Chapter **17**

Next-Generation Products and Greenhouse Gas Implications

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The social and economic benefit of wood harvest from forests depend on the demand for different ecosystem services, including products desired from trees. Although uses of species such as Douglas-fir and western hemlock for finished lumber, plywood, and paper have dominated past demand in moist coniferous forests of the Pacific Northwest, the emergence of new uses and technologies has expanded opportunities for wood utilization. This changes what, when, and how wood is harvested from the forest and how different management activities may intersect with restoration targets and ecosystem services-some of which are only just emerging.

The products most typically associated with trees are things we see or use every day, such as furniture, paper dooring, and building materials. Commonly, logs cut from trees are processed in a number of ways to produce an array of product, including lumber veneer and chips. Lumber and veneer then can be reassembled to make engineered wood products such as cross-laminated timber or laminated-veneer lumber that have improved mechanical properties and can be used in specialized applications. Chips and wood flour may be combined with other materials, such as plastic or concretes to create composites. Alternately, wood can be broken down into molecular and elemental components to produce chemicals, specialty products, and fuels.

The coniferous trees of moist forests have long been prized for their structural and appearance properties in (solid) wood products. A diver-

sity of land-management objectives in response to changing societal demands for our forests has led to a shift in raw material available to the forest-products industry.The properties and quality of these raw materials differ from those previously supplying the manufacturing infrastructure. The economics of manufacturing traditional wood products on a global scale have changed the playing field, and companies constantly look for ways to stay competitive. More complete utilization efficiency that captures high-value wood products and co-products is essential.

At the same me that the base resource available for wood-products manufacturing is changing, national attention is being directed toward energy independence, reducing greenhouse gas emissions, and ensuring economically resilient communities. Trees are becoming a key resource for producing nontraditional forest products such as aviation jet fuel and carbon nanocrystals, playing a role in carbon calculations, and entering into the discussion on national energy security. More is being demanded from our forests. In general, focusing on a single use or issue is not as sound economically as integrating a variety of products throughout the value chain. For example, the chemical market, with its international reach, can be part of the overall economic picture. Scale and product diversity are key. This chapter provides an overview of wood-based produm that can be produced by integrating technologies and growth opportunities for the wood-products industry and addresses the influence of increasing our use of wood in carbon-management strategies.

Mass Timber Products

Although technological developments continue to identitynew products for previously undervalued woody materials from moist coniferous forests, there is still a place for products manufactured from the solid-wood-processing stream. Housing an increasingly urban society presents humanity with one ofits greatestchallenges.High population densities dictate that tall buildings be used-structures that tradionally have been built using concrete and steel, both of which have large carbon footprints. With growing concerns over carbon dioxide (CO_2) emissions and with society increasingly asking questions about the sustainability of its building materials, mass timber construction (sometimes referred to as tall or solid timber construction)is experiencing a renaissance as an alternative for tall buildings. Wood, when used as a building material in place of steel and concrete, can reduce fossil-fuel emissions and also $tores carbon for the

life of the building. Mass timber construction provides opportunities for greatly increased carbon sequestration and low embodied energy in multi-story buildings. Previously, wooden structures were limited to four stories, but buildings ten stories tall have been built with mass timber construction, and plans exist for buildings up to thirty stories.

Mass timber construction addresses the issue of changing resource quality, facilitating the use of low-quality construction lumber by upgrading it to a higher-value product with improved mechanical properties (stiffness and strength). This engineered wood product offers better insulation properties and intrinsic fire safety because the massive timber elements burn slowly.

Solid timber construction systems include glued and nonglued wood prorducts (Smith et al. 2015). Glued-wood products include (1) glue-laminated timber (glulam), lumber glued together to form a beam (plate 15); (2) structural composite lumber, including laminated-veneer lumber built of multiple layers of veneer glued together to form a panel that is then cut into beams; and (32) cross-laminated timber, a composite-panel product consisting of three to nine layers of dimension lumber arranged perpendicular to each other and glued. Nonglued products include (1) dowel-laminated timber, similar to glulam, with dowels fastening the lumber, (2) nail-laminated timber, as above, with nails holding the lumber; (3) cross-nail laminated timber, a panel with nails rather than glue holding layers together; and (4) interlocking cross laminated timber, cross-laminated timber with interlocking layers.

Glulam and laminated-veneer lumber have been used in construction for many years (plate 15), but the emergence of cross-laminated timber-type systems has been relatively recent. The first commercial ceoss-laminated timber was produced Switzerland in 1995 and since has given rise to a new approach to building, using prefabricated wall, floor, and ceiling elements. Panel prefabrication simplifies building construction on-site and provides several advantages compared with steel and concrete. Smith et al. (2015) summarized lessons learned about solid timber construction (table 17.1).

Construction time and cost savings for solid timber construction were estimated for four hypothetical designs of a four-story commercial building: mass timber, structural steel-frame system using open-web steel joists, structural steel incorporating precast hollow-core panels, and reinforced concrete (Canadian Wood Council 2015). Speed of construction was fastest for mass timber (4.5 months) and slowest for steel (7.25 months). Overall, the reinforced-concrete structure provided the lowest cost per

TABLE 17.1. Advantages and disadvantages of solid timber construction (adapted from Smith et al. 2015)

Advantages	*Disadvantages*
Speed: Because building elements are prefabricated, construction time is reduced. Also, a subcontractor can begin work once the first Boor is completed unlike concrete and steel buildings where this cannot be done efficiently.	**Logistics:** Panels arc delivered by truck or in a container in order /?urn foundation to final component, with the first piece to be used on top of the shipment. Storing and rearranging panels is costly and time consuming.
Labor costs: Owing to off-site prefabrication and shorter site-preparation time, labor needs on-site are reduced.	**Job displacement:** Fewer people (and labor hours) arc required on-site owing to ease and speed of construction.
Raw material: Most solid timber products are delivered fully finished and can be exposed as an interior surface.	**Planning:** Designing solid timber construction buildings is completely different, and all design work must be completed (front-loaded) before panels are prefabricated, for example, location of electrical and mechanical systems must be decided before fabrication of panels-
Remote sites: Use of prefabricated panels that are delivered to the site allows buildings to be assembled quickly, which is important in remote locations, locations with a narrow window of time for construction, and locations with minimal labor force.	**Research:** Owing to lack of experi-ence with solid timber construction, information related to construction methods, connection systems, and delivery methods is unfamiliar or not readily available.
Carbon reduction: Wood sequesters carbon, providing a reduction in the carbon footprint of the building compared with concrete and steel.	**Acoustics and vibration:** Owing to the rigid nature of panels, buildings are susceptible to sound and vibration that can be transferred through walls and floors. To mitigate these sects, extra soundproofing is required.
Precision: Tolerances are small, resulting in tight connections and envelope. Energy efficiency of the building is aha increased.	**Component flexibility:** Panels require heavy machinery to install, and the size of the panels limits on-site adjustment.

TABLE 17.1. Continued

Advantages	*Disadvantages*
Weather: Utilizing a "dry process" (building takes place under a large, temporary protective structure), solid timber construction buddings can be erected in any weather.	**Knowledge and labor:** Solid timber construction is very different from traditional forms of construction and is unfamiliar to the majority of designers, contractors, and engineers in North America.
Safety: Because finished panels are delivered and there are fewer parts to assemble and transport, there is less potential for injury	**Wind:** Can be a concern when moving panels with a crane from truck to site, owing to their large surface area.
Weight: Buildings weigh less, hence foundations can be smaller and buildings can be taller for a similar cost as compared with traditional methods of construction. Reduced weight can also be an advantage on sites unfavorable to concrete and steel structures.	**Code and permits:** Solid timber construction is relatively new in North America, so permitting officials are generally not familiar with important aspects of panels related to structural, fire, and acoustic performance As a consequence, permitting can be delayed while documentation and engineering data are obtained.

square meter, while the costs of the other structures were higher by 1% (mass timber), 1.5% (structural steel with open-web steel joists), and 2.5% (structural steel with precast concrete hollow-core panels).

Mass timber construction offers an alternative to traditional methods of erecting tall builds. In Europe cross-laminated timber is well established as an option for multistory buildings, and strong demand supports approximately 30 fabrication facilities that are concentrated in Austria, Germany, and Italy In North America, Canada has led development, while in the United Stares, use of the product is starting to increase with a number of cross-laminated timber building projects recently announced across the nation. One limitation has been access to cross-laminated timber panels, but three facilities in North America now produce commercial-grade cross-laminated timber, and a fourth also produces a variety of cross-laminated timber products, including crane and oil Held mats and furniture. Many

questions about solid timber construction (table 17.1) are being addressed by research.

Raw materials unsuitable for solid timber products are being used in novel applications. Other integrated technologies provide alternative pathways for products that can be manufactured from by-products of the mechanical breakdown process, as well as wood harvested in land-management activities that does not have the necessary quality for particular wood products.

Biorefinery Concept

Biorefining can produce high-value products like chemicals, fuels (solid, liquid, or gas), and high-value specialty products such as automotive parts and biomedical supplies-not what traditionally comes to mind when you think of wood products.

A biorefinery is analogous to a petroleum refinery, where feedstock (crude oil) is converted or refined into fuels (gasoline, jet fuel, or diesel) and a variety of products, including lubricants, waxes, asphalt plastics, solvents, and other chemicals. Many of these chemicals are used in everyday products such as ink, tires, eyeglasses, medicines, shampoo, and toothpaste. In a wood-based biorefinery complex, several conversion options need to be integrated as appropriate, to progressively derive value from the woody biomass at various stages. Feedstock (logs, wood chips, bark forest slash, sawdust, and planer shavings) can be converted into a variety of products, such as lumber, veneer, composite-panel products, energy, wood pellets, cellulose, lignin, sugars and their derivatives, polymers, and other chemical products (fig. 17.1).

The chemical structure of wood enables production of these varying commodities. Chemical components of wood include the macromolecular cell-wall components cellulose (30%-50%), hemicellulose (17%-35%), and lignin (15%-30%), low-molecular-weight components categorized as extractives (2%-8%), and ash or inorganic mineral substances (0.5%-3%). Wood is therefore classified as a nitrocellulose material, which is one of the most abundantly available materials on earth. Cellulose is a linear high-molecular-weight polymer composed of glucose molecules and is the main structural component providing strength and stiles to wood. The main constituents of hemicellulose include 6- and 5-carbon sugars: glucose, mannose, galactose, xylose, and arabinose. Polymer chains composed of

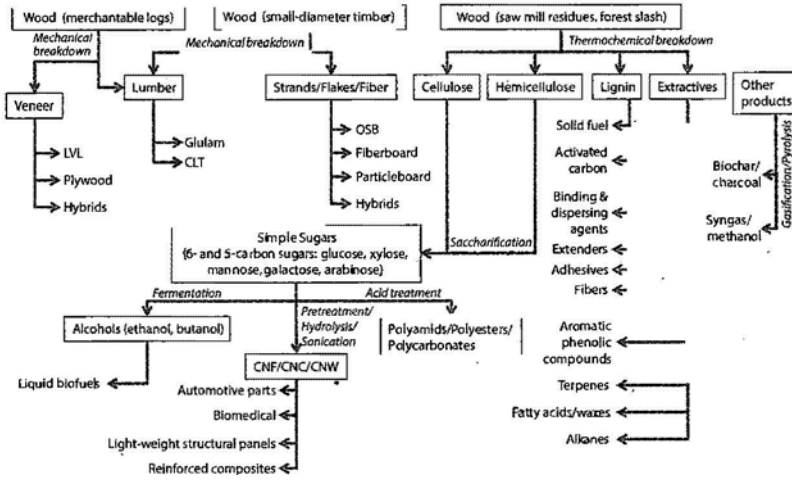

FIGURE 17.1. Examples of processes and products that constitute an integrated bio-based processing facility. Processes are in italics, and not all processes are shown.

these sugars are shorter than those of cellulose and can be branched. Cellulose and hemicellulose, together, can yield sugars for production of biofuels and biopolymers in a biorefinery.

Lignin is an amorphous macromolecule composed of an aromatic system of phenyl propane units. Lignin is incorporated into the cell-wall structure for strengthening, as well as between wood fibers to serve as a natural binder holding the fibers together. The structure of lignin varies between softwoods and hardwoods: generally, softwoods contain more lignin. Lignin can be used to formulate dispersants, binders, emulsifiers, stabilizers, and extenders. Chemical products such as phenols, vanillin, methane, and benzene can be derived from lignin isolated by different processes. Recent developments have led to lignin-based co-products such as carbon fibers for composite-fiber applications (Kubo and Kadla 2005; Ruiz-Rosas 2010).

Extractives, although a minor' component of wood's chemical structure, can influence wood properties (for example, durability) and processing of wood (for example, serving as lubricants during extrusion of wood-plastic composites). Low-molecular-weight extractive s in wood include aromatic phenolic compounds, terpenes, fatty acids, waxes, and alkanes. Potassium, calcium, and magnesium are some of the inorganics found in wood at very low concentrations.

To get from tree to products, wood must undergo initial processing (mechanical breakdown) and then conversion. To produce the aforementioned products from wood in a biorefinery complex, several conversion options need to be integrated to progressively derive value from the woody biomass at various stages. Wood saccharification involves hydrolysis of the carbohydrate components of wood, cellulose and hemicellulose, to 5- and 6-carbon sugars, such as xylose and glucose. Several pretreatment options, primarily involving the presence of acids, organic solvents, or enzymes, have been developed to isolate lignin from the carbohydrate components for pulp and paper production, and hydrolyze wood into lamentable sugars (Jorgensen et at 2007; Zhao et at 2009; Zhu et al. 2009; Pelaez-Samaniego et al. 2013). Sugars isolated from cellulose and hemicellulose by hydrolysis can be fermented into alcohols for biofuels (e.g., ethanol and iso-paraffinic kerosene) and bioplastics (e.g., polyhydroxy alkanoates), commerce acids (acetic acid lactic acid, galvanic acid), acetone, and yeast. These sugars can also be converted through acid treatments into commercial products such as polyamides, polyesters, and polycarbonate s. Sugars derived from hydrolysis of hemicellulose can similarly be converted into value-added commercial products. Isolated lignin in different forms (kraft lignin, lignin sultanates, organelles lignin) is mainly used for production of energy via direct combustion. However, potential for deriving high-value low-molecular-weight chemicals and other products from this amorphous polymer (lignin) has provided impetus for developing innovative technologies. With advances in conversion technology, we are able to further fractionate the cellulosic component of wood fiber to the microbial level, thus enabling production of cellulosic nanofibrils and cellulosic nanocrystals or nanowhiskers. Research on cellulosic nanofibrils began more than 20 years ago (Eichhorn et at 2010). Cellulose nanofibrils found natural in wood have unique properties and sizes that differ from synthetically produced ones, such as carbon nanotubes (Khalil et at 2012). Wood-based nanoscale feedstock can be used for example, to produce biomedical products, fiber-reinforced composites, lightweight structural panels, and automotive parts.

Wood also can be fractionated and converted into a variety of other products, including energy, by means of mechanical, thermal, and chemical techniques. Heat can be produced by burning wood. A kilogram of wood can yield on an average 19 megajoules (MJ) (lower heating value, LHV) of energy, with low ash and sulfur contents. Higher heating value (HHV) of wood which also includes the latent heat contained in the water vapor, ranges between 18 and 21 MJ. However, burning wood for

heat releases stored carbon and precludes implementing other processes to derive chemical products that can extend the benefits of this renewable resource.

Besides being directly burned for energy wood can also be thermally degraded at temperatures up to 500ºC (932ºF) under an inert atmosphere to produce solid components (charcoal and biochar); condensable volatile compounds (tar); and noncondensable volatile gases (CO_2, CO, methane, and other hydrocarbons). This process is referred to as pyrolysis (Fengel and Wegener 1983; Lange 2007). Gasification of wood (Fengel and Wegener 1983; Lange 2007) at temperatures between 850oC and 1000ºC (1,562ºF and 1,832ºF) can yield different products depending on process conditions and water content. Gasification of wood in the presence of air yields CO_2, CO, methane, hydrogen, and nitrogen. Gasification in the presence of oxygen and additional steam can yield gas that can be subsequently converted by cleaning and adding hydrogen to produce synthesis gas.

Conversion of woody biomass to wood products, chemist, energy, and higher-value composites can, in some cases, reduce fossil-fuel emissions if those products substitute for nonwood prod um that generate higher fossil-fuel emissions in their production. In cases in which the production of wood products reduces fossil-fuel emissions but increases wood-fuel emissions, there will be lower overall carbon emissions over time as the wood-fuel carbon emissions are reabsorbed by forest growth. When there is a reduction in fossil-fuel emissions, use of wood products reduces wastage, energy consumption, emissions during processing, and dependency on fossil fuels. Integrating these manufacturing technologies (e.g., a facility that produces pulp and paper, concentrated sugar solution for biofuels, co-products from extracted lignin, and combined heat and power) could further reduce environmental impacts. These impacts should be objectively determined by conducting cradle-to-grave life-cycle assessment of production systems from raw material extraction through materials processing, manufacturing, distribution, and end-of-life disposal.

Greenhouse Gas Implications of Wood-Products Production and Use

Sequestering carbon (C) in forests and offsets carbon emissions with use of wood for energy and products are two of a range of objectives in managing forests. Increasing carbon storage and carbon offsets across a range of

carbon pools and emission sources contributes to stabilizing atmospheric concentrations of CO_2.

Chapter 12 discusses how forest management, in combination with forest-products and wood-energy production, can influence carbon storage over time. Here we review how forestry and forest-products production and use form part of a larger system of processes-including production of fossil-fuel energy and nonwood products. To determine the full effects of forest-products production or wood-energy use we need to evaluate carbon storage and greenhouse gas emissions from this larger system of processes over time.

Evaluating the Effect of Forest-Products Production and Use on Carbon storage and Greenhouse Gas Emissions

Numerous processes are associated with forest management and wood-products production and use that can affect carbon storage and emissions (fig. 17.2). The effect of these processes on the atmosphere can be evaluated by tracking carbon flows across system boundaries over time.

The *forest sector* includes forest, wood products, and wood-energy processes (processes inside the dashed-line box, fig. 17.2). The forest sector

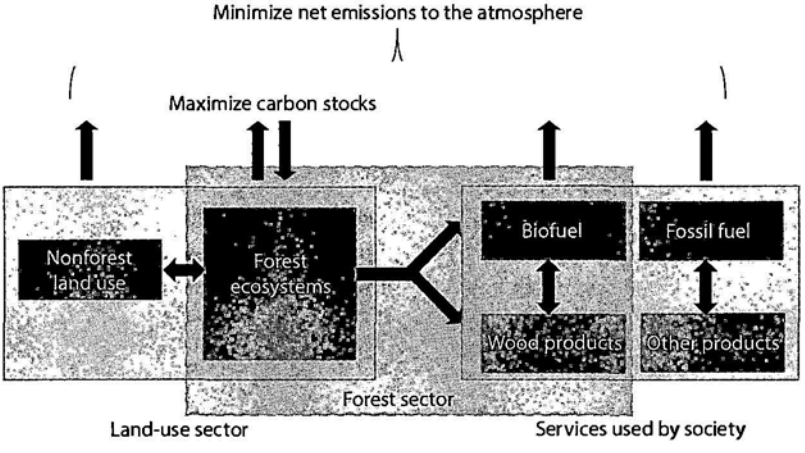

FIGURE 17.2. Forest-sector and non-forest-sector greenhouse gas emissions and stock changes that are influenced by forest management and forest-products production and use.

can be defined to include only carbon fluxes to and from forests and/or wood products, or it may also include carbon fluxes from equipment used to manage forests, to harvest and transport logs, and to manufacture wood products.

Forest management and production of wood products can also affect greenhouse gas emissions beyond the forest sector. If energy is produced from wood this would displace fossil-fuel emissions. Similarly, emissions from the manufacture of wood products could replace emissions from producing substitute nonwood products. Forest-products production can also indirectly cause land-use change by changing market prices for wood products. Higher prices may induce landowners co keep land in forest that they may have otherwise converted, or to convert land to forest, resulting in increased carbon storage.

Evaluation of carbon-management strategies associated with forests and forest products requires projecting carbon-stock changes and emissions for a scenario of altered forest management and/or product production, compared with a baseline (or reference case) projection without such changes (box 17.1). The results of a carbon assessment for forest management and wood-products production will be determined in large part by how system boundaries are defined, including the time period over which carbon storage and emissions are evaluated. Currently, no standard approach exists for selecting system boundaries. Including more processes would give a more complete understanding of impacts. However, as more processes are included the uncertainty in the estimates of effects on carbon storage and emissions would likely increase.

The effectiveness of an economic policy strategy, such as incentives to increase wood use for energy or solid-wood products in place cottonwood products, is determined by changes in forest and nonforest landowner behavior. Decisions relative to harvesting or land-management (e.g., planting) activities could provide more wood for those uses. For example, increased timber demand for products and building construction can alter some landowners' management practices. Although some may change rotation age, others may convert nonforest land to forest plantations. In either case, the additional wood demand changes the time profile for carbon stored on the land. With increased wood demand for energy, landowners may thin more frequently or sell logging residue from existing timber sales, which will also change the time profile of carbon on the land relative to a reference case without such demand.

BOX 17.1. CARBON-STOCK CHANGES WITH WOOD AND NONWOOD PRODUCTS

To evaluate the effect on net carbon emissions (or net carbon storage) of an increase in timber harvest to make wood products, we need to compare a reference-case projection of carbon stored on the Land, in products, or in fossil fuels with an alternate case that involves an increase in wood harvesting. Carbon storage changes with either production of a wood product or a substitute nonwood product *n* years following production (all variables in tons carbon) can be calculated by comparing these two cases.

Carbon storage will be greater as a result of wood products production after *n* years if

$$-EWP - H + W + GNWP + GWPextra > -EWP - ENWPextra + GNWP$$

(for parameter definitions, see table 17.2); or, after simplification,

$$GWPextra - H > ENWPextra - W \quad (1)$$

GWPextra, the extra forest growth after harvest in the case of wood-product production, likely will approach the harvest amount H, over time. GWPextra may fall short of H by an amount that is the sum of extra emissions needed to make nonwood products and the amount of carbon stored in wood products after *n* years.

Thus the carbon storage advantage of wood products after *n* years can be improved by increasing the rate of forest regrowth, decreasing the energy needed to make wood products relative to nonwood products (increasing ENWPextra) and increasing the amount of carbon stored in wood products over a long time period. Another way to increase carbon storage advantage from producing wood products is more complete utilization (Less waste) of harvested wood. For a given amount of harvest a decrease in the right side of equation (1), leaving the left side unchanged, could result in more storage of carbon in wood products (W).

Implementing Strategies to Increase Carbon Storage

Carbon-storage strategies involving forest management and forest-products production and use may be ineffective because of flaws in incentive structures or policies, not owing to the biophysical attributes of the strategy itself. For example, an incentive program might favor harvesting large trees that produce lumber, based on the assumption that the increase in lumber produced would replace building materials that emit more carbon in manufacturing. However, if this incentive strategy were imple-

TABLE 17.2. Parameters used to calculate carbon-storage different with either production of a wood product or a substitute nonwood product ***n*** years following production

EWP = fossil emissions from the manufacturing of wood products
ENWPextra = extra fossil emissions needed to make nonwood products versus wood products
H = amount of wood carbon removed tom a forest to make wood products
W = amount of carbon stored in wood product in use or lands after n years
GNWP = growth in forests, over ***n*** years, when nonwood product is produced (no harvest for forest products)
GWPextra = extra forest growth, over ***n*** years, in the case of forest harvest and wood-products production rather than no harvest

Parameter	***Alternate Case: One unit of wood product is produced***	***Reference case: One One unit of nonwood product is produced (functional equivalent to one unit of wood product)***
Fossil fuel emissions in manufacturing	EWP	EWP + ENWPextra
Timber harvest required (year zero)	H	0
Carbon storage in wood products after ***n*** years	W	0
Forest growth over ***n*** years after product production	GNWP + GWPextra	GNWP
Change in carbon stored over ***n*** years in forests, wood products in use, fossil fuels in ground	-EWP - H + W + GNWP + GWPextra	-EWP-ENWPextra + GNWP

mented, the lumber could go to nonbuilding uses, or an increase in harvest by one landowner could be offset with a decrease by another. This is a flaw of the incentive system, not in the underlying wood-substitution strategy. If there were incentives for builders to use wood in structures instead of other materials, the strategy could be active in reducing overall fossil

emissions from manufacturing; however, the effectiveness depends on the assumed changes in forest management.

Evaluation of carbon-management strategies often focuses on understanding how they change carbon storage per unit area of forest under management over time. It is also possible to evaluate strategies by focusing on the change in carbon storage associated with producing one additional unit of wood energy or one additional unit of wood product. Evaluation of these effects could include the effect of changing demand for several products, including nonwood products, on emission.

In order to compare the carbon-mitigation effect of different strategies to alter forest management or alter forest-products production and use, it will be critical to use a common set of system boundaries (processes) and a common metric for evaluating the effects on the atmosphere.

Economic and Ecological Implications

Novel technologies that efficiently and sustainably use natural resources And reduce demand for fossil fuels are needed to mitigate environmental impacts ranging from net greenhouse gas emissions to unsustainable forest practices. In communities with abundant supplies of lignocellulosic biomass (crop based to forest based), there is also a need for value-added manufacturing opportunities that are economically viable and suitabole for small-to medium-scale operations. Furthermore, there is a national desire to move from reliance on fossil fuels to renewable fuels to reduce fossil emissions. These consitions provide an opportunity to develop a fully integrated biomass-based technology system that meets growing demand for building materials, chemicals, and energy.

Producing cellulosic biofuels from woody biomass can reduce emissions and energy dependence significantly more than crop-based biomass (Lippke et al. 2012). Current sources of biofuels, such as ethanol, from crop-based feedstock (corn or sugarcane) have severe limitations in net displacement fossil fuel. These limitations include reallocation of land from food to biofuel production and net energy efficiency. Efforts toward sustainable management of our forests and an abundant supply of underutilized forest-based biomass (woody biomass) have elevated cellulosic-based biofuels to one of the primary means to achieve our national goal of energy independence. However, because established infrastructure is lacking, economic viability of cellulosic-based biorefineries depends on low-cost feedstock, improvements in transportation systems and conversion

technologies, subsidized costs, and value-added products. High-value added co-products enable the greatest possible economic return from bio--refinery feedstock in an overall global climate change initiative.

Vertically integrated manufacturing and value-chain considerations that make use of raw materials harvested from both natural stands and intensively managed plantations, along with the by-products of harvesting and manufacturing processes, can maximize woods value, considering its life cycle. Biorefining can occur at different scales integrating two or more aforementioned conversion technologies to produce two or more products at one location. Scale and product depend on the available form of raw materials, accessible and market demands. The biorefinery concept provides a means to convert low-value nitrocellulose biomass into an array of higher-value products. Woody biomass can befractionated into its main components by sequential treatments to give separate streams that may be used for different product applications, allowing a maximization of the benefits filma renewable and complex resource that will become increasingly imparts as fossil sources become more constrained or expensive. Economic benefits accrue predominantly to local communities close to the resource base, while the environmental benefits accrue region-wide through the substitution of renewable-based products for fossil-based products. These products also allow for more complete use of harvested trees of many types and sizes. This, in m makes the array offorest thinning strategies that can be economically feasible much more flexible as we adapt to a continually changing environment.

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