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Wood Vs. Non-Wood Materials in U.S. Residential Construction: Some Energy-Related International Implications

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EXECUTIVE SUMMARY

Timber harvest reductions in the Northwest intended to preserve the northern spotted owl and to further other non-timber management objectives will significantly reduce the region's output of structural wood products. Some of the demand for these products will be supplied from timber grown elsewhere in the world, but this supply will be limited by economics and by preservation movements pervasive globally. Major substitution of nonrenewable structural materials such as steel, aluminum, concrete, brick and plastics to replace the shortfall in structural wood products can therefore be expected. Because these nonrenewable structural materials require more energy to extract and manufacture than their wood counterparts, global consumption of fossil fuels and concomitant additions of CO_2 to the atmosphere will be significantly increased. While the magnitude of reductions in Northwest timber harvest remain uncertain, estimates can be made of resultant increases in energy consumption and CO_2 additions based on a range of harvest reduction scenarios.

Federal forest plans will reduce timber harvest by 1.45 billion board feet from the average harvest levels observed in the 1983 to 1987 base period. Assuming 100% substitution of these wood products by nonrenewable structural materials, the reduction in timber harvests would increase oil consumption by 24.9 million barrels annually. This increase in oil consumption would release 10.9 million tons of carbon dioxide into the atmosphere. A federal conservation strategy for late-successional old-growth (LS/OG) forests to maximize the probability of spotted owl preservation would reduce harvest by 4.45 billion board feet, increase oil consumption by 80.1 million barrels, and release 35.1 million tons of CO_2 into the atmosphere. Under the most restrictive scenario, in which the Interagency Scientific Committee (ISC) strategy to preserve the owl is extended to state and private lands, timber harvest would decline by 8.25 billion board feet, oil consumption could increase by 140.8 million barrels, and an additional 61.6 million tons of carbon dioxide would be released into the atmosphere.

This extreme case of full implementation of the ISC strategy on public and private land could result in an additional fuel oil consumption equal to about 70 days' output of the Alaska pipeline operating at capacity. Annually, the Alaskan pipeline presently supplies about one-quarter of the nation's oil requirements. For further perspective, an annual increase in world oil consumption of 140.8 million barrels is about equal to 117 cargoes of tankers the size of the Exxon Valdez--enough to operate a fleet of 11 million automobiles. This increase in world oil consumption and CO_2 additions to the atmosphere are best viewed as upper bounds for two reasons. First, the projections are based on energy data from the 1976 Report of the Committee on Renewable Resources for Industrial Materials. While the energy data in this CORRIM Report were accurate for 1976, recycling and other measures taken since 1976 by the steel and aluminum industries have lowered energy requirements for these materials. The CORRIM Report should now be updated to reflect these changes as well as similar improvements in the cement, masonry, plastics, and wood products industries. Second, all of the harvest loss in the "owl" region will not be replaced by renewables. That is, some additional wood will be imported with related environmental impacts in these alternate supply regions.

Concern about the environment, which fuels much of the passion in the argument over harvest level, often appears to be focused on local and regional issues, not on global effects. Regardless of the uncertainty in assumptions involving the degree of product substitution and those involving harvest reductions, it is abundantly clear that there are substantial environmental consequences beyond the preservation of local forestland.

It is an anomaly that a significant segment of the population of the United States--professional foresters as well as lay public--considers it economically practical, and environmentally ethical, to:

- forego tree plantations on some of the highest quality sites in the United States, while accepting the strategy of purchasing more expensive wood from foreign forests (mostly plantations of introduced pines) even though their lower productivity will result in acreage of habitat lost outside the US exceeding acreage preserved inside the US; or

- accept substitution of more costly nonrenewable materials, largely imported, at the expense of significantly greater global energy consumption, fossil fuel depletion, carbon dioxide additions to atmosphere, and nonrenewable materials depletion.

Logic suggests that the various publics of the United States will ultimately apprehend that substantial harvest reductions to alleviate some perceived local environmental problems within our most productive forests will likely create significantly greater environmental problems around the globe.

It would seem more reasonable to intensify management of the resources provided by forests and to resist any significant diminution of acreage committed to multiple-use forests. Also, research efforts should be intensified to increase the percentage of each harvested tree's volume converted into structural products and to prolong the longevity of wood in service--thereby maximizing carbon capture and minimizing CO_2 additions to atmosphere.

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Wood vs Non-wood Materials in US Residential Construction: Some Energy-related International Implications

Peter Koch*

ABSTRACT

In comparison to the average annual timber harvest for the years 1983-1987 in the "owl" region, the various strategies under consideration for conservation of the northern spotted owl in Washington, Oregon, and California all call for substantial harvest reductions on both public and private lands. These timber harvest reductions will reduce output of structural wood products. If nonrenewable structural materials such as steel, aluminum, concrete, brick, and plastics replace the structural wood shortfall, there will be significant increases in global energy consumption, and in carbon dioxide additions to the atmosphere.

These increases amount to about 717 million gallons of oil annually, and about 7.5 million tons of carbon dioxide addition to the atmosphere annually, for each billion board feet (Scribner) of annual harvest reduction. If the Interagency Scientific Committee recommendations are applied in full to both public and private forestlands within the "owl" region, global increase in annual oil consumption could be as high as 6 billion gallons of oil and the increase in annual additions of carbon dioxide to the atmosphere could total 62 million tons.

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Introduction

We here in the western portion of the United States are embroiled in an increasingly polarized discussion over policy regarding preservation vs sustainable multiple use of forests outside of designated wilderness on our public lands. After-dinner discussions in this western region more frequently than not center around local view-scapes. A dinner table comment frequently voiced can be summarized as: "cessation of harvest will make the world a better place to live." It seems to me that the point is arguable.

Judging from local and regional newspaper articles and letters to the editors, the "not in my backyard" syndrome dominates much of the argument. Global effects of proposed local and regional policies are seldom explored by the press. Two such effects that cause concern in many quarters are draw-down of fossil fuel reserves, and global warming.

One might argue, as has Berry (1991), that global thinking can only be statistical, and that its shallowness is exposed by lack of intention to do something. My intention in preparing this paper, however, is to do something--that is, to persuasively suggest that intelligent local or regional action can yield significant beneficial global effects.

In his thoughtful article, "A second look at the impacts of climate change," Ausubel (1991) concludes that much of the conventional wisdom about global warming would appear to as yet have little support from research, but that "it is very important whether the climatic change is expected". Among other conclusions, he further observes that "there is likely to be a complex and shifting set of winners and losers."

With these thoughts in mind, it is the purpose of this paper to explore some of the energy-related aspects of proposed radical reductions in timber volumes harvested in the Northwest. Wood, with very minor exceptions, is the only renewable resource economically suitable for structural and architectural purposes. As Cliff (1973) pointed out nearly two decades ago, tonnage of raw wood consumed in the United States is approximately equal to the combined production of all metals, cements and plastics. He further outlined alternatives by which usage of wood could be reduced, as follows:

> The alternatives are clear. One is to do with less wood--to reduce our appetite for pulp and paper products and revise national goals for decent housing for our citizens. Another is to rely more heavily on nonrenewable materials which can perform the same functions as wood, accept the increased depletion of the nonrenewables and the greater impacts on the environment and the greater energy consumption which the use of these competitive materials entail.

Bowyer (1991b) enumerated a wider range of options, as follows:

- ○ Shift to the use of raw materials other than wood
- ○ Use wood, but import the needed supplies
- ○ Reduce the rate of raw material consumption in general
- ○ Recycle to a greater extent than currently

It is worth noting that 1990 census data indicate total wood usage in the United States has increased by approximately 50 percent since Cliff made his observations in 1973 and that at the current annual population growth rate of about one percent annually, some 2.3 to 2.5 million people are added to US population annually.

All these observations suggest that if a significant reduction in tonnage of wood consumed in the United States is to be accomplished by substitution of alternative materials, a massive consumption of nonrenewable materials will result. As pointed out by Bowyer (1991a) census data indicate we already import substantial percentages of nonrenewables, wood, and fossil fuels; some examples follow:

Material	**Percent imported**	**Principal foreign sources**
Bauxite/Alumina	97	Guinea, Jamaica, Brazil
Gypsum	38	China, Mexico, Spain
Petroleum	35	Mexico, Canada, Venezuela
Aluminum	23	Canada, Japan, Venezuela
Iron ore	22	Canada, Brazil, Venezuela
Iron and steel	19	EEC, Japan, Canada
Portland cement	17	
Wood pulp products	15	Canada
Wood and wood products	12	Canada
Natural gas	5	Canada, Algeria

A major shift from wood in structures to aluminum, steel, cement, bricks, and synthetic materials derived from fossil fuels will cause a significant increase in energy consumption and a concomitant increase in carbon dioxide additions to atmosphere worldwide--as will be discussed later.

If we opt to maintain the energy advantage of wood through massive increases in the volume of wood we import, we will likely promote significantly expanded harvests in other forests of the world (Perez-Garcia 1991). But it is doubtful that we can substantially increase on a sustained basis the volume of wood imported from Canada--now our principal supplier of wood imports. Canadian foresters are under the same pressures to reduce harvests as foresters in the United States.

In light of world opinion favoring preservation of tropical rain forests--and the pressures of growing populations of hungry people in tropical regions, neither can one look for massive new supplies of wood from that source.

Russia is a possible wood supplier, as are southern-hemisphere countries with substantial plantations of exotic pines. For example, pine plantations of sufficient extent to permit wood export exist in New Zealand, Brazil, and Chile. Plantation wood from these introduced pines, although useful for many purposes, can seldom be directly substituted for structural wood from our more dense (stronger) coniferous trees of the Northwest.

Considering the economics of long-distance transport, it seems likely that only the highest quality wood from these foreign sources will be competitive in North American markets. The bulk of wood exported from Russia and from the southern hemisphere pine plantations will likely go to help satisfy needs of rapidly growing populations in Asia and the southern hemisphere--with some going to a growing European market.

Since all nations are experiencing increased pressures for preservation, the alternatives of reduced consumption, recycling, and material substitution need consideration.

Worldwide reduction in consumption of raw materials generally seems unlikely in view of population trends (world population will probably double in the next century) and the propensity for nations to consume more materials (and energy) as their economies develop. It is undeniable that great economies of energy use in the United States could be accomplished, however. Rosenfeld and Hafemeister (1988) conclude, for example, that if the United States became as energy efficient as Japan, the United States could cut its energy consumption by half.

Recycling of solid wastes unquestionably has much merit, and there is general agreement that this activity should be given high national priority. As Bowyer (1991a) points out, however, there appears to be some practical upper limit to the proportion of recycled woody furnishes incorporated in fiber products; moreover, such fiber cannot be recycled indefinitely but must ultimately be replaced by virgin wood fiber. He concludes, using paper as an example, that if recycling could be pushed to the 50 percent rate, domestic demand for virgin wood fiber for paper could be 12 to 13 percent lower twenty year hence assuming no changes in per capita consumption of paper. In view of historical growth (Whitney 1980; TAPPI 1991) of paper and paperboard production--which averaged 4.0 and 4.5 percent annually from 1950 and 1980, and 2.4 and 2.2 percent annually from 1980 and 1989, attainment of such significant reductions seems problematical.

Repeated recycling of solid wood into structural materials to supplant lumber and plywood presents even more problems than recycling fiber for paper products.

If significant replacement of structural wood lost through reduced harvests cannot be obtained by import or by recycling, then the alternative seems to be a major increase in the consumption of nonrenewables--an action that will have global repercussions.

The balance of this paper estimates increases in energy demand and "greenhouse gas" (CO_2) additions to atmosphere resulting from shifts away from wood as a structural and architectural material to nonrenewable materials (consequent to reduced timber harvest in the Northwest), and ends with brief conclusions, comments, and recommendations. The underlying data behind the energy computations are derived from the 1976 report (Boyd, *et al.*, 1976) of Panel II of the Committee on Renewable Resources for Industrial Raw Materials made at the request of the National Research Council with support from the National Science Foundation. This publication, hereafter referred to as the CORRIM Report, was used as it was deemed the best comprehensive source available.

As previously noted, significant reductions in harvests are now occurring or are contemplated on virtually all National Forests administered by the USDA Forest Service (USFS) and on public lands administered by the Bureau of Land Management (BLM). This paper will not attempt to discuss all of these reductions but will concentrate on the impact of several strategies for protecting late successional old growth (LS/OG) forests within the range of the northern spotted owl (Figs. 1 and 2). Important among these strategies is that developed by the Interagency Scientific Committee (ISC); see Thomas, *et al.*, (1990). Both public and private ownerships will be affected, but the implementation process and the magnitude of effects remain uncertain.

Significant LS/OG areas within the range of the northern spotted owl have been identified and mapped in all or portions of 17 National Forests (Fig. 3) and 6 BLM Districts in Washington, Oregon, and northern California (Gordon, *et al.*, 1991), as follows:

USFS Region 5 (Northern California)
    Klamath
    Shasta - Trinity
    Mendocino
    Six Rivers

USFS Region 6 (Oregon)
    Deschutes (west of Highway 97)
    Mt. Hood
    Rogue River
    Siskiyou

Siuslaw
Umpqua
Willamette
Winema (west of Highway 97)

USFS Region 6 (Washington)
Gifford Pinchot
Mt. Baker - Snoqualmie
Okanogan (west of Chewaukum River)
Olympic
Wenatchee

BLM Districts
Coos Bay
Eugene
Lakeview
Medford
Roseburg
Salem

These National Forests, BLM Districts, and the private (and other public) forests adjacent and intermingled, are hereafter referred to as the "owl" region (Fig. 2).

Historic and Projected Levels of Harvest in the "Owl" Region

In light of the intense and continuing debate over the projected annual harvest of roundwood from the "owl" region, it seems useful to select a base case founded on past harvest levels. With this in mind, the base case selected is the average annual harvest level for the years 1983 through 1987 as reported by Rasmussen (1990). That is, 4.51 billion board feet Scribner log scale from the National Forests (USFS) and from Bureau of Land Management (BLM) lands. Roundwood harvested annually from private (and other public) forests during this period averaged 9.34 billion board feet Scribner log scale. Total roundwood harvested annually from the "owl" region during this time interval therefore averaged 13.85 billion board feet (Table 1).[1]

Other projections of harvest in the "owl" region are more difficult to define. To simplify these projections, and yet cover the range of proposals, only four scenarios in addition to the base case will be discussed.

USFS Forest Plans (scenario 2) have changed substantially over the past several years and are still in contention. These plans included owl conservation measures that predated the ISC report. Gordon, *et al.*, (1991) noted that earlier USFS plans called for 4.3 billion board feet harvest, but they provide their own estimate of 3.4 billion board feet. Their tabulated figure of 3.8 for the USFS and BLM is intermediate, and the figure of 8.6 billion board feet annually from private (and other public) forest is somewhat lower than the 1983-1987 average harvest level (Table 1).

Scenario 3 is the Federal conservation strategy reported by Gordon, *et al.*, (1991) in which harvest from USFS and BLM lands is drastically curtailed to 0.8 billion board feet annually, while private (and other public) harvest remains at 8.6 billion board feet (Table 1).

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[1] To put this in perspective, total annual softwood roundwood consumption in the United States during the years 1983-1987 averaged 12,799 million cubic feet, approximately 64 billion board feet Scribner log scale (Ulrich 1990, Table 5).

In scenario 4 the USFS and BLM harvest is held to the same low level as in scenario 3 (0.8 billion board feet), but the harvest from private (and other public) forest is nearly halved to 4.8 billion board feet as reported by Rasmussen (1990). This estimate is based on possible implementation of the ISC strategy on private lands.

Scenario 5 retains the low level of harvest on USFS and BLM land, but has a harvest from private (and other public) lands intermediate between scenarios 3 and 4 (Table 1). While it is difficult to define a "most-likely" outcome, this scenario at least recognizes that the implementation process so far includes extensive conservation on federal lands and some conservation on private (and other public) lands.

Distribution of Roundwood Harvest by Product Class

To assess energy impacts of the five scenarios by application of data in the CORRIM Report, it is first necessary to estimate the proportion of roundwood entering various classes of primary processing plants. Analysis of these proportions in the "owl" region for the year 1985 show that the preponderance of the logs enter lumber mills, with a significant proportion entering plywood mills (Table 2). The fiber segment of the industry is largely supplied by wood chips residual from manufacture of lumber and plywood.

Most of the logs exported from the West Coast go to Japan and other Pacific Rim countries. Regardless of log export destination, it seems likely that virtually all of the logs are consumed by sawmills (softwood sheathing plywood is little used in destination countries, and pulp mills import most of their wood in chip form). From these export logs, foreign mills in aggregate probably achieve somewhat higher product recovery than those in the United States, and therefore expend at least as much net energy per ton of product output.

If one makes this assumption that the export logs go to sawmills, then the distribution of logs by product class differs significantly with log source; that is, a higher proportion of logs from private land enter sawmills than those from USFS and BLM lands (Table 3).

As noted previously, harvest statistics are generally reported in board feet Scribner log scale. It is useful to convert such volume data to cubic feet of wood (Table 4). A commonly accepted conversion factor is 200 cubic feet of green wood, bark-free, from one thousand board feet (MBF) Scribner log scale of logs of typical diameter from the "owl" region.[2]

To convert the cubic volume of wood in logs to ovendry weight of wood, one must first assign values for wood specific gravity, and then calculate the weight (ovendry) of a cubic foot of wood (Table 5). An unweighted average of the values shown in Table 5, suggests that a cubic foot of wood cut from green logs in the "owl" region has an ovendry weight of about 27 pounds. Application of this conversion factor to data in Table 4, yields the weight data in Table 6.

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[2] In personal communication 27 August 1991 with Darius Adams, University of Washington, he advised that a regional conversion factor of 200 is reasonable. He also noted that a more accurate conversion would be 182 cubic feet/MBF for USFS timber, 200 for non-USFS public lands, 210 for industrial ownerships, and 230 for nonindustrial ownerships. It is also evident that the conversion factor differs for stud mills, large-log mills, plywood plants, post and pole operations, and chip mills. In view of the other approximations made, however, the factor of 200 cubic feet/MBF Scribner log scale was used for all ownerships to simplify calculations.

Weight Yield of Primary Products

Only a portion of total log tonnage ends in primary product. As explained by material-balance diagrams in the CORRIM Report, much of the wood in each log ends as pulp chips, furnish for reconstituted boards of various types, or as fuel. Of softwood logs admitted to a sawmill, about 31 percent of the ovendry weight of wood in the log ends as dry planed lumber. For logs admitted to a softwood plywood plant, about 50 percent of the ovendry weight of wood in the logs ends as plywood (unsanded).

Roundwood consumed in the United States in the form of posts, poles, and piles, loses little volume during conversion to product; probably nine-tenths of wood weight entering such plants leaves as primary product.

Pulp, paper, and paper board (hereafter called pulp and board) yield averages about 50 percent of incoming wood weight; the residual 50 percent is largely consumed within plant to generate process heat and energy.

By multiplying allocation percentages from Table 2 by the product yield factors just described, primary product weight (ovendry) per million MBF Scribner log scale input can be calculated (Table 7). The additional yield of pulp and board, and of reconstituted panel boards such as medium density fiberboard (MDF) and particleboard, from mill residues can be derived from the material balance diagrams in the CORRIM Report. The results of these computations are summarized in Table 7.

Projected Reductions in Annual Product Output

From roundwood input data in Table 1 and product output data in Table 7, the reductions in annual product tonnage output (below the base case scenario 1) can be calculated for scenarios 2, 3, 4, and 5 (Table 8). For example, the extreme case of scenario 4 would result in a decrease in annual lumber production of 5,300,170 tons, ovendry basis; that is, 2,148,847 tons from USFS and BLM lands and 3,151,323 tons from private (and other public) lands.

Energy Consequences of Projected Harvest Reductions

Data in the CORRIM Report, on which this analysis is primarily based, are representative of those processing plants in 1976 that were economically viable and from which a significant percentage of primary structural and architectural materials flow, and may be considered characteristic of progressive manufacturing plants of that year throughout the United States. In the intervening 15 years some improvements in product yield and energy usage have been made. These improvements may be significant, but are not likely to greatly alter the substantial differences between the energy requirements for manufacture of wood and non-wood structural materials.

In making the analysis of energy requirements of various commodities important in structures, gross energy needs for extraction (harvesting in the case of wood), processing into product, and transport to building site were first summed, and then energy available from process residues was subtracted to yield a net total expressed as million BTU (oil equivalent) per ovendry ton of product (Table 9). Energy potentially available from wood residues was credited only against commodity manufacturing energy requirements (that is, not against needs for harvesting, manufacture of resins or wax, or transport to building site). No energy contribution was allowed for residues left in the forest. As fossil fuels become increasingly expensive, practical techniques will undoubtedly be developed for more intensive harvesting of such residues within limits imposed by site requirements for organic material.

To achieve a uniform mode of expressing energy consumed and available from residues, the CORRIM Report used the unit million BTU thermal (oil). For example, a gallon of diesel oil contains 138,336 BTU or 0.138 million BTU thermal (oil). For the purposes of this paper I have referred to this unit as "million BTU (oil equivalent)".

To assess the energy consequences of replacing wood products in structures with nonrenewables, it is convenient to start with the net energy required for one ton of the product computed as described above and summarized in Table 9. For example, to produce and get to the building site one ton of lumber (ovendry basis) requires a net energy expenditure of 2.91 million BTU (oil equivalent).

Next it is necessary to know the weights of the wood products and the replacement products under analysis (Table 10). From these data the ratio of weights of nonwood alternatives to the weight of wood products replaced can be computed (Table 11). This ratio multiplied by the energy needs per ton of nonwood product yields the net energy required by the nonwood product to replace a ton of wood product. Some examples follow.

Lumber

Wood studs vs steel studs: To manufacture and transport to site one ton of 8-foot 2 x 4 wood studs requires a net energy input of 2.91 million BTU (oil equivalent). If these studs were replaced by steel studs (Fig. 4), net energy required (Tables 9 and 11) for the steel studs would be 26.67 million BTU (oil equivalent), that is, (0.53)(50.32).

Wood tongue and groove flooring vs nonrenewable carpet and pad: To manufacture and transport to site one ton of wood flooring requires net energy input of about 2.91 million BTU (oil equivalent). If this flooring were replaced by carpet and pad of manmade fibers , net energy input for the carpet and pad would be 12.27 million BTU (oil equivalent), that is, (0.33)(37.19).

Wood joist floor with plywood subfloor vs 4-inch concrete slab: To manufacture one ton of such a wood floor net energy requirement is 4.14 million BTU (oil equivalent), that is:

$$2.91 \times 1{,}208/2000 + 6.00 \times 792/2{,}000 = 4.14$$

If this ton of wood joist-plywood floor were replaced by a 4-inch concrete slab, net energy required by the concrete would be 86.31 million BTU (oil equivalent), that is, (10.13)(8.52).

Generalization regarding substitution of nonrenewables for lumber: Obviously it is a great oversimplification to suggest that steel studs, carpet and pad, and concrete slabs are the only nonrenewable substitutes for lumber, but the averages of these three cases give some indication of the energy penalty paid for using nonrenewables in place of lumber, as follows:

	Net energy required per ton of lumber product or its nonwood equivalent ——Million BTU (oil equivalent)——	
Products	**Lumber**	**Nonrenewable**
Studs (lumber vs steel)	2.91	26.67
Floor surfaces (lumber vs carpet)	2.91	12.27
Floor structure (joist system vs concrete)	4.14	86.31
Average	3.32	41.75
Penalty per ton of lumber replaced	38.43	

Plywood

Plywood siding vs aluminum siding: One ton of plywood siding requires a net energy input of about 6.00 million BTU (oil equivalent). If this one ton of plywood siding is replaced by aluminum siding, the aluminum siding will require a net energy input of about 32.08 million BTU (oil equivalent), that is, (0.16)(200.47).

Plywood siding vs brick veneer: As noted above, a ton of plywood siding requires a net energy input of 6.00 million BTU (oil equivalent). If this plywood is replaced by brick veneer, the brick will require a net energy input of about 175.22 million BTU (oil equivalent), that is (19.34)(9.06).

Generalization regarding substitution of nonwood for plywood: Two cases cannot represent the spectrum of substitutions for plywood, but they are illustrative. For these two cases the averages are: 6.00 million BTU (oil equivalent) for plywood and 103.65 for the nonrenewables. The energy penalty for replacing a ton of plywood with nonrenewables is therefore 97.65 million BTU (oil equivalent).

Pulp and Board

The argument over relative energy efficiencies of paper products vs plastics and other nonrenewables is so complex, and disagreement so widespread among technologists, that for the purposes of this paper it is considered a stand-off. No energy penalty is assumed for substituting nonrenewables for paper products, therefore, in the computations that follow.

Post, Pole, and Pile

A ton of wood fence posts butt-treated with water-borne copper naphthenate requires a net energy input of about 4.00 million BTU (oil equivalent). An equivalent number of steel fence posts will require about 23.65 million BTU (oil equivalent), that is, (0.47)(50.32). The penalty per ton of wood posts replaced with steel is therefore 19.65 million BTU (oil equivalent), that is, 23.65 - 4.00 .

This example undoubtedly oversimplifies the very complex comparison of roundwood products to the various steel, aluminum, and concrete structures that compete with wood posts, poles, and piles. The example is easily understood, however, and has been used in the computations that follow.

MDF and Particleboards (and Other Residue Boards)

Reconstituted boards of various kinds find a multitude of uses. Should they be replaced by nonrenewables the list of substitutes would be long and complex.

To simplify the comparisons and to utilize the CORRIM data, only two cases are considered--one comparing medium density fiberboard (MDF) siding with aluminum siding, and the other comparing MDF siding with brick veneer (Tables 9 and 11), as follows[3]:

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[3] Since the CORRIM Report was published, structural flakeboard siding and vinyl siding have gained market share over MDF and aluminum siding. While comparison of flakeboard siding with vinyl siding might better depict the current situation, it is likely that energy consequences would be much the same as the consequences tabulated. Today, MDF is much used in furniture, so that a pertinent comparison could be between steel or plastic furniture and that made with solid wood or MDF.

Net energy per ton of MDF siding or its nonwood equivalent
---Million BTU (oil equivalent)---

Products	**MDF**		**Nonrenewables**
MDF siding vs aluminum siding	8.49	(0.17)(200.47) =	34.08
MDF siding vs brick veneer	8.49	(20.23)(9.06) =	183.28
Average	8.49		108.68
Energy penalty per ton of MDF replaced by nonrenewables	100.19		

Energy Consequences of Scenarios 2, 3, 4, and 5

The foregoing computations permit calculation of the total increase in annual energy requirement, above the base case of 1983-1987 average harvest in the "owl" region, attributable to replacing wood in structures with nonrenewables. The totals are massive (Tables 12 and 13), and are summarized (Fig. 5) as follows:

Scenario	**Million BTU (oil equivalent)**	**Million gallons of oil**	**Million barrels of oil**
2	144,209,698	1,045	24.9
3	464,340,661	3,365	80.1
4	815,824,089	5,912	140.8
5	640,082,316	4,638	110.4

To put these quantities in perspective, the Alaska pipeline which supplies about one-fourth of the oil needs of the United States, pumps at maximum about 2 million barrels of oil daily (Hodgson 1990). Thus the projected harvest reductions in the "owl" region could annually cause consumption of from 12 to 70 days of output of the Alaska pipeline, pumping at capacity. In other terms, 140.8 million barrels of oil yearly is about sufficient to annually operate a fleet of 11 million automobiles.

As further perspective, the Exxon Valdez was carrying 1.2 million barrels of oil when she spilled 11 million gallons in April of 1989. Unless our appetite for building materials decreases, or unless we massively increase wood imports, the global increase in annual oil consumption resulting from scenario 4, for example, could amount to the entire cargoes of 117 such tankers.

CO_2 Consequences of Harvest Reductions

To introduce their paper on this subject, Oliver, *et al.*, (in press) wrote as follows:

> There is a given amount of carbon in the world. It exists primarily either as CO_2 in the atmosphere or as "storage" in living or formerly living things. Carbon is taken out of the atmosphere and put in "storage" in organic compounds by photosynthesis of plants. The storage can be in several forms
> - ○ living and recently living plants and animals
> - ○ fossil fuels such as coal, oil, and natural gas
> - ○ limestone and marble, from marine plants and animals

> Carbon is returned to the atmosphere by reduction of one or more of these "storage centers." This reduction can be by rot, combustion, respiration, and dissolution (of calcium carbonate).
>
> There is concern that the carbon is being moved out of storage and into the atmosphere more rapidly than it is being taken out of the atmosphere and put into storage, resulting in an increase in CO_2 in the atmosphere.

Additions of CO_2 to the atmosphere as a consequence of replacement of wood in structures with nonrenewables are significant. These additions are the sum of two components. First is the increase attributable to the higher energy requirements of the nonrenewables--with consequent increase in combustion of fossil fuels. Second is the effect attributable to forest age and productivity, and longevity of wood products in service.

Increase Attributable to Energy Requirements of Nonrenewables

Scenarios 2, 3, 4, and 5 all call for reductions in wood product output below the base case scenario 1 (Table 8). If the wood products eliminated by these reductions are replaced by nonrenewables, the annual consumption of energy will increase significantly. If these increased energy requirements are translated into million BTU (oil equivalent) as shown in Table 12, and then translated into gallons of oil (Table 13), the additional CO_2 added to atmosphere by the increased fuel oil consumption can be computed (Table 14).

The foregoing analysis of increased CO_2 additions to atmosphere attributable to substitution of nonrenewables for wood could be criticized on the grounds that the source for the additional energy needed might be relatively pollution-free hydroelectric power rather than oil. The counter argument would be that our Northwest hydroelectric power is already fully committed, and in view of the possibility (probability?) of placing certain anadromous fish on the endangered species list our available hydroelectric power may in fact be reduced.

In some applications natural gas--which at the moment seems to be in surplus supply--could serve as the energy source with less potential for CO_2 additions to atmosphere than oil. It is true that each gallon of fuel oil burned adds 22.44 pounds of CO_2 to atmosphere, whereas an equal heat content of natural gas adds significantly less (16.55 pounds). The counter argument would be that no matter where the nonrenewables are produced, about 13 percent of the requirement is expended during extraction and transport--expenditures that are normally supplied by diesel fuel. Moreover, as noted in the introduction, a significant percentage of the nonrenewables come from foreign lands where oil or coal are the predominant energy sources.

Over the centuries, it may be that most energy for industrial purposes will come from atomic power plants or from hydrogen processes not yet commercially developed. But for the next several generations fossil fuels will likely dominate.

Under scenarios 2, 3, 4, and 5 wood product output would be significantly reduced. Concomitant with this reduction would be a reduced quantity of woody residues burned as fuel for energy needs of the wood product manufacturing operation (but not for needs of harvesting or product transport). This reduction in combustion of woody fuel would reduce some of the CO_2 consequences of burning additional fossil fuels to manufacture the nonrenewable replacement products.

For the purposes of this analysis it has been assumed that half of the woody residue is bark and the other half wood. Data on ultimate chemical analysis (defining carbon content) and heat content of wood and bark are both available for Douglas-fir from the "owl" region (Wilson, *et al.*, 1987), and have been used in computations of CO_2 additions. Carbon content of bark is about

53.7 percent--slightly more than the carbon content of wood, 52.3 percent. Thus, each pound (ovendry basis) of bark burned yields 1.969 pounds of CO_2, while a pound of wood yields 1.918 pounds of CO_2. The average is 1.944 pounds of CO_2 per pound of woody residue.

The heat of combustion of wood is about 8,600 BTU/ovendry pound, whereas that of Douglas-fir bark is about 10,100 BTU/pound ovendry. The average is 9,350 BTU/pound. From these data it can be computed that production from woody residue of BTUs totalling that in one gallon of diesel fuel (138,336 BTU) will add a maximum of 28.76 pounds of CO_2 to the atmosphere.

Table 7 of the CORRIM Report shows the energy contribution of wood residue to wood product manufacture. That is, it is the lesser of the values tabulated for available energy and energy needs during manufacture (excluding logging and transport).

Application of all these data to the tonnage reductions shown in Table 8 yields the values shown in parentheses in Table 14. Table 14 can be summarized to show the net addition of CO_2 to atmosphere resulting in substitution of nonrenewables for wood products, according to scenario, as follows:

Scenario	Annual CO_2 additions to atmosphere above the base case (scenario 1) -------Million tons of CO_2-------
2	10.9
3	35.1
4	61.6
5	48.3

Increase (or Decrease) Attributable to Forest Age

According to Houghton and Woodwell (1989), carbon addition to atmosphere is increasing by about 3 billion metric tons annually. The major share of carbon additions to atmosphere is estimated to come from burning fossil fuels, that is, 5 billion metric tons of carbon per year (Buchanan 1991).

While it is obvious that both forests and wood products temporarily store carbon, it is equally obvious that such storage can only buy time in the battle to restore balance between carbon additions and carbon subtractions from the atmosphere. That is, sequestering carbon in forests and wood products cannot indefinitely offset the massive infusions of atmospheric carbon resulting from combustion of fossil fuels.

The real driving force in carbon additions is the thermodynamic law of entropy, which provides a measure of change toward unavailable energy in a system. According to the law of entropy, energy in systems tends to move from available to unavailable condition. For example, a gallon of oil or a lump of coal containing available heat energy can be burned to provide heat to boil water and produce high-temperature steam to move a piston and, by overcoming friction, drag a load over a horizontal surface. At the end of movement the lump of coal is reduced to ash, heat from friction and from low-temperature exhaust steam is dissipated to atmosphere, and the load is at rest and has not changed its elevation--hence has gained no kinetic or potential energy. That is, the available energy in the coal is spent, the process is not reversible, and entropy of the system has increased.

Within the time frame of mankind's likely span on earth, the gallon of oil or the lump of coal in the example cited cannot be replaced. Not so with wood, however; through photosynthesis driven by input of solar energy, a lump of wood (containing available energy) can easily be replaced within a single human life span.

It is beyond the scope of this paper to address the increase in entropy (decrease in available energy) in our global situation. Discussion is therefore reduced to the question: Does an unutilized, occasionally burned, late-successional old-growth forest, over the long term, add more or less CO_2 to the atmosphere than a younger forest intensively managed to yield forest products having some discrete life before these products decay or are burned?

Table 1 of Rasmussen's (1990) impact evaluation indicates that total area of USFS, BLM, and State forestland suitable for owl habitat conservation is about 13,502,000 acres in the "owl" region. In Rasmussen's (1990) description of impacts on private lands, he notes that the private forest area suitable for owl habitat conservation is slightly larger than that encompassed by the affected public lands. This suggests that somewhat more than 27 million acres would be affected by owl habitat conservation measures.

Oliver, *et al.*, (in press) make a comparison between several management options for these public and private lands. Two options of interest to this analysis are as follows:

- Protect these acres so that stand-replacing wildfires--which consume the forest--occur only once every 240 years (no on-site management performed)
- Harvest the old growth on these acres, burn (or naturally decay) the logging slash, and grow Douglas-fir plantations on 65-year rotations.

They conclude that over a 400-year time span there would be only a modest difference in the amount of carbon stored per acre under these two options. That is, the plantation would store 18 percent less carbon than the old-growth forest.

Because the two options represent extremes (harvest nothing, or convert all to tree plantations on 65-year rotation), the effect of forest age in scenarios 1 through 5 on CO_2 additions to atmosphere is deemed minimal. Fundamental to this conclusion is the assumption that public and private forest acreages in the "owl" region will not be significantly diminished by conversion to non-forest uses.

Dewar (1990) observed that carbon storage related to forests and harvests is the sum of two components: that stored by the trees and that stored in wood products resulting from timber harvest. His model indicates that when forests are managed for maximum sustained yield of wood, the contribution to long-term carbon storage in living trees is about one-third that in forests of mature trees (age not specified). The contribution from timber products, according to his model, is typically about: (2.5)(average time for product to decay/commercial optimum rotation time). By this rationale, a rotation age of 65 years and a decay time of wood in structures of 78 years would accomplish carbon storage equal to that of a mature forest.

Supporting Dewar's findings, Harmon, *et al.*, (1990) conclude from their model that if carbon storage is to be unaffected by conversion of old-growth forests to young fast-growing forests (60-year rotation), life span of wood in structures should be significantly longer than the 50-year life-span assumed in their model. That is, carbon storage is increased by increasing durability of wood in service.

These findings of Dewar and of Harmon, *et al.*, contain a challenge to land managers to get--on short rotations--high yields of structural wood from multiple-use forests. Just as important are the challenges to wood technologists to maximize yield of structural and decorative products from each cubic foot of wood harvested, and to develop economic and energy efficient ways to increase life spans of wood products in use. Additionally, builders must be taught to use wood intelligently so it will be protected from decay and fire, thereby increasing its longevity in service.

Conclusions, Comment and Recommendations

Conclusions

In comparison to the average annual timber harvest for the years 1983-1987 in the "owl" region (Base Case scenario 1), the various strategies under consideration for conservation of the northern spotted owl, and other harvest considerations, in Washington, Oregon, and California all call for substantial harvest reductions on both public and private lands. These timber harvest reductions will reduce output of structural wood products. If nonrenewable structural materials such as steel, aluminum, concrete, brick, and plastics replace the structural wood shortfall, there will be significant increases in global energy consumption (Fig. 5), and in carbon dioxide additions to the atmosphere, as follows:

Scenario	Reduction in annual timber harvest (Billion bd ft Scribner)	Increase in annual energy energy consumption (Million barrels of oil)	Increase in annual addition of CO_2 to atmosphere (million tons)
	USFS, BLM, PRIVATE (AND OTHER PUBLIC) FORESTS		
1. Base Case 1983-1987 harvest	0.00	0.0	0.0
2. Federal Forest Plans (in flux)	1.45	24.9	10.9
3. Federal Conservation LS/OG strategy	4.45	80.1	35.1
4. Private Conservation ISC strategy	8.25	140.8	61.6
5. Private Conservation Mid-range strategy	6.35	110.4	48.3

The extreme case of full implementation of the ISC strategy (scenario 4) could result in an additional fuel oil consumption equal to about 70 days' output of the Alaska pipeline operating at capacity. Annually, the Alaskan pipeline presently supplies about one-quarter of the nation's oil requirements. For further perspective, an increased world consumption of 140.8 million barrels of oil annually is about equal to 117 cargoes of tankers the size of the Exxon Valdez--enough to annually operate a fleet of 11 million automobiles.

Time will eventually tell what effect extra annual additions of 11 to 62 million tons of CO_2 into the atmosphere will have on global warming trends.

The data developed in the preceding discussion probably represent an upper boundary situation, for several reasons. First, by recycling and other measures taken since 1976, the steel and aluminum industries have significantly lowered their energy requirements. The energy ratios between wood and these metals may therefore be lower than the CORRIM Report suggests.

Additionally, all of the harvest loss in the "owl" region will not be replaced by nonrenewables. That is, some additional wood will be imported. In view of the knot structure and low specific gravity of much of the plantation-grown pine from the southern hemisphere, however, more than one cubic foot of such imported wood will be required to serve the structural purposes served by one cubic foot of Douglas-fir.

Also one might take issue with the material balance diagrams depicted in the CORRIM Report--particularly the rather high percentages of each log going to reconstituted panels. The diagrams accurately depicted the situation in 1976, but may not accurately depict the situation in the 1990s. Moderate shifts in wood allocation among various structural wood products should not, however, have a profound effect on the overall energy advantage of wood compared to nonrenewables.

Comment

Central to any discussion of levels of harvest in the "owl" region is the question of sustainability of the harvest in perpetuity. Obviously there are passionate arguments over the level of harvest acceptable to the Nation's many publics.

Many professionals in the field of silviculture knowledgeable about the outstanding productiveness of the forests in the "owl" region believe that if intensive forestry were practiced on all suitable acres (excluding designated wilderness areas and other areas reserved prior to the "owl" controversy) the 1983-1987 average harvest levels could be maintained in perpetuity. Others are less sanguine, not so much because of doubts about potential forest yield, but because of doubts that USFS, BLM, and private policies will broadly permit long-sustained application of intensive forestry practices to the forests within the "owl" region.

Most silviculturists would agree that over millennia, "owl" region forests intensively managed on 65 to 120-year rotations would grow more tonnage of wood for structural products per acre per year than if less intensively managed over long rotations--for example, 450 years.

Concern about the environment, which fuels much of the passion in the argument over harvest level, often appears to be focused on local and regional issues, but not on global effects. Regardless of the uncertainty in assumptions involving the degree of product substitution, and those involving harvest reductions, it is abundantly clear that there are substantial environmental consequences beyond the preservation of local forestland.

It is an anomaly that a significant segment of the population of the United States--professional foresters as well as lay public--considers it not only economically practical, but environmentally ethical, to:

- Forego tree plantations on some of the highest quality sites in the United States, while accepting the strategy of purchasing more expensive wood from foreign coniferous tree plantations that have been created out of habitat native to the country of origin. Because of the lower productivity of many of these foreign forests, and the knot structure and low specific gravity of wood produced in them, the acreage of habitat lost outside the United States will exceed the acreage preserved inside the United States.

- Forego sustainable tree plantations on major acreages of the Pacific Nothwest--one of the premier timber growing areas of the world, but accept substitution of more costly nonrenewable materials (significant quantities of which are imported) for renewable wood at the expense of significantly greater global energy consumption, fossil fuel depletion, carbon dioxide additions to atmosphere, and nonrenewable materials depletion.

Logic suggests--that after careful consideration of our national and individual interests, and of the global environmental, ethical, and economic forces at work--our publics and our forest managers will ultimately perceive the wisdom of a mid-course that protects certain ecosystems but permits rational multiple-use management of the balance of the forest.

Recommendations

No one knows what humankind's span on earth will be, but it is not unreasonable to design our strategies for management of forest amenities and resources based on millennia rather than decades, or even centuries. Given the propensity of human populations to increase, and the human appetite for material goods and energy--whether renewable or nonrenewable--it would also seem reasonable to intensify our management of the amenities and resources provided by forests, and to resist any significant diminution of acreage committed to forests. In addition to these two general recommendations (for very long-range management, and protection of forested acreages coupled with intensification of management), specific recommendations are as follows:

- Research efforts should be intensified to increase the percentage of each harvested tree's volume converted into structural products, and to prolong longevity of wood in service.
- To the extent technically and economically practical, paper and paperboard products (short lived) should be made from recycled fiber or from wood residual from, or unsuitable for, manufacture of long-lived solid wood products.
- Recent surveys suggest that the northern spotted owl is more numerous, and its habitat more varied, than originally thought. Research should be intensified to develop silvicultural systems and stand structures that will protect owl populations and also permit sustained harvests of wood.
- In spite of the millions of dollars and decades of time devoted to determining levels of sustainable harvests from our national forests and from private forestlands, it appears that few answers are in hand with which knowledgeable silviculturists are comfortable. Perhaps levels of harvest will always be in some degree of flux, but effective research to determine levels sustainable in perpetuity should be intensified.
- New knowledge should be sought, and existing knowledge applied, to maximize periodic wood accumulation (and carbon capture) in our public and private commercial forests. On most commercial forest acres rotations should be timed to maximize yield of wood for structural uses--with effective action taken to protect water flows and quality, fauna, and esthetic values over the centuries and millennia.
- Data contained in the CORRIM Report (particularly Panel II data) should be updated, and resultant information widely disseminated to professional foresters, architects and builders, politicians, and to the nation's various publics.
- Not only humankind will be adversely affected by an extreme buildup of carbon dioxide in the atmosphere; fauna of the world--including the owl--will also be threatened. Efforts should be intensified, therefore, to inform the nation's various publics and politicians of the important role played by intensively managed forests, and structural wood products therefrom, in capturing and sequestering carbon--and slowing drawdown of fossil fuels and nonrenewable materials.

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Figure 1. Range of the northern spotted owl. Drawing after Thomas, *et al.*, (1990).

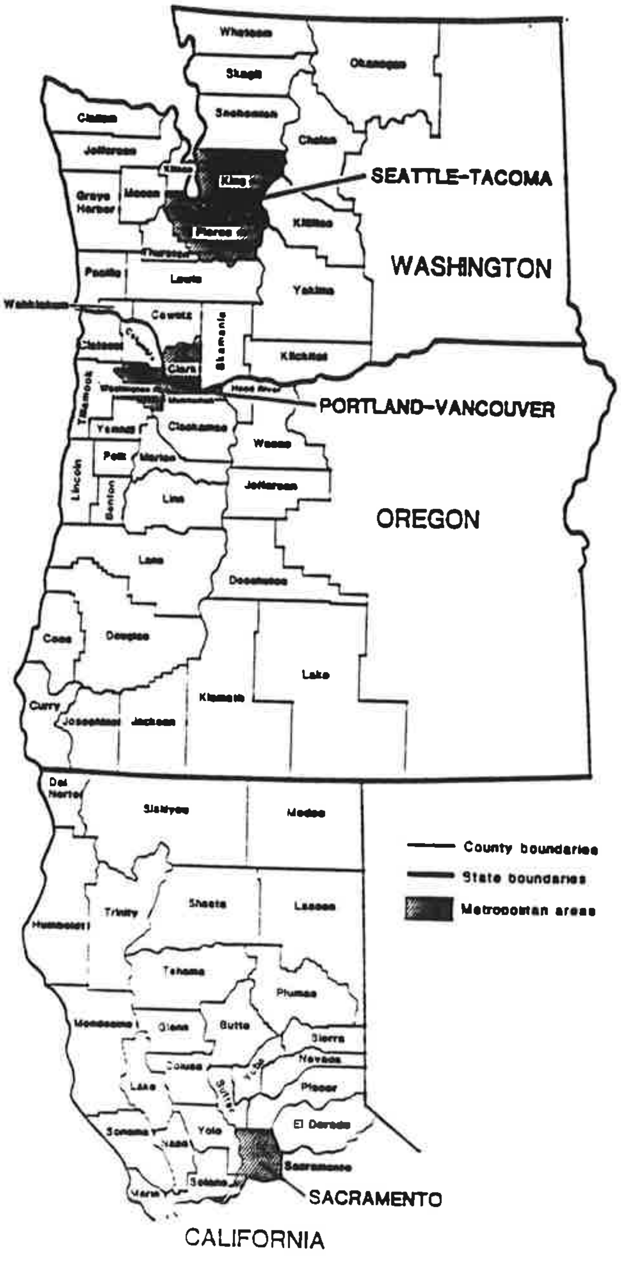

Figure 2. Counties and portions of States within the "owl" region. Drawing after Beuter (1990).

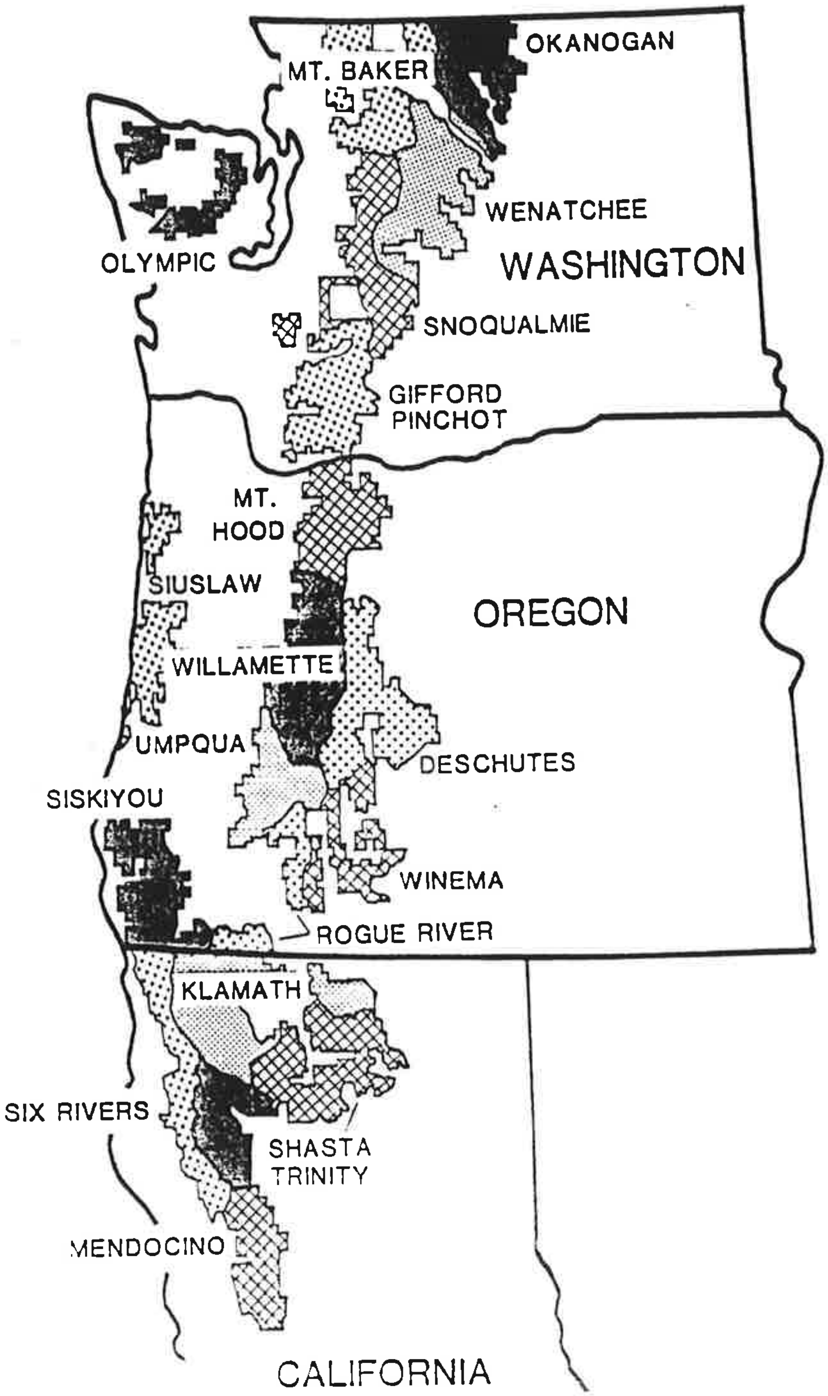

Figure 3. National Forests in Washington, Oregon, and California within the "owl" region. Only westerly portions of the Deschutes, Winema, and Okanogan are within the region (see text).

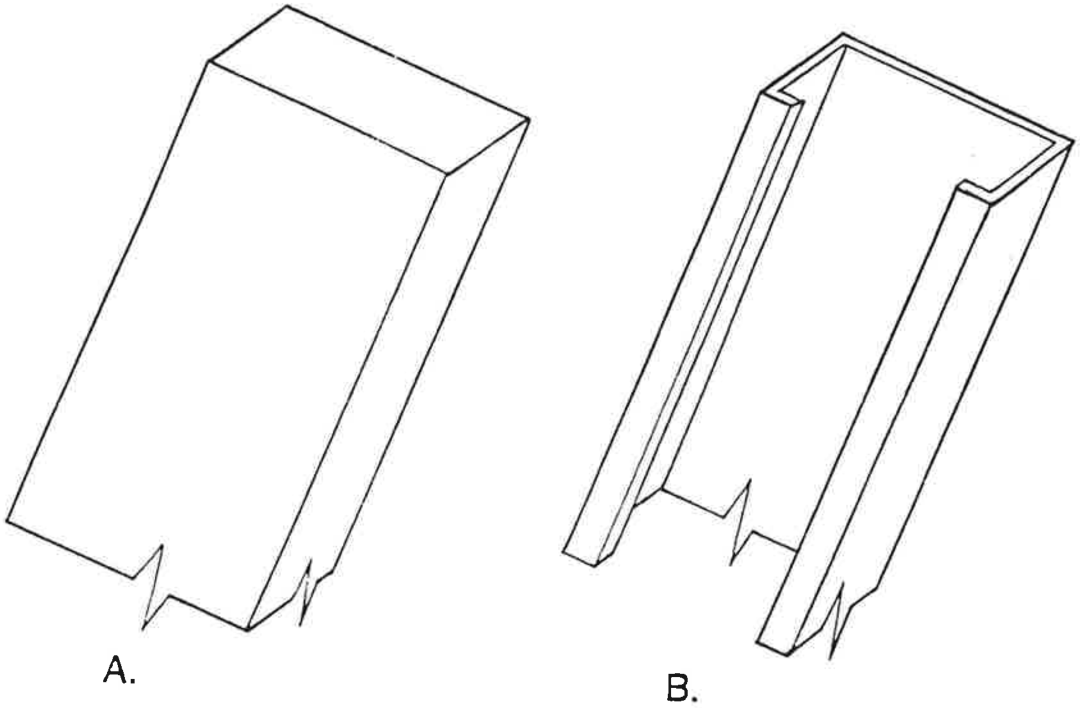

Figure 4. Wood and steel studs. The steel stud (B) weighs about half as much as the wood stud (A), requires up to nine times the energy to produce and transport to building site, and costs about 75 percent more than the wood stud.

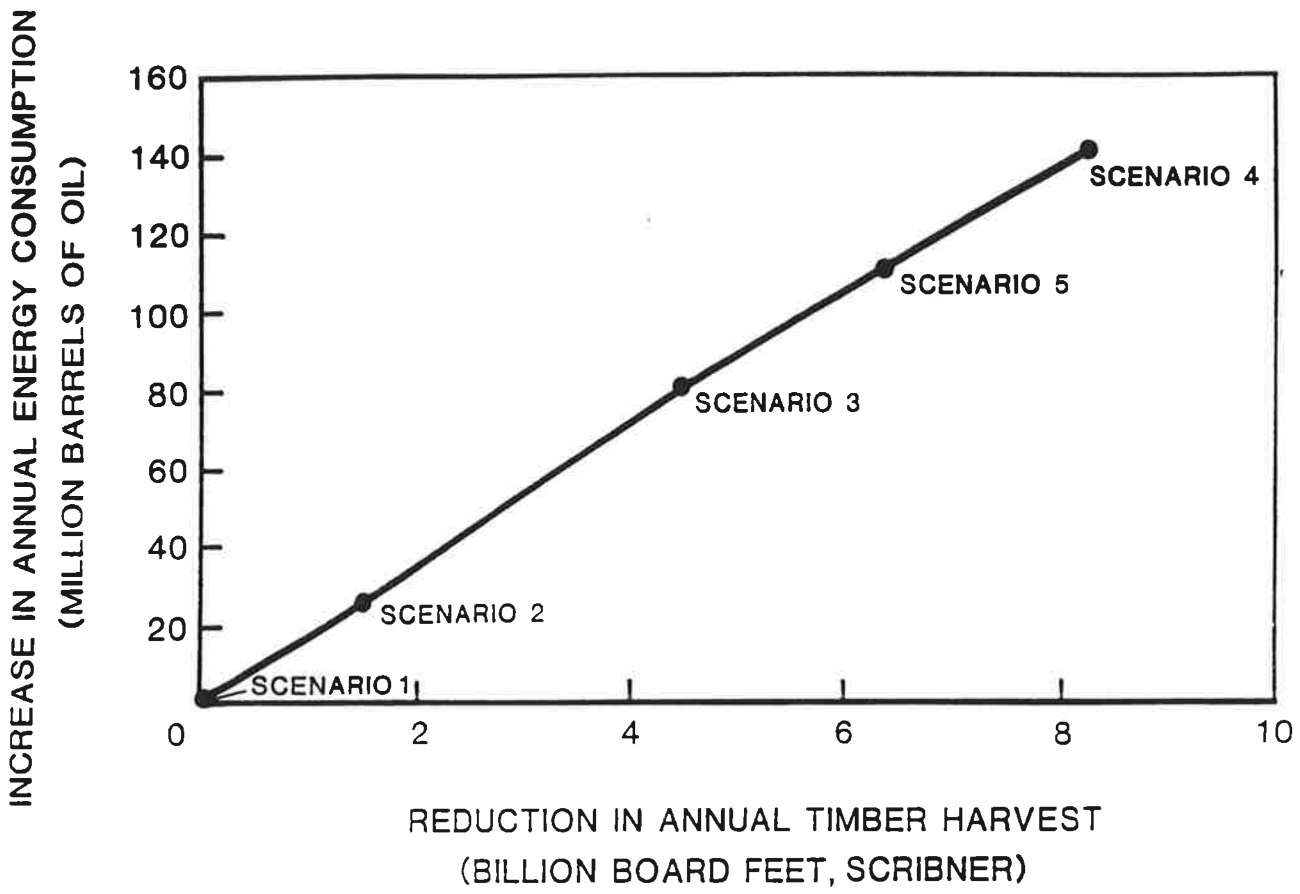

Figure 5. Annual increase in global energy consumption related to reductions in annual timber harvest associated with alternative scenarios for managing forest lands in the spotted owl region of the Pacific Northwest.

Table 1. Annual roundwood harvest projected for the "owl" region according to five scenarios, beginning with the base case of the average harvest for the years 1983 through 1987. (Billion board feet, Scribner log scale)

Scenario	**USFS and BLM**	**Private (and other public)**	**Total**
1.Base Case 1983-87 harvest[a]	4.51	9.34	13.85
2.Forest Plans[ab]	3.8	8.6	12.4
3.Federal Conservation LS/OG strategy	0.8[c]	8.6	9.4
4.Private Conservation ISC strategy	0.8	4.8[a]	5.6
5.Private Conservation Mid-range strategy	0.8	6.7[d]	7.5

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[a] Rasmussen (1990).

[b] Federal Forest Plans have changed substantially over the last several years and are still under contention. These plans include owl conservation pre-ISC. Gordon, *et al.*, (1991) noted the earlier Forest Service studies called for 4.3 billion board feet harvest but they provide their own estimate of 3.4 billion board feet. The tabulated figure of 3.8 is intermediate.

[c] Gordon, *et al.*, (1991).

[d] A mid-range estimate of full ISC impact on private lands; that is, one-half the private-land impact outlined in scenario 4.

Table 2. Proportion of 1985 annual roundwood harvest (Scribner log scale) in the "owl" region consumed by processor according to product class [Olson 1990, Appendix C; derived from Howard and Ward 1988ab, and from Washington State Department of Natural Resources 1990 (and Washington State annual compilations of timber harvest)].

Product class	**USFS and BLM** **%**	**Private (and other public)** **%**
Lumber and shakes	69.04	54.69
Veneer and plywood	29.53	12.44
Pulp and board[a]	1.16	4.25
Export	0.16	28.24
Post, pole, and pile	0.11	0.38
Total	100.00	100.00

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[a] Pulp and board from roundwood only; does not include pulp chip residues from other primary manufacturing operations.

Table 3. Distribution of roundwood harvested from all lands in the "owl" region by product class of processor and by forest ownership, for five scenarios. (MBF, Scribner log scale)[ab]

Product class	**1**	**2**	**Scenario** **3**	**4**	**5**
			USFS AND BLM		
Lumber and shakes[c]	3,120,920	2,629,600	553,600	553,600	553,600
Veneer and plywood	1,331,803	1,122,140	236,240	236,240	236,240
Pulp and board	52,316	44,080	9,280	9,280	9,280
Post, pole, and pile	4,961	4,180	880	880	880
Total	4,510,000	3,800,000	800,000	800,000	800,000
			PRIVATE (AND OTHER PUBLIC)		
Lumber and shakes[c]	7,745,662	7,131,980	7,131,980	3,980,640	5,556,310
Veneer and plywood	1,161,896	1,069,840	1,069,840	597,120	833,480
Pulp and board	396,950	365,500	365,500	204,000	284,750
Post, pole, and pile	35,492	32,680	32,680	18,240	25,460
Total	9,340,000	8,600,000	8,600,000	4,800,000	6,700,000

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[a] Based on product class percentages from Table 2.

[b] See Table 1 for description of scenarios.

[c] Assumes all export logs ultimately go to sawmills for primary conversion to lumber.

Table 4. Cubic feet of wood, allocated by product class, in roundwood to be harvested from forestland in the "owl" region related to scenario and to forest ownership (thousand cubic feet)[a]

Product class	Scenario[b] 1	2	3	4	5
			USFS AND BLM		
Lumber and shakes	624,184	525,920	110,720	110,720	110,720
Veneer and plywood	266,361	224,428	47,248	47,248	47,248
Pulp and board	10,463	8,816	1,856	1,856	1,856
Post, pole, and pile	992	836	176	176	176
Sub total	902,000	760,000	160,000	160,000	160,000
			PRIVATE (AND OTHER PUBLIC)		
Lumber and shakes	1,549,132	1,426,396	1,426,396	796,128	1,111,262
Veneer and plywood	232,379	213,968	213,968	119,424	166,696
Pulp and board	79,390	73,100	73,100	40,800	56,950
Post, pole, and pile	7,099	6,536	6,536	3,648	5,092
Sub total	1,868,000	1,720,000	1,720,000	960,000	1,340,000
Grand total	2,770,000	2,480,000	1,880,000	1,120,000	1,500,000

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[a] Computed from Table 3 using the conversion factor of 200 cubic feet of wood/MBF Scribner log scale.

[b] See Table 1 for description of scenarios.

Table 5. Wood specific gravity (ovendry weight and green volume basis), and ovendry weight of a cubic foot of freshly felled green wood, of important tree species in the "owl" region.

Species	**Specific gravity**[a]	**Ovendry weight, bark-free Pounds/cubic foot**
Douglas-fir	0.45	28.1
True firs	0.36	22.5
Western hemlock	0.42	26.2
Western larch	0.48	30.0

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[a] US Department of Agriculture, Forest Service (1987).

Table 6. Ovendry weight of wood, allocated by product class, in roundwood to be harvested from forestland in the "owl" region, related to scenario and forest ownership[a] (tons, ovendry).

	Scenario[b]				
Product class	**1**	**2**	**3**	**4**	**5**
			USFS AND BLM		
Lumber and shakes	8,426,484	7,099,920	1,494,720	1,494,720	1,494,720
Veneer and plywood	3,595,873	3,029,778	637,848	637,848	637,848
Pulp and board	141,251	119,016	25,056	25,056	25,056
Post, pole, and pile	13,392	11,286	2,376	2,376	2,376
Sub total	12,177,000	10,260,000	2,160,000	2,160,000	2,160,000
			PRIVATE (AND OTHER PUBLIC)		
Lumber and shakes	20,913,282	19,256,346	19,256,346	10,747,728	15,002,037
Veneer and plywood	3,137,116	2,888,568	2,888,568	1,612,224	2,250,396
Pulp and board	1,071,765	986,850	986,850	550,800	768,825
Post, pole, and pile	95,837	88,236	88,236	49,248	68,742
Sub total	25,218,000	23,220,000	23,220,000	12,960,000	18,090,000
Grand total	37,395,000	33,480,000	25,380,000	15,120,000	20,250,000

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[a] Computed from Table 4 using the conversion factor of 27 pounds of wood (ovendry)/cubic foot of green wood.
[b] See Table 1 for description of scenarios.

Table 7. Weight (ovendry) of products from one million MBF Scribner log scale (2.700 million tons of wood ovendry) of roundwood harvested from the "owl" region in each of two classifications of forest ownership.

Product class and source	**Allocation of total incoming wood weight[a]** **Percent**	**Weight yield of primary product[b]** **Percent**	**Ovendry product weight** **Tons**
		USFS AND BLM	
From primary processing			
Lumber and shakes	69.20[c]	31	579,204
Veneer and plywood	29.53	50	398,655
Pulp and board	1.16	50	15,660
Post, pole, and pile	0.11	90	2,673
Total	100.00		
From residues from lumber and plywood manufacture[b]			
Pulp and board			430,500[d]
MDF and particleboard (and other residue boards)			453,837[e]
	PRIVATE (AND OTHER PUBLIC)		
From primary processing			
Lumber and shakes	82.93[c]	31	694,124
Veneer and plywood	12.44	50	167,940
Pulp and board	4.25	50	57,375
Post, pole, and pile	0.38	90	9,234
Total	100.0		
From residues from lumber and plywood manufacture b			
Pulp and board			413,677[f]
MDF and particleboard (and other residue boards)			491,463[g]

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[a] From Table 2.

[b] Derived from CORRIM Report material balance diagrams.

[c] Includes export logs.

[d] 2,700,000 tons x .50 yield [(.32 pulp chips x .6920 lumber proportion) + (.33 pulp chips x .2953 plywood proportion)] = 430,500 tons.

[e] 2,700,000 tons x .94 yield [(.22 residue x .6920 lumber proportion) + (.09 residue x .2953 plywood proportion)] = 453,837 tons.

[f] 2,700,000 tons x .50 yield [(.32 pulp chips x .8293 lumber proportion) + (.33 pulp chips x .1244 plywood proportion)] = 413,677 tons.

[g] 2,700,000 tons x .94 yield [(.22 residue x .8293 lumber proportion) + (.09 residue x .1244 plywood proportion)] = 491,463 tons.

Table 8. Reductions in annual product output[a] below the base case of 1983-1987 average output (Scenario 1) resulting from four alternative scenarios in the "owl" region, on two classes of forest ownership.[bc] (Tons product, ovendry)

	Scenario			
Product class	**2**	**3**	**4**	**5**
		USFS AND BLM		
Lumber and shakes[d]	411,204	2,148,847	2,148,847	2,148,847
Veneer and plywood	283,045	1,479,010	1,479,010	1,479,010
Pulp and board	316,774	1,655,254	1,655,254	1,655,254
Post, pole, and pile	1,898	9,917	9,917	9,917
MDF and particle board (and other residue boards)	322,224	1,683,735	1,683,735	1,683,735
		PRIVATE (AND OTHER PUBLIC)		
Lumber and shakes[d]	513,652	513,652	3,151,323	1,832,487
Veneer and plywood	124,276	124,276	762,448	443,362
Pulp and board	348,578	348,578	2,138,576	1,243,577
Post, pole, and pile	6,833	6,833	41,922	24,378
MDF and particleboard (and other residue boards)	363,683	363,683	2,231,242	1,297,462

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[a] Tons of product not manufactured; that is, product tons lost by adopting scenarios 2 through 5 in place of scenario 1.

[b] See Table 1 for description of Scenarios 1 through 5.

[c] Derived from Tables 1 and 7.

[d] Assumes export logs go to sawmills.

Table 9. Net energy requirements [Million BTU (oil equivalent) per OD ton] for extraction, manufacture, and transport to building site of selected primary commodities (CORRIM Report).

Commodity	**Net energy required**
WOOD-BASED COMMODITIES	
Softwood lumber	2.91
Wood fence post, butt-treated with water-borne copper naphthenate	4.00[a]
Softwood sheathing plywood	6.00
Medium-density fiberboard	8.49
NON-WOOD COMMODITIES	
Concrete slab	8.52
Concrete block	8.77
Clay brick	9.06
Carpet and pad	37.19
Steel studs	50.32
Steel fence posts	50.32
Aluminum siding	200.47

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[a] Estimated; not included in CORRIM Report.

Table 10. Weights (in pounds) of some wood and nonwood structural products.

Product	Weight[a]
WOOD PRODUCTS (OVENDRY-WEGHT BASIS)	
One 8-foot 2 by 4 (net size 1.5 by 3.5 inch) stud	7.9
1000 square feet (coverage) of 3/4-inch tongue-and-groove softwood flooring	1,688
1000 square feet of 5/8-inch plywood siding	1,820
1000 square feet (coverage) of medium density fiberboard (MDF) siding 1/2-inch thick	1,740
One 6.5-foot-long 4.0-inch-diameter wood post, butt-treated with 0.44 pounds copper naphthenate (waterborne)	15.8
NONWOOD PRODUCTS	
One 8-foot steel stud (alternative to 2 by 4 wood stud)	4.2
1000 square feet (coverage) of aluminum house siding	300
1000 square feet of brick veneer for house exterior facing	35,200
1000 square feet 2-core concrete block wall 8 inches thick	37,740
1,000 square feet of 4-inch-thick concrete slab floor	46,600
1000 square feet of carpet with pad	560
One 6-foot steel fence post (alternative to treated wood post)	7.5

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[a] Weight data from CORRIM Report, except for weights of fence posts and studs which are based on recent weight observations.

Table 11. Ratio of weights of nonwood alternatives to serve in place of several important wood products (ovendry basis); that is, weight of nonwood alternative/weight of wood product replaced.

Alternatives	**Weight Ratio**
Steel stud in place of wood stud	0.53
Steel post in place of treated wood post	0.47
Carpeting in place of wood tongue and groove flooring	0.33
Aluminum siding in place of plywood siding	0.16
Aluminum siding in place of MDF siding	0.17
Brick veneer in place of plywood siding	19.34
Brick veneer in place of MDF siding	20.23
Concrete slab floor 4 inches thick in place of wood joist floor (2 by 10s 16 inches on center) with 5/8-inch plywood subfloor-underlayment	10.13[a]

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[a] From the CORRIM Report the concrete slab weighs 2.33 tons per 100 square feet of floor; weights (ovendry) of the components per 100 square feet of the wood floor are estimated as follows:

Component	Tons weight
Joists	0.139
Plywood subfloor	.091

Table 12. Increase in annual energy requirement [Million BTU (oil equivalent)], above the base case of 1983-1987 average harvest in the "owl" region, attributable to scenarios 2, 3, 4, and 5 assuming wood replacement by nonrenewables, by product class and forest ownership.[a]

Product class	Scenario 2	 3	 4	 5
	USFS AND BLM			
Lumber and shakes	15,802,570	82,580,190	82,580,190	82,580,190
Veneer and plywood	27,639,344	144,425,327	144,425,327	144,425,327
Pulp and board	0	0	0	0
Post, pole, and pile	37,296	194,869	194,869	194,869
MDF and particle board (and other residue boards)	32,283,623	168,693,410	168,693,410	168,693,410
Subtotal	75,762,833	395,893,796	395,893,796	395,893,796
	PRIVATE (AND OTHER PUBLIC)			
Lumber and shakes	19,739,646	19,739,646	121,105,343	70,422,475
Veneer and plywood	12,135,551	12,135,551	74,453,047	43,294,299
Pulp and board	0	0	0	0
Post, pole, and pile	134,268	134,268	823,767	479,028
MDF and particleboard (and other residue boards)	36,437,400	36,437,400	223,548,136	129,992,718
Subtotal	68,446,865	68,446,865	419,930,293	244,188,520
Grand total	144,209,698	464,340,661	815,824,089	640,082,316

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[a] Derived from Table 8 and factors in text discussion.

Table 13. Increase in annual energy requirement (oil equivalent), above the base case of 1983-1987 average harvest in the "owl" region, attributable to scenarios 2, 3, 4, and 5 assuming wood replacement by nonrenewables, by forest ownership.

Scenario	**Million BTU (oil equivalent)**[a]	**Million gallons of oil**[b]	**Million barrels of oil**[c]
	USFS AND BLM		
2	75,762,833	549	13.1
3	395,893,796	2,869	68.3
4	395,893,796	2,869	68.3
5	395,893,796	2,869	68.3
	PRIVATE (AND OTHER PUBLIC)		
2	68,446,865	496	11.8
3	68,446,865	496	11.8
4	419,930,293	3,043	72.5
5	244,188,520	1,769	42.1
	TOTAL		
2	144,209,698	1,045	24.9
3	464,340,661	3,365	80.1
4	815,824,089	5,912	140.8
5	640,082,316	4,638	110.4

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[a] From Table 12.

[b] One gallon of diesel oil contains 0.138 million BTU (thermal).

[c] 42 gallons of oil = 1 barrel.

Table 14. Increase in annual CO_2 additions to atmosphere, above the base case of 1983-1987 average harvest in the "owl" region (scenario 1), attributable to increased energy consumption caused by scenarios 2, 3, 4, and 5 assuming wood replacement by nonrenewables[a,b,c] (Tons of CO_2)

	Scenario			
Product class	**2**	**3**	**4**	**5**
	USFS AND BLM			
Lumber and shakes	1,282,527	6,702,160	6,702,160	6,702,160
	(207,658)	(1,085,168)	(1,085,168)	(1,085,168)
Veneer and plywood	2,243,193	11,721,476	11,721,476	11,721,476
	(108,972)	(569,419)	(569,419)	(569,419)
Pulp and board	—(Zero addition; no replacement assumed)—			
Post, pole, and pile	3,027	15,815	15,815	15,815
	(0)	(0)	(0)	(0)
MDF and particle board (and other residue boards)	2,620,120	13,691,059	13,691,059	13,691,059
	(92,156)	(481,548)	(481,548)	(481,548)
Subtotal	6,148,867	32,130,510	32,130,510	32,130,510
	(408,786)	(2,136,135)	(2,136,135)	(2,136,135)
	PRIVATE (AND OTHER PUBLIC)			
Lumber and shakes	1,602,058	1,602,058	9,828,839	5,715,447
	(259,394)	(259,394)	(1,591,418)	(925,406)
Veneer and plywood	984,914	984,914	6,042,566	3,513,740
	(47,846)	(47,846)	(293,542)	(170,694)
Pulp and board	—(Zero addition; no replacement assumed)—			
Post, pole, and pile	10,897	10,897	66,856	38,878
	(0)	(0)	(0)	(0)
MDF and particleboard (and other residue boards)	2,957,238	2,957,238	18,143,037	10,550,134
	(104,013)	(104,013)	(638,135)	(378,074)
Subtotal	5,555,107	5,555,107	34,081,298	19,818,199
	(411,253)	(411,253)	(2,523,095)	(1,467,174)
Grand total	11,703,974	37,685,617	66,211,808	51,948,709
	(820,039)	(2,547,388)	(4,659,230)	(3,603,309)

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[a] Data do not include photosynthetic effects of gradual conversion of unreserved portions of LS/OG forests to more intensively managed forests with shorter rotation age; see text for discussion of age effect.

[b] Entries in the Table show the addition of CO_2 attributable to the increased energy consumption (Table 12) based on the oil equivalent of 0.138 million BTU/gallon of fuel oil; listed below in parentheses is the CO_2 contribution to atmosphere of wood residue burned and utilized for energy during manufacture of the wood product. Net CO_2 addition to atmosphere attributable to substitution of nonrenewables for wood is the top number minus the number below in parentheses.

[c] Each gallon of fuel oil burned adds 22.44 pounds of CO_2 to the atmosphere; an equal heat content (0.138 million BTU) of woody residue (half bark) burned adds a maximum of 28.76 pounds of CO_2 to the atmosphere (see text discussion).