process (1) 100% SULPHITE	273.00
Process (2) 100% KRAFT	252.00
Process (3) 100% MKT PULP	168.00
Process (4) 100% REC	220.50
Process (5) 20% MECH/REC+80% CHEM	105.00
Coated groundwood paper —Canada	
Process (1) 58% CHEM+42% MECH	252.00
Process (2) 56% MKT+MECH+2% REC	220.50
Process (3) 100% REC	252.00
Uncoated groundwood paper —Canada	
Process (1) 35% CHEM+65% MECH	220.50
Process (2) 58% MECH+35% MKT+7% REC	173.25
Process (3) 100% REC	210.00
Tissue and sanitary paper—Canada	
Process (1) 70% MKT+30% REC	194.25
Process (2) 100% REC	236.25
Process (4) 90% MECH+10% REC	220.50
Process (5) 50% MIX+50% ONP	236.00
Process (6) 50% BCTMP+50% MKT	195.00
Specialty packaging and industrial paper—Canada	
Process (1)	273.00
Kraft Pkg. & Industrial converting paper—Canada	
Process (1) 100% CHEM	126.00
Linerboard—Canada	
Process (1) 95% KRAFT+5% OCC	94.50
Process (2) 70% KRAFT+30% OCC	81.90
Process (3) 100% REC	78.75
Process (4) 50% KRAFT+50% OCC	79.00
Process (5) 70% MECH+30% OCC	64.00
Corrugating medium—Canada	
Process (1) 67% SCHEM+33% OCC	100.80
Process (2) 90% SCHEM+10% OCC	102.90
Process (3) 100% REC	57.75
Process (4) 67% MECH+33% MIX	62.75
Solid bleached board—Canada	
Process (1) 100% KRAFT	258.30
Process (2) 70% KRAFT+30% MECH	200.00
Recycled board—Canada	
Process (1)	81.90
Construction paper and board, and other—Canada	
Process (1)	70.35
Market pulp processes—Canada	
Dissolving & special alpha pulp	252.00
Softwood chemical market pulp	241.50
Hardwood chemical market pulp	231.00
Mechanical market pulp (BCTMP)	123.90
Market pulp from recycled fiber	126.00

[a]Costs used by NAPAP Model in formula that calculates annual capacity change, as denominator in Tobin "q" ratio, for each process.

[b]BCTMP is bleached chemithermomechical pulp; CHEM, chemical pulp; GWD is groundwood; MECH, mechanical; MKT, market; OCC, old corrugated container; ONP, old newspaper; REC, recycled; TMP, thermomechanical pulp.

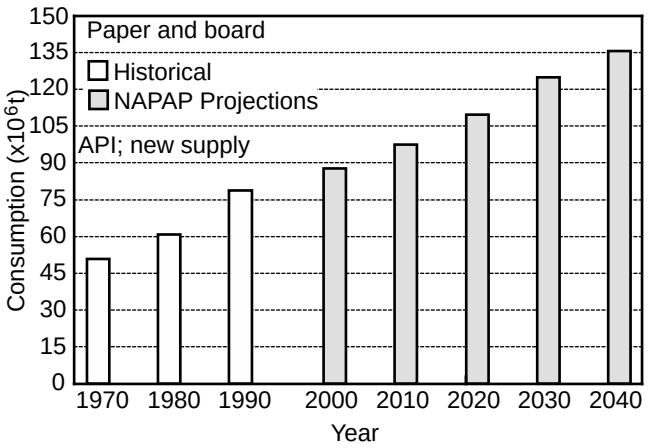

Figure 9—U.S. paper and board consumption.

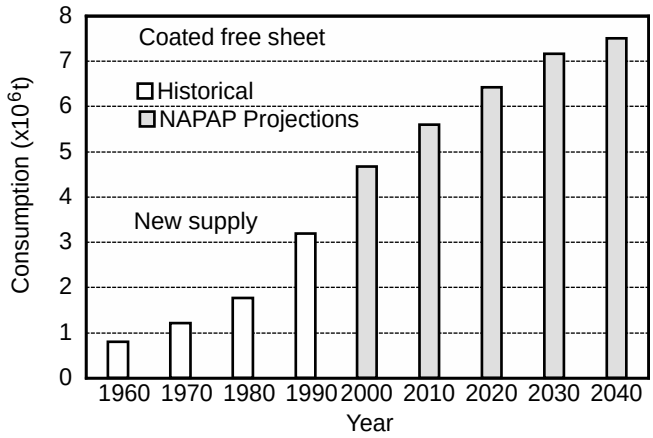

Figure 12—U.S. coated free sheet consumption.

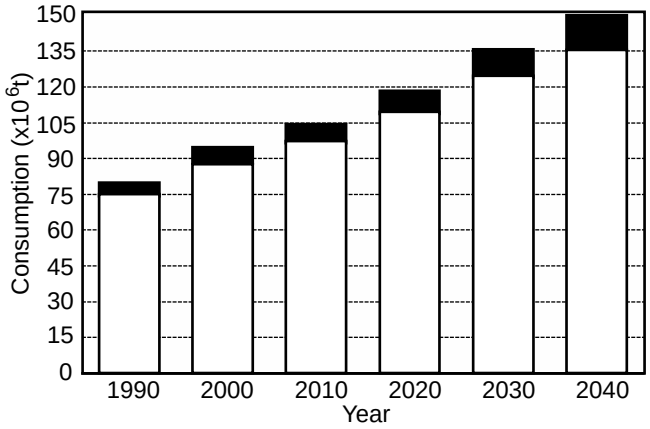

Figure 10—U.S. and Canadian paper and board consumption.

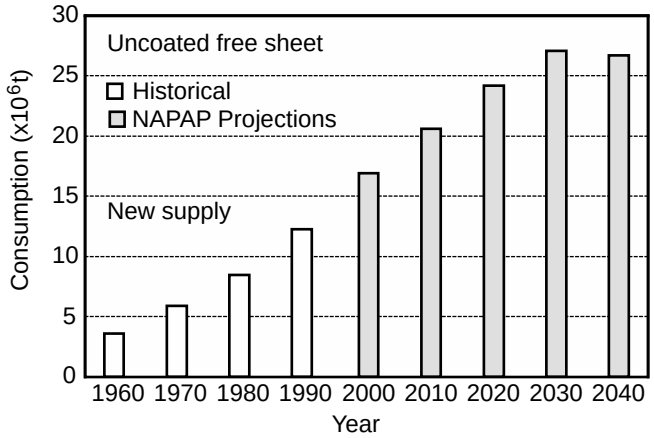

Figure 13—U.S. uncoated free sheet consumption.

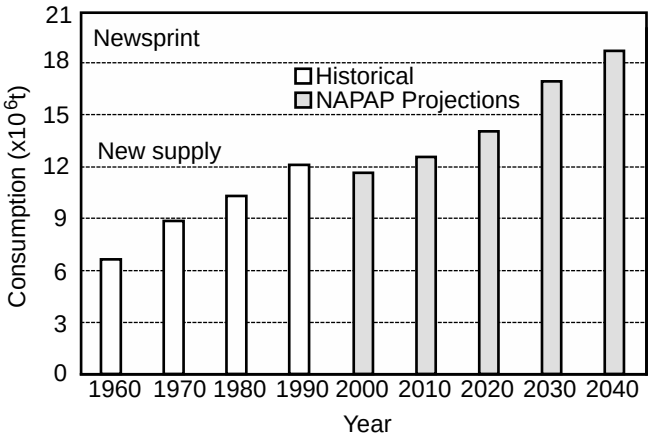

Figure 11—U.S. newsprint consumption.

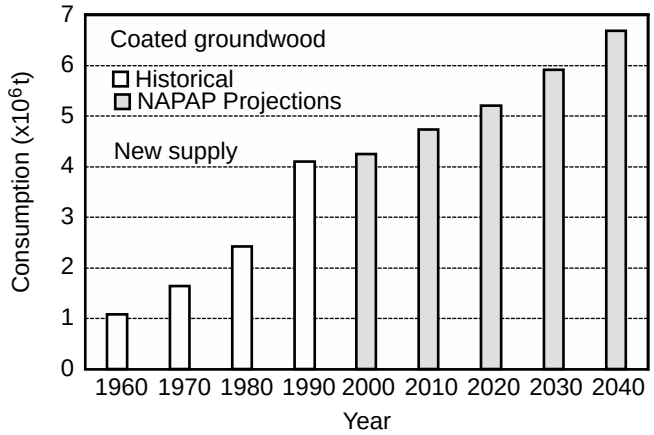

Figure 14—U.S. coated groundwood consumption.

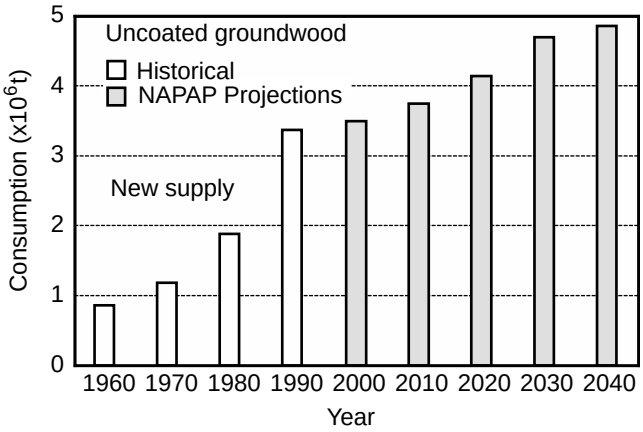

Figure 15—U.S. uncoated groundwood consumption.

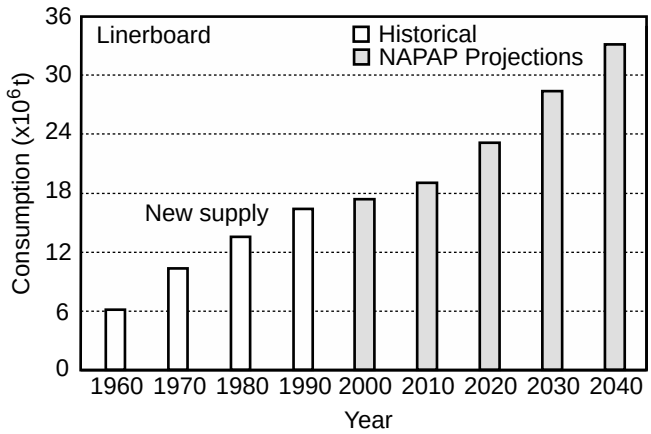

Figure 18—U.S. linerboard consumption.

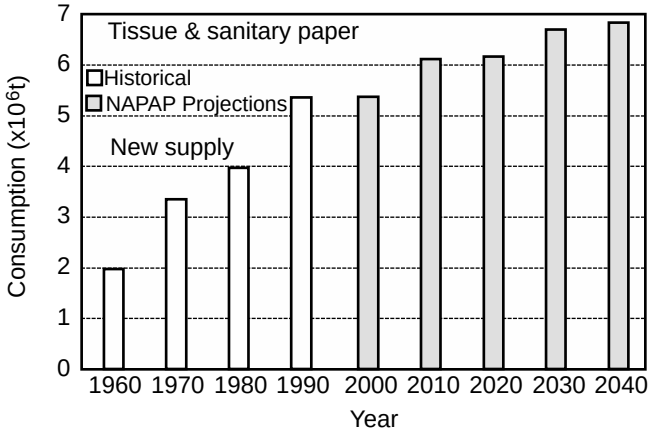

Figure 16—U.S. tissue & sanitary paper consumption.

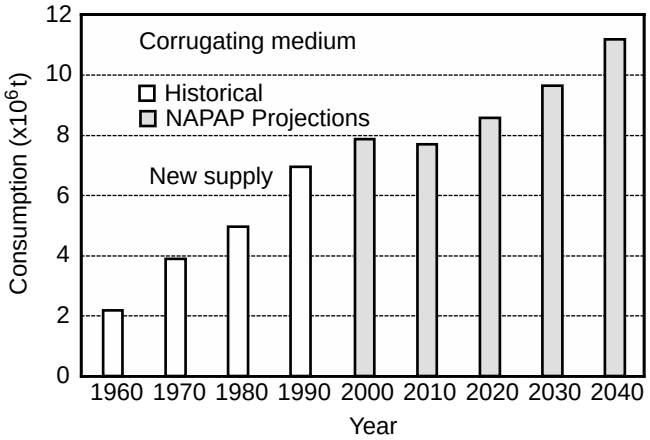

Figure 19—U.S. corrugating medium consumption.

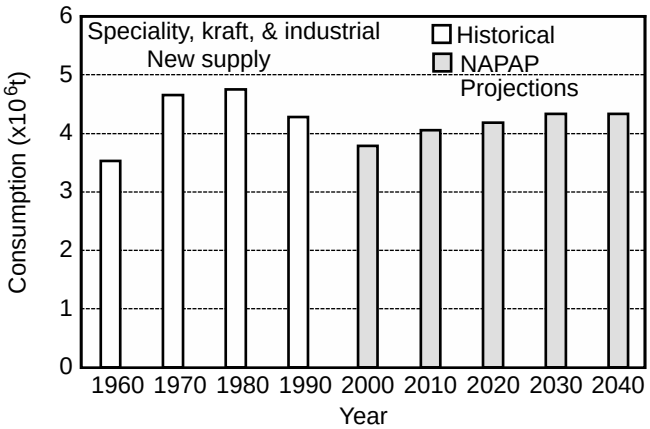

Figure 17—U.S. specialty & kraft packaging and industrial paper consumption.

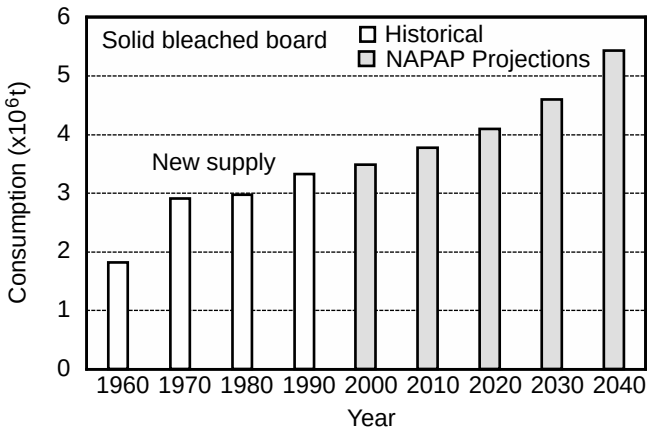

Figure 20—U.S. solid bleached board consumption.

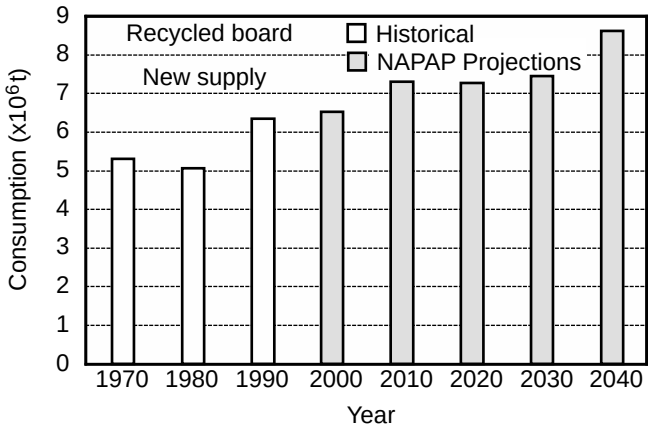

Figure 21—U.S. recycled board consumption.

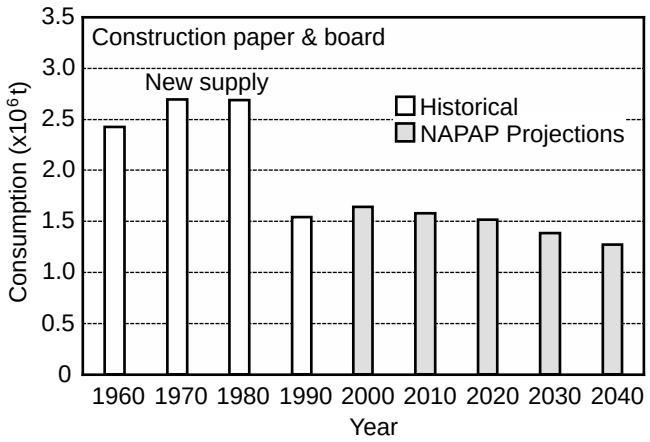

Figure 22—U.S. construction paper and board consumption.

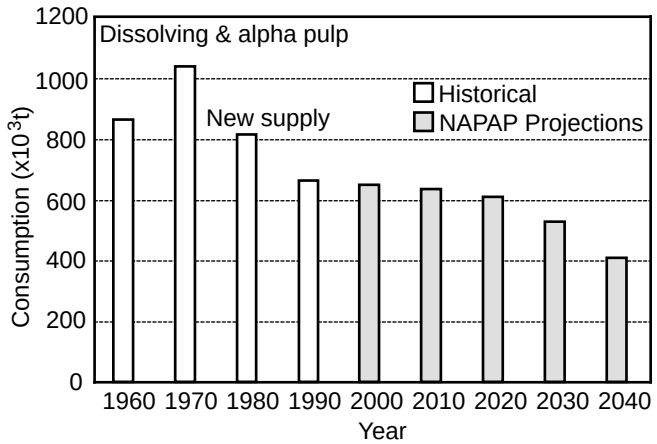

Figure 23—U.S. dissolving & special alpha pulp consumption.

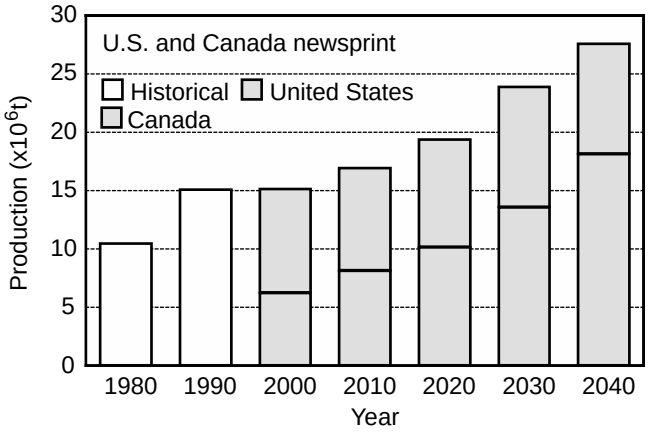

Figure 24—Newsprint production in United States and Canada.

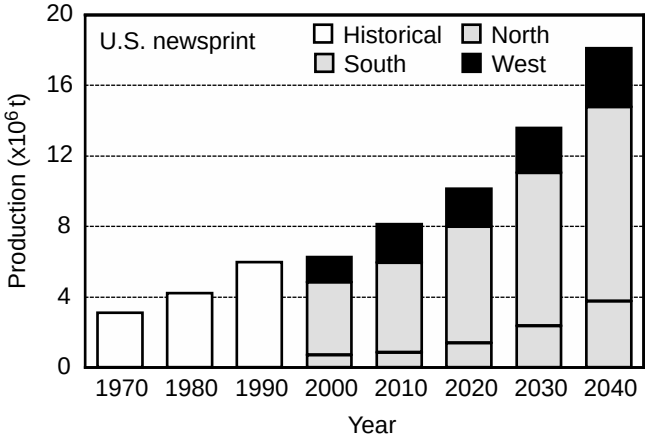

Figure 25—U.S. newsprint production.

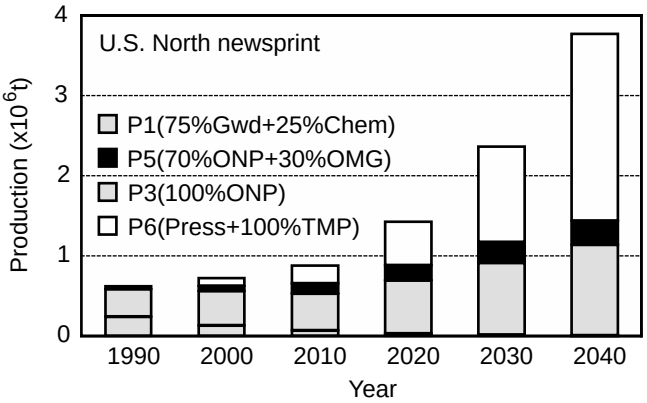

Figure 26—Newsprint production in U.S. North, by process. GWD is groundwood; ONP, old newspapers; OMG, old magazine grade; and TMP thermomechanical pulp.

Regionally, projections indicated that U.S. newsprint production would increase more than threefold between 1990 and 2040, as the United States assumed a larger share of North American newsprint production (Fig. 25). The South would remain the dominant newsprint-producing region of the United States. Newsprint production in the North and West was also projected to increase. Substantial growth in production of recycled newsprint was predicted for all regions.

In the North, newsprint production was projected to be based primarily on recycled fiber processes until around 2020 to 2030, when virgin-fiber processes based on thermo-mechanical pulp and advanced pressing technology gained a larger share of production (Fig. 26). In the South, projections indicated that processes based on recycled fiber would increase, but processes based on mechanical pulp would maintain the largest share of newsprint production (Fig. 27). Similar trends were projected in the West (not illustrated). In all regions, use of market pulp in newsprint was projected to decline, along with the disappearance of conventional groundwood pulping technology.

Figure 28 illustrates projected consumption of recovered paper in U.S. newsprint production. Historically, consumption of recovered paper in newsprint has increased steadily, from 0.34 million tonnes in 1970 to nearly 2 million tonnes in 1991 (API 1992). Consumption of recovered paper in newsprint was projected to increase rapidly in the l990s and throughout the remainder of the projection period (Fig. 28). The utilization rate for recovered paper in U.S. newsprint (tonnes of recovered paper consumed per tonne of newsprint produced) increased from 11 percent in 1970 to 19 percent in 1980 and 32 percent in 1990 (API 1992). Projections indicated that the utilization rate for recovered paper in U.S. newsprint production would exceed 60 percent by the early part of the next century, and then recede to around 50 percent by 2040. Projected utilization rates for Canada were much lower.

Pulpwood consumption in newsprint was projected to decline in the l990s from more than 10 million to around 7 million cubic meters per year, as rapid increases in recycling rates were projected to occur (Fig. 29). Toward the end of the projection period, pulpwood consumption in newsprint was projected to increase as a result of the increase in production based on mechanical pulp. Pulpwood consumption in newsprint was projected to roughly double between 1990 and 2040. Softwood pulpwood was projected to remain the largest component of pulpwood consumed in newsprint.

Printing & Writing Paper

Figure 30 illustrates NAPAP Model projections of printing & writing paper annual production in the United States and Canada (printing & writing paper includes four commodities: coated and uncoated free sheet, and coated and uncoated groundwood paper). The United States has produced over 85 percent of total U.S. and Canadian production of printing & writing paper in recent years. In 1991, Canadian shares of total U.S. and Canadian production were less than 10 percent for uncoated free sheet, around 12 percent for coated groundwood, less than 5 percent for coated free sheet, and just over 50 percent for uncoated groundwood (Miller Freeman 1992). Projections indicated the United States would remain dominant in total production of printing & writing paper throughout the projection period (Fig. 30); Figure 31 shows printing & writing paper production by grade.

Uncoated free sheet was projected to remain the dominant printing & writing paper commodity produced in the United States (Fig. 32). Production was projected to increase for all printing & writing commodities. Although historically the North has always had the largest regional share of printing & writing paper production, projections indicated that the South would gradually become the dominant region in production of printing & writing paper in the United States. In recent decades, the South has been gaining in its share of printing & writing paper production capacity. Between 1970 and 1990, while printing & writing paper production capacity increased by 64 percent in the North, it increased by 83 percent in the South. The NAPAP Model projected that total U.S. printing & writing paper production would approximately double between 1990 and 2040.

Figures 32 through 35 illustrate projected U.S. production by region for each printing & writing paper commodity separately. Production of coated free sheet paper (Fig. 32) was projected to increase in all U.S. manufacturing regions, with the largest projected increase in the South; total U.S. production was projected to nearly triple between 1990 and 2040. Production of uncoated free sheet paper (Fig. 33) was projected to increase substantially in the South, and gradually decrease in the North and West; total U.S. production was projected to approximately double between 1990 and 2040. Production of coated groundwood paper (Fig. 34) was projected to increase substantially in the South and in the West, and remain relatively constant in the North; total U.S. production was projected to approximately double between 1990 and 2040. Production of uncoated groundwood paper (Fig. 35) was projected to increase substantially in the South and West and to gradually decline in the North; total U.S. production was projected to more than double between 1990 and 2040.

The North and South were projected to be the dominant regions for U.S. coated free sheet production. In the North, coated free sheet production was projected to increase based on virgin-fiber chemical pulping (Process 1) (Fig. 36). Production based on market pulp (Process 2) was projected to be displaced, while production based on recycled fiber (Process 3) was projected to gradually increase. Projections indicated that production based on recycled fiber would remain a small fraction of total coated free sheet production

in the North, although most growth in production during the projection period was based on recycled fiber. Similarly, in the South, coated free sheet production was projected to increase based primarily on virgin-fiber pulping (Process 1) (Fig. 37). However, production based on recycled fiber (Process 3) was projected to increase substantially.

The North and South were also projected to be the dominant regions for U.S. uncoated free sheet production. In the North, uncoated free sheet production was projected to gradually decline, with production based on virgin-fiber sulphite pulping (Process 1) declining steadily and production based on virgin-fiber kraft pulping (Process 2) increasing into the next century but gradually declining in the longer term (Fig. 38). Processes based on market pulp (Process 3), recycled fiber (Process 4), and blended mechanical and chemical pulp (Process 5) were not projected to increase in the North. In the South, uncoated free sheet production was projected to increase very substantially, based entirely on virgin-fiber bleached kraft pulping (Process 2) (Fig. 39).

The North and South were projected to be the dominant regions for U.S. coated groundwood production as well. In the North, coated groundwood production was projected to remain relatively constant throughout the projection period, with substantial projected growth in production based on recycled fiber (Process 3), although processes based primarily on virgin fiber (Processes 1 and 2) maintained the largest share of total production (Fig. 40). In the South, coated groundwood production was projected to increase substantially (Fig. 41). Coated groundwood production based on recycled fiber (Process 3) was projected to increase, but production based on virgin fiber was projected to maintain more than two-thirds of total production throughout the projection period.

The South and West were projected to be dominant regions for U.S. uncoated groundwood production. In the South, uncoated groundwood production was projected to increase very substantially (Fig. 42). It was projected that this growth would be based primarily on recycled fiber (Process 3) throughout most of the projection period, although production based on virgin-fiber mechanical and chemical pulping (Process 1) would eventually gain a larger share of total production by the end of the projection period. In the West, production of uncoated groundwood was also projected to increase substantially, and virtually all the growth in production was projected to be based on recycled fiber (Process 3) (Fig. 43).

Figure 44 illustrates projected total consumption of recovered paper in U.S. printing & writing paper production, along with historical data from 1970 to 1991 (API 1992). Historically, U.S. consumption of recovered paper in printing & writing paper has increased steadily, from 0.7 million tonnes in 1970 to more than 1.3 million tonnes in 1991 (API 1992), nearly doubling in that period. However, total U.S. production of printing & writing paper also doubled in the same period, so consumption of recovered paper per tonne of printing & writing paper has not increased significantly in recent decades. The U.S. consumption of recovered paper in printing & writing paper was projected to increase gradually throughout most of the projection period, particularly in the next century (Fig. 44). The utilization rate of recovered paper per tonne of printing & writing paper was projected by the NAPAP Model to increase from around 9 percent in 1990 to around 17 percent by the year 2040.

Overall pulpwood consumption in printing & writing paper was projected to increase steadily throughout the projection period, from nearly 60 million cubic meters in 1990 to nearly 140 million cubic meters in the year 2040 (Fig. 45). In line with historical utilization patterns, the hardwood component of pulpwood in printing & writing paper was projected to remain high, but gradually softwood was projected to assume a more important role toward the end of the projection period (when hardwood pulpwood supplies were projected to become constrained, particularly in the South). Whereas softwood pulpwood represented roughly half of pulpwood consumption in U.S. printing & writing paper production in 1990, softwood pulpwood was projected to provide over 60 percent of the total toward the end of the projection period (Fig. 45). Meanwhile, U.S. consumption of market pulp in printing & writing paper (not illustrated) was projected to decline steadily throughout the projection period.

Tissue & Sanitary Paper

Figures 46 to 49 illustrate NAPAP Model projections of tissue & sanitary paper production in the United States and Canada. Historically, annual production of tissue & sanitary paper has been roughly ten times greater in the United States than in Canada (Miller Freeman 1992). The NAPAP Model projected that total U.S. and Canadian tissue and sanitary paper production would increase from roughly 5 to 8 million metric tonnes annually between 1990 and 2040. Projections indicated that the United States would continue to produce the largest share.

However, projections also indicated that the Canadian share of total production would gradually increase (Fig. 46). Eventually, by the year 2040, Canada was projected to produce roughly one-fifth of the total U.S. and Canadian production.

In the United States, the North was projected to remain the leading region for tissue and sanitary production, followed by the South and West (Fig. 47). Production was projected to increase in all regions, with highest growth projected for the North and West. Figures 48 and 49 illustrate projected technological trends for tissue and sanitary paper in the U.S. North and South, showing production by process. In the North (Fig. 48), production based on market pulp (Process 1) was projected to decline rapidly, while production based on recycled fiber (Processes 2 and 5) was projected to dominate

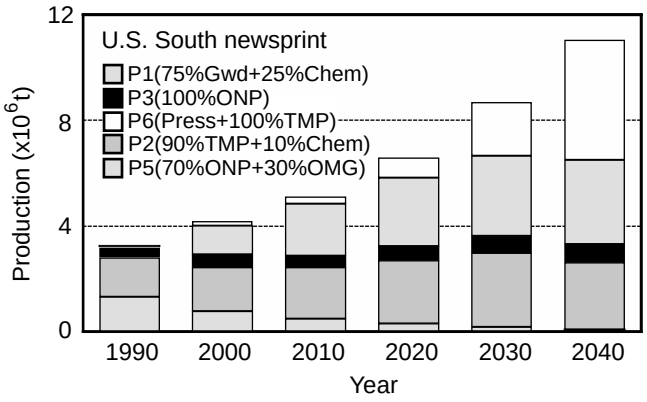

Figure 27—Newsprint production in U.S. South, by process.

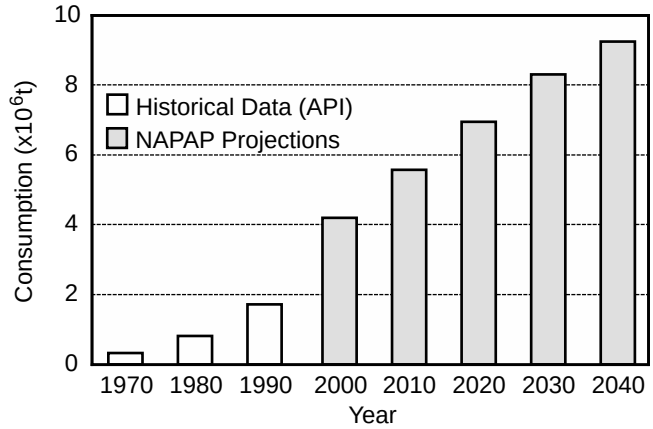

Figure 28—Recovered paper consumed in U.S. newsprint production.

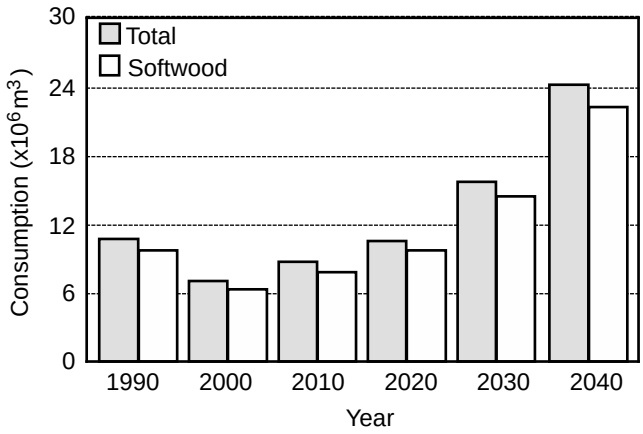

Figure 29—Pulpwood consumed in U.S. newsprint production.

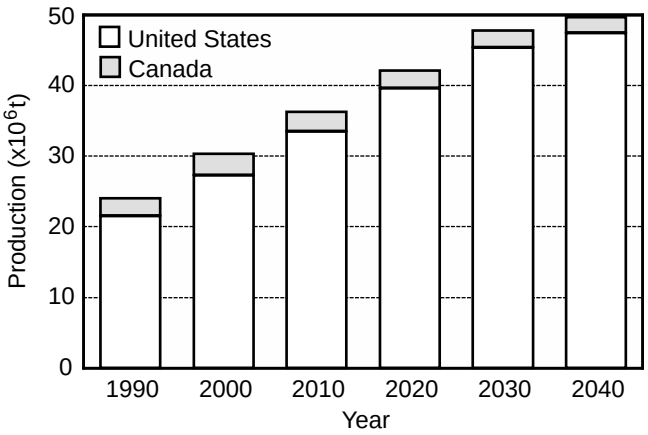

Figure 30—Printing & writing paper production in United States and Canada.

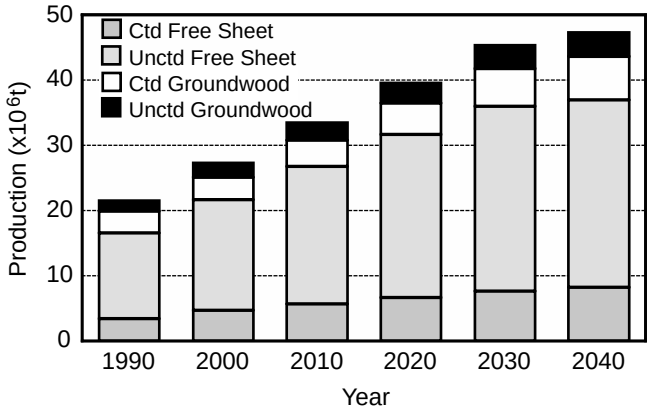

Figure 31—U.S. printing & writing paper production by grade.

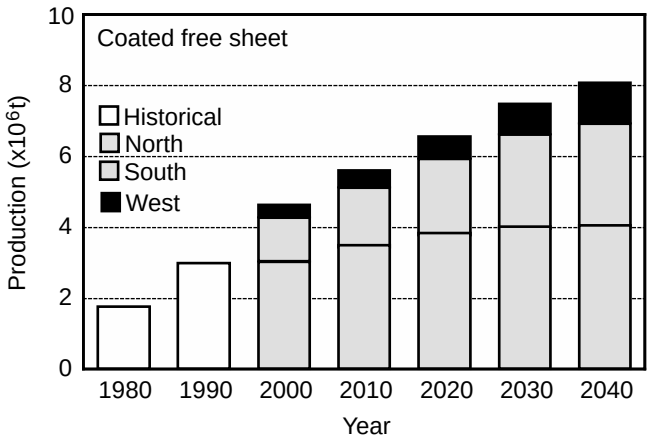

Figure 32—U.S. coated free sheet production.

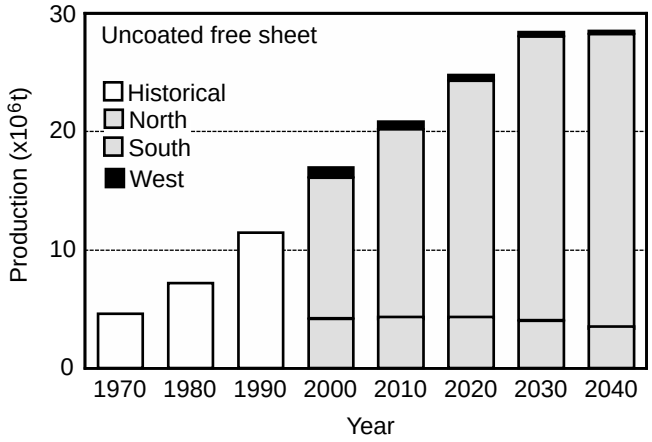

Figure 33—U.S. uncoated free sheet production.

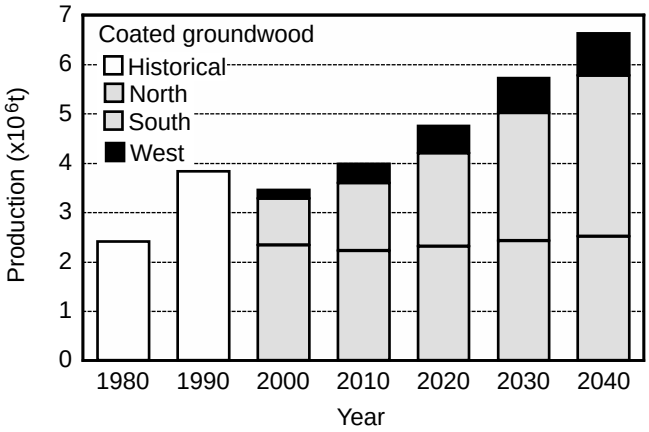

Figure 34—U.S. coated groundwood production.

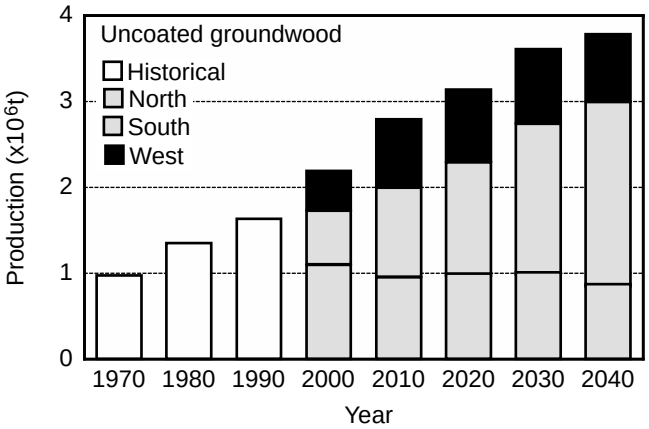

Figure 35—U.S. uncoated groundwood production.

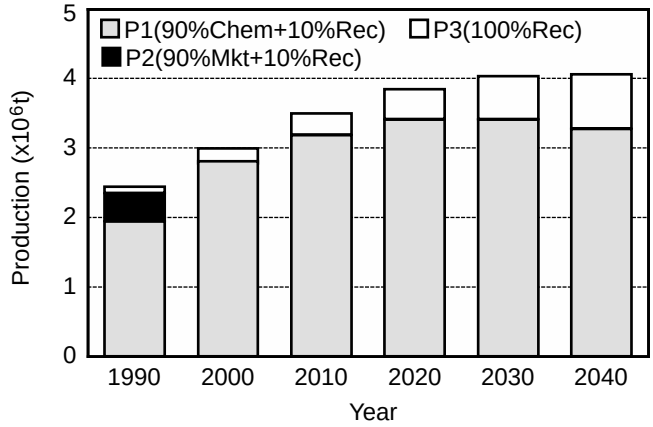

Figure 36—Coated free sheet production in U.S. North, by process.

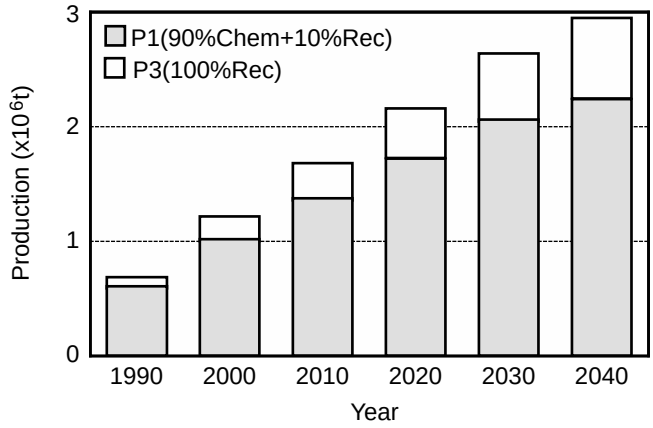

Figure 37—Coated free sheet production in U.S. South, by process.

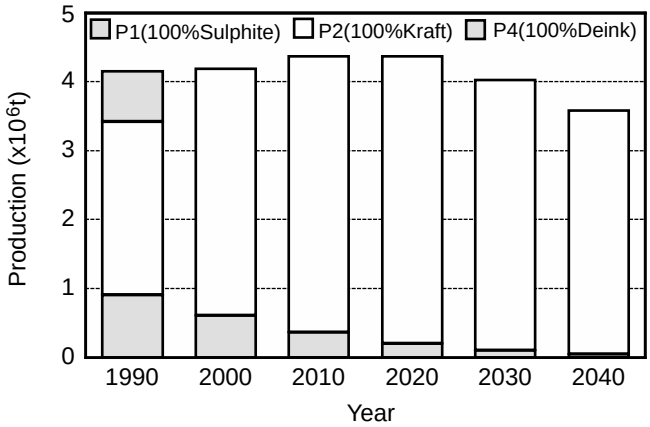

Figure 38—Uncoated free sheet production in U.S. North, by process.

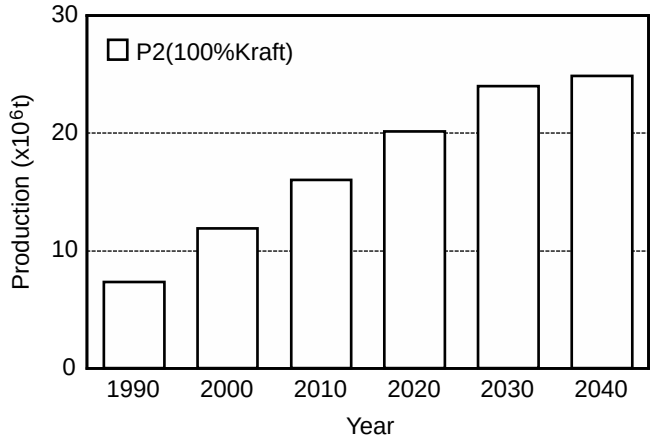

Figure 39—Uncoated free sheet production in U.S. South, by process.

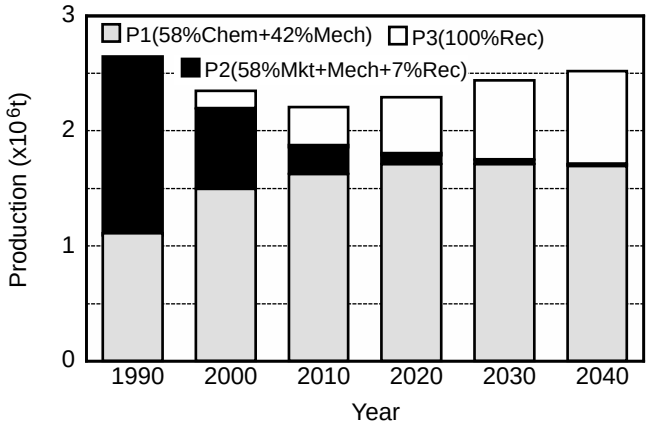

Figure 40—Coated groundwood production in U.S. North, by process.

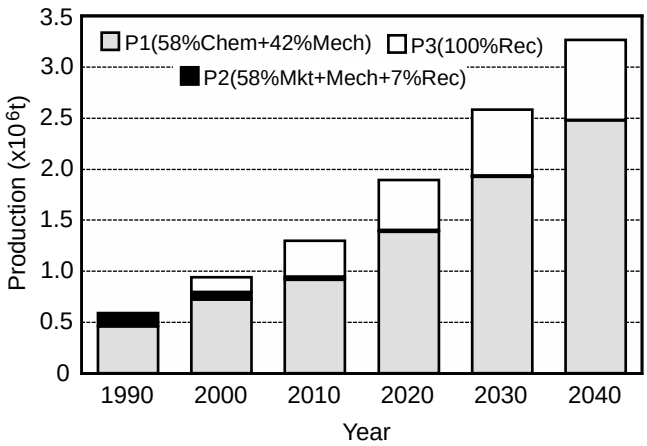

Figure 41—Coated groundwood production in U.S. South, by process.

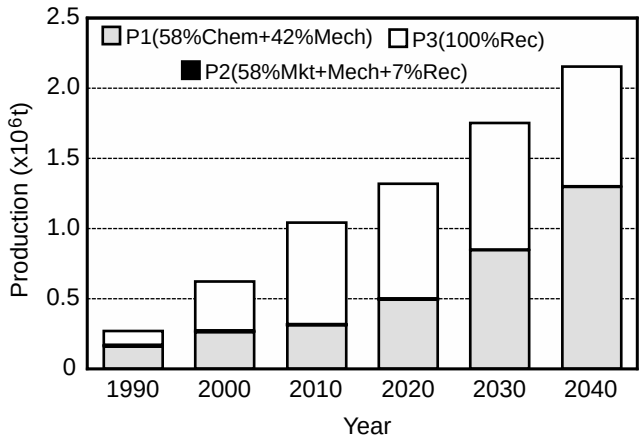

Figure 42—Uncoated groundwood production in U.S. South, by process.

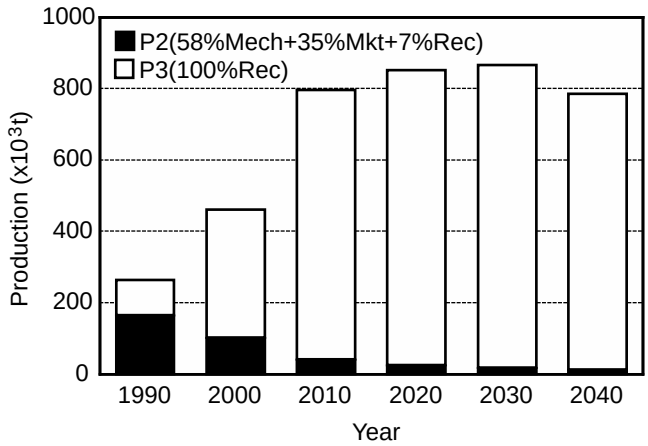

Figure 43—Uncoated groundwood production in U.S. West, by process.

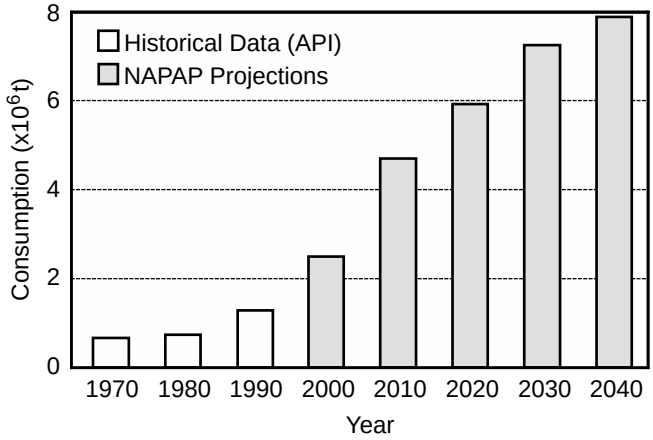

Figure 44—Recovered paper consumed in U.S. printing & writing paper production.

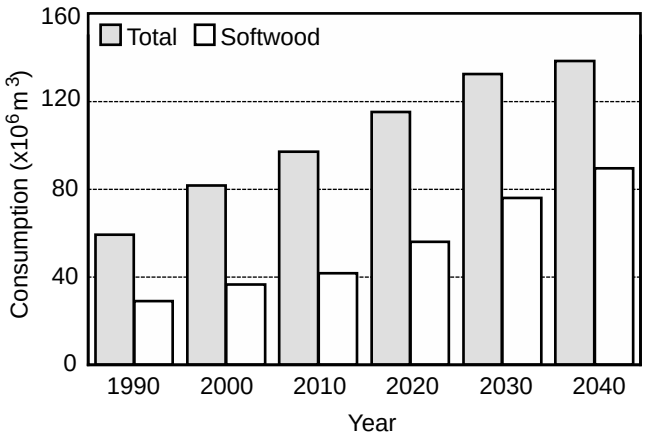

Figure 45—Pulpwood consumed in U.S. printing & writing paper production.

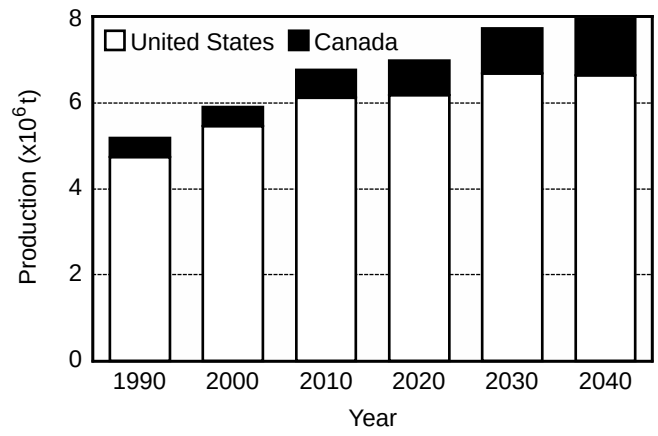

Figure 46—Tissue & sanitary paper production in United States and Canada.

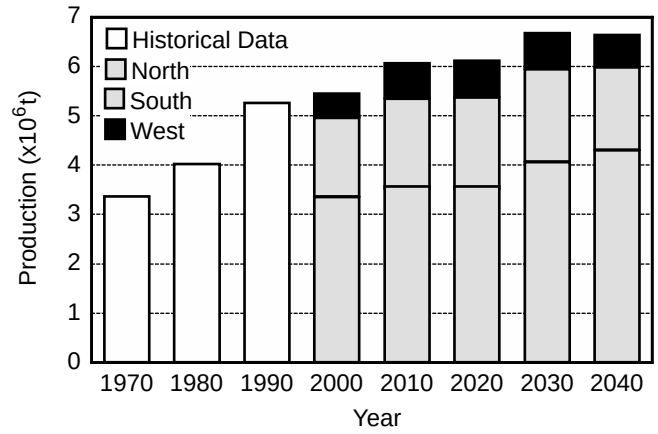

Figure 47—U.S. tissue & sanitary paper production.

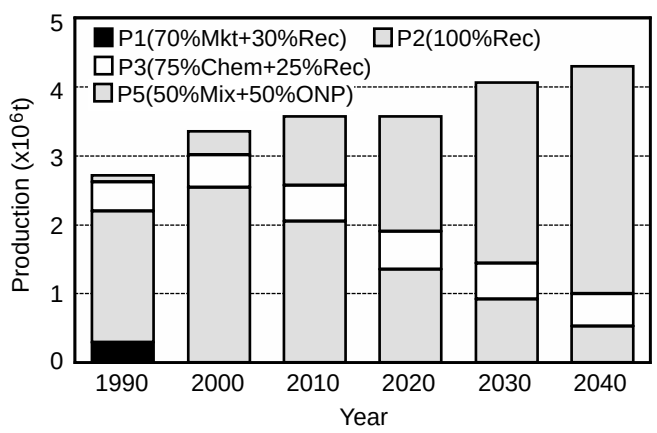

Figure 48—Tissue & sanitary paper production in U.S. North, by process.

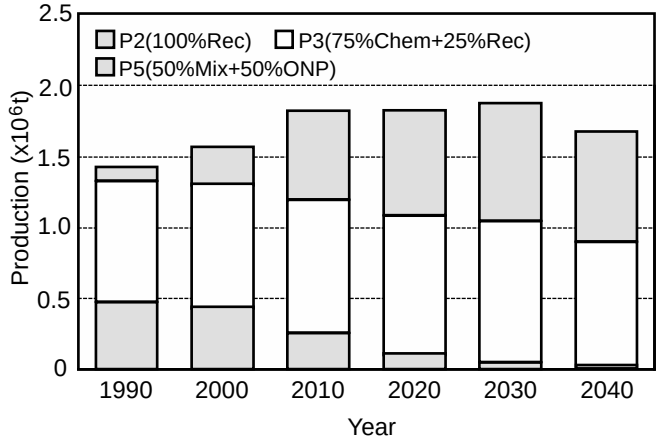

Figure 49—Tissue & sanitary paper production in U.S. South, by process.

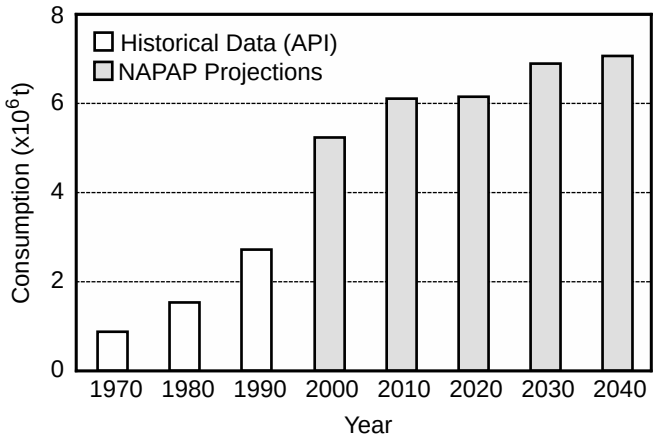

Figure 50—Recovered paper consumed in U.S. tissue & sanitary paper production.

overall production. Production based partly on virgin-fiber chemical pulping (Process 3) was projected to remain relatively constant. Likewise, in the South (Fig. 49), production based on recycled fiber (Processes 2 and 5) was projected to increase. However, production based on virgin-fiber chemical pulp (Process 3) was projected to remain significant and relatively constant throughout the projection period.

Figure 50 illustrates NAPAP Model projections of recovered paper consumption in U.S. tissue and sanitary paper production, along with historical data on the actual trend since 1970 (API 1992). Projections indicated generally that recovered paper consumption in U.S. tissue & sanitary production would increase substantially, continuing the trend observed in recent years. Recovered paper consumption was projected to level off in the next century, when recovered paper prices were projected to increase.

Projections indicated that consumption of pulpwood in tissue & sanitary paper would gradually decline, as recovered paper consumption increased (Fig. 51). The softwood share of pulpwood consumption was projected to recede slightly from roughly 75 to 65 percent.

Specialty and Kraft Packaging & Industrial Paper

In recent decades, Canada generally produced less than 20 percent of total kraft packaging & industrial paper, and less than 2 percent of total specialty packaging & industrial paper. Projections indicated that the United States would continue to produce the largest share of total production for the next several decades, but Canada would assume a larger share of kraft packaging & industrial paper production toward the end of the projection period (Figs. 52 and 53). Between 1990 and 2040, total U.S. and Canadian production of specialty packaging & industrial paper was projected to increase by roughly 75 percent (Fig. 52). Production was projected to decline for kraft packaging & industrial paper in the next several decades, and then increase in Canada toward the end of the projection period (Fig. 53). Much of the projected growth in Canadian production toward the end of the projection period is for export to growing overseas markets. Historically, both U.S. and Canadian production of kraft packaging & industrial paper has declined since peak production levels of the 1970s (Miller Freeman 1992). The historical decline in use of kraft packaging & industrial paper in recent years was primarily due to substitution of plastics for paper, mainly in grocery sacks and to a lesser extent in heavier multiwall sacks. Specialty packaging & industrial paper production had also declined since the 1970s, but its production has rebounded in recent years. As illustrated earlier (Fig. 17), the projected aggregate U.S. demand for specialty and kraft packaging & industrial paper does not appear to depart from historical trends.

Projections indicated that production of specialty packaging & industrial paper would grow primarily in the South, eventually surpassing production in the North beyond the year 2000 (Fig. 54). Production in the North would remain relatively stable, while production in the West was projected to gradually decline. Overall U.S. production of kraft packaging & industrial paper was projected to decline (Fig. 55). Production in the South was projected to decline, but production in the North was projected to increase gradually (based primarily on recycled fiber).

Figures 56 and 57 illustrate projected technological trends for kraft packaging & industrial paper in the U.S. North and South by process. In both cases, production based on recycled fiber (Process 3) was projected gradually to entirely displace production based on virgin-fiber kraft pulping.

Figure 58 illustrates projected total consumption of recovered paper in U.S. packaging & industrial paper production (specialty and kraft paper). Projections indicated a departure from historical trends as a consequence of the significant projected increase in packaging paper production based on recycled fiber. Total consumption of pulpwood in U.S. specialty and kraft packaging & industrial paper production was projected to decline and then level off in the next century, with increased recycling (Fig. 59). Softwood was projected to remain the primary pulpwood raw material.

Paperboard

In the NAPAP Model, paperboard included linerboard (virgin-fiber unbleached kraft board and recycled linerboard), corrugating medium (semichemical and recycled corrugating medium), solid bleached board, and recycled paperboard (excluding recycled linerboard and corrugating medium). Historically, the United States has produced by far the larger share of total U.S. and Canadian paperboard production (more than 90 percent of total annual production in recent decades). The NAPAP Model projections indicated that the United States would continue to produce the larger share (Fig. 60). However, toward the end of the projection period (2020–2040), the projections indicated that the Canadian share of total paperboard production would gradually increase. Total production of paperboard in the United States and Canada was projected to increase very substantially, with approximately a doubling of production volume in the United States between 1990 and 2040.

As with total paperboard production, the United States has produced by far the larger share of total U.S. and Canadian production of container board (linerboard and corrugating medium) (Fig. 61). Projections indicated that the United States would continue this trend. Between 1990 and 2040, container board production in the United States was projected to more than double. Toward the end of the projection period, projections indicated that the Canadian share would gradually increase; Canada was projected to produce around one-sixth of the total container board output by the year 2040. Projected container board production accounts for the bulk of projected total paperboard production in the United States and Canada.

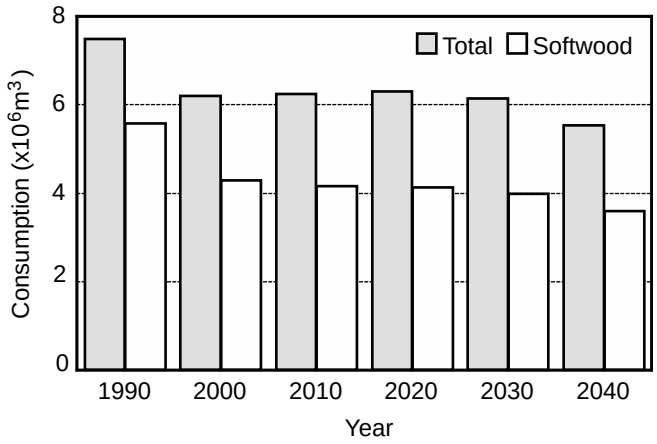

Figure 51—Pulpwood consumed in U.S. tissue & sanitary paper production.

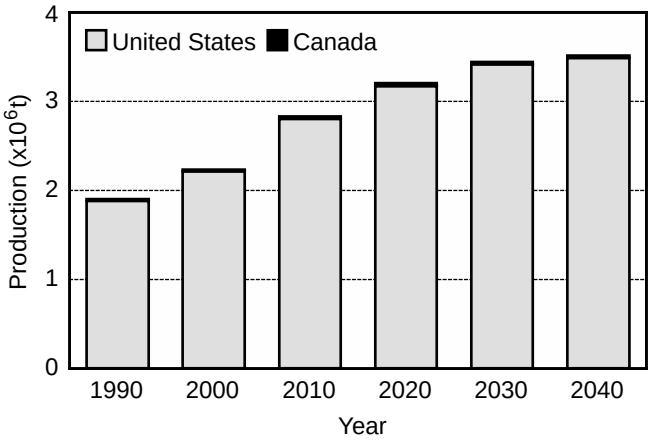

Figure 52—Specialty packaging & industrial paper production in United States and Canada.

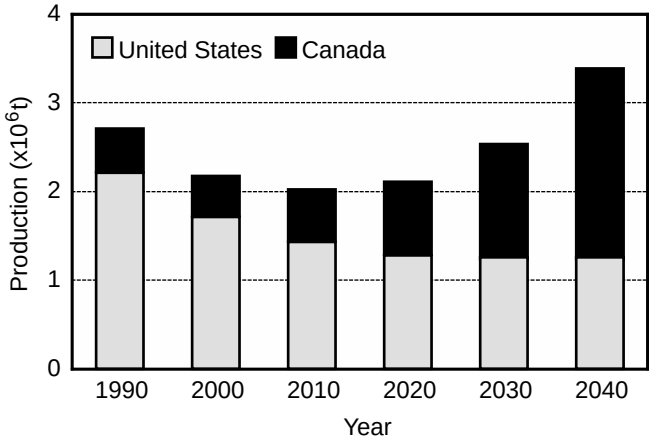

Figure 53—Kraft packaging & industrial paper production in United States and Canada.

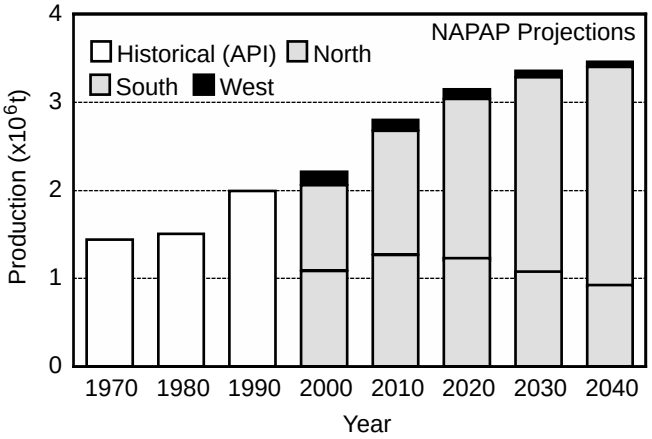

Figure 54—U.S. specialty packaging & industrial paper production.

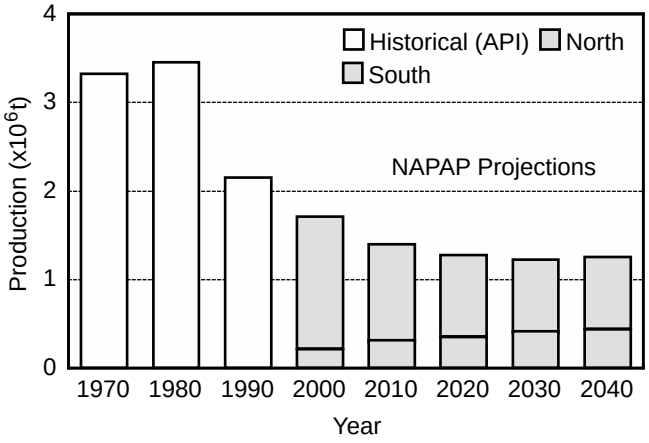

Figure 55—U.S. kraft packaging & industrial paper production.

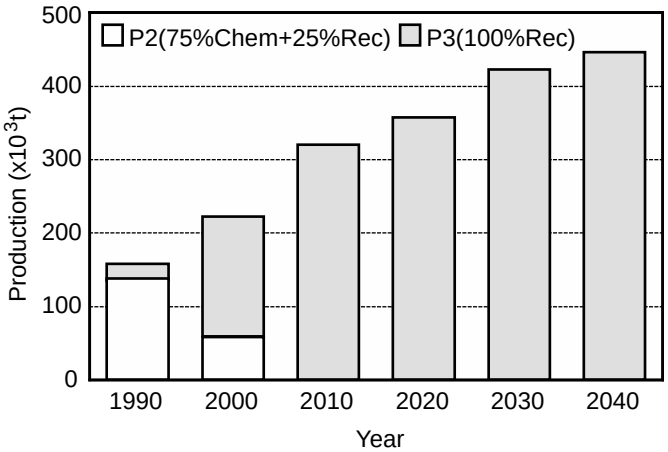

Figure 56—Kraft packaging & industrial paper production in U.S. North, by process.

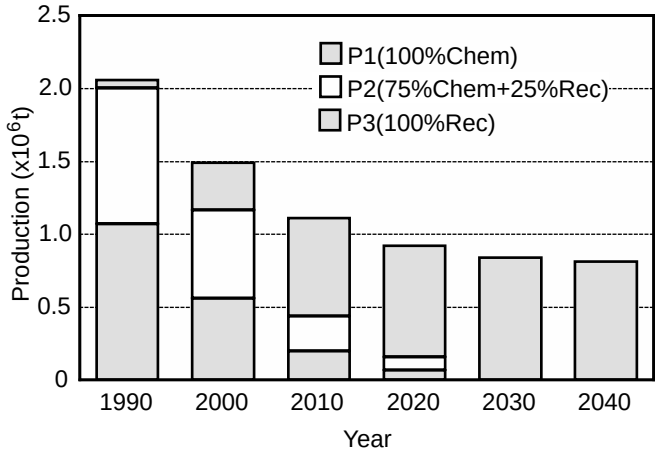

Figure 57—Kraft packaging & industrial paper production in U.S. South, by process.

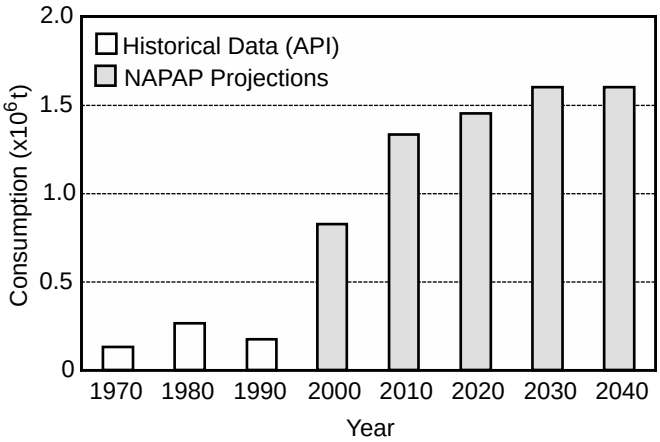

Figure 58—Consumption of recovered paper in U.S. specialty and kraft packaging & industrial paper production.

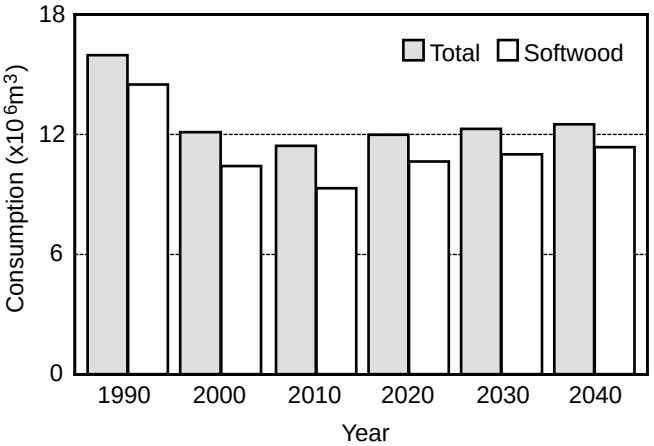

Figure 59—Consumption of pulpwood in U.S. specialty and kraft packaging & industrial paper.

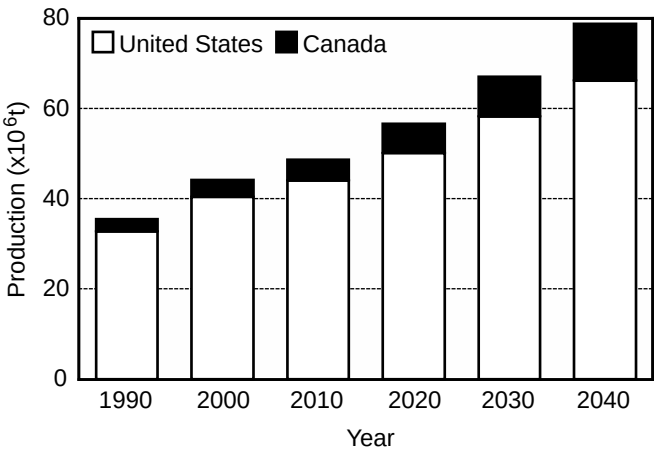

Figure 60—Paperboard production in United States and Canada.

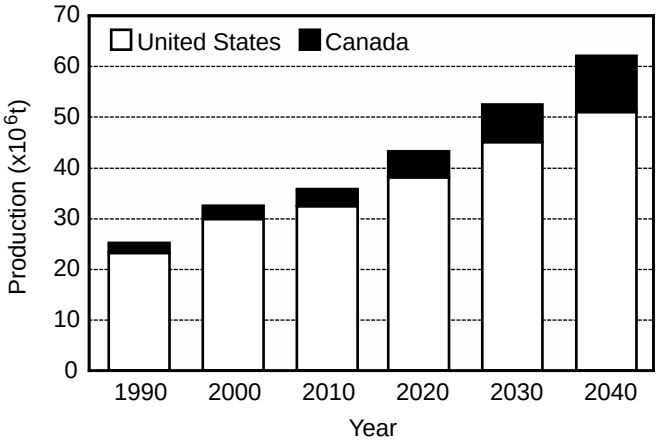

Figure 61—Linerboard and corrugating medium (containerboard) production in United States and Canada.

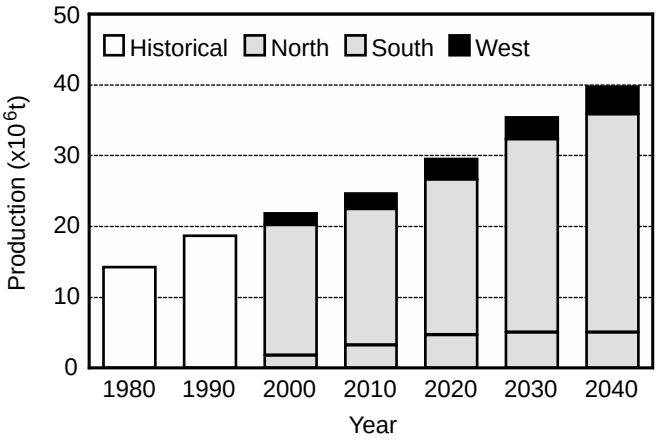

Figure 62—U.S. linerboard production.

Figure 62 illustrates projected linerboard production in the United States by region; linerboard production was projected to approximately double between 1990 and 2040, with the bulk of that increase projected to occur in the South. Linerboard production in the South was projected to increase to approximately 30 million metric tonnes per year by 2040. Linerboard production was also projected to increase in the West, but production in the West was projected to remain substantially lower than production in the South. Although traditionally the North has produced only a very small proportion of total U.S. linerboard production, the projections indicated that linerboard production in the North would increase very substantially (based primarily on recycled fiber in the next several decades).

Figures 63 to 65 illustrate projected technological evolution in linerboard production by process for each region of the United States. For the next several decades, linerboard production in the North was projected to increase substantially, based primarily on recycled fiber (Process 3) (Fig. 63). However, toward the latter end of the projection period, a larger share of linerboard production in the North was projected to be based on virgin-fiber kraft pulp with high proportions of recycled fiber (Process 4) and virgin-fiber mechanical pulp with high proportions of recycled fiber (Process 5). Processes 4 and 5 were assumed to use advanced forming, pressing, and drying technology (i.e., technologies incorporating impulse drying, press drying, or similar concepts). It was projected that eventually such processes would displace production based solely on recycled fiber (Process 3).

Linerboard production in the U.S. South was projected to be based primarily on virgin-fiber unbleached kraft pulp (Processes 1 and 2) for at least the next several decades (Fig. 64). Of the two conventional virgin-fiber kraft linerboard processes used in the South, production based on improved press technology (Process 2) was projected to eclipse production based on older (pre-1980) press technology (Process 1) by the early part of the next century. Production based entirely on recycled fiber (Process 3) was projected also to increase for several decades in the South. However, toward the end of the projection period, a larger share of linerboard production was projected to be based on virgin-fiber kraft or mechanical pulp with high proportions of recycled fiber (Processes 4 and 5), using advanced forming, pressing, and drying technology.

Linerboard production in the West was projected to follow technological trends similar to those in the North and South (Fig. 65). The West was projected to experience a decline in linerboard production volume in the next decade (due in part to projected near-term constraints on fiber supply in the West). Subsequently, linerboard production was projected to increase and eventually exceed current production levels, based largely on technology using recycled fiber (Process 3) and technology using mechanical pulp with high proportions of recycled fiber (Process 5).

Figure 66 illustrates projected production of corrugating medium in the United States, by region. Production of corrugating medium was projected to increase substantially between 1990 and 2040. Production was projected to increase primarily in the North and in the West, and to gradually decline in the South.

Figures 67 and 68 illustrate projected technological evolution for corrugating medium production in the U.S. North and West, by process. In both regions, production based on recycled fiber (Process 3) was projected to predominate. In the North, production based on recycled fiber was projected to generally displace production based on virgin-fiber semichemical pulping technology (Processes 1 and 2) within the next couple of decades. Production based on virgin-fiber mechanical pulping (Process 4) was not projected to obtain a significant share of total production volume. Similar technological trends were projected for the South, where corrugating medium production was projected to gradually decline; however, production based on virgin-fiber semichemical pulping was projected to retain a large share of total production for several decades into the future.

Figure 69 illustrates projected production of solid bleached board in the United States, by region. Between 1990 and 2040, production was projected to increase by more than 60 percent, increasing in all regions by the end of the projection period. The South was projected to remain the dominant region for production of solid bleached board. However, production in the North was projected to increase substantially and to reach a volume nearly one-fourth as large as projected production in the South by the year 2040. Production in the West was also projected to increase, particularly beyond the year 2020.

Figures 70 to 72 illustrate projected technological evolution in solid bleached board production in the U.S. North, South, and West. In all regions, the use of bleached mechanical pulp was projected to increase; production based on a 30-percent blend of high-yield bleached mechanical pulp (Process 2) was projected to increase in all regions. Process 2 was projected to be the primary production technology in the North beyond the year 1995 (the year in which such technology was assumed to be introduced in the NAPAP Model) (Fig. 70). In the South, conventional solid bleached board technology based on 100-percent bleached kraft pulp (Process 1) was projected to remain the dominant production technology throughout most of the projection period, but it was projected to decline toward the end of the projection period, being replaced by Process 2 in the period 2020–2040 (Fig. 71). Technological trends were projected to be similar in the West (Fig. 72). However, production based on 30-percent high-yield mechanical pulp (Process 2) was projected to eclipse production based on conventional 100-percent bleached kraft pulp (Process 1) somewhat earlier in the West than in the South (by around 2010–2020). Near-term constraints on pulpwood supply in the West contribute to the decline in production based on conventional kraft pulping, and favor earlier substitution of higher yield mechanical pulp.

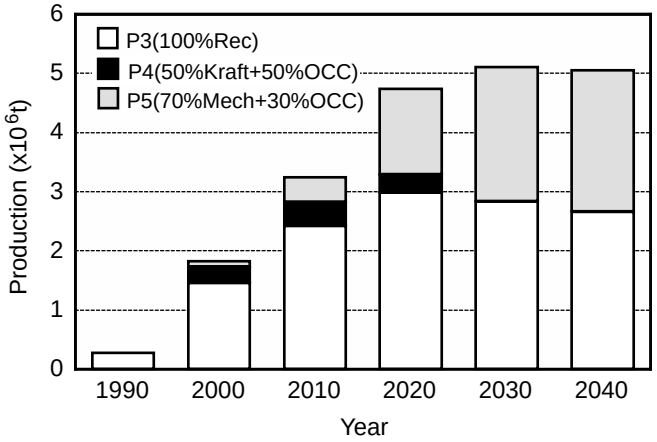

Figure 63—Linerboard production in U.S. North.

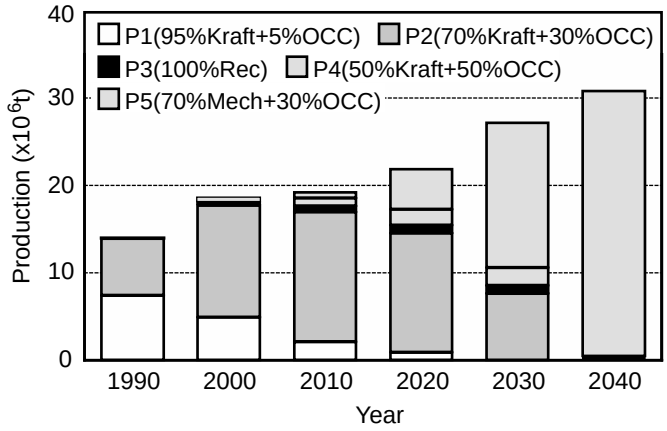

Figure 64—Linerboard production in U.S. South.

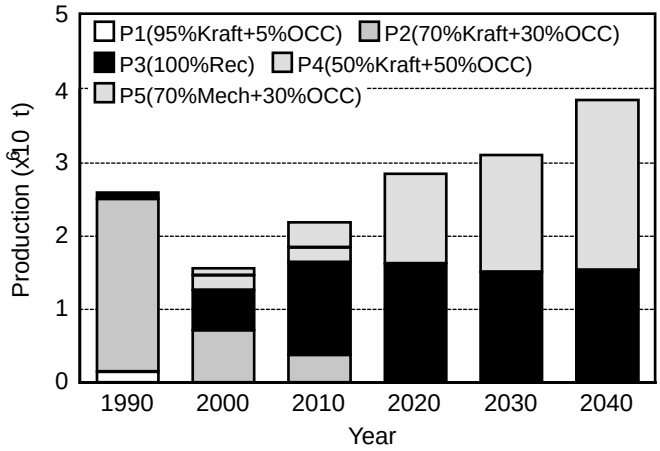

Figure 65—Linerboard production in U.S. West.

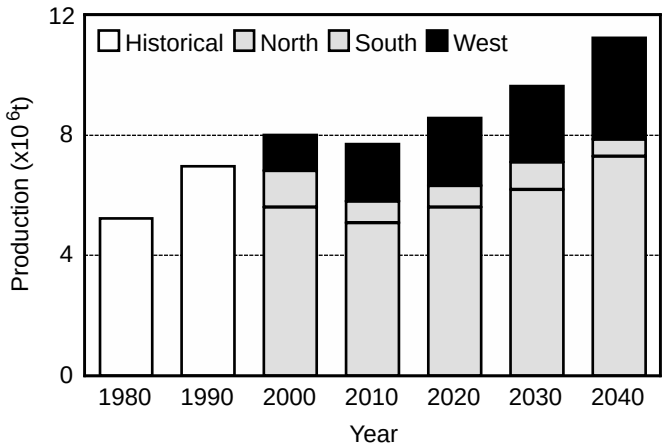

Figure 66—U.S. corrugating medium production.

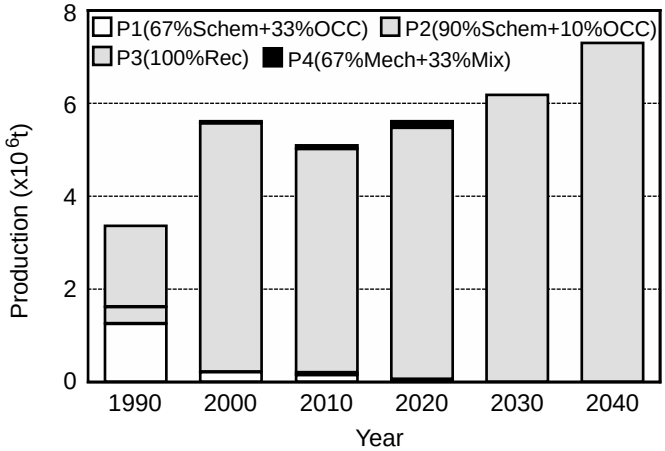

Figure 67—Corrugating medium production in U.S. North.

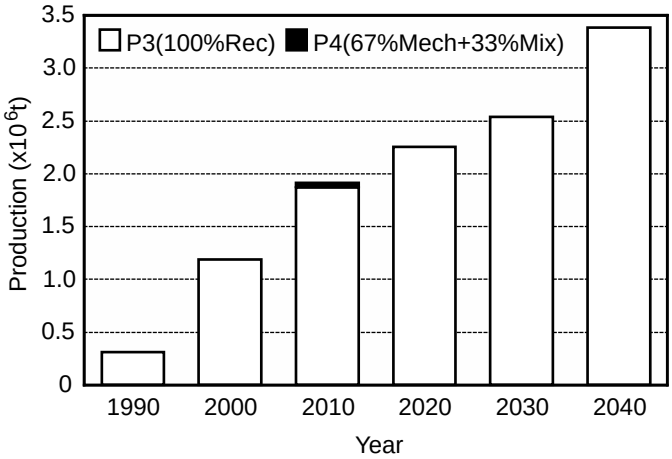

Figure 68—Corrugating medium production in U.S. West.

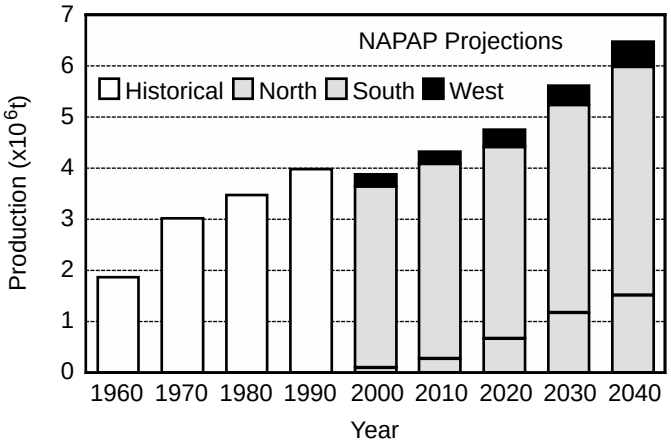

Figure 69—U.S. solid bleached board production.

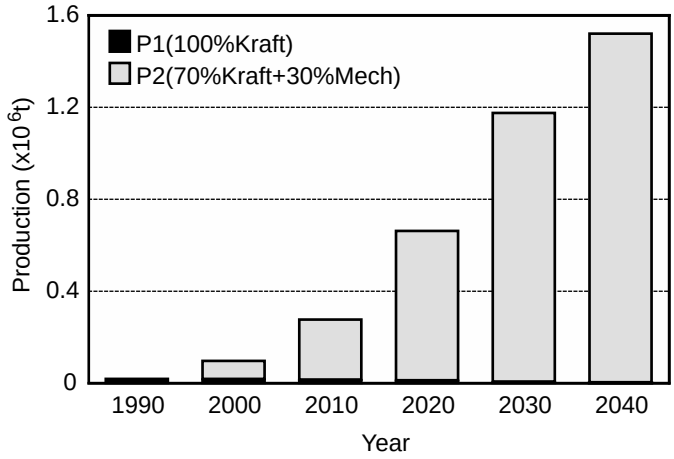

Figure 70—Solid bleached board production in U.S. North.

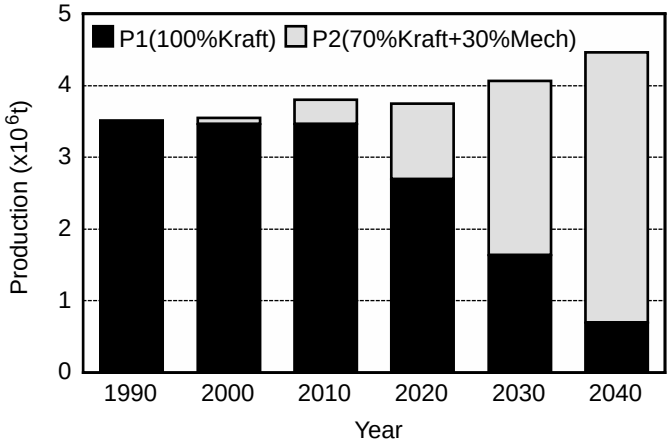

Figure 71—Solid bleached board production in U.S. South.

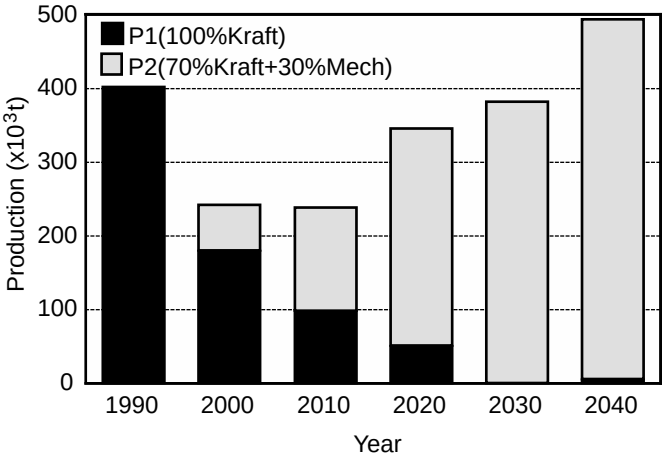

Figure 72—Solid bleached board production in U.S. West.

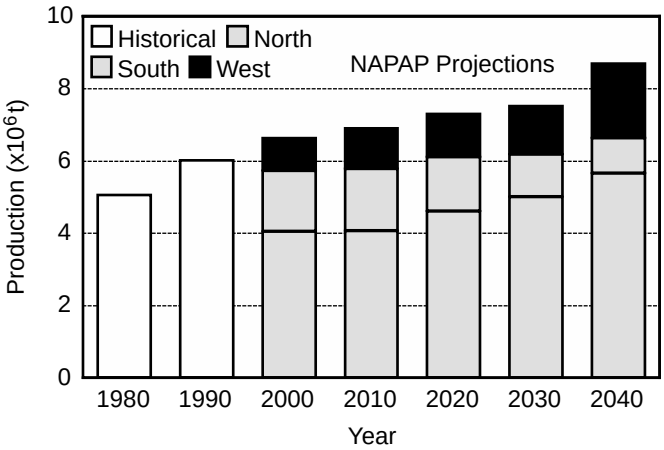

Figure 73—U.S. recycled board production.

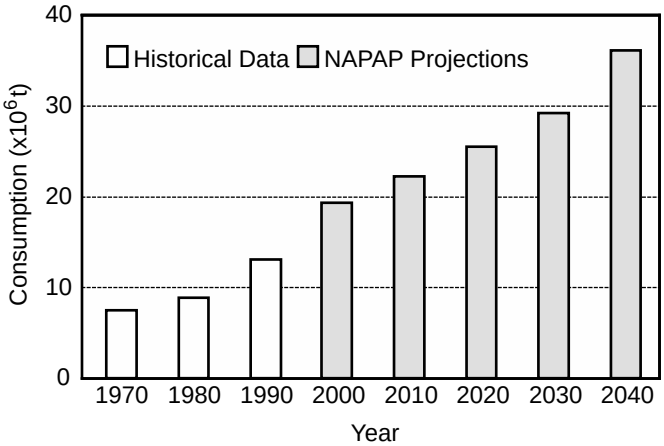

Figure 74—Recovered paper consumption in U.S. paperboard production.

Figure 73 illustrates projected recycled board production in the United States, by region. As defined in the NAPAP Model, recycled board excludes recycled linerboard and recycled corrugating medium. The NAPAP Model projections indicated that production of recycled board would increase by over 40 percent between 1990 and 2040, with the North maintaining the largest share of total U.S. production (Fig. 73). Production in the South was projected to gradually decline, while production in the West was projected to increase.

Consumption of recovered (recycled) paper in paperboard was projected to increase steadily throughout the projection period (Fig. 74). The overall utilization rate for recovered paper in U.S. paperboard production (tonnes of recovered paper consumed per tonne of paperboard output) was projected to increase from approximately 30 percent in the late 1980s to nearly 50 percent in the early part of the 21st century and 55 percent by the year 2040.

With projected increased use of recycled fiber and higher yield pulp in U.S. linerboard production, total pulpwood consumption in linerboard was projected to increase very gradually in the decades ahead (Fig. 75), with roughly a 25-percent projected increase between 1990 and 2020. Pulpwood consumption in linerboard was projected to gradually decline toward the end of the projection period. Softwood pulpwood consumption in U.S. linerboard production was projected to remain relatively constant to the year 2010, but then gradually decline. Whereas softwood pulpwood represented more than 90 percent of pulpwood consumed in U.S. linerboard production in 1990, the softwood share was projected to decline to roughly half by the end of the projection period. The decline in the softwood component reflects projected technological advances in linerboard production along with adoption of corrugated box performance standards based on compression strength, which will favor greater use of hardwood.

With very substantial projected increases in recycled fiber use in corrugating medium (Figs. 67–68), total pulpwood consumption in corrugating medium was projected to decline substantially in the decades ahead (Fig. 76). Eventually, recycled fiber (mainly OCC) was projected to become the primary source of fiber in U.S. corrugating medium production, similar to corrugating medium production in Europe and elsewhere.

Pulpwood consumption in U.S. solid bleached board production was projected to generally increase over the projection period (Fig. 77), although pulpwood consumption and production of solid bleached board were both projected to remain relatively constant for the next two decades.

Construction Paper & Board Production

Figure 78 illustrates NAPAP Model projections of U.S. construction paper & board production, by region. The South was projected to remain the dominant region for production of construction paper & board throughout the projection period. Production of construction paper & board in the United States was projected to gradually decline, in line with projected declines in consumption of this product (Fig. 22).

Pulpwood consumption in U.S. construction paper & board production was likewise projected to gradually decline over the projection period (Fig. 79). Variation in pulpwood consumption projections between 1990 and 2000 was due to projected shifting of production from the South (with higher density pulpwood species) to the North (with lower density species).

Market Pulp

Generally, production of bleached softwood chemical market pulp was projected to decline in both the South and West (Fig. 80); the estimate for 1990 was based on an assumption of 3 million metric tonnes total production—the actual production was probably somewhat higher. The South was projected to remain the dominant region in the United States for production of virgin-fiber bleached softwood market pulp. The projected decline in production of softwood market pulp reflects increased projected use of recycled fiber in paper products, which have traditionally depended on market pulp. Production of bleached hardwood chemical market pulp was projected to more than double between 1990 and 2040, with production volume in the North projected to gradually reach levels in excess of production volume in the South (Fig. 81). Most of projected increases in domestic production were for export.

A very substantial increase was projected for production of recycled market pulp, with very substantial volumes projected for export (Fig. 82). Projections indicated that production of recycled market pulp would expand in all regions, but primarily in the South. In the NAPAP Model, it was assumed that recycled market pulp (made from high-grade deinking and pulp substitutes) could be substituted for bleached hardwood or softwood chemical market pulp with appropriate discounts (added costs for the recycled market pulp substitute). Discounts were set at $55 per tonne to substitute for softwood chemical market pulp, and $25 per tonne to substitute for hardwood chemical market pulp (discounts were based on recently reported price differentials between virgin-fiber chemical grade market pulps and recycled market pulp in the United States; Miller Freeman 1992). Figure 83 illustrates projected U.S. production of dissolving & special alpha pulp, by region. Projections indicated that production in the South would increase, but generally U.S. production was projected to decline throughout most of the projection period.

Following the projected trend in production of recycled market pulp (Fig. 82), a very substantial increase was projected in consumption of recovered paper for market pulp

production in the United States (Fig. 84). Projections indicated that pulpwood consumption in market pulp (including virgin-fiber chemical grade market pulp, mechanical market pulp, and dissolving & special alpha pulp) would remain relatively constant throughout the projection period; the softwood pulpwood component was projected to decline from around 60 percent in 1990 to roughly 20 percent by 2040 (Fig 85).

U.S. Trade Flow Projections

This section describes NAPAP projections of U.S. exports and imports of principal trade commodities, along with recent historical trends. Commodity exports and imports to overseas regions other than Canada are shown in Figures 86-100 and Figures 101-110, respectively. Projected imports from Canada and exports to Canada of pulp, paper, and paperboard commodities are shown in Figures 111 and 112, respectively.

Overseas exports of newsprint and printing & writing grades were projected to increase, among those grades, newsprint was projected to remain the dominant overseas export commodity (Figs. 86 to 91). Linerboard and solid bleached board overseas exports were also projected to increase substantially (Figs. 92 and 93). Note that total U.S. linerboard exports were projected to reach nearly 7 million metric tonnes per year toward the end of the projection period, a level nearly half of current total U.S. domestic linerboard consumption. Projected growth in exports to the Pacific Rim accounted for the largest share of projected export growth for all paper and paperboard commodities.

Overseas exports of market pulp were projected to increase very substantially (Figs. 94 and 95). However, NAPAP Model projections of softwood market pulp exports (Fig. 94) included an increasing share of recycled market pulp (which substitutes for a large share of bleached softwood market pulp by the end of the projection period). Exports of dissolving & special alpha pulp were projected to gradually decline throughout the projection period (Fig. 96).

Exports of recovered paper were generally projected to increase for most commodity categories, in line with historical trends. Total exports of old newspapers (ONP) were projected to increase during the 1990s (Fig. 97) and then gradually decline toward the year 2000 and into the next century, as U.S. domestic and consumption of ONP were projected to increase substantially. In the long run, however, overseas exports of ONP were projected to more than double by the end of the projection period. Total exports of old corrugated containers (OCC) were projected to steadily increase throughout the projection period (Fig. 98), with more than a doubling in exports projected between 1990 and 2040. Total exports of mixed recovered papers were projected to increase substantially until around the year 2000 (Fig. 99), but then were projected to decline as domestic consumption of mixed papers increased. Total exports of pulp substitutes and high-grade deinking were projected to increase substantially throughout the projection period (Fig. 100), with nearly a threefold increase projected between 1990 and 2040.

The U.S. imports of all principal import commodities were projected to remain flat throughout the projection period, after initial modest projected increases (see Figs. 101 to 110). The flat U.S. import trend was not artificially imposed on the NAPAP Model; it reflects the relative economic abundance of fiber products in North America with increased recycling and the capability to satisfy demands with domestic production.

The U.S. imports of pulp, paper, and paperboard commodities from Canada were projected to gradually decline throughout the projection period (Fig. 111). Newsprint and printing & writing paper were projected to remain the principal U.S. import commodities from Canada. Newsprint imports from Canada were projected to gradually decline, as U.S. production of newsprint was projected to increase along with increased recycling. Newsprint imports from Canada were projected to decline from the 1992 level of approximately 6.5 million metric tonnes to approximately 5 million metric tonnes in 2040. Market pulp imports from Canada were also projected to decline, as U.S. consumption of virgin-fiber market pulp was projected to decline along with increased recycling.

The U.S. exports of paper and paperboard end-products to Canada were projected to gradually decline for several decades, and then increase toward the end of the projection period (Fig. 112). On the other hand, Canadian imports of recovered paper from the United States were projected to increase steadily throughout the projection period, from approximately 0.7 million metric tonnes in 1992 to nearly 3 million metric tonnes per year by 2040 (Fig. 112).

Projected Paper Recycling Rates

Figure 113 illustrates trends in the recyclable paper utilization rate of the United States, including historical trends from 1970 to 1990 (API 1970–1991), and NAPAP Model projections of the trend from 2000 to 2040. The utilization rate is a percentage ratio, calculated as the tonnage of recovered paper (i.e., recycled paper) consumed in U.S. paper and board production, divided by the tonnage of paper and board produced in the United States (paper and board includes all paper and paperboard commodities, and construction paper and board). Thus, the utilization rate is a measure of the actual “rate of recycling” in the domestic paper and paperboard industry. The NAPAP Model accurately tracked the historical utilization rate from the base year 1986 to 1992. During that period, there was a very substantial increase in the rate of recycling in the United States, as measured by the utilization rate.

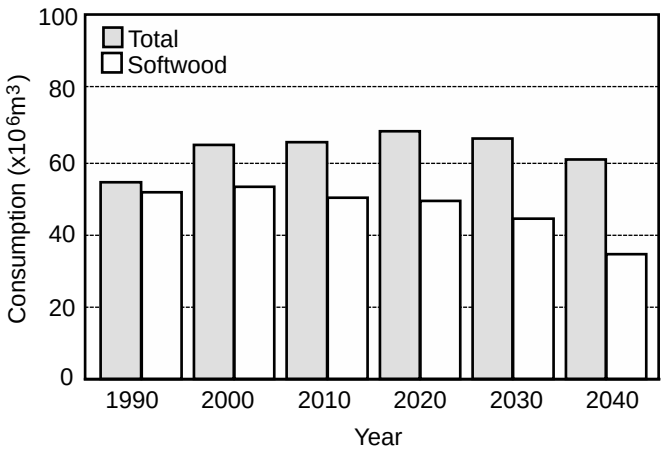

Figure 75—Pulpwood consumption in U.S. linerboard production.

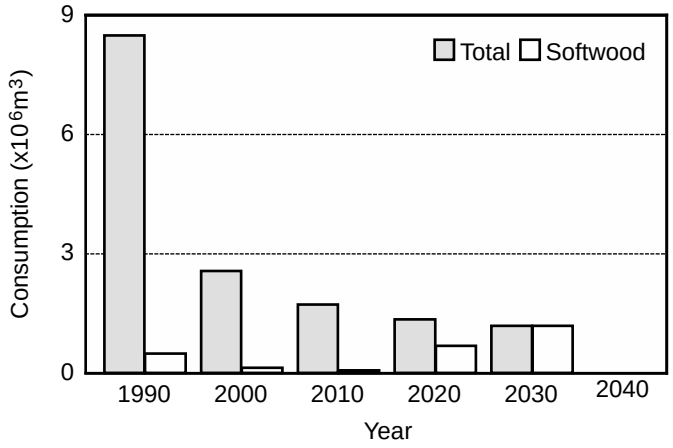

Figure 76—Pulpwood consumption in U.S. corrugating medium production.

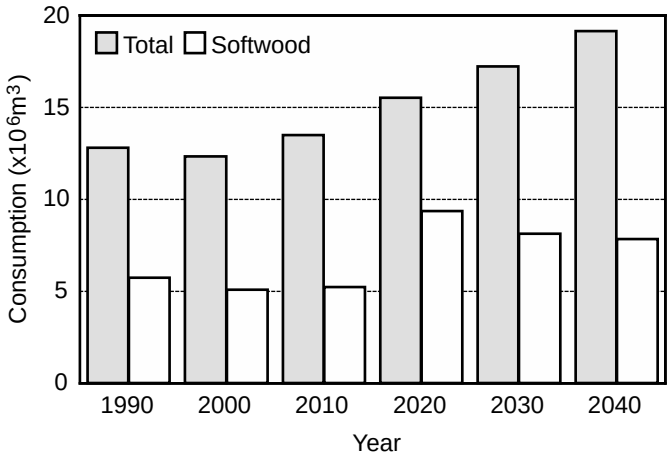

Figure 77—Pulpwood consumption in U.S. solid bleached board production.

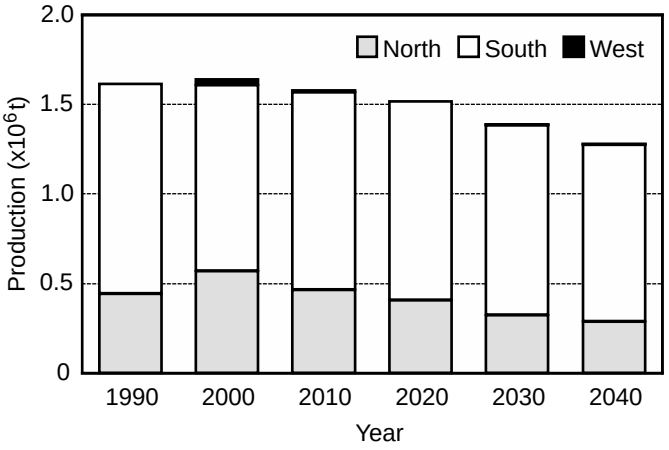

Figure 78—U.S. construction paper & board production.

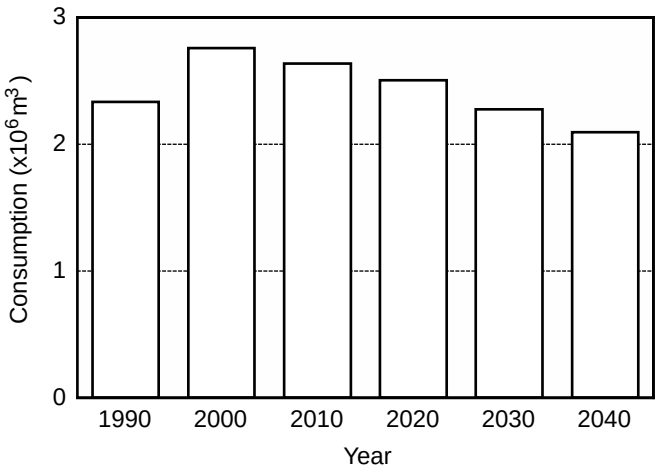

Figure 79—Pulpwood consumption in U.S. construction paper & board production.

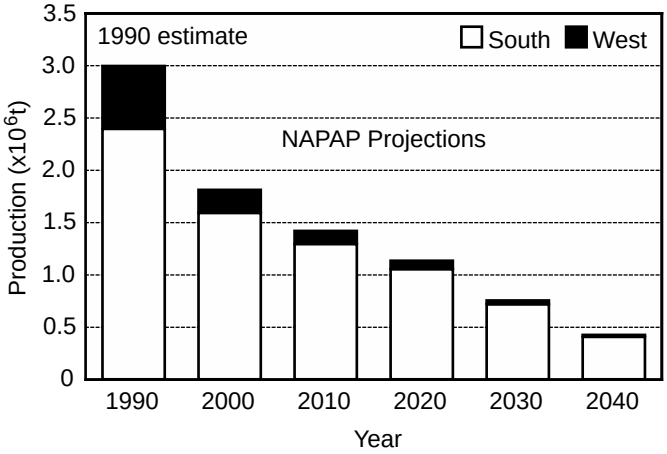

Figure 80—U.S. production of softwood chemical market pulp, by region.

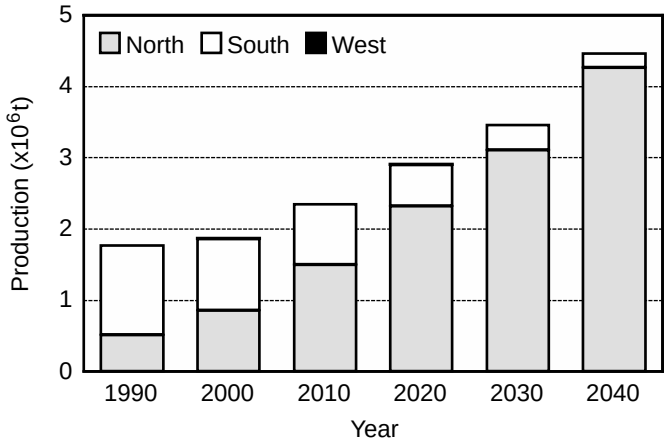

Figure 81—U.S. production of hardwood chemical market pulp, by region.

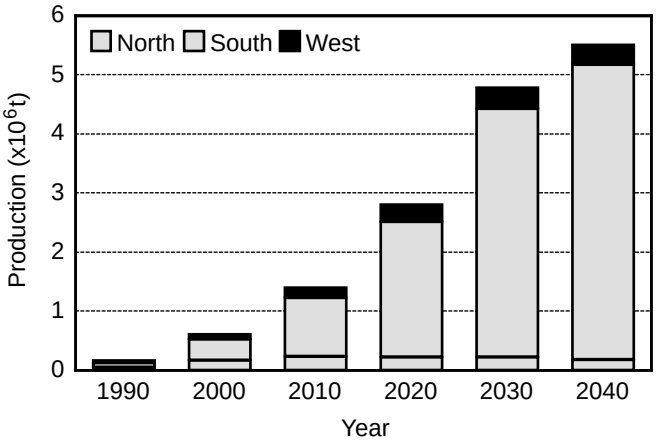

Figure 82—U.S. production of market pulp from recycled fiber, by region.

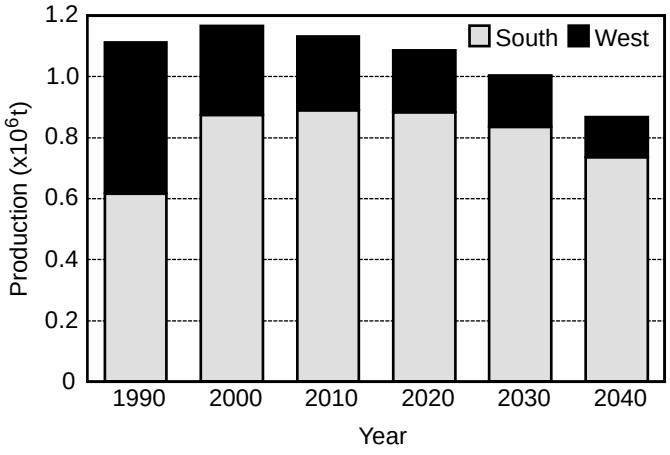

Figure 83—U.S. dissolving & special alpha pulp production, by region.

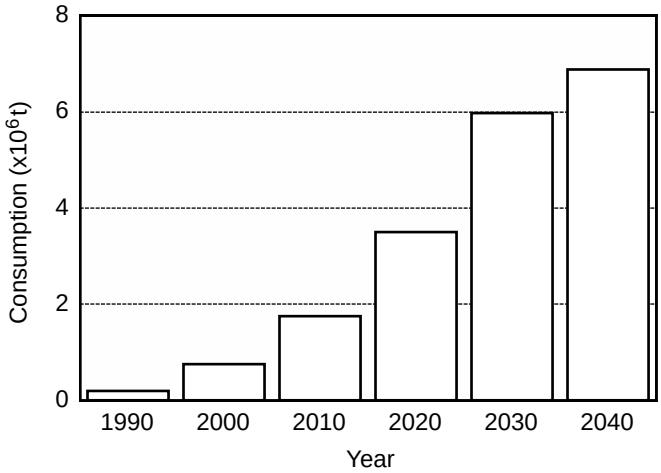

Figure 84—Recovered paper consumption in U.S. market pulp production.

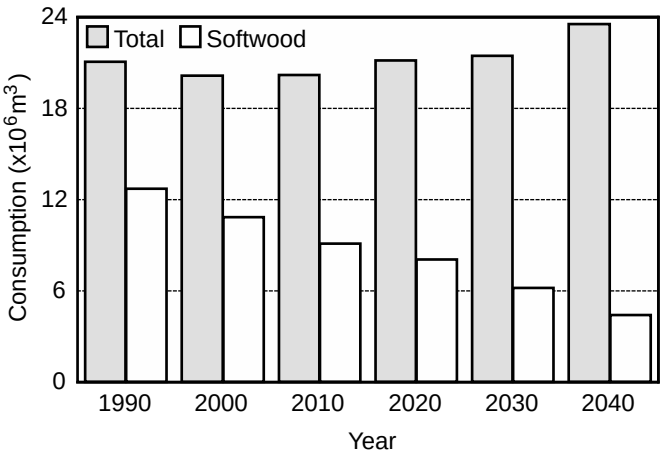

Figure 85—Pulpwood consumption in U.S. market pulp production.

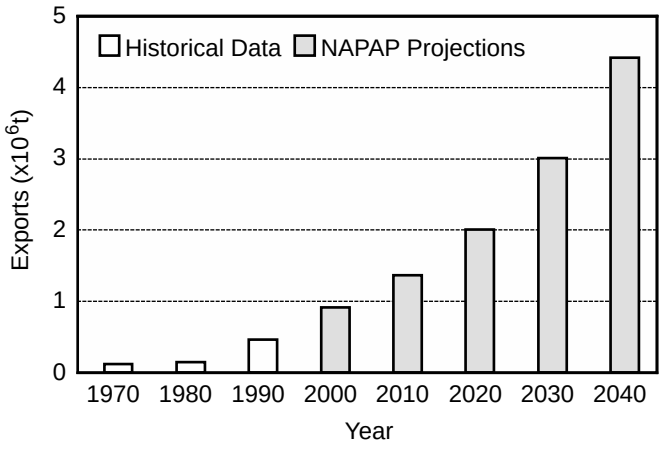

Figure 86—U.S. exports of newsprint, excluding exports to Canada.

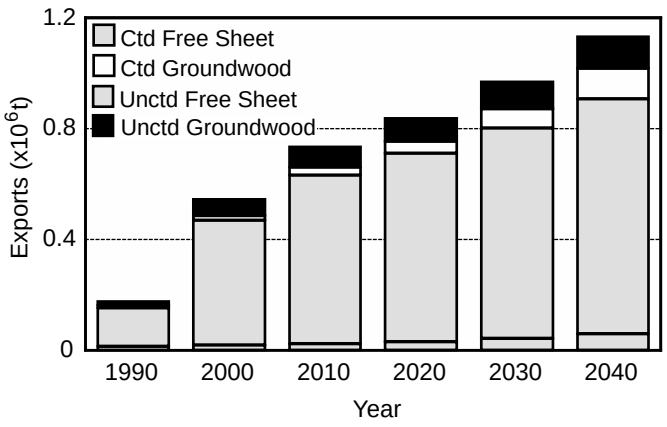

Figure 87—U.S. exports of printing & writing paper, excluding exports to Canada.

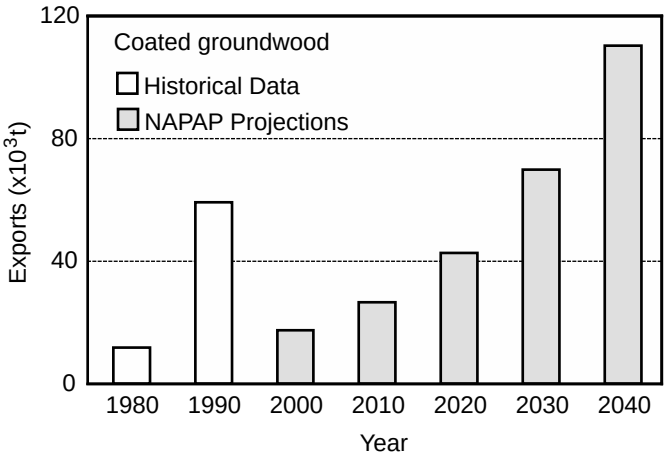

Figure 90—U.S. exports of coated groundwood paper, excluding exports to Canada.

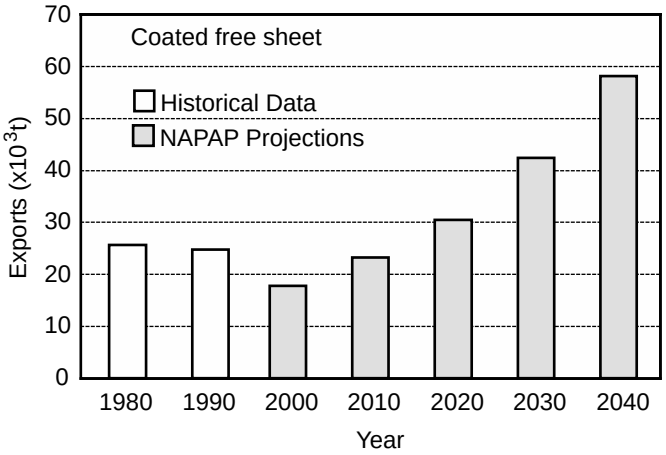

Figure 88—U.S. exports of coated free sheet paper, excluding exports to Canada.

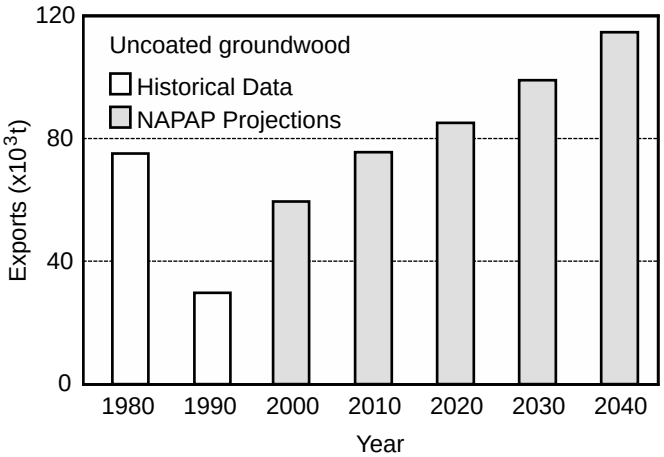

Figure 91—U.S. exports of uncoated groundwood paper, excluding exports to Canada.

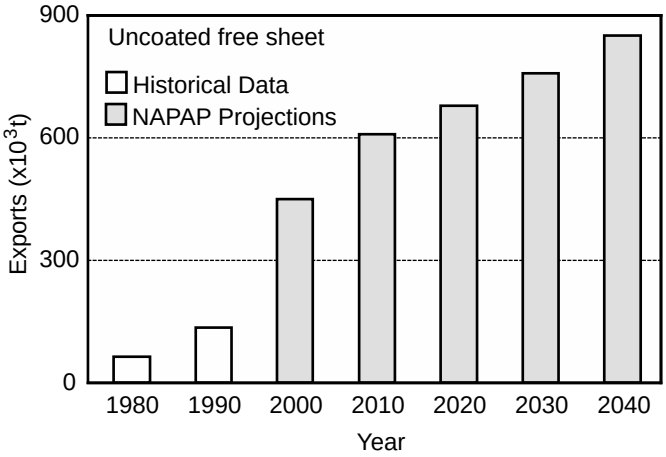

Figure 89—U.S. exports of uncoated free sheet paper, excluding exports to Canada.

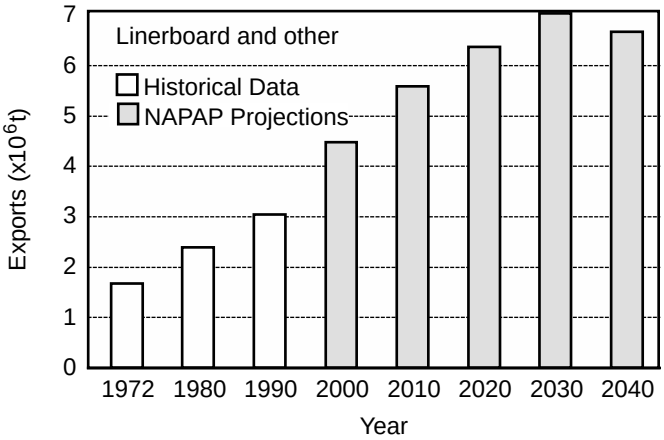

Figure 92—U.S. exports of linerboard & other commodities, excluding exports to Canada.

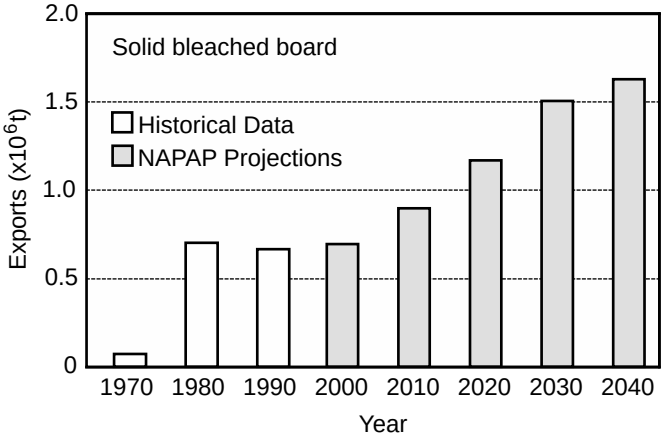

Figure 93—U.S. exports of solid bleached board, excluding exports to Canada.

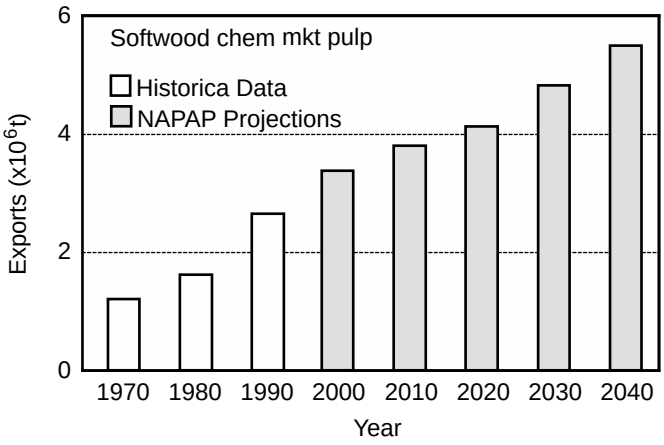

Figure 94—U.S. exports of softwood chemical market pulp, excluding exports to Canada.

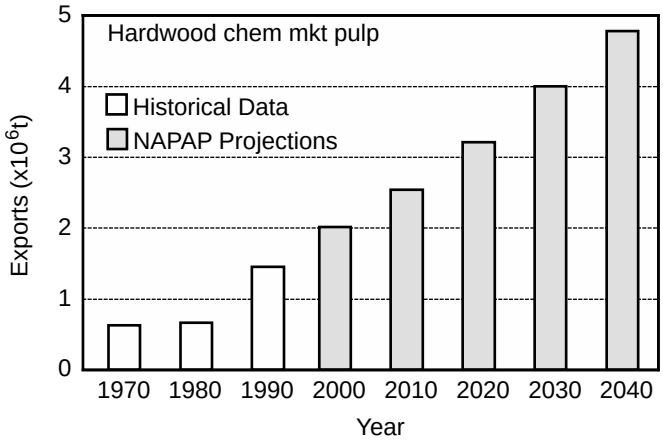

Figure 95—U.S. exports of hardwood chemical market pulp, excluding exports to Canada.

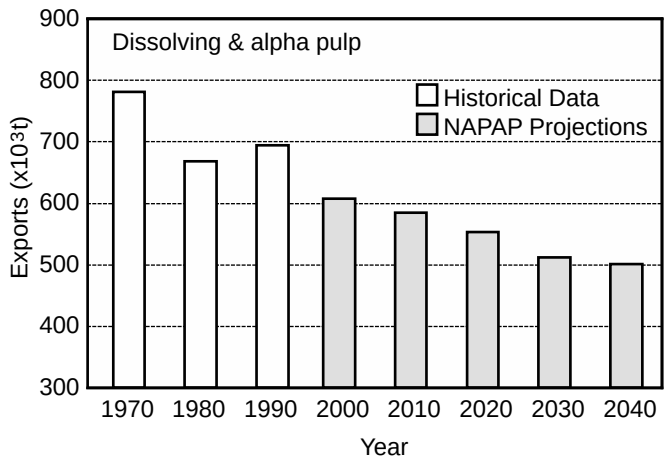

Figure 96—U.S. exports of dissolving & special alpha pulp, excluding exports to Canada.

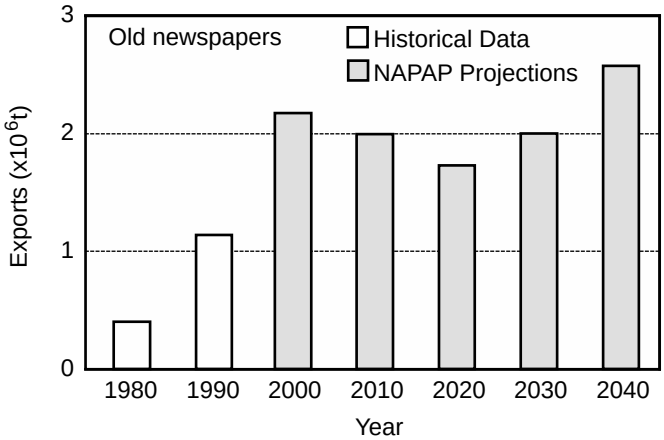

Figure 97—U.S. exports of old newspapers including exports to Canada.

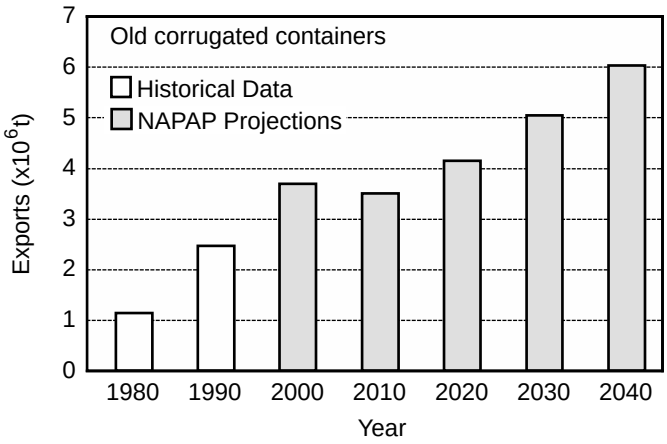

Figure 98—U.S. exports of old corrugated containers, including exports to Canada.

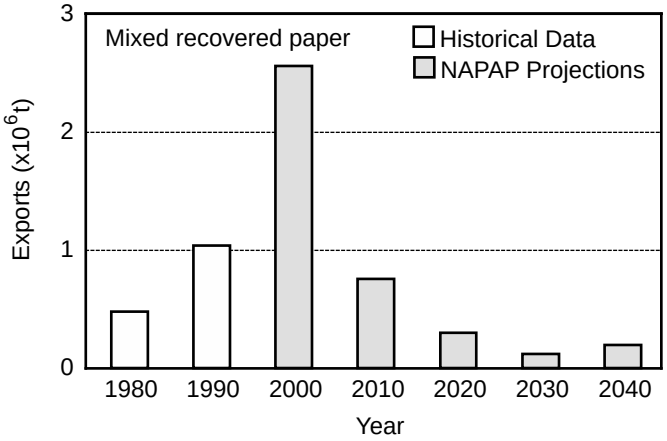

Figure 99—U.S. exports of mixed recovered paper, including exports to Canada.

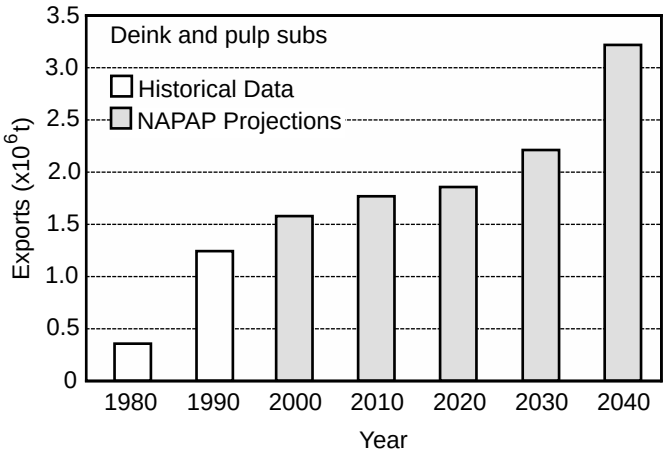

Figure 100—U.S. exports of high-grade deinking & pulp substitutes, including exports to Canada.

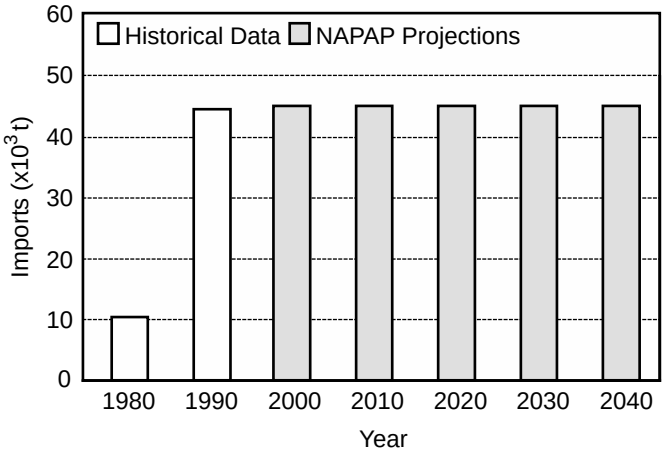

Figure 101—U.S. imports of softwood chemical market pulp from Latin America.

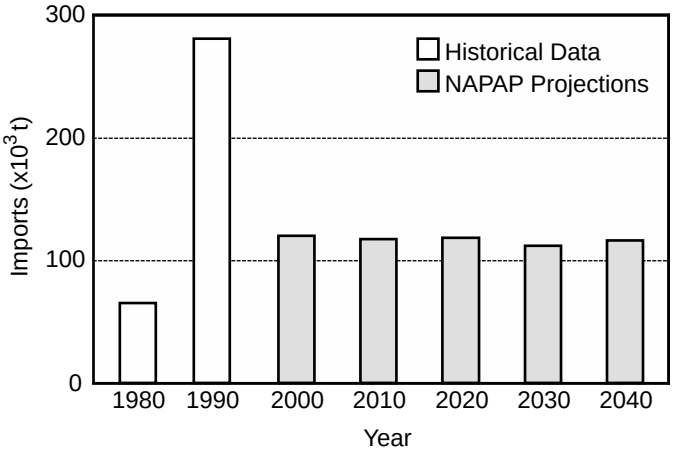

Figure 102—U.S. imports of hardwood chemical market pulp from Latin America.

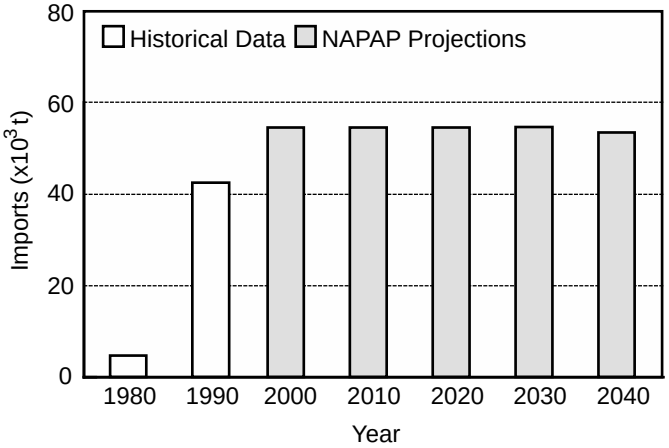

Figure 103—U.S. imports of softwood chemical market pulp from Europe.

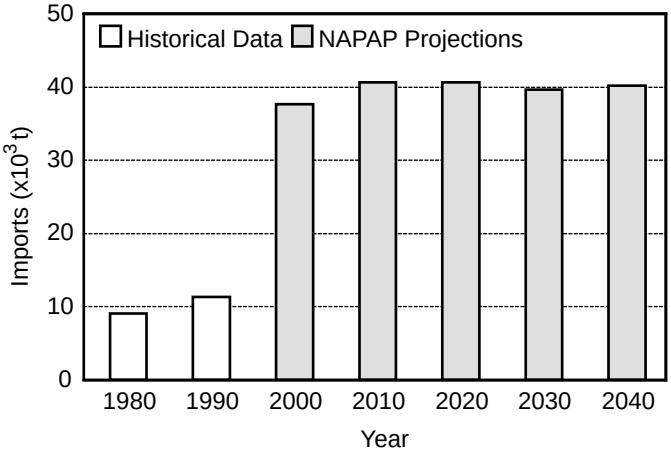

Figure 104—U.S. imports of hardwood chemical pulp from Europe.

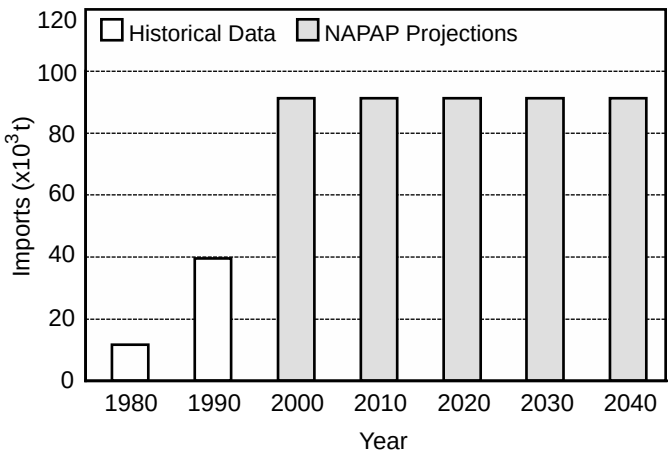

Figure 105—U.S. imports of uncoated free sheet from Latin America.

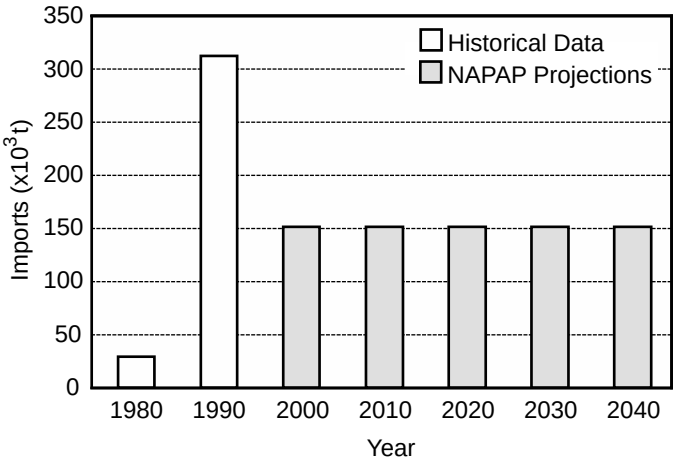

Figure 106—U.S. imports of coated groundwood paper from Europe.

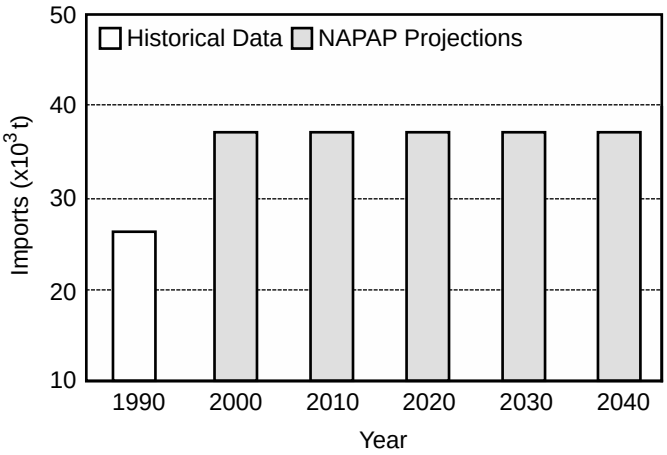

Figure 107—U.S. imports of coated free sheet from Pacific Rim.

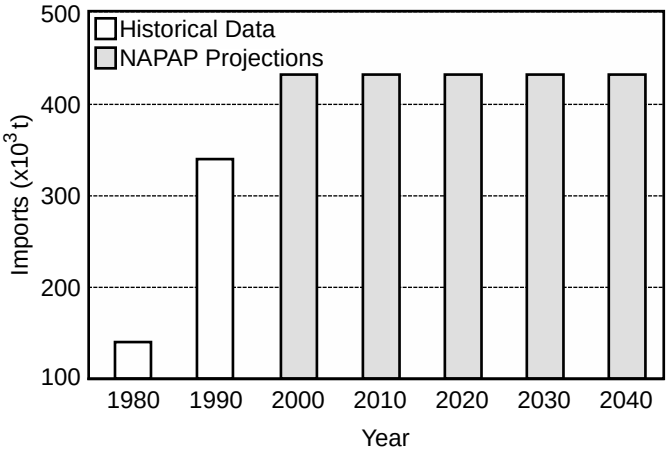

Figure 108—U.S. imports of uncoated groundwood paper from Europe.

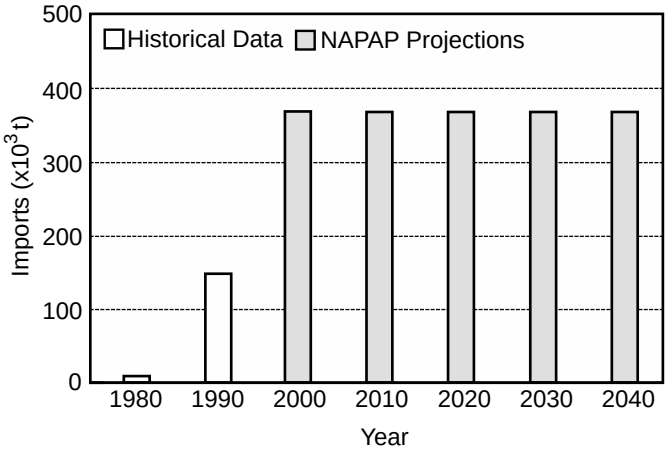

Figure 109—U.S. imports of coated free sheet from Europe.

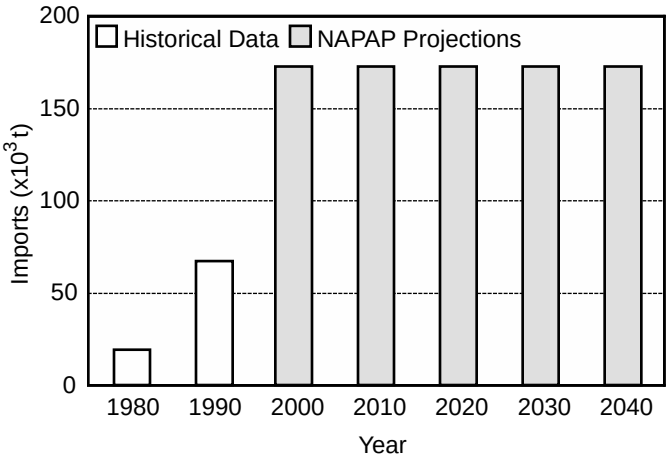

Figure 110—U.S. imports of uncoated free sheet from Europe.

Historically, the utilization rate had remained relatively stable at around 23 to 24 percent between 1970 and 1985. By 1991, the utilization rate had increased to 29 percent and continued to increase at a rapid pace. The NAPAP Model projected that the utilization rate would continue to increase through the 1990s and into the early part of the next century, eventually reaching more than 45 percent by the end of the projection period. As shown in Figure 113, the projections indicate that growth in the utilization rate would be quite rapid over the next decade, but would proceed more slowly in the next century. As discussed below, the NAPAP Model projected that recovered paper prices would rise substantially in the latter part of the 1990s, overcoming the current market glut situation. Thus, growth in the recycling rate was projected to be gradually dampened by increased prices and by physical limits on supply as upper limits on recovery were approached in the next century. It can be noted also that pulpwood supplies were projected to be relatively more abundant by the end of the projection period, enabling greater proportional use of pulpwood during that period. Nevertheless, projections indicated that the utilization rate would continue to gradually increase throughout the projection period, reaching approximately 48 percent by the year 2040. Thus, the projections indicated that the United States would eventually approach domestic paper recycling rates that would rival recycling rates achieved in other industrialized countries (e.g., currently in the vicinity of 50 percent in Germany and Japan.

Historical trends in the recyclable paper recovery rate of the United States from 1970 to 1990 (API) and NAPAP Model projections of the trend from 2000 to 2040 are shown in Figure 114. The recovery rate is a percentage ratio, calculated as the total tonnage of recyclable paper (ONP, OCC, mixed papers, and pulp substitutes & high-grade deinking) that is recovered for domestic use and for export (for recycling), divided by the total domestic consumption of paper and board products in the United States. Thus, the recovery rate measures how much paper and board is actually recovered for recycling (including export), relative to domestic paper and board consumption. The NAPAP Model accurately tracked the historical recovery rate from the base year 1986 to 1992. As with the utilization rate, there was a very substantial increase in the recovery rate between 1986 and 1992. Historically, between 1970 and 1985, the recovery rate had been increasing gradually as a result of increasing exports (whereas the domestic utilization rate had remained stable during the same period). Total U.S. supply of recovered paper more than doubled from 11.1 million metric tonnes in 1970 to 22.4 million metric tonnes in 1991 (API 1992). Increases in the recovery rate between 1970 and 1985 were primarily due to substantial increases in U.S. exports of recovered paper (exports increased from less than 0.4 million metric tonnes in 1970 to 6.0 million metric tonnes in 1991; API 1992). The recovery rate increased from around 28 percent in 1986 to nearly 37 percent in 1991, and was continuing to increase at a rapid pace (API 1992). The NAPAP Model projected that the recovery rate would continue to increase throughout the projection period, although growth was projected to gradually subside to a slower pace in the next century. The recovery rate was projected to exceed 40 percent by 1995 and to reach 49 percent around the year 2000 (Fig. 114). Beyond the year 2000, the recovery rate was projected to increase more gradually to a level of just under 60 percent by the year 2040. Exports of recovered paper were projected to increase, and recovered paper prices were projected to reach generally higher levels, resulting in projected steady growth in recovered paper supply and the recovery rate.

Projected Supply and Price Trends

The following text describes historical trends and NAPAP Model projections for supply and real prices of pulpwood and recovered paper, gross wastepaper disposal burden, roundwood and residue pulpwood supply, and sawtimber stumpage prices.

Pulpwood Supply

Figure 115 illustrates total pulpwood supply of the United States (total quantity of pulpwood consumed domestically in pulp, paper, and paperboard production, plus export quantity, including roundwood and residues). The NAPAP Model projections indicated that total pulpwood supply would increase in the decades ahead, rising from roughly 200 million cubic meters in 1990 to nearly 300 million cubic meters in 2040. However, as the domestic rate of recycling was projected to increase, and as other ongoing technological changes were projected to occur, softwood pulpwood supply was projected to reach a relatively stable plateau by the 1990s. Projections indicated that total softwood pulpwood supply would remain in the vicinity of 130 million cubic meters per year for the next couple of decades, and then increase gradually toward the end of the projection period. Projections indicated that hardwood pulpwood supply would increase, particularly in the next several decades, but that hardwood pulpwood supply would not increase substantially beyond the year 2010. Constraints on hardwood pulpwood supply were projected to occur in the South beyond the year 2010 due to projected declines in hardwood timber inventory. The projected near-term increase in the hardwood component of total pulpwood supply represents a continuation of a long-term historical trend in the United States (Fig. 115). Technologically, commodities that have been produced mainly from softwood pulpwood (e.g., linerboard) were projected to use more hardwood fiber and recycled fiber.

Trends in total pulpwood supply of the U.S. North, South, and West are shown in Figures 116–118. The charts include total volumes of roundwood and residues delivered to mills for domestic consumption, and quantities supplied for export. In the North (Fig. 116), projections indicated a general continuation of historical trends in pulpwood supply,

with projected increases in both softwood and hardwood pulpwood supply. Likewise, in the South (Fig. 117), projections indicated a continuation of historical growth trends for at least the next couple of decades, although growth in hardwood pulpwood supply was projected to be constrained beyond the year 2010. Softwood pulpwood supply was projected to increase beyond the year 2010, a period that will coincide with maturation of extensive pine plantations now being established in the South. In the West (Fig. 118), beginning around 1990, pulpwood supply was projected to decline for the next several decades, reaching a stable level just over 20 million cubic meters per year beyond the year 2010. The decline in projected pulpwood supply is associated with projected declines in National Forest timber harvest levels (discussed below) and corresponding reductions in volumes of sawmill and plywood mill residues for pulpwood in the West.

Recovered Paper Supply

Figure 119 illustrates trends in total recovered paper supply of the United States (i.e., total quantity consumed in domestic pulp, paper, and paperboard production, plus export quantity). The supply of all four categories of recovered paper (ONP, OCC, mixed recovered papers, and pulp substitutes & high-grade deinking [DPS]) has been increasing historically; the NAPAP Model projected substantial future increases in supply, in line with historical trends. Projections indicated a very rapid continued increase in supply from the late 1980s into the 1990s, until projected increases in recovered paper prices dampen domestic demand in the late 1990s. After rapidly increasing up to the year 2000, recovered paper supply was projected to increase at a more gradual pace in the early part of the next century and then to increase substantially again toward the end of the projection period when pulpwood prices were projected to increase. Thus, by the year 2040, total U.S. recovered paper supply was projected to exceed 80 million metric tonnes per year (at a recovery rate of nearly 60 percent; see Fig. 114). As has been the case historically, the largest element of U.S. recovered paper supply will continue to be OCC.

Figure 120 shows trends in U.S. domestic consumption and exports of recovered paper. In line with historical trends, projections indicated that exports would account for a growing share of total U.S. recovered paper supply, particularly in the 1990s, when U.S. recovered paper prices were projected to remain depressed in the current market glut. Beyond 2000, however, exports of recovered paper were projected to recede somewhat as prices were projected to increase and exports were projected to face stronger competition from U.S. mills for recycled fiber. Domestic consumption was projected to continue to increase throughout the projection period.

Projected trends in domestic consumption of recovered paper were similar to projected trends in total U.S. supply; Figure 121 shows recovered paper trends by grade (compare Figs. 121 and 119). Projected trends in U.S. exports of recovered paper were also similar to projected trends in total U.S. supply (compare Figs. 122 and 119), except that exports of mixed paper were projected to decline in the next century due to increased prices and increased domestic consumption.

Projected trends in U.S. supply of each principal category of recovered paper by supply region are shown in Figures 123 to 126. The NAPAP Model projections tracked the historical total supply trends quite accurately over the 7-year historical period from 1986 to 1992. Projections indicated that supply would continue to increase for each principal commodity category, in line with recent historical trends; the U.S. North was generally projected to provide the largest regional share of total supply. The patterns of projected growth in recovered paper supply varied somewhat depending on commodity category. Supply of ONP was projected to increase rapidly in line with recent trends until the late 1990s, and then increase at a more modest pace into the next century (Fig. 123). Similar trends were projected for supply of mixed recovered paper (Fig. 125), but with less abrupt inflections in supply growth for OCC (Fig. 124) and pulp substitutes and high-grade deinking (Fig. 126).

Real Price Trends for Delivered Pulpwood

Real price trends for delivered pulpwood in U.S. manufacturing regions include hardwood and softwood delivered pulpwood prices in the U.S. North and South, and delivered softwood residue prices in the West. All prices were expressed in constant 1986 dollars per cubic meter of pulpwood.

In the North (Fig. 127), the projections indicated that the differential between softwood and hardwood delivered pulpwood prices would expand for the next two decades, and then gradually narrow beyond the year 2010 and for the remainder of the projection period, as hardwood pulpwood prices were projected to increase. In the South (Fig. 128), the projections indicated that the differential between softwood and hardwood delivered pulpwood prices would disappear by the year 2010, and that on a cubic meter basis, the price of delivered hardwood pulpwood would exceed the price of softwood beyond the year 2010. This projection was due to increased consumption of hardwood pulpwood and projected constraints on hardwood pulpwood supply in the South beyond the year 2010 due to projected declines in hardwood timber inventory in the South during that period. The projected relatively low price for softwood pulpwood in the South resulted in projected growth in Southern softwood pulpwood consumption (and supply) toward the end of the projection period (see Fig. 117).

In the West (Fig. 129), softwood pulpwood prices were projected to remain relatively stable, but the projected decline of pulpwood supply (Fig. 118) was associated with relatively small projected growth in paper and paperboard production in that region.

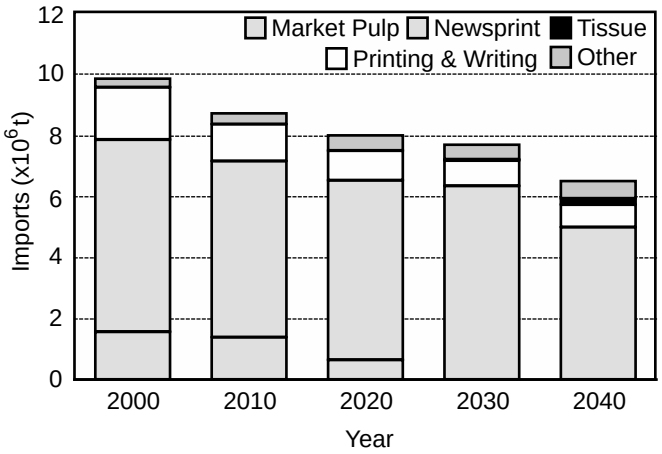

Figure 111—U.S. imports of pulp, paper, and paperboard from Canada.

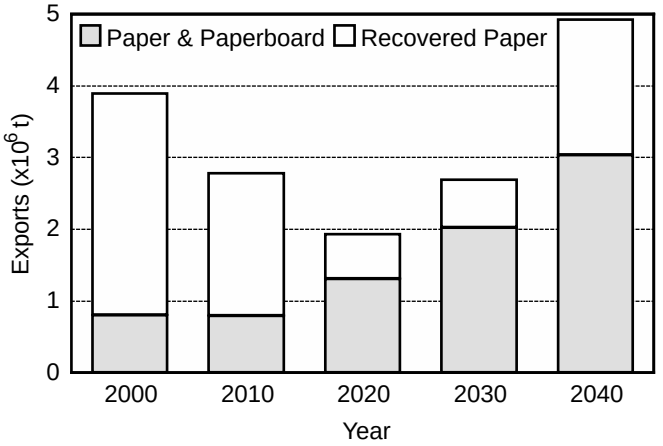

Figure 112—U.S. exports of paper and paperboard, including recovered paper, to Canada.

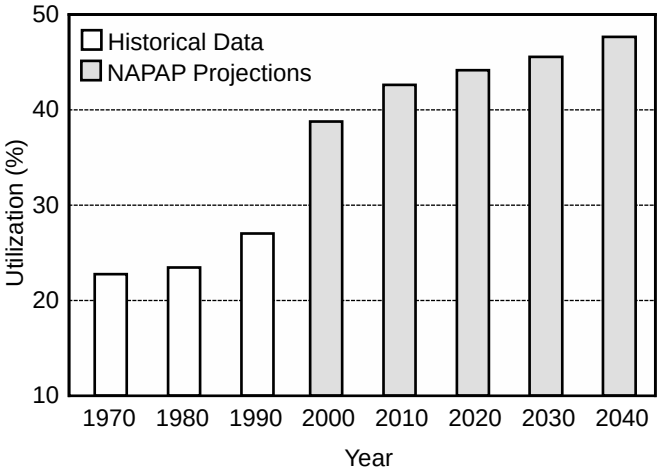

Figure 113—U.S. recyclable paper utilization rate.

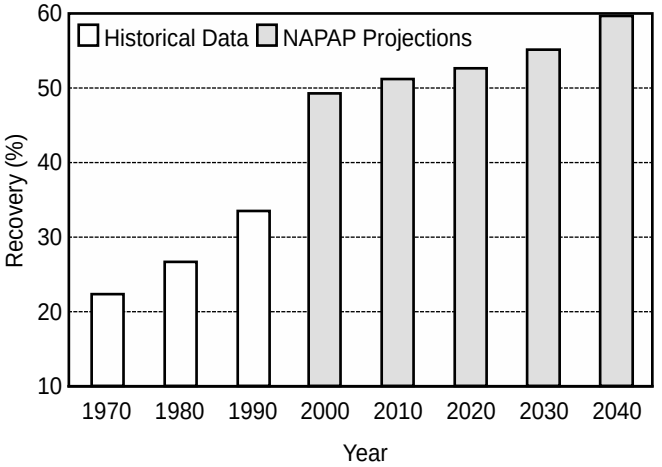

Figure 114—U.S. recyclable paper recovery rate.

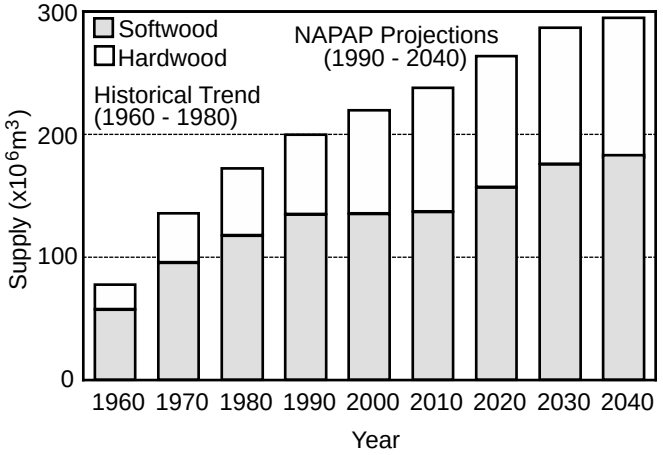

Figure 115—Total U.S. pulpwood supply, roundwood and residues.

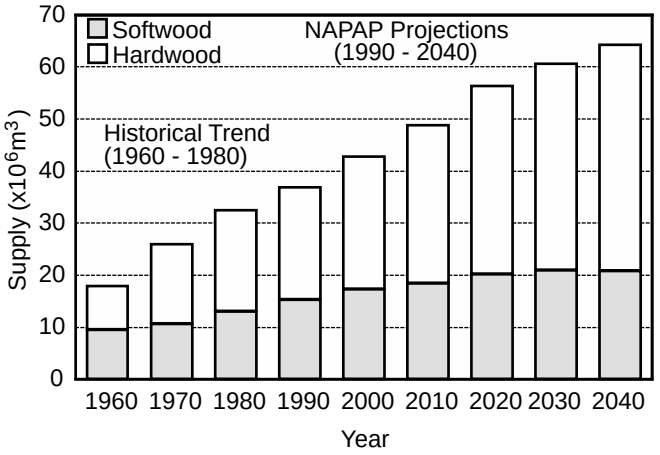

Figure 116—Total pulpwood supply of U.S. North.

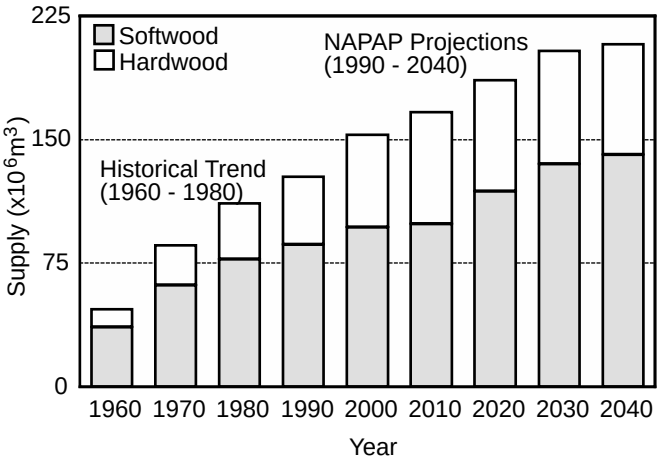

Figure 117—Total pulpwood supply of U.S. South.

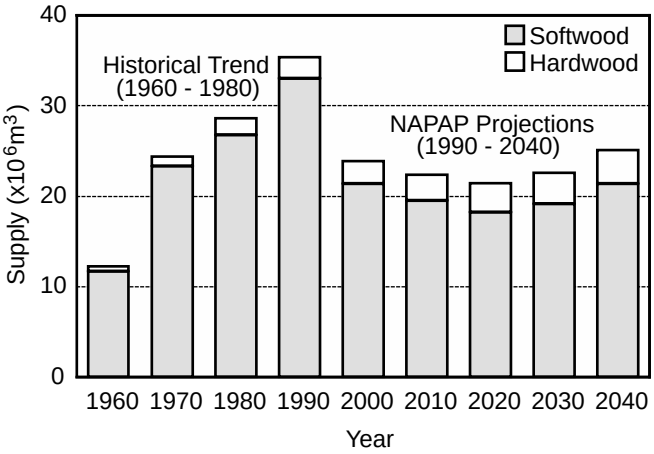

Figure 118—Total pulpwood supply of U.S. West.

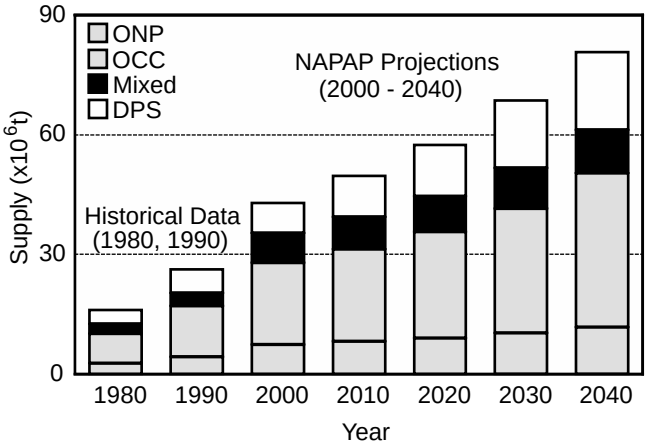

Figure 119—U.S. supply of recovered paper.

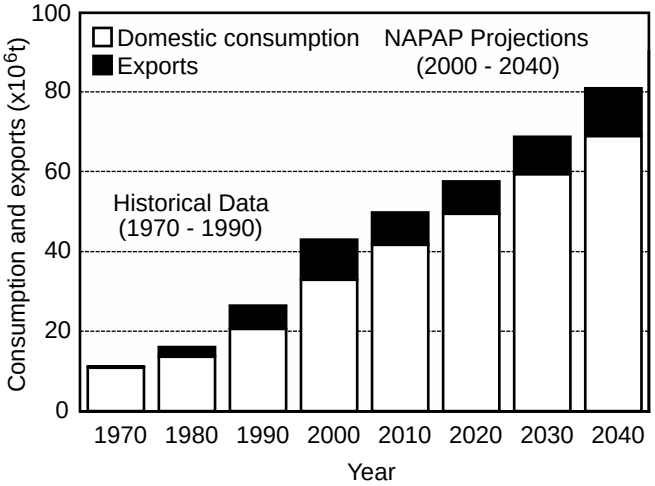

Figure 120—U.S. domestic consumption and exports of recovered paper.

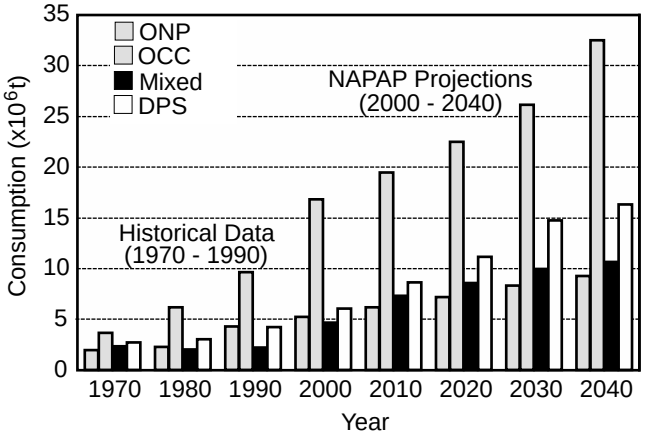

Figure 121—U.S. domestic consumption of recovered paper, by grade.

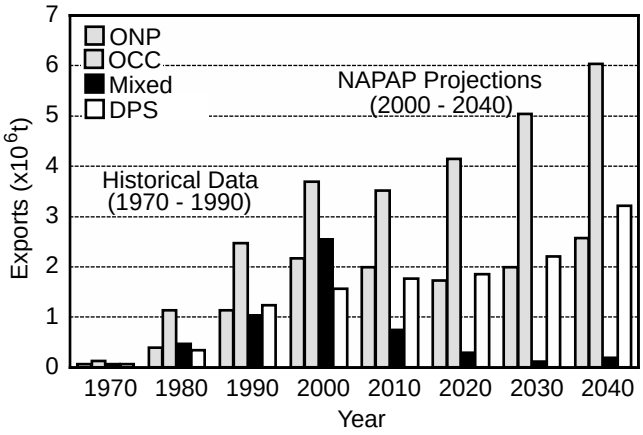

Figure 122—U.S. exports of recovered paper, by grade.

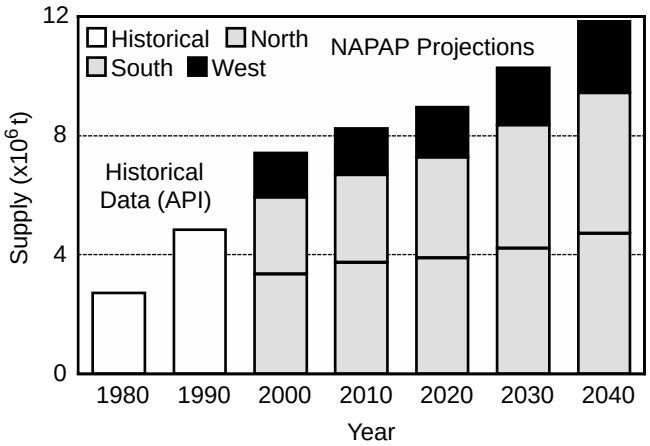

Figure 123—U.S. supply of old newspaper, by region.

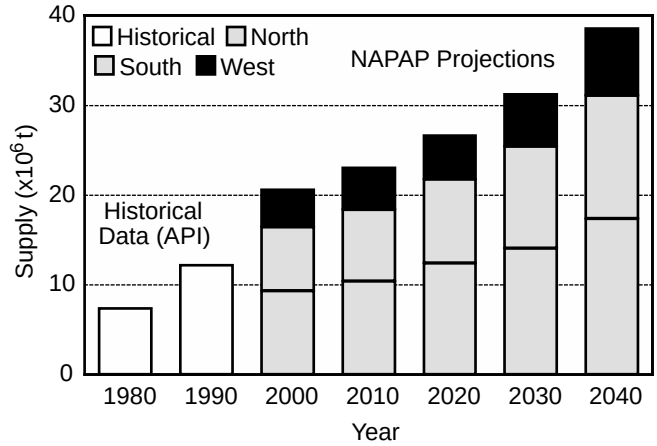

Figure 124—U.S. supply of old corrugated containers, by region.

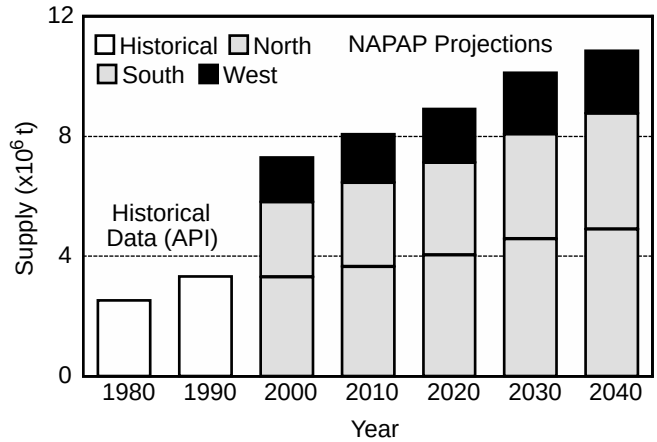

Figure 125—U.S. supply of mixed papers, by region.

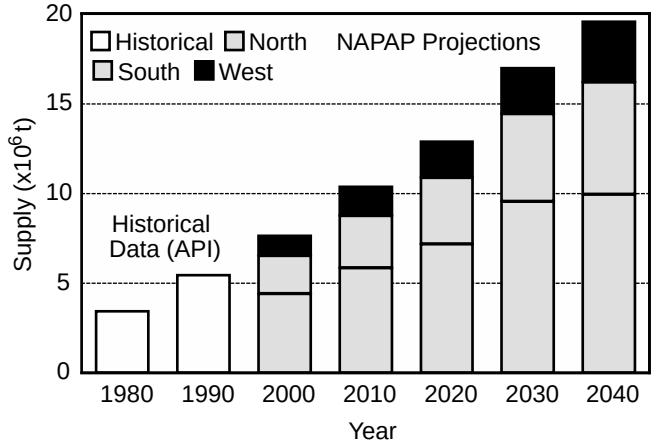

Figure 126—U.S. supply of high-grade deinking & pulp substitutes, by region.

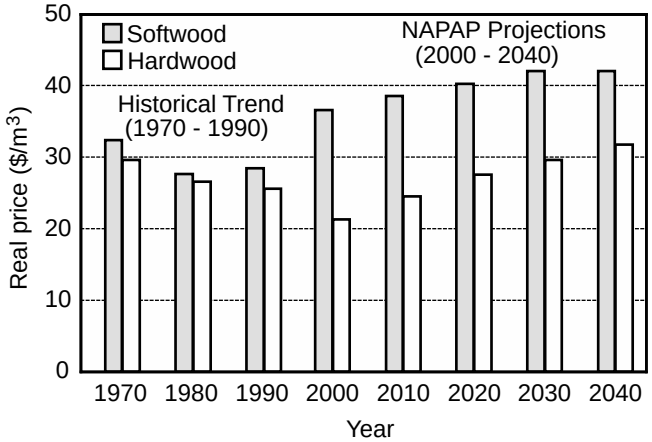

Figure 127—Real prices for pulpwood roundwood for U.S. North.

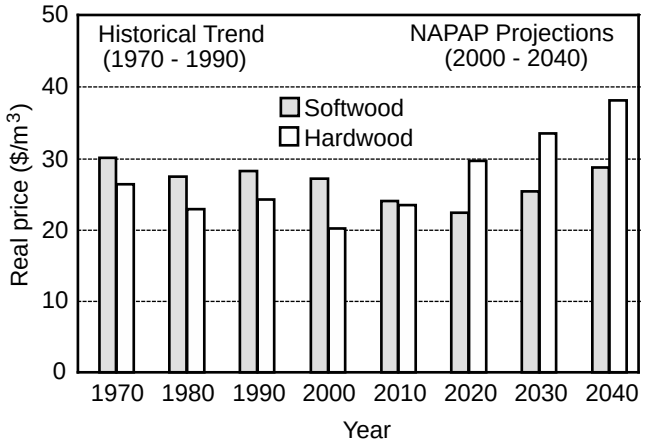

Figure 128—Real prices for pulpwood roundwood for U.S. South.

In general terms, pulpwood prices were projected to remain relatively stable well into the next century, particularly for softwood pulpwood in the South. The projected relative stability in pulpwood prices is due in large part to the projected impact of increased paper recycling and corresponding modest growth rates for pulpwood consumption.

Real Prices for Recovered Paper

Trends for real prices for recovered paper by region are shown for ONP (Fig. 130), OCC (Fig. 131), mixed recovered papers (Fig. 132), and pulp substitutes & high-grade deinking Fig. 133). All prices were expressed in constant 1986 dollars per metric tonne. The projections generally indicated that although the current glut in recovered paper markets may last for a number of years, eventually prices for all recovered paper commodities will rebound, with significant upturns projected for most commodity prices in the decades ahead. Projected increases in recovered paper prices are expected to occur, given the substantial ongoing increases in consumption of recovered paper (i.e., increasing demand) and the fact that supplies of recovered paper resources are ultimately limited (e.g., by paper and paperboard consumption levels and by maximum feasible recovery rates, as defined in the NAPAP Model).

In the case of ONP, for example, the projections indicated that a substantial increase in ONP prices would occur during the 1990s (Fig. 130). Prices were projected to reach levels higher than historical real price levels. Prices for OCC were also projected to increase in the mid-1990s and into the next century, reaching levels above the peaks of historical OCC prices (Fig. 131). Mixed recovered paper prices were projected to remain in a glut market for the next couple of decades, with very low prices, but then eventually rebound beyond the year 2005 (Fig. 132). A stable trend was projected for the prices of pulp substitutes & high-grade deinking, at levels somewhat lower than historical levels (Fig. 133).

The projected trends in prices for recovered paper commodities help to explain many of the technological changes projected by the NAPAP Model. For example, the ongoing market glut (depressed prices due to oversupply) favors expansion of recycling capacity to utilize relatively cheap and abundant recovered paper resources. In the long run however, the projected upturn in recovered paper prices results in less economic incentive for expansion of recycling capacity, which explains the projected leveling of the domestic recyclable paper utilization rate later in the projection period (see Fig. 113); in turn, this helps to explain the projected long-run growth in domestic pulpwood consumption (e.g., see Fig. 117, Southern pulpwood supply). As recovered paper prices were projected to eventually reach higher levels, the economic incentive for expansion of recycling capacity was reduced, resulting in projected long-run expansion of production capacity using processes based on virgin-fiber resources (discussed previously).

Gross Wastepaper Disposal Burden

The gross wastepaper disposal burden is calculated as the total tonnage of domestic paper and board consumption minus the tonnage of paper and board recovered for recycling (for domestic use and export). The actual net discard volume of wastepaper (e.g., that which must be landfilled or incinerated) is somewhat less than the gross disposal burden because some domestic paper and board consumption goes into long-term storage (e.g., paper in books) and some is disposed of by other means (e.g., flushed into sewage systems). However, the gross wastepaper disposal burden provides a measure of the total volume of paper and paperboard that must be ultimately discarded; it is equivalent to the volume of paper and board consumption that is not recovered for recycling.

The projected increase in the domestic utilization of recovered paper (Fig. 113), along with the increased export of recovered paper (Fig. 122), would be expected to result in a decrease in the wastepaper disposal burden. The historical data show that the gross wastepaper disposal burden has been increasing over the past two decades (Fig. 134). However, in the past few years, it has declined slightly from the peak level reached just before 1990. The NAPAP Model projections indicated that the gross wastepaper disposal burden would continue to decline through the mid-1990s, and then level off. The wastepaper disposal burden was then projected to gradually increase beyond the year 2000. Generally, the gross wastepaper disposal burden was projected to remain in the range of roughly 45 to 55 million metric tonnes per year, throughout most of the projection period, climbing to approximately 55 million metric tonnes per year toward the end of the projection period.

In the future, it is likely that the growing wastepaper disposal burden will be managed much more efficiently than it is today. Increased incineration and derivation of fuels from nonrecoverable (or nonrecyclable) categories of wastepaper, and increased use of low-quality wastepaper in new nonpaper products, are likely to become important elements of waste reduction strategies in the future, reducing burdens on landfills. As discussed previously, paper that can be recovered and recycled into paper products (recyclable paper) is likely to increase substantially in use and value, and will therefore contribute substantially to ameliorating a large share of the future paper disposal burden in the United States.

Roundwood and Residue Pulpwood Supply

Figure 135 illustrates NAPAP Model projections of roundwood and residue pulpwood supply for the United States (total quantity of pulpwood consumed domestically in pulp, paper, and paperboard production, plus export quantity); projections for the U.S. North, South, and West are shown in Figures 136, 137, and 138, respectively.

Historically, wood residues from lumber and plywood mills have provided an increasing share of total pulpwood supply in the United States, reaching approximately 40 percent of total supply by the late 1980s. Several decades ago, residues accounted for less than 20 percent of total pulpwood supply. As shown in Figure 135, projections indicated that most future growth in U.S. pulpwood supply would be provided by roundwood (i.e., timber harvest). The pulpwood residue supply was projected to remain relatively constant throughout the projection period, while roundwood pulpwood supply was projected to increase. Residue output of the lumber and plywood sectors, along with lumber and plywood production, were projected by the TAMM/ATLAS model (projections discussed below). Although total lumber and plywood production was projected to grow in the future, improvements in product recovery were projected to result in less residue output per unit of lumber and plywood produced.

Likewise, the residue component of pulpwood supply in the U.S. North was projected to remain relatively constant throughout the projection period (Fig. 136); roundwood pulpwood supply was projected to increase. In the South, roundwood pulpwood supply was projected to increase throughout the projection period, although modest increases in residue supply were also projected (Fig. 137). In the West, roundwood pulpwood supply was projected to remain relatively constant, but residue supply was projected to decline for several decades (Fig. 138). Improvements in lumber and plywood production efficiency, coupled with projected declines in National Forest timber harvests, were projected to substantially reduce the volumes of wood residues available for pulpwood in the West. Pulpwood supply was projected to increase again only toward the end of the projection period.

Sawtimber Stumpage Prices

The TAMM/ATLAS model (linked to NAPAP Model) provided projections of real prices for softwood sawtimber stumpage (in constant 1982 dollars per thousand board feet, log scale). Figure 139 illustrates the projected softwood sawtimber stumpage prices for the U.S. North, South, and West (TAMM run LR125).

Projections indicated that very substantial increases would occur in softwood sawtimber stumpage prices during the next two decades in the South and West, followed by relative stability in stumpage prices toward the end of the projection period. In the North, softwood sawtimber stumpage prices were projected to increase steadily throughout the projection period, eventually reaching levels close to stumpage prices in the West.

Real prices for softwood sawtimber stumpage were projected to nearly double in the South between 1990 and 2010. A more rapid initial increase in sawtimber stumpage prices was projected in the West, although stumpage prices were projected to begin leveling out in the West beyond the year 2010 (Fig. 139).

Since the 1989 RPA Assessment, adjustments were made to the TAMM/ATLAS model, including introduction of an assumption that National Forest timber harvest levels in all regions would decline very substantially in the decades ahead. Other TAMM/ATLAS adjustments since the Assessment included higher volumes of softwood lumber and plywood demand in the United States (due to adjustment of end-use factors in housing), lower Canadian lumber production (due to constraints on lumber production in British Columbia and Interior Canadian region, reflecting a move to lower allowable cuts in those regions, lower private industrial sawtimber harvests in the U.S. West (Pacific Southwest and Northern Rockies, reflecting limits on regional timber inventories), increased imports of softwood lumber to secondary processing facilities in the Northwest, and lower projections of softwood log exports from the Pacific Northwest. The net effect of the TAMM/ATLAS adjustments was to project a more constrained timber supply and demand situation, particularly for softwood sawtimber in the United States. Although the current analysis projected very substantial increases in recycling, which will extend pulpwood supplies, the other adjustments (particularly the set-aside of timber on National Forests) have an offsetting impact on projected sawtimber markets. Thus, a very substantial increase in softwood sawtimber stumpage prices was projected to occur, particularly in the South and the West, during the next two decades, despite the benefits of increased recycling.

Projected Lumber, Plywood, and OSB Production

Imports of softwood lumber are mainly from Canada (around 99 percent of total (Fig. 140)). The projections indicated that growth in U.S. softwood lumber production would be constrained in the next two decades, partly due to projected increases in sawtimber stumpage prices in the West and South. Total U.S. softwood lumber production was projected to remain relatively flat for the next two decades, and then gradually increase through the remainder of the projection period (Fig. 140). Imports of softwood lumber (mainly from Canada) were projected to increase for the next two decades, but eventually decline in the latter half of the projection period.

Figure 141 illustrates TAMM/ATLAS projections of U.S. production of softwood plywood and oriented strandboard (OSB). In recent decades, softwood plywood has been the dominant category of structural wood panel product produced in the United States. However, in the last decade, OSB has gained a substantial share of the market, as a substitute for softwood plywood. Technologically, softwood plywood production generally requires softwood sawtimber, whereas OSB can be made from a wider range of species (including hardwoods) and from pulpwood-quality logs. Thus, as softwood sawtimber prices were projected to increase substantially in the decades ahead, U.S. structural panel production was projected to shift toward greater OSB production. The projections were in line with historical

trends of the past decade. Projections indicated that OSB production in the United States would eventually account for a larger share of total structural panel production than does softwood plywood.

Projected Timber Trends

Trends were projected for both timber harvest (Figs. 142–150) and timber inventory (Figs. 151 and 152).

Timber Harvest

Figures 142 to 147 illustrate TAMM/ATLAS projections of timber harvest trends for softwood and hardwood timber in the U.S. North, South, and West, including sawtimber and non-sawtimber harvest. The non-sawtimber component includes pulpwood roundwood harvest. The sawtimber component is timber used primarily for lumber or plywood production, although a substantial share of that wood is also recovered as pulpwood residues from lumber and plywood production. In the North, for both softwood and hardwood, the non-sawtimber component of timber harvest was projected to remain larger and to grow more substantially than the sawtimber component (Figs. 142 and 143). Hardwood timber harvest was projected to remain much greater than softwood timber harvest in the North, reflecting the relative abundance and greater utilization of hardwood timber in the North (note that Figures 142 and 143 use different scales).

Softwood sawtimber harvest was projected to increase substantially in the South, with the largest projected increase between 2010 and 2030 (Fig. 144). Modest growth was projected for softwood non-sawtimber harvest in the South. In contrast, hardwood non-sawtimber harvest was projected to increase substantially in the South for the next couple of decades, largely due to projected increases in hardwood pulpwood consumption (Fig. 145). However, beyond the year 2010, hardwood non-sawtimber harvest was projected to remain relatively constant due to projected constraints on hardwood pulpwood supply in the South (associated with projected declines in hardwood timber inventory in the South). Hardwood sawtimber harvest was projected to increase gradually in the South.

In the West, sawtimber was projected to remain the largest component of softwood timber harvest. However, softwood non-sawtimber harvest was projected to gradually increase throughout the projection period, while softwood sawtimber harvest was projected to decrease for several decades (Fig. 146). The decline in softwood sawtimber harvest in the West reflects a projected decline in National Forest timber harvest levels. Hardwood represents a much smaller component of timber harvest than does softwood in the West. Hardwood timber harvest in the West was projected to increase gradually, primarily in the non-sawtimber component (Fig. 147).

Figure 148 illustrates TAMM/ATLAS projections of total U.S. timber harvest, including softwood and hardwood. Both softwood and hardwood timber harvest levels were projected to increase, although the level of softwood timber harvest was projected to remain relatively flat until around 2010, and then gradually increase. Hardwood timber harvest was projected to increase steadily throughout the projection period, but remain less than softwood timber harvest.

Figure 149 illustrates TAMM/ATLAS projections of total U.S. timber harvest by region. Total timber harvest was projected to increase substantially in both the North and the South between 1990 and 2040. In the West, timber harvest was projected to decline by about one-fifth in the next decade, but then gradually return to current levels toward the end of the projection period. Generally, the projections indicated a substantial shift in the geographic proportions of timber harvest, from the West to the North and South. The pattern of this shift follows recent historical trends.

Figure 150 illustrates TAMM/ATLAS projections of total U.S. timber harvest by timberland ownership category. The analysis currently assumes that National Forest timber harvest levels in all regions will decline over the next decade, and then stabilize at lower levels for the remainder of the projection period. Those assumptions reflect a view that timber harvesting on the National Forests will be significantly reduced to preserve habitat for endangered species, to preserve integrity of forest ecosystems, and to satisfy public demands for maintenance of scenic and recreational areas on the National Forests. The projected decline in National Forest timber harvests is part of an ongoing trend that can be traced to the last decade. Timber harvest on other public timberlands (state and Federal) was assumed to remain fairly constant throughout the projection period. Whereas public timberlands provided nearly 20 percent of total U.S. timber harvest in 1990, projections indicated that public timberlands would provide closer to 10 percent toward the end of the projection period. The projections indicated that increases in timber harvest will occur primarily on privately owned timberland and forest industry lands. The largest share of U.S. timber harvest, and the largest growth in timber harvest, was projected to occur on “other private” (nonindustrial) timberlands. Timber harvest on forest industry land was projected to decline slightly until around 2010, and then increase gradually.

Timber Inventory

Figures 151 and 152 illustrate TAMM/ATLAS projections of timber growing stock inventory on private timberland in the United States (public timberlands and other noncommercial forest lands are excluded from the figures). Timber growing stock inventory on private timberland was projected to increase gradually throughout the projection period. Inventory on private timberland was projected to increase in the West and the North, and to remain relatively constant in the South.

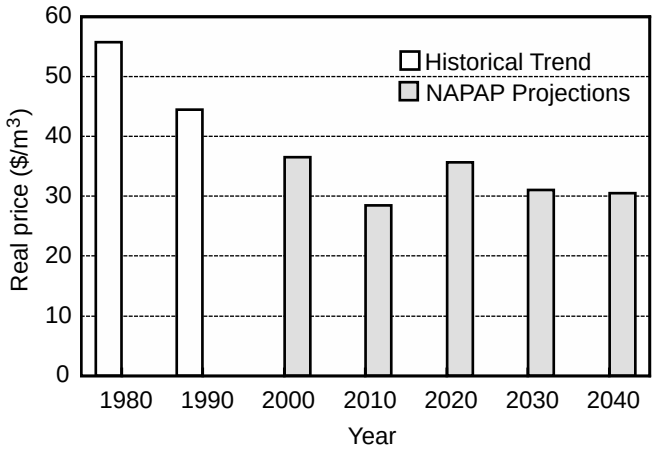

Figure 129—Real prices for softwood residues for U.S. West.

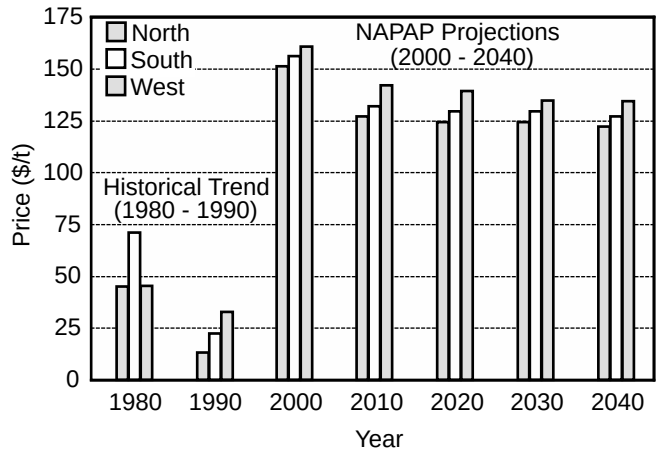

Figure 130—Old newspaper prices, by region.

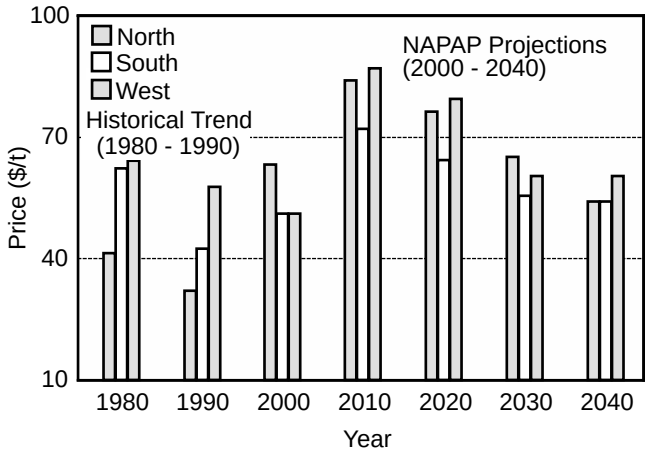

Figure 131—Old corrugated container prices, by region.

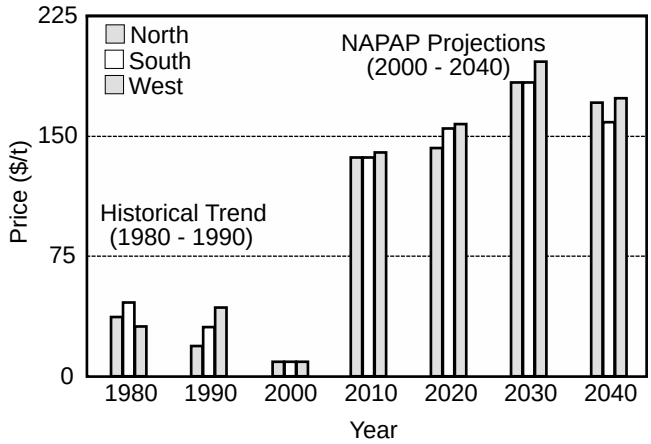

Figure 132—Mixed recovered paper prices, by region.

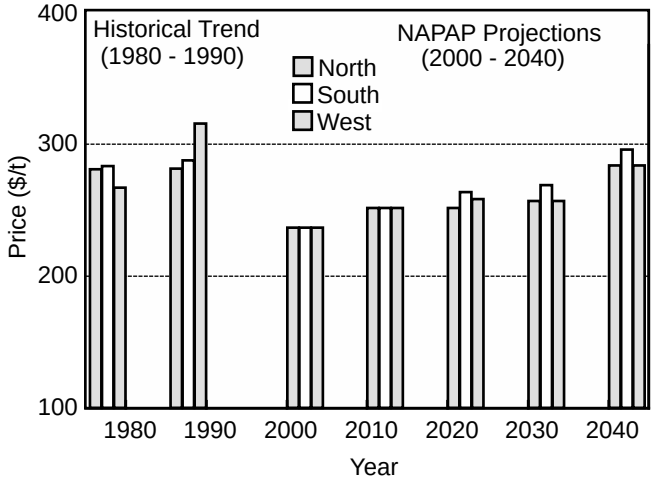

Figure 133—Pulp substitutes & high grade deinking prices, by region.

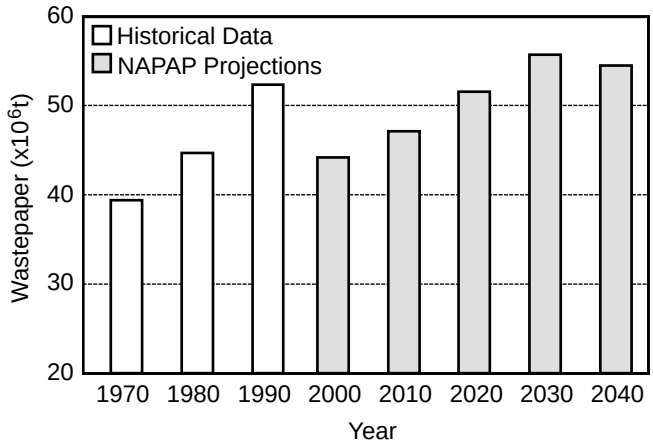

Figure 134—U.S. gross wastepaper disposal burden (paper and board consumption minus recyclable paper recovery).

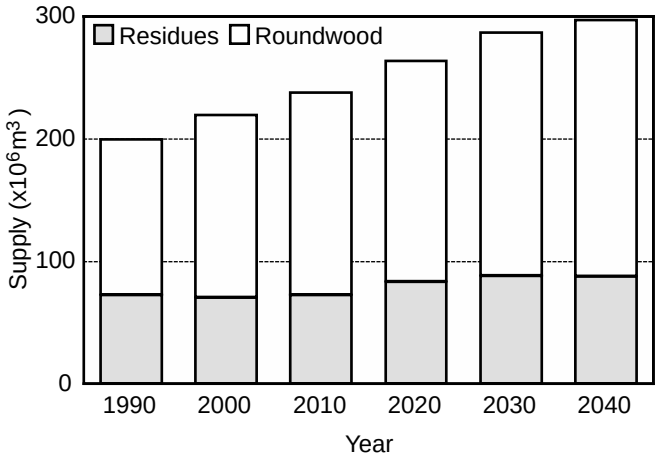

Figure 135—Projected U.S. pulpwood supply, roundwood and residues.

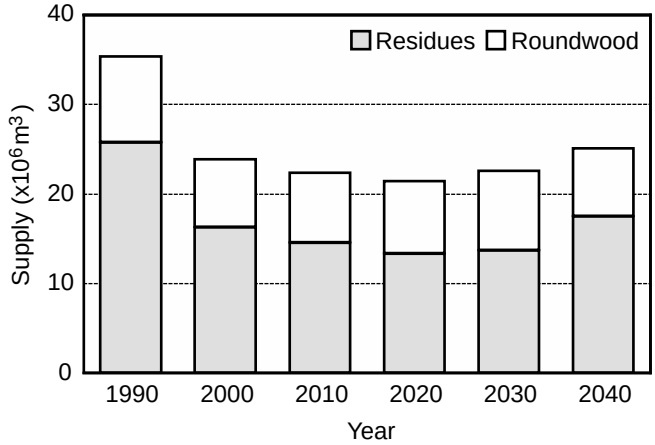

Figure 138—Projected pulpwood supply, roundwood and residues, for U.S. West.

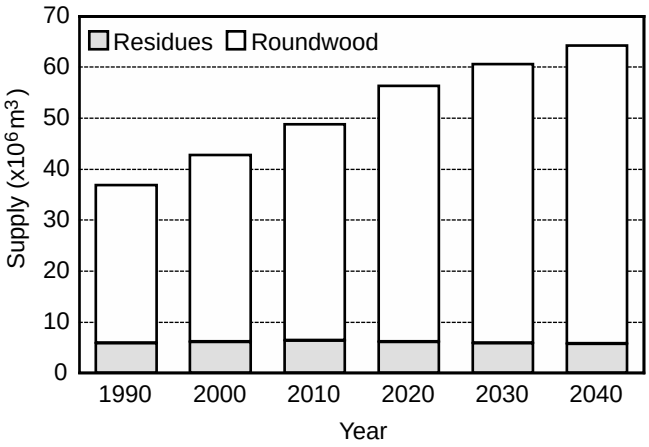

Figure 136—Projected pulpwood supply, roundwood and residues, for U.S. North.

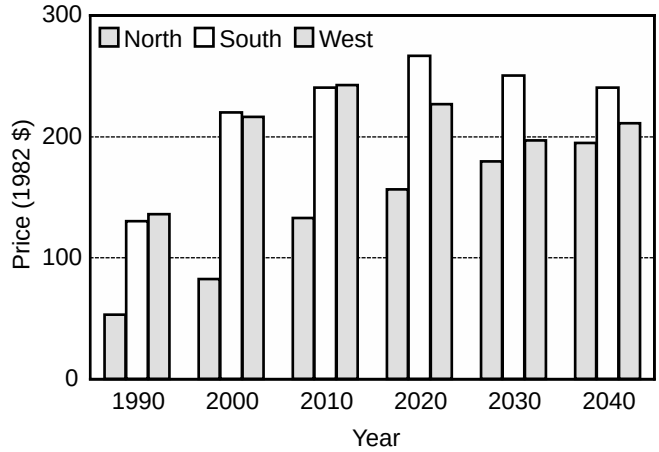

Figure 139—Projected softwood sawtimber stumpage prices (constant 1982 dollars per thousand board feet), by region (TAMM/ATLAS projections).

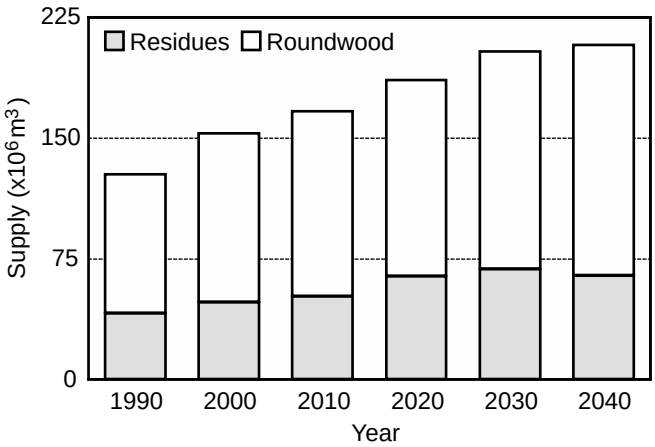

Figure 137—Projected pulpwood supply, roundwood and residues, for U.S. South.

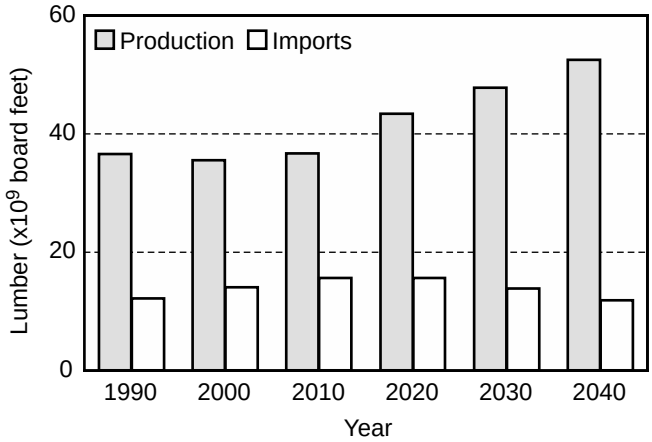

Figure 140—Projected U.S. softwood lumber production and imports, mainly from Canada (TAMM/ATLAS projections).

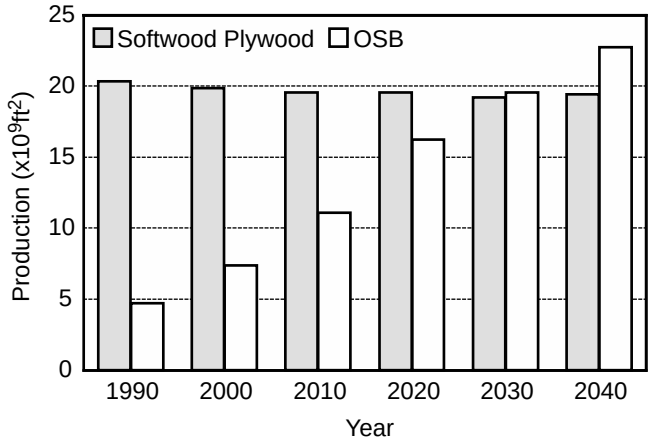

Figure 141—Projected U.S. softwood plywood and oriented strandboard (OSB) production (3/8-in. basis) (TAMM/ATLAS projections).

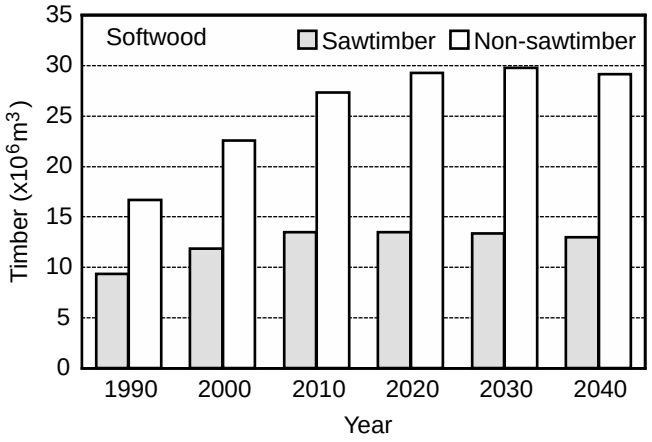

Figure 142—Projected softwood timber harvest of U.S. North (TAMM/ATLAS projections).

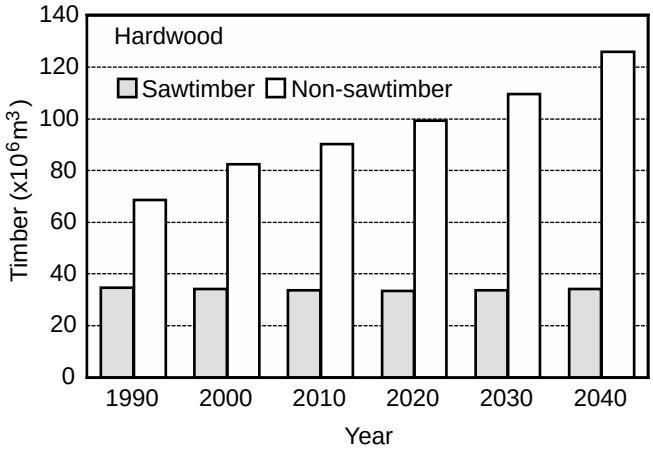

Figure 143—Projected hardwood timber harvest of U.S. North (TAMM/ATLAS projections).

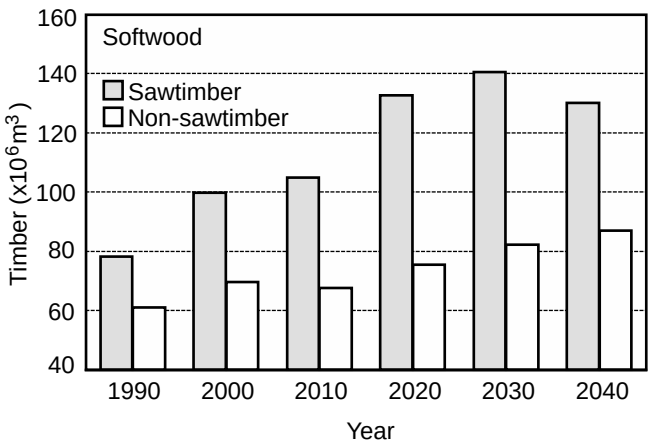

Figure 144—Projected softwood timber harvest of U.S. South (TAMM/ATLAS projections).

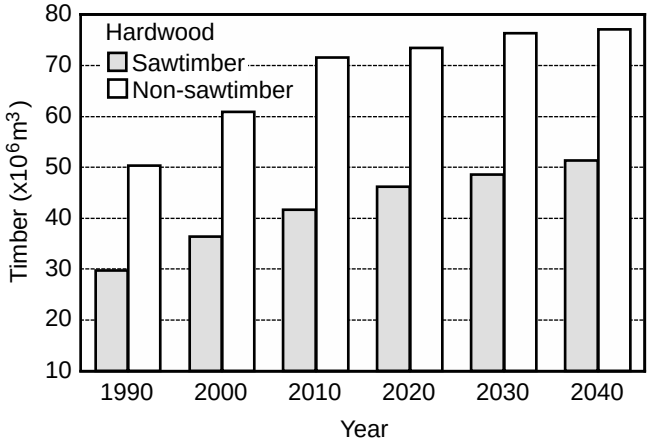

Figure 145—Projected hardwood timber harvest of U.S. South (TAMM/ATLAS projections).

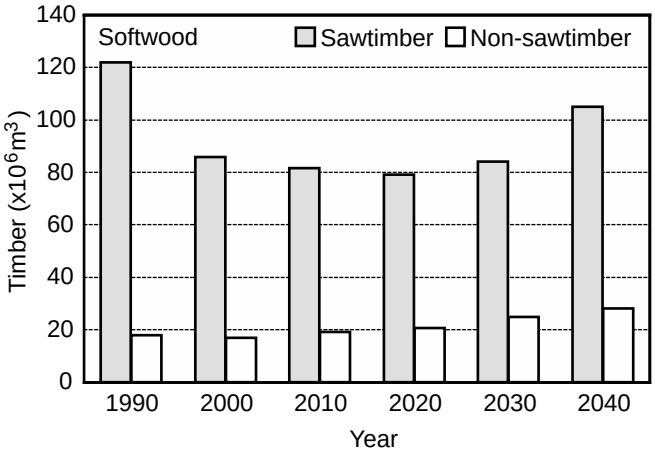

Figure 146—Projected softwood timber harvest of U.S. West (TAMM/ATLAS projections).

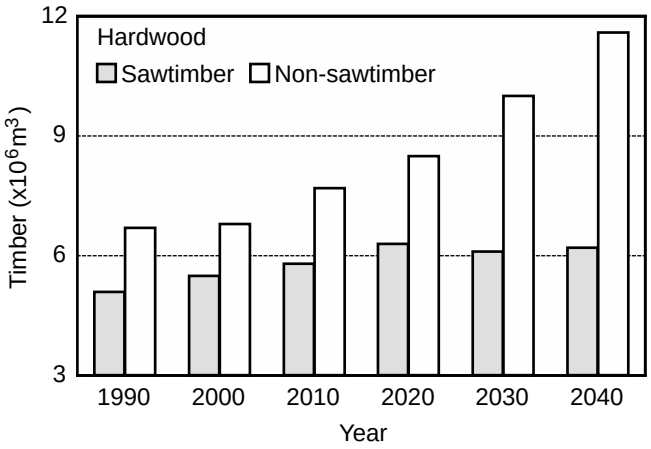

Figure 147—Projected hardwood timber harvest of U.S. West (TAMM/ATLAS projections).

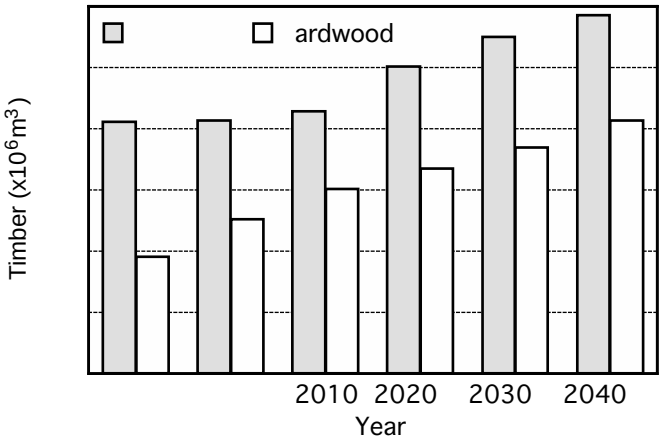

Figure 148—Projected total U.S. timber harvest (TAMM/ATLAS projections).

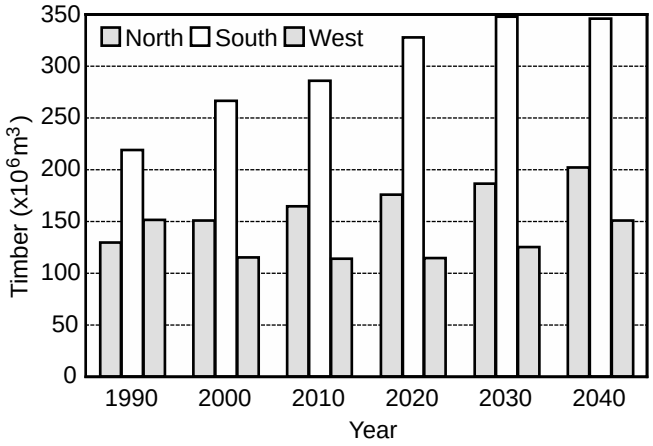

Figure 149—Projected total U.S. timber harvest, by region (TAMM/ATLAS projections).

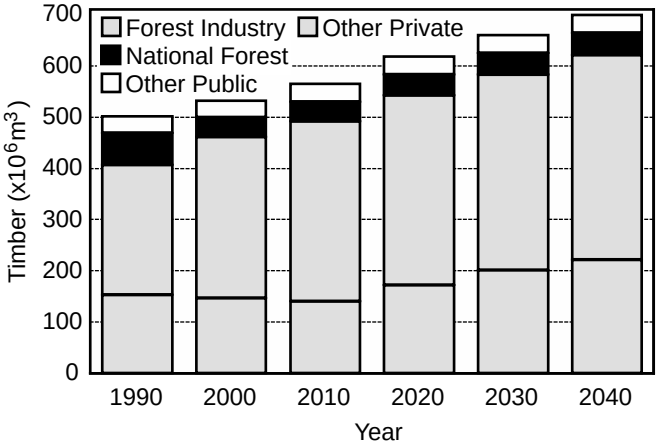

Figure 150—Projected total U.S. timber harvest, by timberland ownership category (TAMM/ATLAS projections).

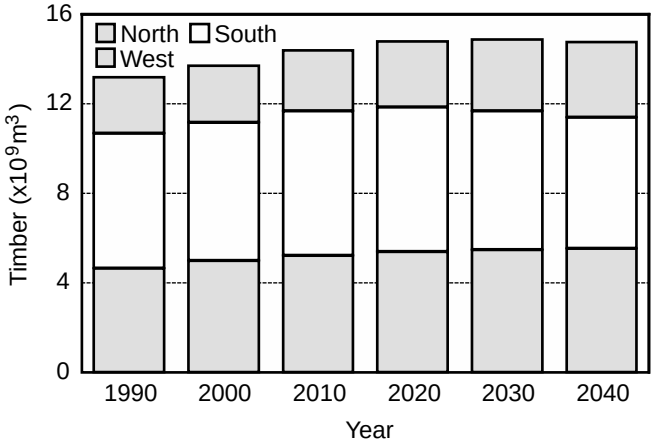

Figure 151—Projected timber growing stock inventory on private U.S. timberland, by region (TAMM/ATLAS projections).

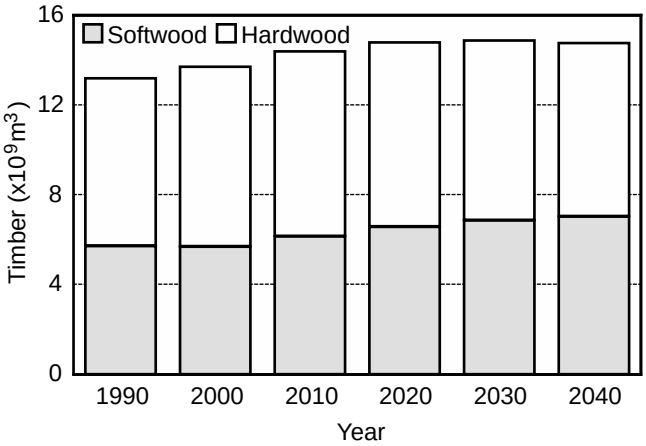

Figure 152—Projected timber growing stock inventory on private U.S. timberland (TAMM/ATLAS projections).

Hardwood timber inventory on private timberland was projected to remain relatively constant, while softwood timber inventory was projected to gradually increase.

Projected Employment Trends of Pulp and Paper Sector

Figure 153 illustrates employment trends in U.S. pulp, paper, and paperboard mills, showing historical data on total employment from the 1970s to 1985, and NAPAP Model projections of employment by region from 2000 to 2040. The projections were derived by applying an assumption of 2 percent annual growth in labor productivity and real wage rates to NAPAP Model labor input projections. In line with historical trends, the projections indicated that employment levels will gradually decline in the decades ahead, despite projected increases in pulp, paper, and paperboard production. Regionally, employment levels were projected to gradually decline in the North and West, and remain relatively stable in the South. The projections indicated that the South will gradually gain in its share of total employment in the pulp and paper sector.

Conclusions

In general, results of this analysis led to the conclusion that rapid increases will occur in U.S. paper recycling rates in the 1990s, in line with current trends, followed by more gradual increases in subsequent decades, as a result of the competitive evolution of fiber markets and pulp and paper technology. Rapid increases in recycling rates and export of recovered paper in the 1990s will result in recovery from the current market glut, with projected increases in most recovered paper commodity prices, particularly for old newspaper and old corrugated containers. The utilization rate of recyclable paper in the United States will eventually exceed 45 percent toward the end of the projection period. The recovery rate will increase to around 49 percent by the year 2000 and climb to nearly 60 percent by the year 2040.

With more abundant fiber resources (due to increased recycling), paper and paperboard consumption in the United States and production of pulp, paper, and paperboard commodities were projected to increase very substantially in the decades ahead. Exports of paper and paperboard products were also projected to grow very substantially, while imports were projected to generally decline (particularly imports from Canada). Thus, although recycling rates were projected to increase, total consumption and export of pulpwood (pulpwood supply) was projected to increase in the decades ahead. Delivered pulpwood prices were projected to remain fairly stable in both the U.S. North and South. Technological changes and market conditions will favor more use of hardwood pulpwood, but use of softwood pulpwood will also increase toward the end of the projection period.

In the context of increased paper recycling, lumber production and structural wood panel production will increase. However, increased demand for sawtimber, coupled with projected declines in timber harvest on National Forests will result in substantial increases in softwood sawtimber stumpage prices, with roughly a doubling (in constant dollars) of real stumpage prices in the South and West between 1990 and 2010. Timber harvest in the United States will continue to shift from the West to the South and North. The bulk of timber harvest in the future will be on private nonindustrial timberland. Overall timber growing stock inventory on private timberland in the United States will remain relatively stable, although some declines in inventory will occur in the South for hardwoods.

Implications of Results

The implications of results are discussed in the context of questions about specific timber resources.

Will increased paper recycling extend timber resources?

Yes, results indicate that increased recycling will extend the timber resources of the United States, particularly pulpwood. In comparison with results of the 1989 RPA Assessment, this analysis projected slower growth in overall timber harvest and less increase in pulpwood prices, primarily as a result of higher projections of paper recycling rates.

Will paper recycling eliminate future U.S. timber supply problems?

No, although increased recycling will improve the situation, the United States faces serious timber supply problems in the decades ahead, particularly for softwood sawtimber. Figures 154 and 155 illustrate current projections of National Forest timber harvest levels, and compares these projections to those of the 1989 RPA Assessment Base scenario. The 1989 RPA Assessment Base scenario had assumed much higher future harvest levels on the National Forests; most harvest reduction was at the expense of projected softwood sawtimber harvest in the West. Other adjustments in data assumptions since the 1989 RPA included higher volumes of softwood lumber and plywood consumption in the United States per unit of new housing, lower Canadian lumber production, lower private industrial sawtimber harvests in the U.S. West, increased imports of softwood lumber, and reduced softwood log exports from the Pacific Northwest. Consequently, although projected U.S. recycling rates were higher and growth in timber harvest lower than earlier projections, the conclusion that increased recycling will cause a stabilization in softwood sawtimber markets is no longer warranted (cf. Ince 1990). Although delivered pulpwood prices will increase somewhat in the North and South, particularly for hardwoods, the rate of increase in pulpwood prices is not nearly as substantial as the projected rate of increase in softwood sawtimber stumpage prices.

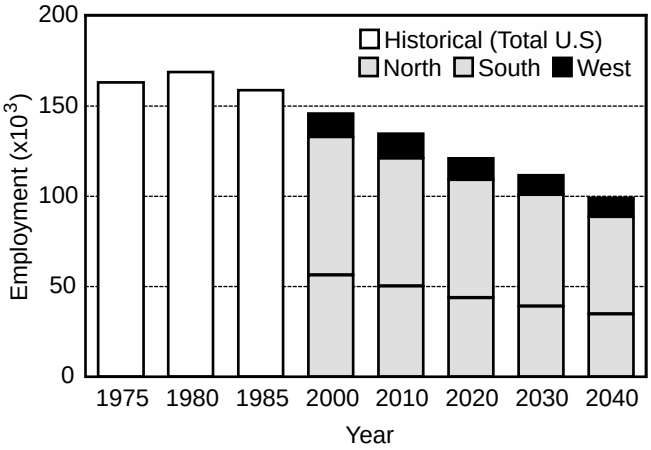

Figure 153—Employment in U.S. pulp, paper, and paperboard mills (NAPAP Model projections, assuming 2-percent annual growth in labor productivity and real wages @1,800 h/year).

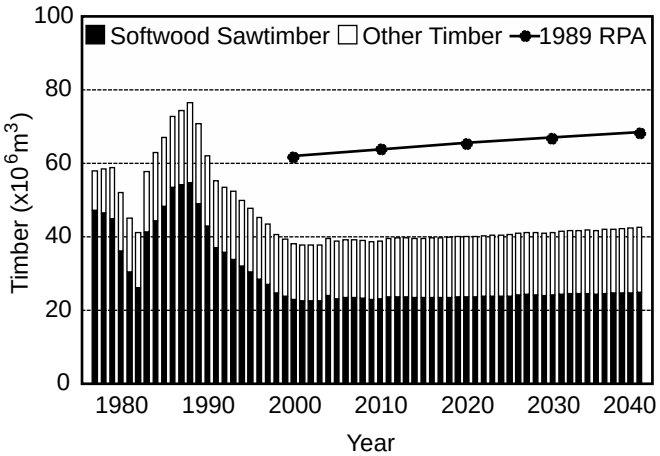

Figure 154—Trend in National Forest timber harvest from 1977–2040, comparing current TAMM/ATLAS projections to 1989 RPA projections.

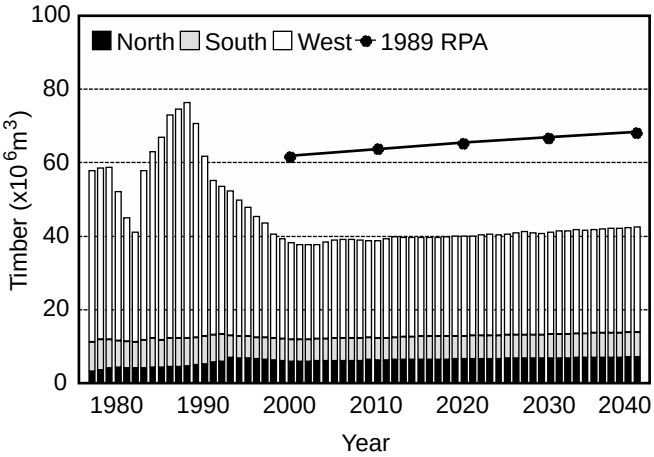

Figure 155—Trend in National Forest timber harvest from 1977–2040, by region, comparing current TAMM/ATLAS projections to 1989 RPA projections.

Increased paper recycling will extend fiber resources, and will contribute to stabilization of pulpwood prices and growth in the pulp and paper sector, but increased paper recycling will not be sufficient to compensate for projected reductions in National Forest timber harvest levels and other recent adjustments to the analysis.

What aspects of the future timber supply and demand situation will remain problematic?

Supplies of softwood sawtimber will remain constrained and prices will increase, limiting growth and competitiveness for softwood lumber and plywood. Technology of the solid-wood products sector will likely continue to shift from traditional "solid-wood" products such as softwood dimension lumber and softwood plywood toward alternative products such as oriented strandboard (OSB) or other composite materials that can be made from pulpwood-type raw material. Production capacity will also continue to shift from the West to the South and North. The pulpwood supply and demand situation is quite stable, with projected increases in pulpwood prices not likely to seriously impair historical growth trends of the pulp and paper sector. Increased recycled fiber supply will augment the fiber resource needs of the pulp and paper sector. Some reductions will occur in hardwood timber inventories, particularly in the South.

What are some implications for forest management?

Projected increases in softwood sawtimber stumpage prices may enhance future timberland investment returns and provide incentive for more intensive forest management practices, such as conversion of natural forest stands to plantations, more intensive application of herbicides and pesticides, and generally more intensive silvicultural practices. In this context, the need for policies designed to stimulate timberland investment could decline, given substantial private sector investment in response to higher sawtimber prices. However, such an investment response by the private sector is not certain to occur. Also, other public policy concerns, such as sequestration of atmospheric carbon in growing trees, may continue to require public investment in timber management. Timber policies may need to focus on resolving conflicts between more intensive silviculture on private timberlands and concern about forest ecology. The projected escalation in sawtimber prices would substantially increase timber sale revenues per unit of timber sold on National Forests as well as on private lands. Thus, although the quantity of timber sold on the National Forests may decline in the decades ahead, timber sale revenues may not necessarily decline in direct proportion to declining harvest volume.

Will increased paper recovery (for recycling and export) either eliminate or reduce the disposal burden associated with wastepaper in the United States?

No. The gross wastepaper disposal burden of the United States will remain in the range of 45 to 55 million metric

tonnes per year well into the 21st century. Although the competitive evolution of recycling technology will result in a decreased wastepaper disposal burden in the 1990s, and although recovery of paper for recycling and export will continue to grow, domestic demand and consumption of paper and paperboard products will also continue to grow in the future. Thus, the United States will continue to face a gross wastepaper disposal burden in the decades ahead, which will be similar in magnitude to the current disposal burden.

Will paper recycling be offset by alternative disposal options in the United States, such as wastepaper incineration?

No. For economic and environmental reasons, incineration of wastepaper will probably not offset supplies of recovered paper for recycling or export. Incineration of wastepaper will continue to be an important element of waste management in the United States, but paper that can be recovered and recycled into paper or paperboard products will likely have much higher value in the future. Public policy favors recycling over incineration in waste management, for environmental reasons. In addition, energy conserved by recycling of paper has been estimated to be more than twice the energy generated by incineration (Jaakko Poyry 1992). At present, energy can be generated economically only if wastepaper fuel is not much more than $50 per tonne. With projected higher prices for recyclable paper, only incineration of nonrecyclable wastepaper will be likely in the future.

Will increased recycling and economic growth in the pulp and paper sector contribute to increased regional employment in pulp and paper mills or to a better balance of trade?

Despite projected increases in production of pulp, paper, and paperboard products, and projected increases in recycling, total U.S. employment in pulp, paper, and paperboard mills is not likely to increase substantially. This prognosis is in line with historical trends. This projection assumes continued increases in labor productivity at the modest rate of 2 percent per year (historical productivity increases have actually been slightly higher). However, although the numbers of employees are likely to decline in the North and West, and to remain relatively constant in the South, increasing productivity will be associated with increasing wage rates. In real terms, total wages of the pulp and paper sector are likely to more than double during the projection period. Thus, the pulp and paper sector of the United States will continue to make an enormous and growing contribution to the economic stability of regional and local communities. In addition, increased export and decreased import of pulp, paper, and paperboard commodities will signficantly improve the U.S. balance of trade.

What are the implications for forestry research and forest products research, associated with projected trends in recycling and timber markets?

Although many elements of the current analysis are substantially different from the analysis presented in the 1989 RPA Assessment (e.g., much higher recycling rates and much lower future National Forest timber harvest levels), many of the same conclusions will remain valid. Forestry research should continue to focus on the need to sustain forest productivity while maintaining the integrity of forest ecosystems. Forest productivity and management practices on private timberlands will be important areas of research as private timberland harvesting intensifies. Management of forest ecosystems, ecosystem integrity, new forms of management, and new timber harvesting techniques will be important areas of research related to public lands. Forest products research will need to maintain a focus on extending timber resources, particularly in extending sawtimber supplies and finding alternative technologies for producing solid-wood products from non-sawtimber resources. Research related to the pulp and paper sector will need to focus on producing quality products from recycled fiber.

In addition to general areas of foresty and forest product research, results of this study suggest specific topics that require additional research related to economics, recycling, and future timber markets. One area concerns emerging issues of the pulp and paper sector, including environmental issues, product demand, and trade. This study focused mainly on recycling, but other emerging environmental concerns are also important in the pulp and paper sector, such as the role of forest management and product use in relation to global carbon cycling. Pulpwood supply, recovered paper supply, export demand, and trade also remain areas of uncertainty, requiring further investigation or updating of current estimates. The modeling methods developed in this study can be further improved and applied in analyses of these and related issues.

Alternative Scenarios

A final question concerns alternative future scenarios in paper recycling and related policy options. Such analyses can be developed using the methods applied in this study, such as the NAPAP Model. One plausible future scenario could be developed to represent the possiblity of significant government policy changes related to paper recycling. As noted previously, most states have adopted some form of legislative or policy approach to encourage paper recycling. State legislative trends in paper recycling have been extensively documented. Federal policies or programs might be enacted to encourage or stimulate paper recycling, or to reduce the disposal burden associated with wastepaper. Such policies or programs could subsume one or more of the following objectives:

1. to increase collection, sorting, and processing of recyclable wastepaper so as to recover larger volumes of paper for recycling or export

2. to increase recycling by offering incentives (e.g., tax credits) for investment in processes that use recycled fiber

3. to reduce the wastepaper disposal burden by way of source reduction

Even though the specific policies that might accomplish these objectives are not yet mandated at the Federal level, the methods developed in this study could be employed to examine their potential economic implications. The NAPAP Model can be adjusted easily to simulate the effects of (1) increased recovered paper supply resulting from increased collection, (2) application of credits for recycled fiber processes, and (3) decreased product demand caused by "source reduction." One or more alternative future scenarios may be developed to simulate potential effects of such policy options.

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Glossary

Demand function. A mathematical relationship defining the quantity of a commodity that will be consumed in a particular demand region as a function of the market equilibrium price and other shifter variables, such as population and gross domestic product; shifter variables are projected exogenously to change over time in each demand region, causing change in regional commodity demands. Most demand functions in the NAPAP Model were estimated using statistical (econometric) techniques based on long-term historical data relationships.

Demand region. A region in which market equilibria for end products are modeled, and for which consumption of end products are modeled by demand functions.

Delivered pulpwood. Pulpwood delivered to manufacturing facilities (i.e., pulp, paper, or paperboard mills) or delivered to port for export. Delivered pulpwood has a substantially higher price than does stumpage, reflecting costs of pulpwood harvesting and transportation; delivered pulpwood markets may follow somewhat different trends than stumpage markets.

Elasticity (coefficients). Mathematical coefficients in supply or demand functions that specify how much the supply or demand quantity will change or "shift" given a change in price or shifter variables.

End product. Commodity that satisfies product demand, as represented by demand functions for various demand regions in the NAPAP Model. End products include all paper and paperboard commodities and dissolving pulp; also include commodities that satisfy export demands, including exports of market pulp, recovered paper, and pulpwood.

Growing stock. Classification of timber inventory that includes live trees of commercial species meeting specified standards of quality or vigor. Cull trees are excluded. When associated with timber volume, growing stock includes only

trees 5.0 in. (12.7 cm.) diameter-at-breast-height (dbh) and larger.

Import ad-valorem tax. Tariff imposed by a demand region (importer) on a commodity imported to the region.

Input. Commodity that must be entered into manufacturing processes for end products or intermediate products. Inputs include pulpwood commodities, recovered paper commodities, labor, purchased fuel, and electrical energy.

Intermediate product. Commodity that is manufactured in North America or imported to North America and that satisfies input requirements of manufacturing processes for end products. Intermediate products include paper-grade market pulp commodities.

Manufacturing cost. Cost of producing a product (per tonne of output) using a particular manufacturing process, including the cost of inputs plus "other manufacturing costs," including capital, chemicals, supplies, and other factors. Cost estimates used in the NAPAP Model were approximations, intended to represent aggregate averages by type of process, and do not represent actual costs for any particular mill in North America.

Manufacturing region. A region in which the production of a commodity takes place and in which the supply markets for input commodities are modeled.

Process. A production technique used to produce intermediate or final products (pulp, paper or paperboard) in a particular manufacturing region; a process is defined completely by its manufacturing input requirements, other manufacturing costs, and production capacity; each process generally represents an approximation or average of actual technologies used in the pulp and paper sector. (In reality, many mills have used more than one process, so the process definitions do not necessarily correspond to the technology of any individual mill in North America.)

Production capacity. Upper limit on annual production of a particular process in a particular manufacturing region. In the NAPAP Model, capacity was estimated for each process and region in 1986, and projected to change over time in relationship to market conditions and comparative advantages of regions and processes.

Pulpwood. Roundwood (including whole-tree chips) and wood residues used for the production of pulp, paper, or paperboard. Pulpwood is the primary virgin-fiber raw material input in U.S. production of pulp, paper, or paperboard products. It includes wood obtained directly from timber harvesting (so-called roundwood, including whole-tree chips) and wood residues (usually in the form of chips obtained as by-products from lumber or plywood mills.

Recovered paper. Recyclable paper recovered for recycling or export; includes paper or paperboard recovered from pre- or post-consumer sources, but excludes mill broke. The four principal commodity categories include old newspapers (ONP), old corrugated containers (OCC), mixed papers, and high grade deinking & pulp substitutes.

Residues. Category of pulpwood that consists of wood by-products (primarily chips, but also including slabs, edgings, trims, and veneer cores) generated primarily by sawmill or plywood mill operations and used as pulpwood.

Roundwood. Category of pulpwood (or timber generally) obtained directly from timber harvest operations, as opposed to mill residues; roundwood actually consists of pulpwood logs and whole-tree chips from on-site harvesting operations.

Sawtimber. Live trees of commercial species containing at least one 12-ft (3.66-m) log or two 8-ft (2.44-m) logs, and meeting regional specifications for freedom from defect. Softwood trees must be at least 9.0 in. (22.85 cm) diameter-at-breast-height (dbh), and hardwood trees at least 11.0 in. (27.94 cm) dbh.

Stumpage. Standing timber (trees) in the forest. The value of timber sold "on the stump" (stumpage price) represents the market value of timber prior to harvesting and delivery to mills; generally, pulpwood stumpage prices are much lower than delivered prices and may follow somewhat different trends.

Supply function. A mathematical relationship that defines the quantity of a commodity that will be supplied by a particular supply region, as a function of the market equilibrium price and other shifter variables, such as timber inventory for pulpwood supply or landfill tipping fees for recovered paper supply. Shifter variables are projected exogenously to change over time for each supply region, causing projected changes in regional supply of input commodities. (Most supply functions in the NAPAP Model were estimated using statistical (econometric) techniques based on long-term historical data relationships.)

Supply region. A region in which market equilibria for input commodities are modeled, and for which the supply of each input commodity is modeled by a supply function, giving quantity supplied as a function of price and other shifter variables. In the NAPAP Model, all manufacturing regions are supply regions, and additionally some overseas supply regions are represented only by supply functions (without a detailed representation of manufacturing technology).

Timberland. Forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization or timber harvesting by statute or administrative regulation.

Timber inventory. Volume of timber growing stock on timberland.

Transportation cost. Shipping cost of a commodity from one region to the other.

Virgin wood fiber. Wood fiber obtained directly from pulpwood, either roundwood or residues, as opposed to recycled fiber.