Summary/synthesis:
What Role Will Forests Play in America's Long-Term Energy Future?

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Introduction

As a renewable carbon-neutral resource, wood, woody biomass, and wood-derived fuels are playing an increasing role in meeting the nation's energy needs. This is not the first time the country has relied upon its forests as a key energy resource. Wood has been the primary source of energy for a greater part of the nation's history than fossil fuels, and lessons from that era can offer some important insights as we embark upon the next era of wood energy.

Until the latter part of the 19th century, wood was the leading source of energy for heat, industrial processes, and transportation. Public concern over the loss of forests and depletion of wood supplies, particularly by the railroads, largely launched the movement for forest conservation and the creation of public forest reserves. But by this time, the nation was already shifting from wood to coal as its major energy source, reducing the pressure on forests to provide fuelwood. In the early 20th century, the shift to the automobile and its petroleum-powered internal combustion engine as the primary means of transportation freed millions of acres of pasture and cropland used to provide hay and fodder, allowing many of these lands to revert to forest and begin the long process of restoration.

The shift to fossil fuels gave the nation's forests a century in which to recover, but it exacted its own price in the form of greenhouse gases, climate change, and the creation of a physical, economic, and social infrastructure premised on the continued availability of abundant, inexpensive energy. Today much of the nation's forest land has been restored, and we once again look to wood and other forms of biomass as potential sources of energy for heat, power, and transportation fuel. In our urgency to develop new technologies for utilizing forests as a source of renewable, domestic, carbon-neutral energy, will we give up the gains we've made in conserving forests for wildlife, water, biodiversity, and an array of other essential ecosystem services?

It is clear that wood will be an important component in the nation's broader comprehensive energy strategy. Woody biomass can provide advanced biofuels to reduce net carbon emissions and dependence on imported oil. It can provide heat and power through a variety of different means, and at different scales, depending on local circumstances. What is the optimal combination of these technologies that will maximize the contribution of woody biomass to the nation's renewable energy goals, most efficiently utilize wood resources, and ensure that forests continue to be sustainably managed for a range of public values? How will we realign the framework of federal, state, and local policies, mandates, and incentives such that rational economic decisions will result in private capital investment that will produce this outcome?

Forests, energy, and the roots of the 19th-century conservation movement

Well into the 19th century, wood was the only significant source of energy for heating, transportation, and industrial processes. As late as 1870, more than half of all energy for domestic and industrial heating and for transportation came from wood (see Table __). Lumber production receives most of the attention in the story of how America's forests were consumed during the westward expansion of the 19th century, but it was not until after 1860 that the volume of wood going into lumber surpassed the volume going into fuelwood (U.S. Bureau of the Census 1977). During the decade 1850-1859, consumption of fuelwood in the US is estimated to have been more than 878 million cords, or 3.4 billion tons (Olson 1971). A significant portion of this was likely supplied through the clearing of more than 40 million acres of forest for farmland during this same period. The census of 1839 recorded 5,341,445 cords of wood sold in the major cities of the Northeast, with cordwood sloops supplying Boston from the coast of Maine, New York from the pine barrens of New Jersey, and Philadelphia from the headwaters of the Delaware. As early as the mid-18th century the rising cost of wood in the nation's major urban areas, and concerns about resource depletion, prompted inventive individuals like Benjamin Franklin to look for alternatives to open-hearth fires which lost nine-tenths of their heat up the chimney. Franklin's stove could supply about four times as much heat as an open fireplace for the same amount of wood (Hoglund 1962).

Although the use of fossil fuel surpassed the use of fuelwood in relative terms by 1880, the country's population and thus its energy consumption was expanding rapidly, and the consumption of fuelwood continued to increase in absolute terms. The US population rose from 23 million in 1850 to more than 76 million by 1900. Fuelwood consumption in the US reached its peak in 1933, when the population had reached 126 million people, declining only gradually with the spread of rural electrification (Williams 1989).

The impact on the American landscape was profound. Between 1860 and 1910 another 152 million acres of forest were cleared for agriculture. Roughly half the wood that was cut went into lumber. Much of the rest went toward the national consumption of fuelwood, estimated at more than 6 billion cords (22.8 billion green tons) during this period (Reynolds and Pierson 1942).

Wood energy in transportation

For most of the nation's history, wood has fueled the transportation sector as well, both directly and indirectly. Well into the early years of the 20th century, several million horses provided most of the country's transportation of people and goods. Millions of acres of pasturage and cropland for both food and fodder were required in order to maintain this vast population of livery.

But the component of the wood-fueled transportation sector that had the most extensive and far-reaching impact on the nation's forests were the railroads. It was not until the 1870s that coal began to take over as the primary fuel for steam locomotives. The US Department of

Agriculture's 1865 annual report calculated that railroads at the time were consuming roughly 21,555 cords daily (Starr 1865) or roughly 6.5 million cords (24.7 million tons) annually.

Even as the use of wood as the railroad's primary fuel declined, the use of wood for supporting functions such as ties, bridges, and trestles continued to increase. Wooden bridges and trestles had to be rebuilt on an average of less than ten years, but wood was much more available and much less expensive than iron and steel at the time.

The demand for ties alone created an almost insatiable appetite for wood. The roughly 2,600 ties per mile of track had to be replaced on an average of every 5-6 years, meaning that the ties on 15-20 percent of entire mileage of track had to be replaced in a given year (Hough 1878). Total track length in the country climbed from 30,000 miles in 1864 to 90,000 miles in 1875, 180,000 miles by 1885, to 350,000 miles by 1895. The USDA's 1885 annual report estimated that 567,714 acres were being cleared annually just to supply the railroads with replacement ties (Egleston 1885).

Public dismay at the accelerating depletion of the nation's forests by the needs of the railroads may have been the single most important factor in the launch of the forest conservation movement in the late 19th century. Throughout the 1870s and 1880s, there was a steady stream of grim government reports on the worsening condition of US forests, and dire predictions of future wood shortages if action was not taken. An 1887 bulletin from the USDA Forestry Division put it plainly. "Considering the stupendous amounts of timber already withdrawn from native forests, the annual demands of railways now in operation, and the increase in mileage from year to year, it becomes necessary to take a more accurate survey of the fields of demand and supply, unbiased by the popular delusion of the inexhaustible forest wealth of America. The necessity is no longer either to be ignored or lightly treated as in the past" (Kern 1887).

Of particular concern was the reach of the railroads, which by this time included several transcontinental routes with numerous branch lines reaching into ever more remote regions of the country. Indeed, railroads were seen as the key to opening new territories to settlement and agriculture, and the federal government gave roughly 128 million acres of public land to the railroads through a series of railroad land grant laws enacted between 1850 and 1871 (Dana 1956). These lands provided not only rights-of-way across public land, but granted 10 square miles for every mile of track built in order to provide the necessary wood, and to serve as a source of capital to the railroads through the subsequent sale of these lands to settlers.

As early as the 1860s, concern was being expressed that, wherever the railroads extended, deforestation soon followed: "Even where railroads have penetrated regions abundantly supplied [with wood], we soon find all along its track timber soon becomes scarce. For every railroad in the country requires a continued forest from one end to the other of its lines" (Fuller 1866). Efforts by the railroads to extend the useful life of ties actually exacerbated their impact on local forests. Because the heartwood of choice hardwood species such as black locust (*Robinia pseudoacacia*), white oak (*Quercus alba*), and chestnut oak (*Q. prinus*) was considered more rot-resistant, the outer parts of every tree harvested were stripped off and discarded. Even the lumbermen of the time were appalled. Noted one, "there is no branch of the lumber industry

where there is more waste of raw material . . . each tie represents about 75 [board] feet of good merchantable lumber in the standing timber destroyed for it" (Kern 1887).

Those concerned about the impact of railroads on forests also recognized that the railways were an essential component of the nation's economic infrastructure and were not going away. Their recommendations thus focused on two responses: (1) increase the useful life of railroad ties through treatment with rot-resisting chemicals such as creosote, and (2) undertake a massive program to replant trees wherever possible in order to supply the railroads' needs from second-growth forests rather than virgin forests in new territory. Two experimental treatment plants were established in the 1880s, one in New Mexico and the other in Nebraska, but for the railway companies there was still an abundant supply of cheap timber available. It was not until after 1900 when timber prices rose significantly in response to dwindling supplies that the railways invested in more creosote plants and treated railroad ties came into general use (Olson 1971).

The tree-planting idea seemed very appealing at the time, and several railways invested in plantations, some of which experimented with exotic species such as eucalyptus (*Eucalyptus spp.*) and catalpa (*Catalpa bignoniodies* and *C. Speciosa*) that were thought to have to potential for faster growth and greater resistance to decay. In spite of the enthusiasm for tree planting, and projections by USDA Forest Service economists that wood prices would continue to rise, railways' investment in plantations was minimal. "In reality, the plantations were few and insignificant. In all, about four dozen locations can be identified, and perhaps, at most, about 15,000 acres were affected during the space of about 30 years, which, if the trees had all come to maturity and been good, merchantable timber, would have supplied ties for less than 10 days at the 1910 rate of consumption" (Williams 1989). These experiments in tree plantations for railway wood needs had ceased by 1915, although the right-of-way plantations themselves came to serve a valuable alternative role as snow fences and windbreaks (Olson 1971).

Transition to fossil fuels

Considering the conditions of America's forests toward the end of the 19^{th} century, fossil fuels showed up just in the nick of time. Just as the country's population growth was accelerating, and the industrial capacity and number of households were rapidly expanding, Appalachian coal stepped in to take over supplying much of the energy for heating and industrial processes.

In transportation, coal also had completely replaced wood as the primary fuel for the railroads by 1900. The development of oil for transportation purposes brought along with it cheap, abundant new supplies of natural gas, a key cost component in the manufacture of Portland cement, which facilitated the substitution of relatively inexpensive concrete instead of wood construction in buildings, homes, bridges—and eventually even railroad ties.

Not to be overlooked is the enormous effect of replacing millions of bio-powered horses and other livery with oil-powered automobiles as the nation's primary means of transportation. This liberated literally millions of acres of cropland and pastureland that had been producing hay and fodder, some of which was abandoned for agricultural purposes and allowed to revert to forest. The steady decline in the area of forest land in the US, a trend that had continued unabated for

nearly three centuries, flattened out and then reversed in the two decades following Henry Ford's introduction of the Model T in 1908 (Fedkiw 1989). The area of forest land in the US today stayed roughly the same from 1930 through the end of the 20th century, as the reversion of marginal crop and pastureland and new losses of forest land to development roughly balanced out one another.

Unfortunately, as we entered the 21st century the area of forest land in the US seems to have returned to its downward trend. It is estimated that an average 6,000 acres of forest and open space were lost each day to development over the decade 1995-2004 (Harper 2007), rivaling the rate at which forest land was being lost to agricultural clearing on the frontier during its heyday in mid-19th century (Powell et al. 1993). It is ironic that this reversal in fortunes for US forests is largely attributable to urban sprawl—made possible by the ubiquitous automobile—and more recently by the return of agricultural forest clearing, this time to expand the production of corn for the manufacture of ethanol as a substitute for gasoline.

Wood in the nation's energy future

The hundred-year respite that fossil fuels provided for the nation's forests came at a heavy price, of course. There is now little scientific doubt that this reliance on fossil fuels for most of our energy and transportation needs has contributed, and continues to contribute, to changes in global climate patterns that will challenge the ability of both human communities and natural ecosystems to adapt. It should be kept in mind that the deforestation of 285 million acres in the US from 1630 to 1900 (Powell et al. 1993), much of which was never replanted to forest, made an enormous net addition of carbon dioxide and other greenhouse gases to the atmosphere—wood is a "carbon neutral" fuel only if the carbon released in its combustion or oxidation is sequestered again through reforestation and forest regrowth. That process continues today in forests around the globe that are being deforested and often burned—increasingly to make room for oil palm, soybeans, sugar cane and other crops planted to produce biofuels.

If wood-based biofuels and bioenergy are to be a major element in America's energy future, how can this be accomplished without having effects on US forests that are environmentally, economically, and socially unacceptable? The papers in this volume describe five major components of such a strategy:

1. Better information and methodologies for calculating the truly available—and *sustainable*—local supply of woody biomass to help guide decisions by local governments and the energy companies themselves on the type, scale, and location of a biofuels or bioenergy facility that will be best suited to local conditions and circumstances.

2. Better information on the characteristics of alternative biofuels and bioenergy technologies in terms of the volume and type of feedstock requirements, needs for additional supporting infrastructure (e.g., transportation, wood handling), fuel efficiency, ability to help meet local energy needs, and likely environmental and economic effects on nearby communities.

3. Better state and local government planning and coordination to ensure that the proximity of new and existing biofuels, bioenergy, and wood products manufacturing facilities does not create excessive demand on local forest resources and/or such intensive competition for scarce woody biomass supplies that the financial viability of the facilities is jeopardized, and local economies destabilized.

4. Better state government wood harvesting guidelines to ensure that, where more intensive systematic removal of woody biomass takes place, it does not threaten long-term soil productivity, water quality, biodiversity, or other important ecosystem services provided by well-managed forests.

5. Better coordination in the development of federal, state, and local policies that are aimed at supporting the development of renewable biofuels and bioenergy industries, so that there are adequate incentives for the full range of biofuels and bioenergy technologies, from large-scale to community-scale, and communities are not forced into accepting facilities that are poorly suited to local circumstances.

Biomass supply estimates

Domestic renewable energy production has become a national priority in the United States to help reduce net emissions of carbon dioxide and other greenhouse gases, but primarily to respond to increasing concern over international political instability and the potential for significant unexpected interruptions in imported oil supplies. In 2005, Congress enacted the Energy Policy Act (P.L. 109-58), setting mandatory goals for producing biofuels (mostly ethanol) for blending with gasoline for transportation fuel, and providing increased federal support for many types of renewable energy including wind, solar, geothermal, and biomass. Meanwhile, several state governments enacted laws requiring electric power producers to meet goals for producing a significant percentage of their power from renewable sources. The goals and timetables vary from state to state, and it is widely expected that Congress will act soon to standardize this to a requirement of 25 percent of power production from renewable sources by 2025.

The Biomass Research and Development Advisory Committee established by Congress asked the Department of Energy to examine the feasibility of producing enough biofuels to replace 30 percent of the nation's petroleum consumption by 2030. The paper by Skog and Buford describes the groundbreaking 2005 analysis by the US departments of Energy, Agriculture, Interior, and the Environmental Protection Agency. It was anticipated that replacing 30 percent of the nation's present petroleum consumption would require as much as a billion tons of biomass. The study results estimated the potential biomass supply for energy at 1.3 billion tons nationwide. Of this, 368 million tons were projected to come from the nation's forests: 52 million tons from fuelwood harvested from forests, 145 million tons from residues from wood processing facilities, 47 million tons in urban tree waste, 64 million tons from logging residues, and 60 million tons from hazardous fuels treatments.

Based in part on the findings of this study, Congress in 2007 enacted the Energy Independence and Security Act (P.L. 110-140), which contained a Renewable Fuels Standard establishing ambitious goals for increasing domestic production of both “first generation biofuels” such as corn ethanol (15 billion gallons per year), and “advanced biofuels” such as cellulosic ethanol (21 billion gallons per year) by 2022. In the subsequent study described by Skog and Buford, the woody biomass projected to come from forests is estimated at 40 million tons per year, based on more precise county-level data and simulation modeling of thinning operations. By 2022, this is expected to provide an estimated 4 billion gallons of liquid biofuels. Skog and Buford describes important adjustments in assumptions, and highlights the need for caution in interpreting the earlier results. Woody biomass previously assumed to be available from federal lands, especially through thinning and hazardous fuels treatments, dropped out of the second study because biomass from federal lands was made ineligible as a source for producing biofuels to meet the Renewable Fuels Standard in EISA. This was based on concerns that demand for biomass could place an unacceptable strain on federal forests, which have been at the center of controversies over timber harvesting for more than three decades.

The paper by Gan, Jarrett, and Johnson illustrates that even on private forest lands theoretical supply may not equate to actual availability of woody biomass. Private woodland owners, who collectively control nearly 60 percent of the nation’s productive forest land, are noted for the diversity of their ownership objectives, their variable response to financial and other incentives, and the resulting high degree of uncertainty and unpredictability when it comes to projecting biomass supply from private lands. For private woodlands in the South, they estimate available biomass supply as anywhere between 1 million and 12 million tons annually.

The paper by Mater and Gee arrives at a similar conclusion using a very different methodology. They take a geographically more specific approach, identifying a number of possible locations around the US for a biofuels or bioenergy facility, based on apparent local availability of woody biomass supplies. Correcting for terrain, road types, and other transportation factors, they define a circle depicting the area from which such a facility could reasonably expect to draw its woody biomass supply. Through a series of surveys and interviews with the owners or managers of all the public and private forest lands within the circle, they estimate the volume of woody biomass that each area of forest land is actually likely to supply, considering ownership objectives, responsiveness to changes in market prices for wood, and possible environmental or legal constraints. Finally, they examine the likelihood that public and private forest managers within the circle can coordinate to provide a stable or “levelized” supply of woody biomass to a local biofuels or bioenergy facility through a mechanism they refer to as a Coordinated Resource Offering Protocol (CROP). These CROP evaluations have been conducted on 60 National Forests around the US, and additional studies are under way. Based on these studies, the authors conclude that in most instances federal forest lands would not be able to supply more than one-third of the woody biomass needed to supply a 50 MW power plant (estimated at 12,000 green tons (gT) per MW annually). In most instances, however, a 15 MW power plant could be reliably supplied, particularly if it is integrated with a wood processing facility that has the infrastructure already in place for harvesting, transportation, wood handling, and separation of woody biomass from wood that is suitable for higher value-added products such as lumber. This analytical approach could be especially valuable to communities and energy investors

considering new or expanded wood bioenergy or biofuels facilities, and striving to "right-size" these facilities to match the level of woody biomass that will actually be available on a sustainable basis.

According to the paper by Smith and Parhizkar, earlier projections of biomass supplies from residues and wood waste from wood processing facilities such as sawmills and pulp mills may have to be scaled back. These residues and wood waste are increasingly being utilized by the mills themselves. Smith and Parhizkar demonstrate an alternative approach to estimating these kinds of residues based on a county-by-county study conducted in Virginia in 2007. The significant decrease in the projected biomass supplies mill residues and wood waste mean that there will be much more immediate and substantial competition for roundwood among biofuels and bioenergy facilities, and with existing wood using industries such as solid wood products manufacturers and pulp and paper facilities.

This finding is supported in the paper by Abt in his analysis of wood markets in the US South. Abt concludes that the entrance of the biofuels and bioenergy industry will have a greater effect on roundwood prices in the region than on harvest levels. With the federal and state subsidies available for biofuels and bioenergy production, these industries are likely to be less affected by roundwood price increases than the existing wood products industry in the region, at least in the short run. Abt predicts that this will lead to continued growth in biofuels and bioenergy capacity in the region, and a decrease in capacity in the region's wood products manufacturing sector.

To what extent can the demand on forests for biomass be offset by dedicated energy crops, and advances in biotechnology that improve the growth and yield of non-forest sources of biomass? Theoretically, energy crops such as hybrid poplar, hybrid willow, and switchgrass have the potential to supply more than 170 million green tons annually (EIA 2003), but a key uncertainty is the availability of sufficient land for large-scale expansion of energy crops given the competition with conventional crops that are more profitable. The amount of cropland in the US has been declining for much of the past 50 years due to development, and it is unlikely this trend would reverse for energy crops given their low value. A study by the Department of Energy suggests that the most significant opportunity for expanding energy crops is on marginal crop and pasture land that is currently in the Conservation Reserve Program (CRP) (EIA 2007a). While the productivity of these lands is too low to grow corn or soybeans, there may be opportunities to grow "low impact" energy crops such as perennial native grasses and short-rotation woody crops. Whether such cultivation can be done while preserving the environmental purposes of CRP lands has yet to be determined.

Energy crops compete for land not only with conventional agricultural crops but with one another. In most instances, perennial native grasses such as switchgrass are preferred over short-rotation woody crops like poplar and willow because of higher average yields, lower production costs, and less than one-third the moisture content at harvest (EIA 2003). As described in the paper by Costanza et al., forest biotechnology research is under way to determine whether there are cost-efficient opportunities to increase growth and yield of short-rotation woody crops through genetic improvement or genetic modification. Although there have been some promising results, there is significant uncertainty over the social acceptability of large areas of

cropland dedicated to genetically modified native tree species, and the degree to which this may limit the application of this technology.

The paper by Hinchee, Mullinax, Cunningham, and Ramsey explores opportunities for substantially increasing the growth and yield of both native tree species such as loblolly pine (*Pinus taeda*) and poplar (*Populus spp.*), and through genetic improvements that allow highly productive non-native species such as eucalyptus (*Eucalyptus grandis* x *E. urophylla* hybrids) to be grown in the US. The paper explores opportunities through traditional tree breeding and genetic improvements, and well as gene insertion (e.g., to improve freezing tolerance) in tacit recognition that some opportunities for increasing biomass supply through forest biotechnology may be more socially accepted than others in the near term.

[State governments are using a mix of market-based approaches and incentives to achieve their particular goals for biofuels and bioenergy development. A diversity of different states' approaches is described in the paper by Patton-Mallory and Aguilar, which notes that state policies tend to pay more explicit attention to objectives such as locally-generated distributed power, employment opportunities along the entire value chain from wood harvesting to energy plant operation, improving the health of forest lands, and achieving climate change mitigation goals. To some extent, states may be able to play off federal policies, adjusting state-level incentives to either complement or buffer the local impacts of federal policies, and thus better align outcomes with individual states' particular goals.]

Alternative biofuel and bioenergy technologies

In America's energy future, wood is likely to play not just one role, but many. The type of facility that is well suited to one community and its surrounding forest resources may be poorly suited to another. Fortunately there is a wide array of options—different types of biofuels or bioenergy facilities, operating at a range of different scales. Some of these technologies are still in the developmental stages and are unlikely to operate at a commercial scale for some time to come, while other technologies are mature and have already been widely and successfully applied. With the current emphasis on renewable energy research and development, the picture is continuously changing. What is the status of the most promising technologies for wood biofuels and bioenergy? What information do federal, state, and local governments need to make informed choices about what technologies are feasible and most appropriate to the needs and opportunities in their communities?

Because of the pressing need to find renewable, domestic substitutes for imported oil as the nation's primary source of energy for transportation purposes, most of the research and development emphasis in recent years has been on liquid biofuels. Yet already it is clear from the rushed experience with corn ethanol that it is possible to move too quickly, to devote enormous resources to technologies that are not nearly as productive as they seem at first blush, and that have significant environmental, economic, and social consequences that do not become apparent until multi-billion dollar commitments are made to new plants and equipment, and we are set on a course that will take decades to play out.

The Energy Independence and Security Act of 2007 communicated clearly that corn ethanol was not the answer Congress had thought it was even as recently as the 2005 Energy Policy Act. Incentives for the production of corn ethanol were reduced, and even greater incentives than those originally given for corn ethanol development were enacted in support of advanced biofuels—cellulosic ethanol and other liquid transportation fuels derived from wood and agricultural products. Congress established production goals for advanced biofuels going from essentially zero today to 21 billion gallons annually by 2022, from a technology that has yet to be proven at the commercial scale.

The status of the conversion technologies for producing cellulosic ethanol is examined in detail by Dwivedi, Alavalapati, and Lal, with an emphasis on the US South where large-scale wood-based ethanol plants are already being constructed. In their paper they also examine the economics of cellulosic ethanol production, and the key assumptions that will determine the financial feasibility of cellulosic ethanol production in the US in the foreseeable future. Phillips, Jameel, and Clark point out that commercial production of cellulosic ethanol has been impeded by large capital investment requirements and the scarcity of low-cost feedstock, and suggest that both challenges might be overcome through the adaptation of existing kraft pulp mills to produce cellulosic ethanol. In their economic analysis, they note the advantages of this approach relative to a greenfield cellulosic ethanol plant, including the existing supply chain of growth, harvest, and delivery of forest biomass. Their analysis also suggests that the financial feasibility of this approach is much more sensitive to the assumed market price of ethanol than to either the wood cost or the cost of hydrolysis enzymes.

Wood-fired boilers for electricity production have been in use for decades, but there is nearly as much innovation going on with bioenergy technology as there is with biofuels. Johnson describes the Southern Company's experience using biomass to generate electricity in large-scale (20-200 MW) power plants, and draws important contrasts between the two basic methods for generating power from biomass. The first, biomass-only in dedicated plants are reliable, accept a wide variety of biomass feedstocks, and there is a lot of experience with them. They also require large capital investments, have very low efficiency, and are therefore expensive both to build and to operate. The second, biomass co-firing in existing plants, particularly with pulverized coal, requires a relatively small capital investment, is a low cost option with which the Southern Company has had success.

At the other end of the scale, new and improving technologies for smaller community-scale wood bioenergy plants are making them an attractive option for communities across the country, especially those that can take full advantage of the thermal energy for space heating or industrial process heat. Large-scale wood-fired electricity-only power plants are only 20-25 percent efficient, but some of the small- to moderate-scale (5-25 MW) combined-heat-and-power (CHP) facilities can reach efficiencies as high as 85 percent. In addition, there are efficiency gains from making and using power in close proximity, without incurring the "line drop" of as much as 50 percent associated with transmitting electricity over long distances from central power plants to consumers.

The *sustainable* supply of woody biomass is still a scarce resource, and the adoption of wasteful technologies when more efficient ones are both available and affordable seems like a poor strategy. It seems clear that a more distributive approach to energy production, using highly efficient CHP and thermal technologies, will be an important component of the nation's energy future. Maker's paper describes the accelerating pace of innovation in community-scale energy, both for CHP and thermal energy alone. Particularly dependent upon oil for heating, the Northeast began experimenting with wood-fired CHP and heating systems after the oil shock of the 1970s. The latest oil shock has further catalyzed innovation in the use of wood-chip and wood-pellet based systems for schools, hospitals, college campuses, and other public buildings. Maker concludes that market demand is forcing suppliers of wood energy equipment to grow rapidly and improve the performance of their products, many of which were originally adapted from equipment used in Europe. Development of community-scale bioenergy technology in Europe using wood chips and wood pellets has continued to outpace that in the US, and US producers are once again looking to these technologies to help them catch up to demand.

CHP at the industrial scale has been around for many years, but there are opportunities to significantly expand its contribution to the overall energy future—if we can get the incentives right. Many kinds of manufacturing produce steam or heat as byproducts, and have invested in equipment to utilize these byproducts to generate electricity and/or provide industrial process heat. The wood products industry is ideally suited for this, and has a higher degree of energy self-sufficiency (average ~65%) than any other major industry. Pulp and paper manufacturers utilize bark, waste wood, and hydrocarbon-rich pulping liquors to generate electricity and produce heat for paper-drying. Solid wood products facilities that manufacture lumber or wood panels utilize virtually all of their sawdust, slabs, edgings, and planer shavings to produce electricity and to provide heat for dry kilns.

Co-generation systems like these that utilize the heat and power on-site are deemed "closed-loop" systems. As such, most federal and state renewable energy credit (REC) programs do not recognize or reward the energy that is generated, even though it is generated from a renewable resource—wood—and collectively accounts for an enormous volume of heat and electricity that would otherwise be generated using fossil fuels. In addition, federal rules designed to protect investors in traditional electric utilities require that major electricity consumers like manufacturers continue to pay utilities based on their historic demand, even if they have increased their co-generation capacity to the point where they are no longer drawing outside power. Given that manufacturers are required to pay for outside power, whether or not they use it, they have very little incentive to make even modest capital investments in increased co-generation, using existing and widely available technology. Kowalczyk's paper details the ways that current energy policy actively discourages investment in co-generation and CHP in industries that could easily increase their energy production from biomass. Many pulp and paper facilities in the US have the potential to further increase CHP, but recent changes to the Public Utilities Regulatory Policies Act (PURPA) create significant regulatory barriers for new CHP installations to gain access to the grid and generate favorable returns despite the development of interconnection standards. The New Source Review regulations under the Clean Air Act poses barriers to smaller CHP facilities, even though CHP can significantly reduce emissions.

Wood pellet manufacturing

A smaller but growing source of demand for woody biomass comes from the wood pellet manufacturing industry. From a technology development standpoint, wood pellets are a superior fuel and one that is increasingly sought after. Compared to wood chips they have a high energy-to-weight ratio, burn cleaner with lower emissions and less ash residue, and are easier to handle because of their consistent size, weight, and energy content characteristics. From a biomass supply standpoint, pellet manufacturing requires relatively low capital investment, can operate efficiently at a variety of scales depending on local wood supply, and can operate close to the wood supply to minimize the high cost of transporting wood to the plant, and take advantage of the lower cost of shipping finished pellets to the end-user. Wood pellet manufacturing is often ideal for utilizing varying volumes and species from thinnings, logging residues, hazardous fuels treatments, and salvage of insect or disease mortality. This is especially true in regions where wood supply from these kinds of sources is high, and primary end-use markets are not local.

Worldwide, wood pellet production has grown to about 10 million tons annually, driven largely by demand in European countries operating under the rules of the Kyoto Protocol (Kotrba 2009). An estimated 25 percent of this total is exported from the countries where the pellets are produced, and a large majority of this is pellets shipped from North America to Europe. The relatively low cost of wood in North America, combined with the high prices for wood pellets in Europe provide an economic justification for shipping these woodfuels across the Atlantic, even though consuming large quantities of oil to ship “green energy” to Europe certainly raises questions about the net effect on carbon emissions and climate change.

Wood pellet production in the US is climbing quickly, from a few relatively small regional suppliers a decade ago to a capacity of more than 2 million tons annually today. Much of the increase has come in the US South where new large-scale pellet plants with a production capacity of 500,000 tons per year or more are exporting virtually all of their pellets to the European market. A significant portion of this production is for export to Kyoto Protocol signatory countries, where carbon emissions from renewable resources such as wood are not counted against allowable emissions caps. But many pellet producers that until lately were in the export business are now struggling to keep up with accelerating domestic demand.

The traditional wood pellet industry in the US is characterized by plants producing 30-50 million tons annually. Located primarily in the Northeast and Lake States regions, this part of the industry has largely shifted away from exports in order to meet accelerating demand in the domestic market. The paper by Niebling describes the recent acceleration in demand for wood pellets, both for domestic heating and for export, and the challenge in expanding manufacturing capacity to meet this demand. Thousands of households have acquired pellet-fuel stoves and furnaces in the past two years, and there is an increasing number of industrial and commercial bulk purchasers. Supply limitations, rising consumer prices for wood pellets, and the prospect of higher fossil fuel energy prices in the future suggest that this portion of the wood bioenergy industry will steadily expand. In Niebling’s analysis, it is freight cost that is the controlling factor in plant design capacity. The push for high efficiency and low emissions is catalyzing new technology development for the use of pellet fuels for space heating, industrial process heat, and

CHP, and regional and federal limits on carbon emissions is likely to further stimulate this development. But while there are financial incentives for biofuels and biopower, there are none focused on bio-based thermal energy. Niebling calls for incentives to be based not on particular technologies, but on desired policy outcomes such as reduced demand for imported oil, increased energy efficiency, lower air emissions, and reduced carbon emissions.

Socioeconomic considerations

We now are in an extraordinarily dynamic period in which the pattern of energy production and consumption that is set in the next few years will determine the path of growth and prosperity within the US and around the globe for decades to come. We have created a society that runs on energy, and much of today's physical, economic, and social infrastructure was developed during a period of cheap, abundant fossil energy. Whether we can expect profound changes in this existing infrastructure is no longer in doubt. The question is what kinds of changes are likely to take place, and whether by taking appropriate and timely action we can influence the pattern along which the new energy future develops.

Whether these technologically feasible approaches to biomass energy will also prove to be economically feasible in the long term will be determined by the cost of traditional fossil fuels we are trying to replace. By their nature, fossil fuels will continue toward eventual depletion, and will become increasingly scarce in economic terms. Their price will continue to rise in real terms, making alternative energy sources increasingly attractive. In the near term, however, there is tremendous volatility—crude oil prices in 2008 varied between $142/barrel in July and $38/barrel by December; ethanol was selling at nearly $4.00/gallon in late 2006, but is selling at $1.57/gallon in March 2009. These wild price swings create great uncertainty among investors and limit the availability of private capital for investments in biomass energy. New cellulosic biofuels plants that had no shortage of investor interest in 2007 were seeking federal loan guarantees by the end of 2008, just to complete construction and begin earning the $1.01/gallon federal production subsidy.

Gaining a greater measure of stability and control over energy costs is one of the prime motivating factors for rural, forest-based communities seeking to increase the share of their energy that comes from sustainably-managed local forest resources. The paper by Maker and Sherman describes the particular vulnerability of rural communities to swings in the price of fossil fuel, especially imported oil. With little or no pricing power in the market, these communities don't know from one year to the next whether their energy costs will remain roughly the same, or triple almost overnight as they did in 2008. Where possible, rural communities are exploring the extent to which wood-chip or wood-pellet heating or CHP can reduce their dependence on outside power and imported fuels. Certainly the prospect of lower cost energy is a factor in the decisions of rural communities to make this shift. The new opportunities this represents for local income and employment in operating and supplying community energy facilities is important too, as DeBonis describes in his paper. But even more critical is the opportunity to increase the reliability and predictability that comes with a higher level of energy self-sufficiency that is based on the sustainable use of local forest resources.

The current high level of uncertainty about the scope and timing of biomass energy markets is reverberating through every level of the biomass energy industry, from the largest producers of biofuels and bioenergy, to biomass harvesters in the woods. In his paper on individual investor preferences, Aguilar describes some of the factors that are key to sources of private capital choosing to invest in bioenergy relative to other investment options, helping to explain why many of these investors have now retreated to the sidelines. The broader limitations on investment capital are even slowing the construction of wood pellet plants, despite the fact that this is well proven technology. Mueller's paper points out that wood pellet-based equipment purchased recently has created a demand capacity in the US that is at least 30 percent greater than wood pellet supply capacity. According to Niebling, the rapid increase in wood pellet prices brought about by these supply constraints is already dampening demand, and leading consumers to revert back to fossil energy—at least for the moment.

High costs for materials handling and transportation were already limiting factors in determining just how much of the available woody biomass could actually be harvested. The paper by Evans, and the field study in Minnesota by Abbas and Arnosti, suggest that the portion of the available woody biomass that can be economically removed from the site depends heavily upon forest characteristics such as timber type, stand density, and age, and on landscape characteristics such as slope, elevation, and distance to road. But these papers, as well as the one by Eichacker, also suggest that there are other factors that may reduce the sensitivity to current market prices for woody biomass. Where wildfire hazards, insect or disease infestations, or other serious forest health conditions exist, the emergence of biomass energy markets is seen more as a means of reducing the cost of stand treatments that would have been undertaken anyway for environmental or public safety purposes. In such instances, the extent to which the market price for woody biomass can "buy down" the cost of treatments is less of a decision factor than in instances where woody biomass supply is the primary objective.

Even when wood bioenergy markets are weak, government-mandated goals and financial incentives can still drive local demand for woody biomass to unsustainable levels. Focusing particularly on the forests of the US South, Comatas notes that this highly productive forest region produces 60 percent of the total US output of wood products, and may not be able to accommodate significant additional wood removals without long-term impacts to resource productivity, regional biodiversity, water quality and other values. Normally, market forces would limit removals as prices rise with increased demand. But the availability of substantial subsidies, aimed at enabling the biofuels industry to achieve the ambitious goals in EISA, makes the biofuels industry less sensitive to increased feedstock prices. Assuming some degree of price elasticity of supply, significantly more wood may be harvested than in a market not distorted by government subsidies.

Environmental considerations

The systematic removal of a large proportion of the woody biomass from a forest is not something that has typically characterized wood harvesting in American forests. Forest practices laws and voluntary guidelines aimed at protecting long-term resource productivity and key environmental values such as wildlife habitat, water, and biodiversity have generally focused on

methods by which "merchantable" timber for lumber or pulpwood for paper and paperboard products should be harvested and removed. Many of the nutrients and minerals in trees are held in the leaves, needles, small limbs, and root systems. As long as these portions of the trees are left in the forest during the harvest of the main trunks, these nutrients and minerals will recycle naturally into the soil to maintain fertility and soil structure.

The possibility that the harvesting of woody biomass would systematically remove these "logging residues" for their energy content has raised concerns that existing forest practices laws and voluntary guidelines are inadequate to protect forest productivity and environmental values. This has prompted more intensive research into the potential impacts of woody biomass removal in major forest types in different regions of the country. It has also prompted several state governments to undertake a review and evaluation of their existing forest practices laws, and to augment them where it was deemed necessary. The paper by McDow summarizes the overarching sustainability concerns regarding woody biomass removal, and then gives more detailed consideration of the effect of woody biomass harvesting on specific environmental resources (wildlife, water, air, and climate). Lal, Alavalapati, Dwivedi, and Matta examine potential economic and social effects as well as environmental effects, and they suggest a set of indicators that might be used to both guide and monitor the effects of woody biomass harvesting. Keeping these kinds of indicators in mind, Evans and Perschel assess the effectiveness of existing forest practices laws and guidelines around the US, and offer recommendations for their expansion or augmentation. Several papers chronicle actual recent efforts to review and expand forest practices laws and guidelines in Minnesota (Zumeta), Wisconsin (Herrick, Padley, Kovach, Wagner, Zastrow, and Pingrey), Pennsylvania (Roth), and Oregon (Misek).

The paper by Lattimore, Smith, Titus, Stupak, and Egnell provides another perspective on the environmental risks associated with woody biomass harvesting, and suggests ways in which existing frameworks for sustainable forest management such as the Montreal Process Criteria & Indicators might be applied to these risks. They also evaluate the principles and criteria currently used in independent certification programs such as those of the Forest Stewardship Council (FSC) and Canadian Standards Association (CSA) for ways they can be augmented to guide the harvesting of woody biomass as well as merchantable timber.

The Southern Environmental Law Center has developed a map of the southeastern United States with a dot placed in every location where a new wood biofuels, bioenergy, or wood pellet manufacturing plant has been proposed or announced. Each dot was circumscribed with a circle depicting the area within a 50-mile radius, showing the area from which each plant was expecting to draw its supply of woody biomass. In many locations on the map, forest areas were overlaid by more than one circle, and in some instances by three or four. No explanation was needed. The implication was clear.

To make it even more interesting, dots could be added showing the location of each existing wood products manufacturing plant of significant size, and each surrounded with its own 50-mile radius circle. Finally, this map could be overlaid with one showing habitat for rare, threatened, and endangered species, watersheds critical to water supplies for the region's burgeoning

population, and high conservation value forests identified in the state wildlife habitat conservation plans. Again, no explanation would be needed. The implications would be clear.

Implications for US forests

What are the potential implications of these policies for forests? Americans have always expected much from their forests, often many different things at once. Much of the debate over forest policy during the past half-century, in Congress, in state legislatures, and frequently in the courts, has been over how best to balance competing demands for biodiversity conservation, water quality, wildlife habitat protection, and outdoor recreation opportunities with the demand for wood and fiber. Rising energy costs have increased the pressure on forests as sites for the development of subsurface fossil fuels—coal, petroleum, natural gas, oil shales, creating major new challenges for the conservation and sustainable management of forest resources on the surface. Now the forests themselves are seen increasingly as a major source of renewable energy, and the sheer magnitude of the goals for biofuels and bioenergy that federal policymakers are considering could set up conflicts between different forest uses that would be more difficult to reconcile than any that have come before.

It is the combination of new and expanding demands on forests for energy that makes it so challenging to assess the adequacy of woody biomass supplies, and to anticipate how best to meet renewable energy needs while sustaining forest productivity and the host of other environmental, economic, and cultural values of forests. Thinking about only one use at a time when considering the capacity of forests to absorb and accommodate additional demands has gotten us in trouble before, and simultaneously balancing the multiple uses and demands on forests has become one of the central challenges of forest policy and sustainable forest management. Large-scale demands on forests for energy production are for the most part new to 21st century America, and add to the existing challenging set of competing uses and needs from forests.

Because of somewhat different motivations and policy drivers, the energy sector itself is fragmented in its approach to forest resources. The pressing need to find substitutes for transportation fuels derived from imported petroleum was the motivation behind the goal of producing enough biofuels to supply 30 percent of the nation's transportation fuel needs by 2030, which was the basis for the US Department of Energy's 2005 study on the supply of biomass to meet this need (Perlack et al. 2005). The results of the study found over 1.3 billion dry tons per year of biomass potential, including 368 million tons from woody biomass, as available for producing enough biofuels to substitute for a third of the current demand for transportation fuels. But the biomass that is necessary to meet the 25x'25 goal for renewable electricity production must come from this same resource. What will be the combined effect on forests from achieving both these goals?

A 2007 study by the Department of Energy attempted to address this very question—it examined the environmental and economic impacts of implementing both a 25x'25 renewable electricity standard and a 25 percent renewable fuel standard by 2025 (EIA 2007b). The demand this would place on US forests for increased biofuels production, together with the even greater

demand for biomass for power generation, could be more than the nation's forest can sustain. It could price most of the US wood products industry out of existence, and have impacts on soil and water resources, biodiversity, and other values that the American public would almost certainly find unacceptable.

Biofuels

To meet these twin goals by 2025 would require the production of 61 billion gallons of ethanol, 28 billion gallons of which would be cellulosic ethanol (EIA 2007b). These goals are significantly higher than those in the Renewable Fuels Standard established by 2007 Energy Independence and Security Act (EISA), which called for 36 billion gallons of ethanol production by 2022, with 21 billion gallons of this coming from advanced biofuels such as cellulosic ethanol.

Increased competition for feedstocks is expected to push up the price of energy from all sources. With an increase from the current $1.70 per million Btu to about $4.00 per million Btu, the US will be operating near the estimated maximum level of biomass availability (EIA 2006). Based on supply curves developed by DOE using the National Energy Modeling System, there would be a strong supply response from other forms of biomass for energy at this price, resulting in an additional 173 million dry tons of biomass from energy crops, 162 million dry tons from forest residues, 127 million dry tons from agricultural residues, and 29 million dry tons from urban wood waste (EIA 2006), for a total of 491 million dry tons.

It takes roughly 1 dry ton, or 2 greens ton of wood to produce 86 gallons of cellulosic ethanol. A cellulosic ethanol plant producing 50 million gallon/year, such as the Range Fuels plant currently nearing completion in central Georgia, will require about 600,000 dry tons of woody biomass annually. In the near term, a significant portion of the supply for this plant is expected to come from wood waste and residues, but as the plant gradually scales up to full capacity, an increasing proportion of its woody biomass will come from roundwood harvested for this purpose (Barmore 2009). At stocking rates typical of forests in the Southeast, this will require the equivalent of harvesting an average of 28,000 acres of forest each year.

Producing 28 billion gallons of cellulosic ethanol will require approximately 325 million dry tons of biomass.[1] If 275 million dry tons can be supplied by energy crops, urban wood waste, and forest and agricultural residues, this would leave 50 million dry tons to be supplied from roundwood (see Figure __). Meeting these production goals would require constructing the equivalent of more than 83 biofuels facilities of the size and capacity of the Range Fuels plant described above. Wood consumption would be approximately 3.0 billion cubic feet annually. At timberland stocking levels typical of forests in the US South, this translates to the equivalent of harvesting roughly 2.3 million acres annually.

[1] 1 bone dry ton (bdT) of wood is equivalent to 2 green tons (gT) and produces approximately 86 gallons of cellulosic ethanol.

Wood bioenergy

Electric power generation from woody biomass is expected to have a far greater demand on forests. In the DOE study, both wind and biomass power capacity are expected to increase ten-fold from current levels. Electric power generation from biomass is projected to rise to 495 billion kilowatthours from the current 55 billion kilowatthours (EIA 2007b).

In 2007, renewable energy from all sources accounted for 8.4 percent (351 billion kilowatthours) of total electricity production nationally (EIA 2008a). Of this, electricity from wood accounted for 38.5 billion kilowatthours or 11 percent. Most of the electricity currently generated from woody biomass, about 76 percent, is from industrial cogeneration, and most of that (94 percent) is generated and used by the pulp and paper industry (EIA 2008b) (see Table __). Since this power is generated as a byproduct, the woody biomass that is utilized results in no significant increase in wood harvested. Much of the remaining 24 percent of electricity generated from woody biomass is generated from wood residues and waste products, so the area of forest land currently harvested specifically to provide wood for energy is negligible.

This picture is expected to be the reverse under a mandatory 25x'25 goal. As the amount of electricity generated from renewables increases toward this goal, an increasing proportion is expected to be generated from wood and other biomass (See Figure __) (EIA 2001). More importantly, although the amount of electricity produced through cogeneration by 2020 is expected to increase by 66 percent, from 29 billion kilowatthours to 49 billion kilowatthours, the proportion generated from additional harvesting of biomass is projected to increase from 8 billion kilowatt hours to more than 475 billion kilowatthours (see Figure __) (EIA 2003).

Harvesting roundwood is not the lowest cost source of woody biomass for energy production, but it is the most plentiful. There are lower-cost sources such as urban wood waste that are currently underutilized (see Figure __), but as the demand for renewable fuels increases this will reach its limit. Mill residuals and logging residues are another lower-cost source, but like co-generation they depend on the production of existing wood-based industries. After the limits are reached for woody biomass supply from residuals, energy producers will shift to roundwood harvesting from existing forests, where they will compete directly with wood-based industries for feedstock. As prices for roundwood increase, marginal existing wood-based industries will be displaced, further reducing the supply of residuals and accelerating the price increase for roundwood (Galik et al. 2009).

If under a 25x'25 Renewable Electricity Standard power generation from woody biomass rises to 495 billion kilowatt hours as projected (EIA 2007b), the area of forest land harvested annually would increase sharply when the limits of residuals is reached, possibly around 2012 (Galik et al. 2009), and continue to rise quickly in subsequent years. Assuming that a combination of energy crops, urban wood waste, and agricultural and forest residues would be able to supply 219 million dry tons of biomass annually (see Figure __), an additional 329 million dry tons would have to be supplied by roundwood. Using accepted conversion rates of 1.1 bdT (2.2 gT) of wood required per thousand kilowatthours, and 30 cubic feet of wood per green ton, generating this amount of electricity will require 19.7 billion cubic feet of wood. Growing stock volume on

timberland in the US South averages 1,322 cubic feet per acre (Smith 2002), which means that the equivalent of 14.9 million acres of timberland would have to be harvested annually to supply this volume of wood.

Meeting combined goals for wood bioenergy and biofuels

So for forests, the combined effect of simultaneously implementing a 25x'25 renewable electricity standard and a 25-percent renewable fuels standard would require 22.7 billion cubic feet of roundwood annually, not including forestry residues. This would require harvesting the equivalent of all of the growing stock on 17.2 million acres—an area more than 14 times the size of Delaware—each year.

The current net growth of growing stock on all 504 million acres of timberland in the US is 23.7 billion cubic feet annually (Smith et al. 2004) so just meeting these energy requirements would utilize the equivalent of more than 95 percent of growth. The average annual harvest of wood for all wood products over the past two decades is roughly 15.5 billion cubic feet (Smith et al. 2004), so the combination would represent over 39 billion cubic feet per year, more than double recent harvest levels. Even allowing for some displacement of existing wood products manufacturers due to increased wood prices, the demand on forests for a combination of energy and wood products could exceed 150 percent of current net growth.

All the competitive jostling for this forest resource presumes that, in the end, all of the accessible and practically available woody biomass will get harvested and go into one bioenergy or biofuels application or another. Such intensive harvesting may not be possible in some areas due to the potential for soil nutrient depletion and loss of productivity (Scott and Dean 2006). This would place even greater pressure on those forest areas where harvesting is feasible. In all the excitement it is also easy to forget that some of these resources are serving other important purposes—conserving biological diversity, protecting water quality, providing wildlife habitat, and perhaps sequestering more carbon where it is than will be saved by substituting it for a gallon of oil.

Can wood bioenergy and biofuels goals be achieved?

Is it likely that every acre of the nation's forests will be cut down to feed electric power plants or to keep filling the gas tanks of America's persistent fleet of SUVs? Hardly. Do large categories of public and private forest lands need to be placed off-limits to harvesting for biomass energy in order to prevent overharvesting or other environmental degradation? No. In fact, taking large areas of US forest land out of the total potential supply base would concentrate demand on an even smaller area of forest land, and increase the likelihood of unsustainable management on the remaining forests.

Two-thirds of US forest land is in the hands of ten million private woodland owners, many of them families, and survey after survey has shown that the objectives for which these forests are managed are as diverse as the owners themselves. A majority of them consistently report that income from wood production is not their primary objective (Butler 2008). Nevertheless, if there

is a major rise in wood prices because of increased competition for wood supplies as projected, there undoubtedly would be a significant number of forest landowners who would sell their timber. In some states, forest practices laws provide a safety net to ensure that wood harvesting is done in a sustainable manner, and some states have taken additional steps to ensure that woody biomass harvesting is done sustainably (Evans and Perschel 2009). Other states have very few such safeguards.

The third of the nation's forests that are in public ownership also have a variety of safeguards in place to prevent overharvesting or unsustainable management, and most of them are monitored as closely by local citizens as they are by the public officials responsible for their management. A provision in the Energy Independence and Security Act of 2007 essentially placed all federal forest lands off-limits to harvesting for biofuels to satisfy the national Renewable Fuels Standard. As of this writing, a more flexible approach is being considered in proposed federal legislation to create a national 25x'25 Renewable Electricity Standard. While wilderness areas, old-growth forests, and other high conservation-value areas would continue to be off-limits, there would be flexibility to utilize woody biomass from hazardous fuels reduction and other kinds of ecosystem restoration activities. In parts of the western US where these fuel buildups pose a significant risk of catastrophic wildfires (and major additions to atmospheric carbon), the amount of woody biomass that could be utilized on a sustainable basis is substantial—up to 60 million tons per year (Perlack 2005).

It may simply take longer than expected to reach the established goals for renewable biofuels and bioenergy, and the goals themselves may have to be extended. The Annual Energy Outlook for 2009 projects that the US will fall short of the Renewable Fuels Standard goals for biofuels production by about 6 billion gallons by 2022 (EIA 2008c). It is predicted that this goal can be met by 2030, however, assuming a further doubling of biofuels production from biomass between 2022 and 2030, and a quadrupling of net ethanol imports.

A Department of Energy study of alternative goals for renewable energy production describes enormously different implications for biomass energy in going from a 10 percent renewable energy requirement to a 20 percent requirement. To reach a 10 percent goal by 2020 would require an increase in biomass-fired generating capacity to approximately 15 gigawatts, whereas the 20 percent goal would require this to increase to approximately 70 gigawatts (EIA 2003). At the 10 percent goal, much of the demand for renewable bioenergy could be supplied by wind power, which is more economical than biomass. Shifting to a 20 percent goal translates to a much larger demand for biomass feedstocks—70 gigawatts of additional electrical generation capacity from biomass translates to 700 new 100MW power plants, each of them consuming an average of 1.2 million green tons of wood annually. The DOE analysis raises the question of whether there would be sufficient land to sustain the required level of biomass production, estimating that 9.6-14.4 million acres of land would have to be devoted to energy crops, including up to 37 percent of all land currently in the Conservation Reserve Program (CRP) (EIA 2003).

Careful planning will be needed at the community level to fully capture the environmental and economic benefits that new markets for woody biomass represent, while also ensuring that the

local siting of new or expanded bioenergy or biofuels facilities does not create cumulative new demands on local forests that cannot be supported. State and local governments today are facing decisions about what approaches to renewable energy are best suited to their particular needs and circumstances, and to the level of woody biomass production their local forests can supply sustainably. The useful life of a power plant may be 30 years or more, so the decisions made today will affect the region's communities and forests, and potentially limit other options, for many decades into the future. Once these decisions are made, and the resources committed, this may also limit the flexibility to consider other options in the future. So it is important for state and local governments to have access to information that is the most complete, accurate, and up-to-date as possible.

The single most critical set of information is a realistic estimate of woody biomass availability within a feasible transportation distance. Overestimates of local supply will mislead energy companies into decisions to site facilities that are of the wrong type or scale, and the resulting boom and bust will work in no one's best interest. There will be pressure to overharvest the available resources in the short term, and then disruptions in local employment as the facility is forced to downsize or close. For energy companies and their investors, this will result in a financial setback, and a reluctance to invest in other renewable energy facilities in the future. As Mater and Gee point out in their paper on the Coordinated Resource Offering Protocol (CROP), a realistic estimate has to entail much more than just an examination of standard forest inventory information. There are both public and private forest lands that will be off limits due to statutory constraints or landowner preferences. Terrain, transportation distance, truck weight limits, and other factors will further constrain the proportion of the woody biomass supply that is economically recoverable. All of these constraints that take some portion of the local forest resource "off the table" shift a greater burden to the remaining forest lands to meet supply expectations, thereby increasing the likelihood of overharvesting and its associated impacts.

These local attributes and characteristics will strongly influence the type, scale and location of the most suitable bioenergy or biofuels facility. Efficiency is a key consideration, but not the only one. A combined-heat-and-power facility operating at a typical 80 percent efficiency will get much more energy out of a ton of wood than an electricity-only power plant operating at a typical 20 percent efficiency. But communities in warmer regions where there is little way to utilize the additional thermal energy may find that it is more practical to choose the electricity-only power plant. A community that is considering a 50MW power plant, but is concerned about sustainably supplying 650,000 tons of wood annually, may be best served by facilitating the construction of three 20MW power plants in the general vicinity, each of them located in conjunction with an existing wood products manufacturing facility that can provide wood waste as fuel, and utilize the thermal energy and electricity. Other process-related factors may need to be considered as well. For example, biofuels plants typically use large volumes of water, so the critical questions may be as much about water consumption or effects on local water supply as they are about woody biomass supply.

Communities in Europe have installed more than a thousand small-scale (10 MW or less) power plants using advanced wood combustion technologies (AWC) that are remarkably efficient (up to 90%), produce minimal amounts of greenhouse gases or other air pollutants, and are linked to the

sustainable management of local forests (Richter et al. 2009). More than 100 of these plants combine heat and electric power to serve towns, portions of cities, industrial complexes, and public institutions. It is estimated that if one state, North Carolina, were to construct one facility of this type each year in each of its 100 counties over a 5-year period, the $100 million annual investment costs would soon be offset by fuel savings of up to $180 million each year, and fossil emissions of greenhouse gases would be reduced by up to a million tons annually (Richter et al. 2009). Policy initiatives that would facilitate this kind of development in the US include: (1) carbon management policies that encourage the substitution of carbon-neutral fuels such as wood for fossil fuels, (2) make AWC the energy system of choice for new construction and renovations in communities with adequate local wood supplies, (3) make more efficient use of urban wood waste from tree removals and construction, and (4) expand construction of AWC-powered district-energy systems in which heat is supplied from a central source to complexes of commercial/institutional buildings.

Conclusion

When the US last relied upon wood as its primary source of energy, up through the end of the 19th century, the nation's forests were down to their smallest area in history and were being rapidly depleted (Starr 1865). In many ways, the shift to fossil fuels in transportation, heating, electricity, and industrial processes in the late 1800s came just in time, and gave America's forests a century to recover (Williams 1989). Will our reliance upon forests for energy in the 21st century return them to the conditions of the 19th century? Presumably we will not let that happen, but there is no guarantee.

Mitigating global climate change by reducing greenhouse gas emissions is perhaps the most urgent challenge facing humanity in our era. It is not simply an environmental issue. It is an economic and social issue of enormous proportions here in the US, in other industrialized nations, and especially in developing nations around the world. Energy conservation and the expansion of zero-carbon energy sources like wind, solar, and geothermal will get us part of the way there, but renewable, carbon-neutral energy sources like wood and other biomass must inevitably play a large and essential role.

Finding a substitute for petroleum-based transportation fuels will become an increasingly urgent priority as well. More than almost any nation, the basic physical infrastructure of the US—the layout of our cities, suburbs, highways, and transit systems—developed after the near-total shift to fossil fuels. The functioning of this infrastructure, and on society itself, is premised on the continuation of abundant, cheap energy. The Department of Energy points out that achieving the 25-percent renewable fuel target in both the electricity generation and transportation fuel markets will lead to higher energy prices, as producers substitute more expensive renewable fuels for less expensive fossil fuels, and that these higher energy prices will have an impact on economic activity (EIA 2007a). There are multiple alternative energy sources for electricity and heat, but for domestic, renewable transportation fuels there are few significant alternatives to biomass. Our physical infrastructure of suburbs and highways cannot be changed overnight. If Americans are faced with the choice of enduring the economic and social impacts of higher energy costs, or

accepting greater environmental impacts on the nation's forests, it will not be an easy decision and the outcome is far from certain.

The papers in this collection provide information that is essential for state and local government officials trying to decide how to best meet their constituents' needs for energy while protecting and sustainably managing natural resources that meet those same constituents' needs for clean water and the other essential ecosystem services that forests provide. It is essential to the energy industry and community leaders as they try to decide the type, scale, and location of a biofuels or bioenergy facility that will be best suited to the locally available and sustainable supply of biomass, and that will be financially viable as competition for feedstocks increases. It is essential for natural resource managers charged with the responsibility of ensuring that forests continue to be managed in accordance with accepted standards of sustainability, but who also recognize that even the best standards are of little value if too many wood-dependent facilities get placed in too close a proximity to one another and wood demand simply overwhelms local supply.

Perhaps most importantly this information is essential to national and state policymakers who will establish the mandatory goals, and who will design the subsidies, tax credits, trade tariffs, and other incentives that they think will best support the development of a biofuels and bioenergy industry that will meet those goals. Policymakers in the earlier era of wood energy in the US had goals of settling the western frontier and growing the economy of a developing nation, and the policies they established to achieve those goals were premised on a plentiful if not inexhaustible forest resource. America grew strong, but the impacts on its forests came close to undermining the very prosperity they helped to create.

It is clear that forests will play a major role in the nation's energy future. This can be an enormously positive development from the standpoint of mitigating climate change through a shift to more carbon-neutral energy sources, making the transition to renewable energy, and even improving the health and productivity of US forests. But it is essential that policymakers, energy producers, and all of us as energy consumers do not lose sight of the fact that US forests, extensive though they may seem, are a scarce resource relative to what they are expected to provide. Almost too late did we comprehend that forests were not an inexhaustible resource during an earlier era in which we depended on forests as our primary energy source. Their utilization must be guided, by informed, insightful policies that encourage innovation in the efficient use of this limited resource; that facilitate a diversity of different types, scales, and locations of biofuels and bioenergy facilities that are well matched to local circumstances; and that are grounded in a continued commitment to the conservation and sustainable management of forests for the full range of values and services they represent.

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