CARBON 101: UNDERSTANDING THE CARBON CYCLE AND THE FOREST CARBON DEBATE

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Introduction

Even though Congress is unlikely to adopt "cap and trade" or other approaches to reduce the emissions of carbon dioxide and other greenhouse gases for the foreseeable future, the Environmental Protection Agency is seeking to curtail emissions through new regulation, and the result could be substantial for communities, the environment and the economy. So what is the fuss all about? What exactly is the carbon cycle? What is meant by such terms as "carbon dioxide equivalence", "carbon neutrality", "fossil carbon," and "substitution effect"? And, to what are people referring when using the term "carbon debt"? This report starts from square one of the carbon cycle to explain this and other aspects of the carbon debate and what it all means.

Background

For the past nearly twenty years carbon has been associated with the evolving discussion of climate change and global warming. In short, accumulations of various greenhouse gases in the atmosphere, including carbon dioxide, trap heat and serve to insulate the planet. Without greenhouse gases the earth would have such extreme temperature fluctuations that life on the planet would be impossible as we know it. However, essential as they are, high concentrations of greenhouse gases in the atmosphere create uncertainty in the earth's climate and increased risks to economic stability and sustainability.

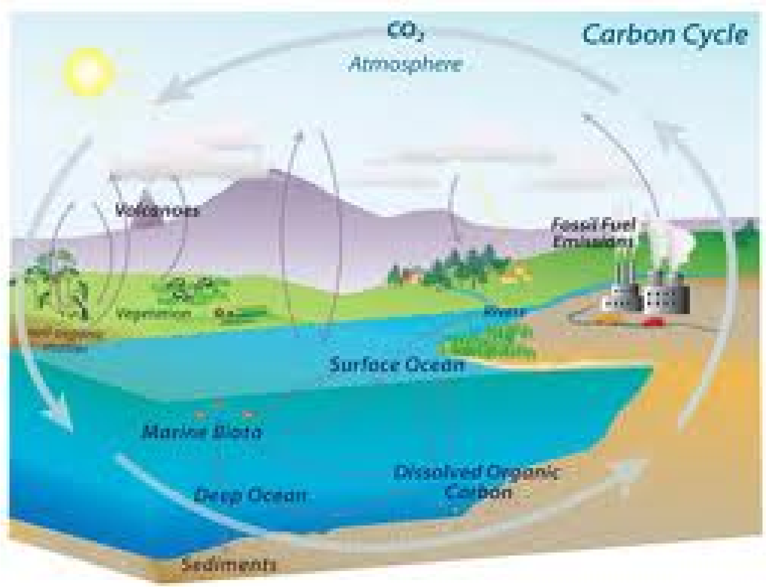
While carbon dioxide is the compound most often referred to as a greenhouse gas (GHG), a number of compounds have the ability to trap heat when present in the outer atmosphere. These include methane, nitrous oxide, chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), and sulfur hexafluoride. The heat trapping potential of these compounds varies widely, with some that are 25, 300, and as much as 22,000 times more effective than carbon dioxide in inhibiting heat loss from the earth's surface. Scientists use measurements of the presence of various greenhouse gases in the atmosphere and a weighted average of their respective heat trapping ability to determine the carbon dioxide equivalence of GHG concentrations.

The chemical influence of greenhouse gases is a scientific fact; these gases do capture heat and inhibit re-radiation to space. Increased accumulation of greenhouse gases in the atmosphere is also an indisputable fact. Where there remains room for debate in this discussion is in identifying the appropriate response. Should we continue business as usual and just let things take their course? Might consideration of adaptation measures be worthwhile? Should we actively try to limit the atmospheric accumulation of additional greenhouse gases? Should we go so far as to find high-tech methods for removing greenhouse gases from the atmosphere or altering the atmosphere's chemical composition through the release of other compounds? While these and other questions warrant informed and timely discussion, for nearly twenty years the global consensus has been to pursue policies that manage and mitigate the release of greenhouse gases. The United Nations Framework Convention on Climate Change (UNFCCC) provides the foundation for this approach and the framework for the resulting debate about managing carbon.

The Carbon Cycle

To understand the debate about carbon, we must start with understanding where carbon occurs on, in and around the earth and how it cycles. Carbon is a basic chemical component of all living organisms and many non-living substances. Carbon exists in plants, soils, the air, people, buildings, and many other things. The places where carbon is stored are called "carbon pools." The largest such pools are the oceans, the land and its vegetation, and the atmosphere. When a pool *gains* more carbon than it loses over a period of time, it is called a "carbon sink." When a pool *lose*s more carbon than it gains over a period of time it is called a "carbon source." Currently, the oceans, the land, and the atmosphere are all carbon sinks. Pools of carbon stored in fossil fuel deposits – petroleum, coal, and natural gas – are major carbon sources, with massive quantities of carbon released to the atmosphere as they are burned to create energy. The conversion of limestone to lime in the process of cement production is another substantial carbon source.

Figure 1
The Global Carbon Cycle



Source: National Oceanic and Atmospheric Administration

Carbon is continually "cycled" between various "carbon pools" and "carbon sinks." For example, one type of cycle occurs annually with living things as plants or plant parts grow during the spring and summer and then die in the fall and winter. Similar cycling of carbon occurs between the oceans and the atmosphere. In this case, carbon is captured by growth of phytoplankton, returned to the atmosphere as these simple plants die, then recaptured again with growth of new plant life. The continual movement of carbon between the atmosphere and living things in oceans and on the land is described as the "carbon cycle," a process that has been ongoing for millions of years. Collectively, the carbon associated with the oceans and land is termed "biogenic carbon".

A significant contributor to atmospheric carbon that hasn't been in play for millions of years is the release of carbon that results from burning of fossil fuels. Emissions from this activity have developed only in the course of the past 100 years, and substantially over only the past 60. Similarly, emissions resulting from conversion of limestone to lime are a relatively recent phenomenon. Collectively, carbon liberated through these activities is termed "fossil carbon."

Biogenic Carbon and Fossil Carbon

The biogenic carbon cycle is relatively balanced and continuous and it occurs with or without human intervention. Human actions, including land clearing, agricultural production, and forest management can influence the cycle; however, the cycle itself doesn't rely upon human action to occur or continue. Even without human action, plants and animals continue to grow, live and die and to absorb and emit carbon during various life stages.

The liberation of fossil carbon results in a one-way stream of carbon emissions without a naturally occurring counter balance for re-absorbing the emissions. While the carbon released can be absorbed by the oceans or land-based plants, it does not return to the pool from which it came on anything other than a geologic time scale. Thus the release of fossil carbon disrupts a natural carbon cycle that has long been in balance. When it comes to understanding the problem posed by fossil carbon, what it boils down to is that millions of years ago that carbon was captured and stored in the earth, and today there is no natural mechanism for either capturing the full amount of carbon released through its burning, or for restoring that carbon to the pool where it originated. The net effect is an increase in carbon-containing greenhouse gases in the atmosphere.

Life Cycles of Trees

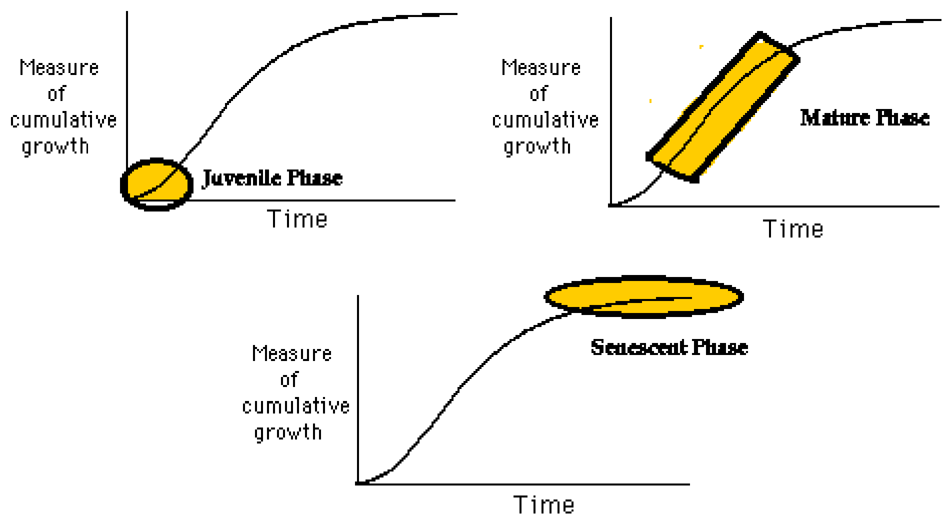
Even though trees are plants and humans are part of the animal kingdom, there are nonetheless a number of similarities in the life cycles of trees and people. Like humans, trees are delicate when young and typically grow vigorously when given proper nutrition and a suitable environment. As juveniles, they form tissues that differ from those formed in mature trees. They respire, and they require a balanced intake of minerals to maintain health. They metabolize food (but unlike humans, trees also synthesize their own foods). If wounded, they react quickly to effect healing. As age progresses, vigor is maintained for a lengthy period but then begins to wane. The top may begin to thin. Life processes eventually slow to the point that the tree has difficulty healing wounds and warding off disease. Finally, the tree dies.

One thing that trees face during their life cycle is fierce competition for survival in the forest. As noted above, growth rates in young trees and newly established forest stands tend to be rapid. As trees grow in size, they grow into the space occupied by others, crown closure occurs, and competition between trees for sunlight, water and nutrients from the soil intensifies.

The rates of growth and carbon capture slow in forest stands as a result of aging, and may even decline at advanced ages due to increasing natural mortality. The reduction in growth with age is substantial. The result is that while older forests can *store* more carbon, the *rate* at which they remove additional carbon from the atmosphere is substantially lower, eventually plateaus (Figure 2), and can become negative if mortality increases to the point that it exceeds net growth. In addition, older forests are often more susceptible to catastrophic disturbance and unscheduled loss of stored carbon than are younger, managed forests.

Because the rate of forest growth slows, then reaches a point where new biomass accumulation is matched by biomass loss, and (sometimes) thereafter even becomes negative, carbon accumulation does not continue forever. Recent and increasing numbers of news headlines about catastrophic fire, insect, and disease events have shown that a prolonged situation of forest growth in excess of removals is no more sustainable than one in which removals exceed growth. Increasing forest volume can accentuate competition between trees, risking the health of the forest overall and raising the chances of catastrophic fire, disease, and insect infestation.

Figure 2
Slowing of Tree Growth with Increasing Age

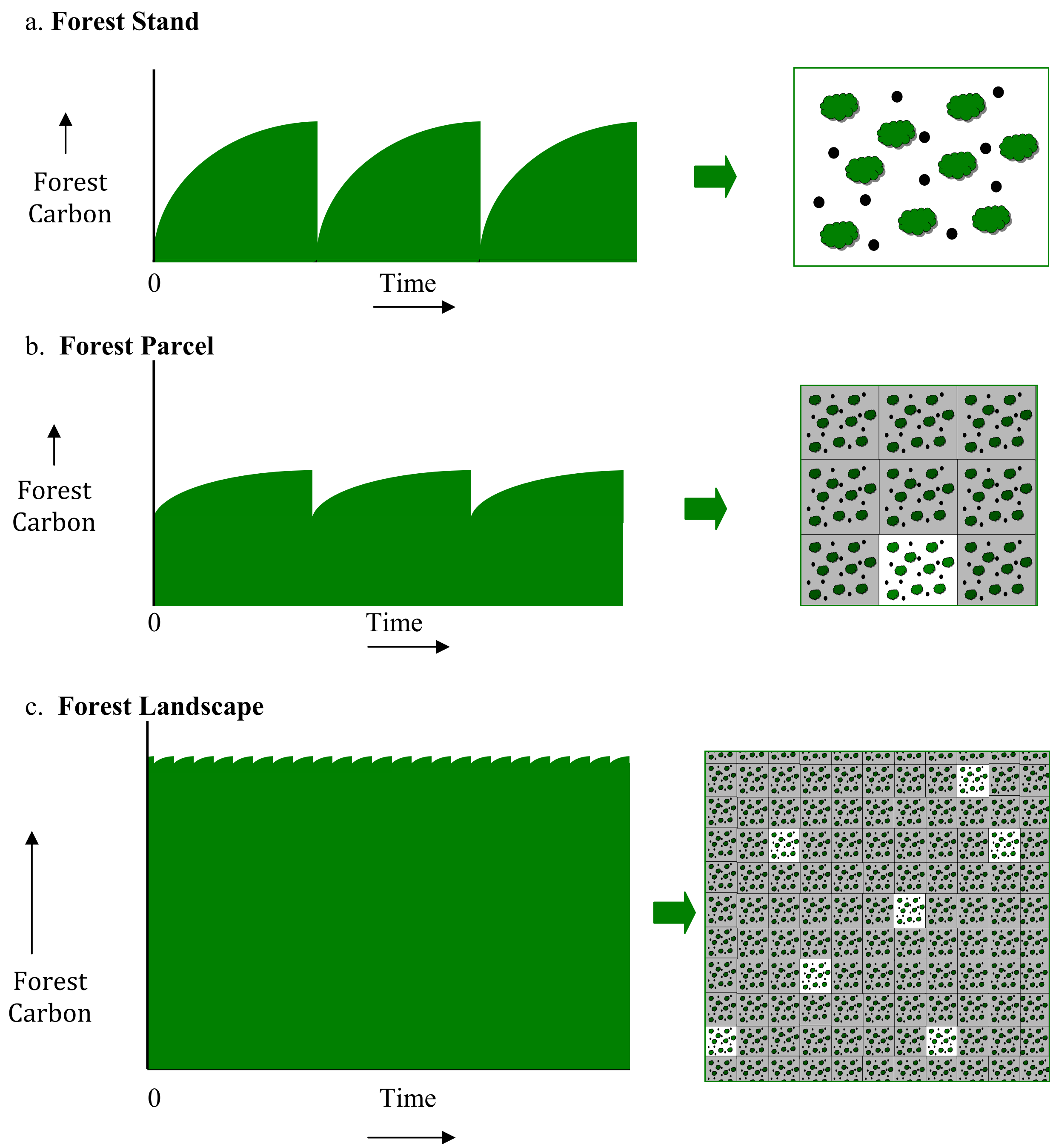


Source: Brack, C. (1997) Australian National University

Forest Carbon Dynamics

To understand forest carbon dynamics, it is important to look at the different sizes of forests that are considered. Natural resource managers frequently talk about forest "stands", "parcels" and the "landscape" (Figures 3a, 3b, 3c). The forest stand is the smallest unit and corresponds to individual treatment areas. Depending on the forest type and region, a forest stand may be as small as one acre or more than twenty acres in size. Forest stands are typically delineated on the basis of a common characteristic such as tree species, tree age, habitat type or another consideration. Forest parcels are a slightly larger size of forest area and correspond to the size of the ownership. There is no generalized size for a forest parcel since it is defined by legal ownership boundaries. Finally, the "landscape" scale refers to the largest consideration of forest area. The size of the "landscape" varies depending on the forest type or the characteristics of greatest interest. A forest landscape typically includes forests of multiple landowners and stands of many different ages. The carbon dynamic of a landscape considers a weighted average of carbon capture rates of stands of all ages, including rapid capture rates in young and maturing stands and flat to negative rates in older stands. Land managers may talk about the forest landscape of a county, state, region, or nation. For purposes of forest carbon accounting, the larger the area defined as a landscape, the clearer the carbon picture. For purposes of reporting carbon pools under the UNFCCC, reporting is done at the national level.

Figure 3
A Depiction of Forest Carbon in a Sustainably Managed Forest at Stand, Parcel, and Landscape Levels



Source: Adapted from Colnes (2011)

At the level of the forest stand, forest carbon cycles periodically rise with regeneration and growth, and fall with periodic harvests or disturbance (e.g., fire, insects or disease outbreaks) (Figure 3a). Under sustainable management, similar forest treatments are progressively applied over a period of time to individual stands across a forest parcel and result in more stable carbon dynamics (Figure 3b). The stability of carbon stores resulting from balanced forest management is even more evident at the landscape scale (Figure 3c). At this scale the amount of carbon stored in the forest remains essentially the same, even though every year a portion is harvested. The stability of carbon stocks is attributable to growth of trees across the landscape which offsets the small portion of trees harvested in any given year.

Carbon Implications of Forest Harvesting

Carbon is stored in the main stem, branches, bark, and roots of trees, in forest litter, and in the shallow and deep soils. Of the carbon found in forest soils, a small portion of the volume resides in the upper 3 to 5 inches, with most in the deeper soil (Malmsheimer et al. 2011).

Harvesting typically removes wood of the main stem, and if harvesting for energy production, many of the larger branches may be removed from the forest as well. The other parts of the tree are left on the forest floor where they degrade quickly or slowly depending on whether the site is wet or dry; degradation releases carbon to both the soil and atmosphere. When wood of the main stem is converted to long-lived products, the carbon within that wood is stored for as long as the wood lasts. Conversion of wood to energy immediately releases the carbon stored in the wood.

Harvesting also has an impact on the carbon contained within soils. Reduction in shallow forest soil carbon immediately after harvesting is common. Carbon concentrations within the deeper soils, however, often increase as a result of forest harvest activity (Malmsheimer et al. 2011).

Landowners who are unable to realize ongoing financial returns from forests have an economic incentive to convert their lands to agriculture or some other use that will yield income.

An obvious implication is that an effective way to maintain or increase forest carbon stocks on private lands is to ensure the existence of a strong market for forest products.

References to periodic harvesting in forests evoke strong emotions in some people who tend to equate harvest with deforestation such as seen in the world's tropical forests. However, the extent of forested land in the United States (and in Canada) is today within one percent of the same area as in the early 1900s, despite ongoing harvest activity. This is consistent with the recent finding that the lowest rates of deforestation and net forest carbon emissions occur in global regions with the highest rates of industrial wood harvest and forest products output. Conversely, global regions with the highest rates of deforestation and forest carbon emissions rank lowest in industrial roundwood harvest and forest products output (Ince 2010). In short, forest landowners who are unable to realize ongoing financial returns from forests have an economic incentive to convert their lands to agriculture or some other use that will yield income. An obvious and perhaps counterintuitive implication is that an effective way to maintain or increase forest carbon stocks on private lands is to ensure the existence of a strong market for forest products.

The Carbon Equation and Production and Use of Forest Products

Wood Building Materials

One-half the dry weight of wood is carbon, and when wood is used a new carbon pool is created. For example, a new carbon pool is created by framing a home with wood where carbon will be stored for as long as that home lasts. As reported by the Idaho Forest Products Commission, an average new single family home contains about 15,800 board feet of lumber and 10,900 square feet of wood panels, a quantity of wood that incorporates about 21,300 pounds of carbon. The carbon dioxide equivalent is over 78,000 pounds (39 tons). Within over 60 million such homes in the United States, a similar number of townhouses and multiple occupant residences, and a growing number of commercial/ industrial and other structures, a massive quantity of carbon is stored.

The energy required to produce wood products is lower than any other construction material. Lumber, in particular, requires little energy to produce since only minimal processing is needed to convert the naturally grown wood to desired shapes. Wood products requiring more steps in processing need more energy to produce, but significantly less energy than non-wood materials.

The production of lumber and wood products requires relatively little additional energy beyond the solar energy that fuels tree growth and wood production. Also, very little of the added energy that is used for making wood products is produced from fossil fuels. Over one-half of the energy used in manufacturing wood products in the U.S. is bioenergy, produced from tree bark, sawdust, and by-products of pulping in papermaking processes. In some regions over two-thirds of process energy is produced in this way.

The fact that wood is grown using solar energy, that the manufacture of lumber and other wood products requires little additional energy, and that only one-third to one-half the energy consumed is fossil energy, means that total emissions from wood products manufacture, including emissions of carbon dioxide, are typically far lower than for potential wood substitutes. What this means is that there is a carbon benefit associated with wood use that goes beyond the new carbon pool that is created when wood products are put into long-term use. This benefit is sometimes referred to as the *substitution effect*, since substitution of wood in building construction and other applications has the effect of reducing energy consumption, and particularly fossil fuel energy consumption and associated emissions of fossil carbon. There is also a substitution effect when wood is used to generate energy in place of fossil fuels.

An example of the significance of the substitution effect is provided by the Library Square project in Kamloops, British Columbia (Figure 4). This development incorporated 2,927 cubic meters of wood into a combined commercial/residential structure built of five stories of wood over a concrete first level.[1] Wood used in the Library Square project stores over 638 tons of carbon,

[1] The project includes 140 condominium units, 14,000 square feet of street level commercial space, and a community library.

equivalent to 2,340 tons of carbon dioxide. Carbon storage would not have occurred with use of any other material. Even more significant is the fact that by substituting wood for concrete and steel, which would normally have been used in building the top five floors, emissions of about 4,500 tons of carbon dioxide were avoided. The total carbon benefit from wood use in this project is equivalent to removing 1,269 average passenger vehicles from the road for a year.

Figure 4
The Library Square Project

Source: WoodWorks Canada (2011)

Wood-Derived Energy

The forest sector has long used mill residues to produce heat and power, with bioenergy today providing about 70 percent of the energy needs of the U.S. forest products industry. There is also a long history of wood use for home heating (indeed it was the nation's principal fuel for several hundred years), but it is only recently that interest has developed in wood as a fuel for large-scale production of electricity, heat, and liquid fuels. Energy from biomass has become a hot topic of discussion in scientific, business, and government policy circles, with wood one of many fuels gaining considerable attention. Woody biomass can be in the form of forest products mill residues (sawdust, bark, and trim), logging residuals, or small diameter trees obtained from forest thinning.

Just as there is a beneficial substitution effect when wood is used in place of steel or concrete in construction, there are also substitution benefits when wood fuels displace the use of fossil fuels. Wood fuels are typically sourced locally, are renewable, and their combustion releases biogenic rather than fossil carbon. When the use of fossil fuels is avoided, the geologic storage of carbon is preserved and new additions of carbon to the carbon cycle are prevented. While combustion of wood fuels also releases carbon dioxide, the carbon released is biogenic carbon that was captured from the atmosphere in the relatively recent past.

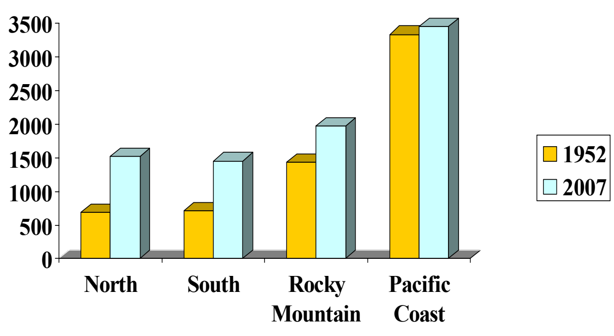
The Significance of Renewability in the Carbon Equation

As noted, the use of wood in place of more energy intensive or fossil carbon intensive materials yields tangible carbon benefits through the substitution effect. In addition, wood is renewable, whereas the materials for which it is commonly substituted are not, a reality that has major implications for both the carbon balance and long-term sustainability.

An example of a non-renewable material is petroleum. It is a vital source of liquid transportation fuels, heating oil, liquefied refinery gas, kerosene, asphalt and road oil, lubricants, waxes, and feedstocks for a variety of industrial products including plastics. From 1950 through 2010, 163 billion barrels of petroleum were extracted in the U.S. Because it is non-renewable, the *domestic reserves of petroleum available (known and unknown) to this and future generations are 163 billion barrels less than in 1950*. Consumption of that petroleum released over 75 *billion* tons of carbon dioxide, and carbon dioxide equivalent emissions to the atmosphere.

An example of a renewable material is wood. In the sixty-years ending in 2010, over 847 billion cubic feet of timber were harvested from U.S. forests, a volume approximately equivalent to that covering a football field and piled almost 3,000 miles high! This wood was used in building some 90 million homes and in producing countless other products. And what was the impact on domestic forests? Because it is renewable, *the volume of wood within domestic forests increased by more than 50 percent during those 60 years.* The volume of timber per acre increased in all regions (Figure 5), and the U.S. also maintained a stable forest land area during this time period. Accompanying the massive use of wood was an increase in the volume of carbon stored within U.S. forests, long-term storage of billions of tons of carbon within residential structures and other buildings, and avoidance of even greater quantities of carbon through use of wood rather than other more energy and fossil-energy intensive products.

Figure 5
Growing Stock Volume Per Acre on Timberland
by Region, 1952 and 2007



Source: Smith et. al. 2007. Forest Resources of the United States 2007. USDA-Forest Service.

The differences between renewable and non-renewable materials are fundamental and dramatic. These differences are sometimes overlooked or discounted in discussions of environmental policy.

The Carbon Debt Concept

In the carbon debate there is discussion of forest harvesting in the context of a "carbon debt," the idea being that since trees contain carbon, their removal from a forest takes away carbon that would otherwise remain, and that must be restored to the forest (i.e., the "debt" must be repaid) before the carbon balance is whole again.

The concept of a "carbon debt" is often discussed in terms of the specific trees harvested or at the level of the forest stand (See again Figure 3a); however, as noted earlier, no "debt" is evident at the landscape scale (Figure 3c). These realities aside, consider for a moment the carbon debt concept in the context of fossil fuels. In fossil carbon extraction there is no natural mechanism for "repaying" a carbon debt. Thus, applying the notion of a "carbon debt" to woody fuels gleaned from forests has the effect of penalizing the renewable nature of wood when compared to non-renewable fossil fuels. This masks the benefit of preventing the release of carbon from virtually permanent storage.

Within the carbon debt debate thus far there has been no discussion of the carbon debt that can result when a decision is made to forego forest harvest in order to retain stored carbon in the forest. If the result is use of non-wood materials in construction applications for which wood is well suited then, as shown in the Library Square example, one consequence will be substantial increases in fossil fuel-consumption and, as noted previously, removal of fossil carbon from long-term storage. Again, there is no chance of the carbon debt being repaid, since carbon emitted from fossil fuel combustion, whether ultimately taken up by land, ocean, or forests, is not returned to fossil fuel reserves on anything less than a geologic time scale.

When wood is used to produce energy (e.g., heat or electricity) there are other carbon consequences to consider. When wood is burned, the carbon within it is released to the atmosphere. However if the wood is being used in place of fossil energy, then most of the fossil carbon that would otherwise have been released to the atmosphere is not. Depending on the efficiencies of the system and other factors, the quantity of carbon released through wood combustion can actually be greater than the quantity of fossil carbon emission avoided because of the amount of carbon released per unit of energy produced. Yet as long as wood used in producing energy originates in a sustainably managed forest, where as much or more carbon is captured as is removed from the forest through harvest, a quantity of carbon equivalent to that released will soon be recaptured from the atmosphere by the same forest. As noted previously, that cannot be said for emissions of fossil carbon.

Forests and Carbon Policy

One of the difficult aspects of carbon discussions is in identifying the appropriate role and scale of various carbon pools and carbon sinks. For example, since forests absorb carbon from the atmosphere, why not expand forest areas and plant growth to absorb the extra fossil carbon in addition to the 'normal' atmospheric carbon they store? In fact, if trees are capable of absorbing and storing carbon, shouldn't we think of their carbon sequestration service as their most important function and stop harvesting trees for other uses? This simple proposition – to let forests grow as a carbon solution – defines much of the current carbon debate relative to forests. *Yet, such a proposition is high risk, and acceptance could worsen rather than improve the atmospheric carbon problem.* The problem is that this proposition is narrowly focused and fails to consider carbon dynamics in a larger context. This omission is critically important.

The Bottom Line

In ongoing discussions about carbon and forests it is important to realize that forests are dynamic, and that forests undergo change with or without management. It is also important to recognize that growth in excess of removals over the long term is no more sustainable than one in which removals exceed growth. With these realities in mind, it becomes clear why seeking to "let it grow" and accumulate as much carbon as possible into a forested landscape is a bad idea. While it is critical that management be conducted responsibly and sustainably, recognition that choosing not to manage has its own consequences is essential to development of rational policy.

References

Brack, C. 1997. Forest Mensuration Class Notes. Australian National University (http://fennerschool-associated.anu.edu.au/mensuration/BrackandWood1998/T_GROWTH.HTM)

Colnes, A. 2011. Sustainable Forest Biomass Energy: Carbon, Efficiency, Current Policy, Future Directions. Energy Foundation Strategy Session, St. Paul, MN, February 22-23. (http://files.eesi.org/colnes_022211.pdf)

Idaho Forest Products Commission (2011). How Much Wood Goes Into Building a House? (http://www.idahoforests.org/woodhous.htm)

Ince, P. 2010. Global Sustainable Timber Supply and Demand. In: Pessoa, F. (ed.). Sustainable Development in the Forest Products Industry, Chapter 2, pp. 29-41. Portal, Portugal. (http://www.fpl.fs.fed.us/documnts/pdf2010/fpl_2010_ince001.pdf)

Malmsheimer, R., Bowyer, J., Fried, J., Gee, E., Izlar, R., Miner, R., Munn, I., Oneil, E., and Stewart, W. 2011. Managing Forests Because Carbon Matters: Integrating Energy, Products, and Land Management Policy. Society of American Foresters, Task Force on Forest Climate Change Offsets and Use of Forest Biomass for Energy. Journal of Forestry 109 (s9), October/November. (http://www.safnet.org/documents/JOFSupplement.pdf)

National Oceanic and Atmospheric Administration. 2011. The carbon cycle (http://www.education.noaa.gov/Climate/Carbon_Cycle.html)

Smith, W., Miles, P., Perry, C., and Pugh, S. 2009. Forest Resources of the United States. 2007. USDA-Forest Service, Gen. Tech. Rep. WO-78, p. 61. (http://www.fs.fed.us/nrs/pubs/gtr/gtr_wo78.pdf)

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