World Resource Review Vol. 5 No. 4

REDUCTION OF ATMOSPHERIC CARBON EMISSIONS THROUGH DISPLACEMENT OF FOSSIL FUELS

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SUMMARY

Renewable resources, particularly wood, can make significant contributions in reducing carbon emissions to the atmosphere during the next several decades. Fuels made from renewable resources can displace long-term fossil fuel carbon emissions directly, provided the renewables continue to be regrown on a sustainable basis. Materials made from renewable resources are generally less energy intensive than materials produced from minerals. Therefore, renewable resource materials involve less expenditure of all forms of energy, including fossil fuels. Moreover, renewable organic materials contain carbon and therefore sequester carbon in place when used in products over varying lengths of time.

Using various economic growth scenarios, a recent report from the Office of Technology Assessment indicates that an increase in energy from renewables could range from 2.2 to 14.7 Quads (2.3 to 15.5 EJ) per year by 2015. Renewables could include increased use of (a) firewood for space heating in buildings, (b) fuels derived from biomass in the transportation sector, (c) biomass fuels in industries, mainly the forest products industry, and in power generation.

Energy savings may come about through increased recycling of materials as well as use of renewable materials that are less energy intensive. The advantage of recycling is increased when it is renewable materials that are being recycled. Recycled waste paper, or secondary fiber, can be used to make various paper and paperboard products. Using recycled fiber for some paper products, e.g., newsprint, printing paper and tissue, may require less energy. Research is underway to use recycled fibers in durable products such

as structural panels for buildings or composite products such as headliners, dashboard, and interior door panels for automobiles.

Increasing renewable material use in durable products means that carbon is sequestered over time instead of being emitted to the atmosphere through combustion, decay, anaerobic digestion, or other scavenging processes. Work is underway to model carbon in products in use to refine knowledge of the overall carbon cycle.

Today, biomass fuel derived from corn is the only nonfossil liquid fuel for transportation applications. The industrial sector uses 2 Quads (2.1 EJ) of energy, mostly from wood and bark in the pulp, paper, and lumber industries. The residential sector uses 1 Quad (1.06 EJ) of firewood. This is a foundation from which to build. The U.S. Department of Energy estimates a total energy potential of at least 55 Quads (58 EJ) in 2000. Today, more than 10 Quads (10.6 EJ) are available each year from wood residues.

INTRODUCTION

Renewable resources, particularly wood, can make a significant contribution in reducing carbon emissions to the atmosphere during the next several decades. However, predictions for additional use of wood fuels in the United States by the year 2010 are at fairly low levels. We estimate about 4.0 Quads (4.2 EJ), which is only about a 1.3-Quad (1.4-EJ) increase from the current level of about 2.7 Quads (2.8 EJ). On the other hand, a recent report from the Office of Technology Assessment (U.S. Congress, 1991) indicates that an increase in energy from renewable could range from 2.2 to 14.7 Quads (2.3 to 15.5 EJ) per year by 2015. However, considerably more residue wood and wood from intensive silviculture are potentially available that could be burned profitably and with a positive environmental impact.

Wood fuels are beneficial from the standpoints of reduced net carbon dioxide emissions, increased energy conservation, and increased sequestration of terrestrial carbon as opposed to increased atmospheric carbon. Renewable fuel could include increased use of (a) firewood for space heating in buildings, (b) fuels derived from biomass in the transportation sector, (c) biomass fuels in industries, mainly the forest products industry, and in power generation.

Reduced Carbon Dioxide Emissions

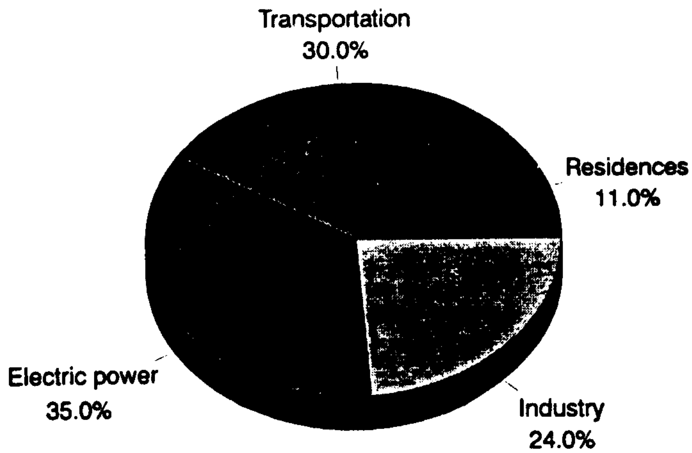

Figure 1 US sources of carbon dioxide from combustion (1987)

As I have mentioned at previous Global Warming International Conferences, fuels from renewable biomass are more advantageous than fossil fuels, because there is no net gain in carbon dioxide accumulation in the atmosphere when biomass fuels are burned followed by regrowth of new plants. The carbon dioxide that is given off to the atmosphere during combustion is reused by new growth through photosynthesis. Thus, carbon dioxide from disintegration of plant products is recycled.

According to Lovins and Lovins (1990), among the approximately 57% of the current worldwide contributions to global warming estimated by the U.S. Environmental Protection Agency (EPA) coming directly from energy use, 20% is ascribed to transportation, 22% to industry, and 15% to buildings. A similar breakdown for U.S. sources of carbon dioxide from combustion is shown in Figure 1. Liquid fuels predominate in the transportation industry, and solid or gaseous fuels are more commonly used in the building and manufacturing industry. It is in the high- and low-temperature heat applications of the

Table 1 Comparative energy recovery from wood

Compound	Yield[a] (lb/t ovendry)	Heat value[b] (Btu/lb)	Total potential heat value ($x10^6$/t ovendry)
Wood, direct burning	2,000	8,500	17.0
Charcoal	670	12,500	8.38
Oil	370	14,380	5.32
Methanol	647	9,788	6.33

[a]1 lb = 0.45 kg.
[b]1 Btu/lb = 2.324 kJ/kg.

building and manufacturing industry that biofuels could have the most impact in reducing carbon dioxide emissions when substituted for fossil fuels. The reason being that conversion of solid fuel, as in the form of solid wood, requires significant expenditure of energy for conversion to liquid form. Relative efficiencies of wood fuel use in various forms are shown in Table 1 (Forest service, 1976).

Table 2 Fuel composition and carbon dioxide production for different fuels[a]

Fuel	Carbon weight(%)	Hydrogen weight(%)	Oxygen weight(%)	Ash weight(%)	kg CO_2/kg	g CO_2/MJ
Wood, chip	50	6	43	--	1.85	97
Wood, chip 25% water	37.5	4.5	32.3	--	1.38	102
Bark,50% water	25	3	21.5	2-3	0.92	117
Bark pellets	50	5.5	42	2.5	1.83	108
Refuse derived fuel	47	5	38	10	1.72	105
Waste	32	4	26	37	1.17	128
Methane	75.0	25.0	0	2.75	55	0
Light oil	86.2	12.7	0	0.001	3.16	74
Heavy oil	85.7	11.0	0	0.03	3.14	79
Coal	88	5	5	3-7	3.23	103

[a]-- is data not available.

In direct burning of wood, there are other considerations that require more wood mass and greater energy content than fossil fuels to provide the same useable heat. The release of carbon dioxide in combustion for the amount of energy content is greater for wood than for fossil fuels. Table 2 (Sonju, 1991) shows fuel composition and carbon

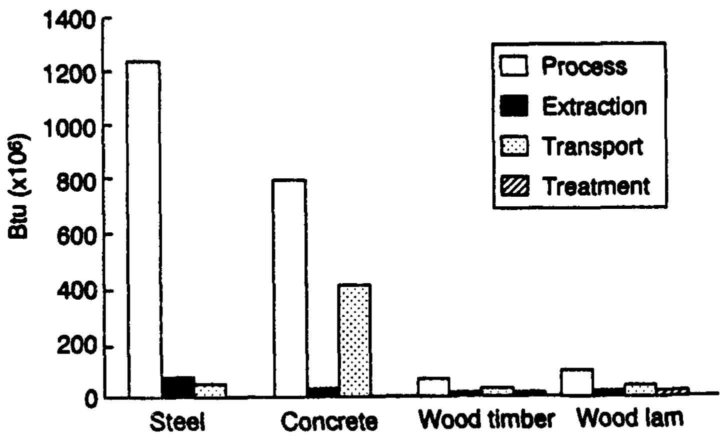

Figure 2 Comparison of total energy investment for timber, steel, and prestressed concrete bridges (1970s)

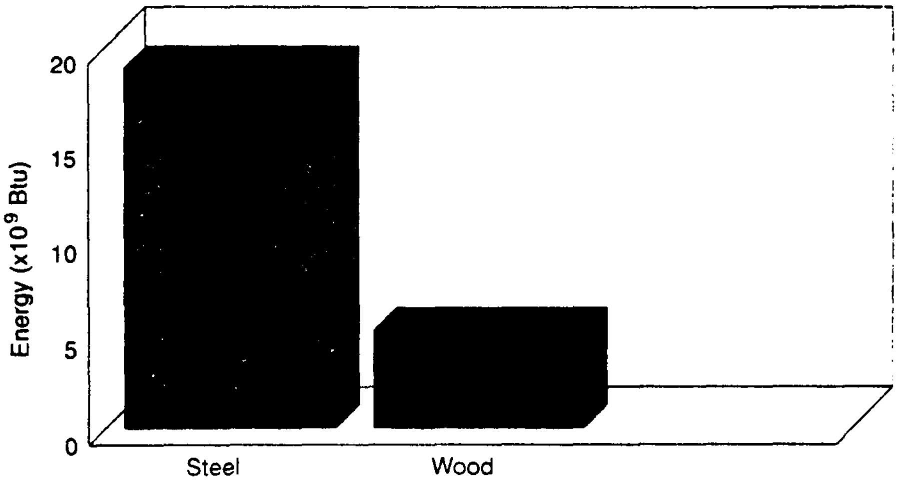

Figure 3 Energy required for institutional buildings constructed from steel and wood (1990s)

dioxide production for different fuels. Most biofuels listed, including refuse derived fuel, produce about 100 g CO_2/MJ of thermal energy release. Raw bark and municipal solid waste (MSW) produce 20% to 30% more than this amount; oil produces less release; methane, the least amount. The efficency of biofuel combustion equipment is generally less than that for oil and gas, thus increasing the difference in the derived energy per unit of fuel input even further.

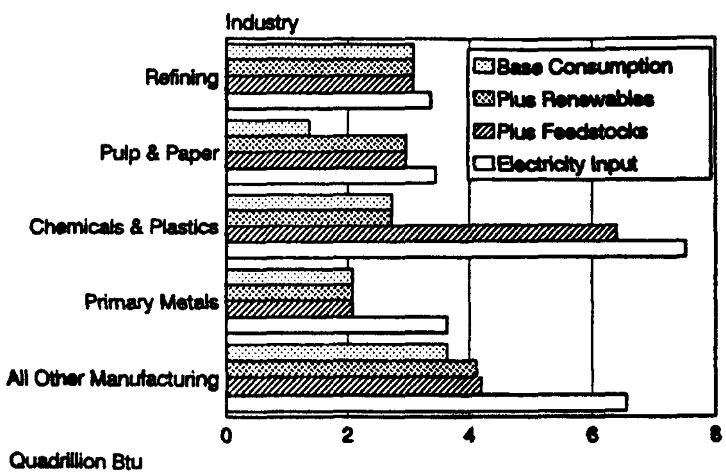

Figure 4 Energy consumed in manufacturing; four ways of measuring

Energy Conservation

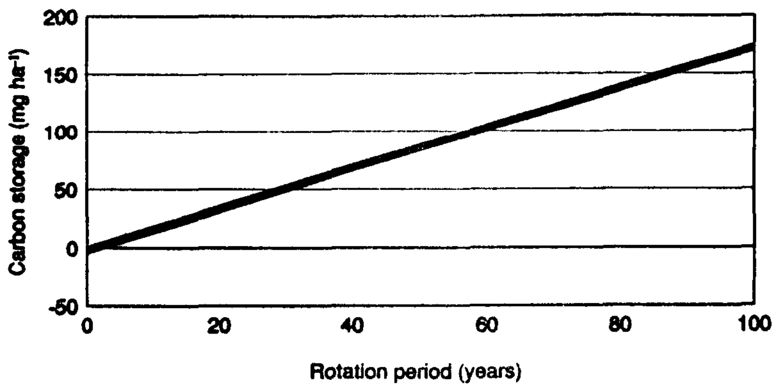

Figure 5 Result of average carbon storage with various rotations, using gc(t) = m.a.i.(T)T (Eq. 1)

I mentioned that wood can be used most efficiently as a fuel when it is burned directly, and even with that most effective use, burning of wood is often still less efficient than burning fossil fuels. However, other ways are available in which use of wood can improve efficiency and result in less carbon dioxide emissions.

Use of wood as a material is usually effective in reducing energy consumption. Wood is less energy intensive than steel, aluminum, plastics, and concrete in that wood consumes less energy in recovery, processing, and fabrication. To evaluate a material completely, it is important to consider life-cycle analysis. Besides initial cost in energy and money, consideration must be given to maintenance requirements, recyclability, and durability. Figures 2 and 3

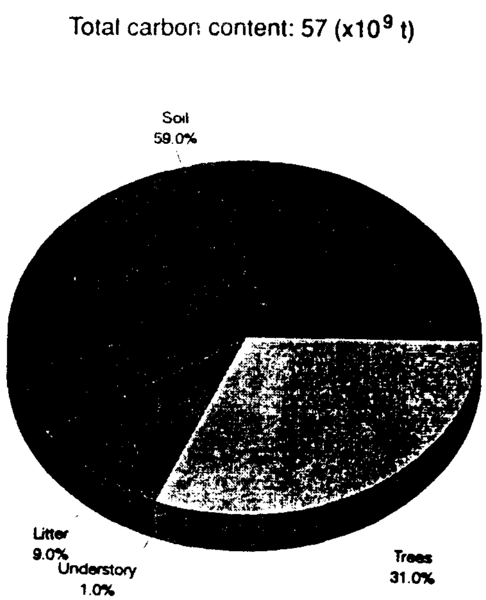

Figure 6 Carbon content of US forest ecosystems; total carbon content is 57 x 10’t

demonstrate changes in energy intensity analyses during the last 20 yearn. Figure 2 is a comparison of energy use with steed and wood construction with information from the early 1970s. At this time, the amount of energy used by the steel construction was about eight times the energy used in wood construction. Figure 3 is a comparison using recent data with benefits for improved processing and recycling of steel. Here, the advantage of wood is four times the energy savings compared to steel.

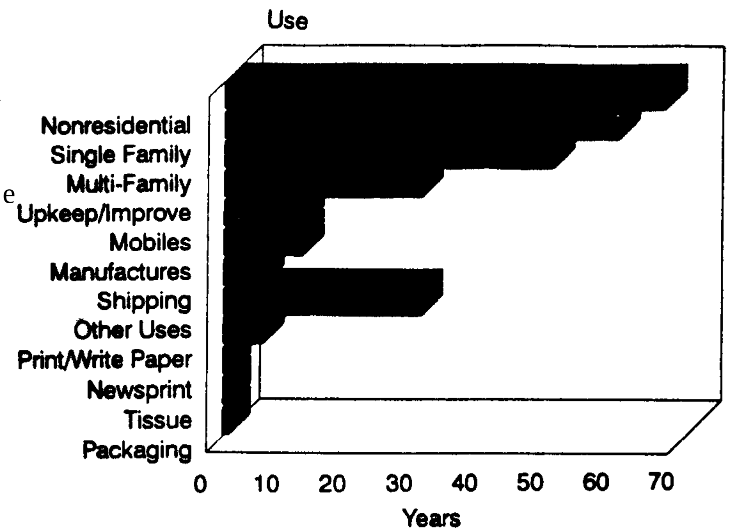

Figure 7 Average life in use for various wood products

Additional energy benefits in manufacture of forest products are shown in Figure 4, which compares energy consumed in manufacturing for pulp and paper with refining, chemicals, and plastics, primary metals, and all other manufacturing areas.

Carbon Sequestration

Previously (Zerbe, 1990), I demonstrated sequestration of carbon in tree stands through the organic matter contained in the living tree. In Figure 5, I present an equation of the following form

$$gc(t) = m.a.i.(T)T \tag{1}$$

where

gc(t) = mass of carbon stored by the forest at time (t) after planting (Mg ha^{-1})

m.a.i.(T) = mean annual carbon increment of the forest over the rotation period (T) (Mg ha^{-1} $year^{-1}$), and

T = rotation period (year).

Equation (1) is valid if m.a.i.(T) is a constant for all rotation periods, but this is not the case because rates of growth vary with tree age and other factors.

Equation (1) can be further modified and made more useful by using a variable m.a.i. and adding a component to reflect sequestration of carbon in products from trees in use. It would also be desirable to add a factor to account for carbon in detritus and soil and organic matter in the ground cover, but this aspect is not considered in this paper. As shown in Figure 6, almost 70% of the carbon content in U.S. forest-ecosystems is in soil, litter, and understory. An average life in use for various wood products is given in Figure 7 (Row, 1990), and carbon remaining in sink during various periods is shown in Figure 8 (Row, 1990).

According to Dewar (1990), when forests are managed for maximum sustained yield of biomass, the contribution n to asymptotic carbon storage from timber products is about 2.5D/T* times the contributio n from living trees, where D is the characteristic decay time for reconversion of timber products to carbon dioxide, and T* is the normal rotation period for maximum sustained yield. Dewar gives the following for the relationship between asymptotic carbon storage, $\langle C\rangle_\infty$, and the forest growth curve, $g_c(t)$:

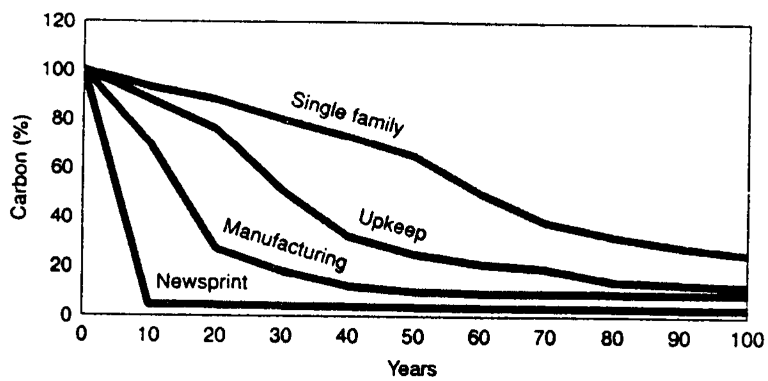

Figure 8 Parentage of carbon remaining in sink for newsprint manufactures upkeep, and single-family homes

$$\langle C\rangle_\infty = m.c.p.(T) + m.a.i.(T) \times D \qquad (2)$$

where m.c.p.(T) is the mean cumulative production of the forest during the rotation period, and m.a.i(T) is the average mass of carbon per hectare stored by the forest during one rotation.

A logistic forest growth curve maybe determined if values for& (initial carbon content of the forest) or $g_c(t = \mathbf{0})$, (asymptotic maximum carbon content per hectare of the forest) or $g_c(t_o)$, and k (logistic growth constant) arc known. If the growth curve is held constant (i.e., g_i, g_f, and k held constant), the curves in Figure 9 showing asymptotic carbon storage as a function of the rotation period for various values of the product decay time may be drawn.

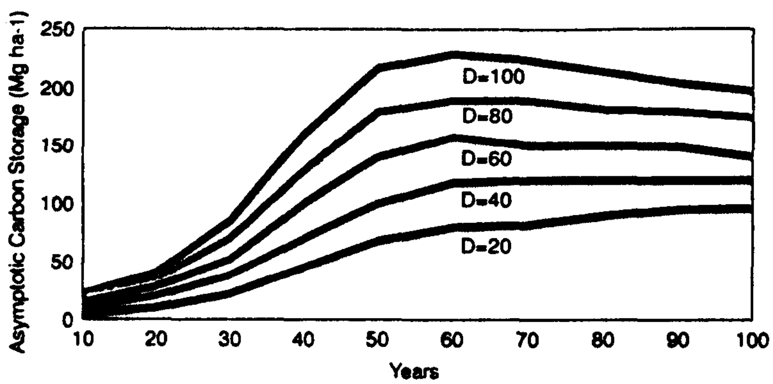

Figure 9 Asymptoticcarbon storage as a function of the rotation period; D = characteristicdecay time for reconversion of timber products to carbon dioxide

Figure 9 illustrates the linear increase of $<C>_\infty$ with respect to D, and also the development, as D increases, of a peak (T_o whose position approaches the enormal rotation period (T*). Figure 9 also illustrates that, as the rotation period becomes larger, all curves tend to g_f .

Figure 10 uses a Similar plot for various values of the growth constant k, with parameters D, g_i, and g_f held constant. The

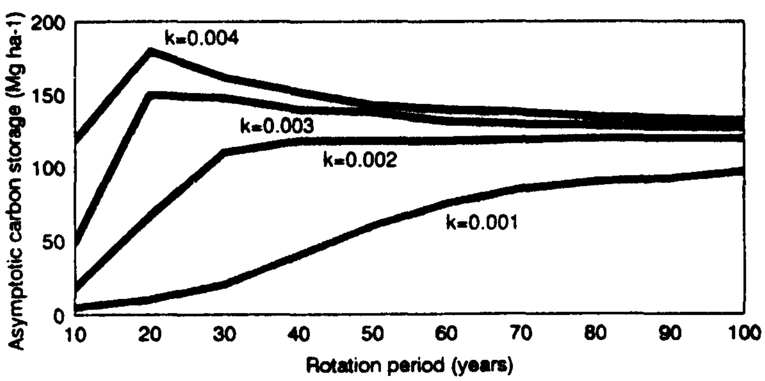

Figure 10 Asymptoticcarbon storage as a function of the rotation period; k = logistic growth constant

figure illustrates that $\langle C \rangle_\infty$ increases when the forest grows rapidly, both for the simple case when the rotation period is fixed and for the more realistic case when it is chosen as the normal rotation period.

CONCLUDING REMARKS

Of the ways in which renewable may be used to mitigate adverse impacts of global change, the least consideration has been given to carbon sequestration in products manufactured from wood and a few other resources such as sugarcane bagasse. However, products in use represent a carbon sink that deserves intensive research. Biota and soils are other terrestrial media that should also be given more consideration. These terrestrial carbon sinks are suspected of harboring many annual carbon dioxide emissions of fossil fuels that are not accounted for in the atmosphere and the oceans.

This paper is a preliminary look at the magnitude of carbon sequestration in wood products in the United States and the opportunities for reducing fossil fuel consumption and conserving energy through wood utilization.

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