Projections of Forest Contributions to Global Carbon Cycles

7

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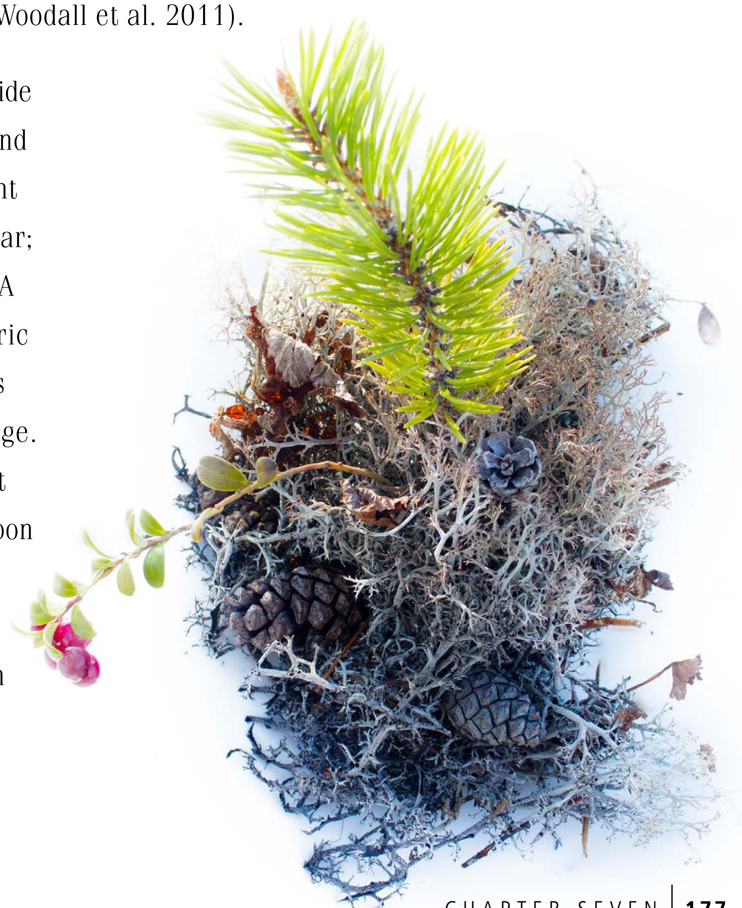
Introduction

FORESTS COVER 42 PERCENT of the Northern United States, and collectively they store 13 billion tons of carbon in live trees (29 percent), roots (6 percent), forest floor (9 percent), dead trees (6 percent), and soils (50 percent). About half the biomass of a live tree (dry weight basis) is sequestered carbon (Woodall et al. 2011)—not the largest but the most dynamic source of sequestered forest carbon over time. Through photosynthesis, live trees emit oxygen in exchange for the carbon dioxide that they pull from the atmosphere, storing the carbon in wood above ground and roots below ground as they grow. Dead trees and down logs are also reservoirs of stored carbon, which is released back into the atmosphere slowly through decomposition or rapidly through combustion (McKinley 2011, Woodall et al. 2011).

Society emits enormous amounts of carbon dioxide during electricity production, transportation, and other activities. Emissions for each U.S. resident average about 18 tons of carbon dioxide per year; this corresponds to 5 tons of carbon (USDOE EIA 2010, US EPA 2011). Increases in atmospheric carbon dioxide and other greenhouse gasses have been implicated in global climate change. Forests, because of their geographical extent and their capacity to sequester additional carbon or to release stored carbon, serve as important sinks or sources of carbon, thereby playing an important role in regional and global carbon cycles (McKinley et al. 2011, Pan et al. 2011).



Key Findings

PRESENT DAY

- In the United States, the total amount of sequestered carbon in forests is equal to about 27 years of carbon dioxide emissions.
- The yearly accumulation of carbon in U.S. forests is estimated to offset 13 percent of total annual carbon emissions.
- In 2007, 2 percent of the energy consumed in the United States came from wood firing by industry (1.3 percent), residential units (0.4 percent), utilities (0.2 percent), and other (0.1 percent) users.
- Less than 1 percent of the U.S. electric power is generated from wood.

PROJECTED

- Total carbon sequestered by northern forests is expected to decrease by about 2 percent from 2010 to 2060, primarily the result of reduced forested acreage combined with the slower growth that is typical for mature trees.
- Aboveground forest biomass is expected to increase by 3.9 percent from 2010 to 2060.
- Both sequestered forest carbon and aboveground woody biomass are expected to increase in the Midwest and decrease in many eastern States.
- By 2030, U.S. electrical power generated from all biomass is expected to increase 350 percent over 2010 levels; in the North, biomass will still be used in <6 percent of total electric production.
- The potential for increased woody biomass use in co-firing (with coal) is highest in States that border the Great Lakes and in the Northeast; the potential increase for co-firing across the region would improve if power plants were upgraded to higher efficiency co-generation status.

Global climate change associated with changes in atmospheric carbon dioxide can have significant impacts on the condition of future forests, and consequently on the plant and animal (and human) communities that depend on forest habitats and services (Kurz et al. 2008). Some forest management activities can increase carbon sequestration to partially offset the human activities that emit carbon dioxide and associated greenhouse gases. For example, afforestation and certain thinning protocols can increase the quantity of carbon sequestered in trees (Hoover and Stout 2007). Energy production from woody biomass can offset carbon that otherwise would be released by burning fossil fuels, provided that a comparable amount of the carbon is reincorporated into the new trees that regenerate to replace those harvested (Malmsheimer et al. 2008). In contrast, the energy production from fossil fuels, such as coal and oil, emits carbon that has been sequestered underground for millennia.

The projections of forest biomass and carbon presented in this chapter are juxtaposed with projections of energy consumption at State, regional, and national scales (USDOE EIA 2010). This facilitates the comparison of three important carbon-cycle considerations for the North: (1) projected carbon sequestration in forests, (2) projected woody biomass growth and utilization, and (3) projected total and renewable energy consumption and likely consequences for carbon emissions. Together these provide insight into the dynamics and interactions among forest biomass, forest carbon, and energy utilization.

The following sections present:

- Total quantity of carbon stored in forests
- How forest carbon is expected to change over time
- The role of woody biomass for energy production
- Current and projected energy profiles for the Northern States
- Current and projected capacity to curb carbon emissions by substituting woody biomass for fossil fuels in electricity production
- Current status and future potential of co-firing biomass with coal for energy production

CARBON SEQUESTRATION

Through photosynthesis, trees sequester (absorb and store) carbon in wood, bark, leaves, flowers, roots, and seeds. Carbon is found in cellulose, hemicellulose, lignin, and other compounds that form the wood and other parts of the tree, all of which are defined as woody biomass. When a tree or some part of a tree dies, the carbon it contains is released during decomposition. Carbon in decomposing roots can remain in the soil and gradually add to the large store of sequestered carbon in forest soils. Leaves are short-lived and release carbon back to the atmosphere quickly as they decompose, but carbon can be sequestered for centuries in the wood of long-lived trees. Large dead and down trees can sequester carbon for decades as they decompose slowly and gradually release carbon dioxide back to the atmosphere.

When trees are harvested, the carbon they contain is removed from the forest, but it can continue to be sequestered for decades as long-lived wood products or as wood and paper products in landfills. Harvested forests and those that suffer heavy mortality will typically regenerate to new forests and accumulate carbon over future decades as they grow, provided the land is not converted to agricultural, urban, suburban, developed, or other uses. When forests are converted to other land uses, the carbon sequestered in aboveground woody biomass is typically released. Soil carbon can be retained following the conversion, but that soil carbon is no longer classified as forest carbon and therefore is excluded in future estimates of forest carbon storage and sequestration.

The 2010 per capita carbon emissions in the United States, largely resulting from combustion of fossil fuels, amounted to 5 tons of carbon which equates to 18 tons of carbon dioxide gas (USDOE EIA 2010). This is roughly equivalent to the carbon in 20 tons of green wood (i.e., wood weight when harvested). Based on storyline A1B (Chapter 2; IPCC 2007) that assumes a moderate level of future greenhouse gas emissions, the per capita emissions in the United States would decrease by about 15 percent to 4.5 tons of carbon (16.5 tons of carbon dioxide) by 2030. However, the U.S. population is expected to increase by 55 million (18 percent), resulting in a net increase of 0.2 percent in total carbon emissions.

Carbon in Wood

Comparing estimates of carbon from different sources requires attention to details. Typically, roughly half the weight of green, freshly cut biomass is water, and half of the remaining dry biomass is elemental carbon. Carbon is customarily reported in metric units (metric tons/hectare) rather than English units (tons per acre). Carbon sequestration in forests and carbon emissions from human activities or natural causes are usually reported in metric tons of carbon dioxide gas rather than as elemental carbon alone. Thus if the equivalent of a metric ton of carbon dioxide is sequestered in a forest, 12/44th of that ton is actual carbon based on the proportional weight of carbon in a carbon dioxide molecule.

For the same time period the population in the North is expected to increase by only 10 percent (12 million people), potentially leading to a small net decrease in carbon emissions in the North relative to the 2010 level (U.S. Census Bureau 2009, USDOE EIA 2012).

The total amount of sequestered forest carbon in the region (including carbon in forest soils) is expected to decrease slightly in the next five decades, falling to about 97 percent of the 2010 total by 2060 (Fig. 7.1). This overall decrease in carbon occurs even though the total dry weight of live aboveground forest biomass (which is 50 percent carbon) increases slightly under all storylines (Table 7.1). The decrease in total forest carbon occurs primarily because of a decrease in forest area and a resulting decrease in carbon levels associated with forest soils.

Thus, the predicted gradual decrease in sequestered carbon in northern forests from 2010 to 2060 (Fig. 7.1) is primarily attributable to conversion of forest area to other land uses. Forest conversion results in a corresponding decrease in forest area and the "loss" of aboveground and soil carbon that was previously considered part of the forest carbon pool. This does not imply that the carbon stored in forest soils is eliminated through conversion of forest land to other uses, but rather that it ceases to be part of the forest carbon pool.

In addition to forest carbon losses resulting from land-use changes, sequestered carbon in aboveground woody biomass is affected by changes associated with forest age, species composition, and location (Nowak and Crane 2002).

FIGURE 7.1

Sources of forest carbon sequestration in the North, 2010 to 2060, under a greenhouse gas emissions storyline A2 that assumes high levels of greenhouse gas emission associated with moderate urbanization gains (rapid population growth and moderate income growth) combined with high energy consumption (Miles et al. 2015, USDA FS 2012b).

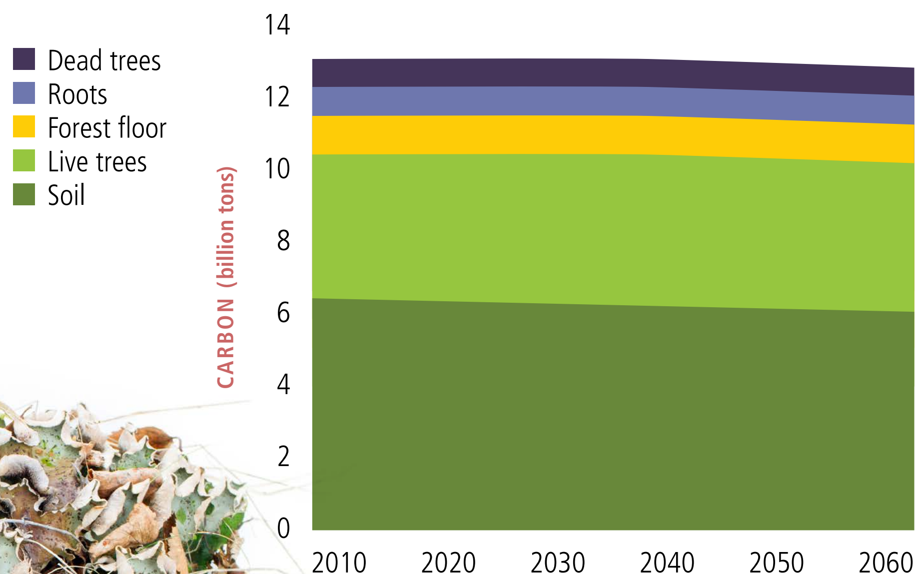


Table 7.1—Aboveground biomass on timberland in the North, 2010 to 2060, under three scenarios—A1B-C assumes moderate levels of greenhouse gas emissions associated with moderate gains in population growth and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio), A2-C assumes high levels of greenhouse gas emissions associated with large gains in population growth and energy consumption with moderate gains in income, and B2-C assumes low levels of greenhouse gas emissions associated with moderate gains in population growth, income, and energy consumption—combined with the assumption that harvesting will continue at rates observed from 1995 to 2005 and not increase substantially to meet future demand for bioenergy.

State	Initial for all scenarios	Projected for 2020 to 2050 (A2-C only)				Projected for 2060 (all storylines)					
		2020	2030	2040	2050	A2-C	A1B-C	B2-C	A2-C	A1B-C	B2-C
	(million dry tons)					(million dry tons)			Change from 2010 (percent)		
Connecticut	119	123	123	120	117	107	113	113	-9.8	-4.7	-5.3
Delaware	23	23	22	21	20	20	20	22	-12.4	-14.9	-6.1
Illinois	229	236	234	232	230	231	223	241	1.1	-2.5	5.4
Indiana	250	261	261	257	253	271	259	268	8.4	3.7	7.2
Iowa	111	126	129	128	127	134	125	134	20.3	12.4	20.9
Maine	647	670	679	676	674	666	651	672	2.9	0.5	3.8
Maryland	168	160	147	136	126	117	120	126	-30.0	-28.4	-24.7
Massachusetts	198	194	195	190	184	178	172	184	-10.0	-12.9	-7.1
Michigan	774	794	796	789	780	812	805	840	4.9	4.1	8.5
Minnesota	428	443	472	468	464	487	481	471	13.7	12.2	10.0
Missouri	606	640	648	643	638	675	668	689	11.3	10.2	13.7
New Hampshire	270	281	282	277	272	265	264	273	-1.6	-2.0	1.3
New Jersey	101	89	89	82	75	70	70	82	-31.3	-30.8	-19.1
New York	880	936	955	949	941	962	962	985	9.3	9.4	12.0
Ohio	452	493	497	492	487	505	525	521	11.8	16.2	15.2
Pennsylvania	980	962	972	957	939	951	932	983	-3.0	-4.9	0.3
Rhode Island	22	22	19	18	17	16	17	19	-27.1	-22.0	-12.8
Vermont	270	272	284	282	280	284	271	277	5.3	0.4	2.5
West Virginia	766	756	748	742	734	744	714	750	-2.9	-6.9	-2.1
Wisconsin	595	640	664	659	654	690	676	691	15.9	13.6	16.0
Total for North	7,890	8,121	8,215	8,119	8,011	8,184	8,069	8,342	3.7	2.3	5.7

National assessments based on greenhouse gas emissions storylines predict that sequestered carbon in forests will decrease by 2.3 to 2.8 billion tons—half of which is expected to occur in the North—from 2040 to 2060 (USDA FS 2012a). The expected decrease for the North as a whole would be unevenly distributed among the States (Fig. 7.2).

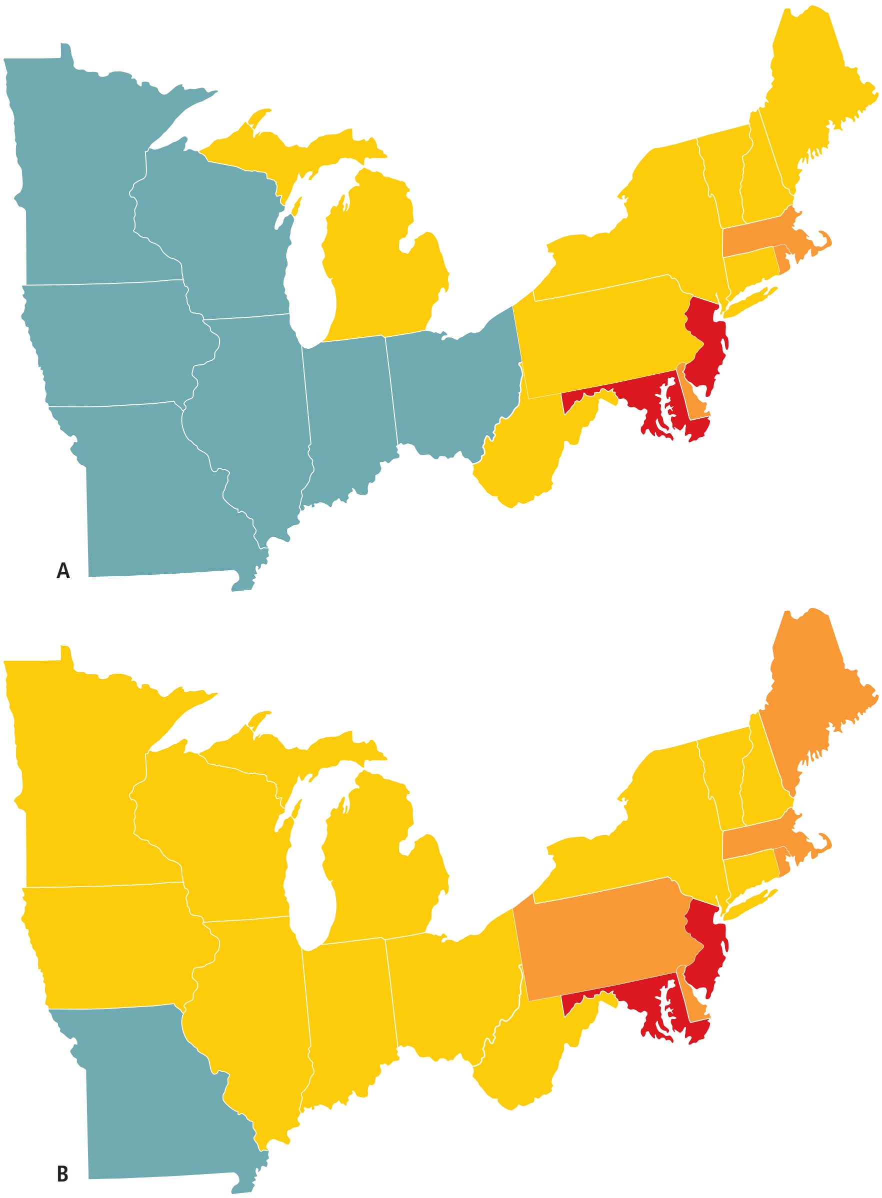


FIGURE 7.2

Projected change in sequestered carbon on forest land including soil, 2010 to 2060, in the North under greenhouse gas emissions storyline A2 that assumes high levels of greenhouse gas emission associated with moderate urbanization gains (rapid population growth and moderate income growth) with (A) harvest rates continuing to follow historical trends (scenario A2-C), and (B) increased harvesting to satisfy greater demands for bioenergy (scenario A2-BIO).

CHANGE IN SEQUESTERED CARBON (percent)

- -35 to -25
- -25 to -10
- -10 to 0
- 0 to 5

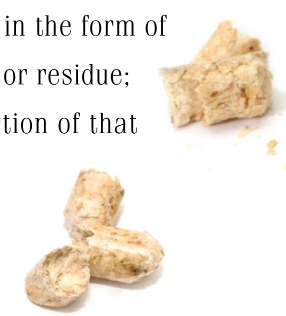
Three scenarios examined for the North resulted from adding accelerated woody biomass utilization to the assumptions for storylines A1B, A2, and B2 (Chapter 2). These scenarios (A1B-BIO, A2-BIO, and B2-BIO) were based on the implications of increasing oil prices (peak oil) and corresponding increases in demand for energy from woody biomass (Chapter 2). The assumed increased biomass utilization for energy would have a noticeable effect on sequestered carbon, as demonstrated by the substantial decreases in sequestered carbon for scenario A2-BIO compared to A2-C (Fig. 7.2). This change would primarily result from increased removals of aboveground biomass, which would decrease the total carbon sequestration capacity of the live trees (Figs. 7.1, 7.2; Appendix 2).

Most sequestered carbon in northern forests (Fig. 7.1) is primarily stored in soil organic matter and aboveground biomass (Shifley et al. 2012). Second only to soil organic matter, aboveground biomass is a highly dynamic component of the carbon sequestration profile and is constantly changing as trees grow, die, or are removed. As a forest ages in the absence of major disturbances, the quantity of aboveground biomass and carbon typically increases. Cut, dead, dying, and down trees serve as reservoirs of sequestered carbon that will be emitted to the atmosphere gradually as the trees decompose. When cut trees are converted to forest products, the carbon in those products will continue to be sequestered until the products decompose or are burned.

For perspective, a cubic foot of wood in a living or freshly harvested oak tree (*Quercus* spp.) weighs about 60 pounds (green weight), with roughly half that weight in water. This means that the dry weight of a cubic foot of oak is about 30 pounds, about half of which is carbon (i.e., 15 pounds or roughly a quarter of the green weight). Fifteen pounds of carbon is equivalent to the amount of carbon in 55 pounds of carbon dioxide gas.

PROJECTED WOODY BIOMASS IN NORTHERN FORESTS

Projected changes in forest area, tree size distribution, and tree species composition that are expected to result from the climate change and disturbance scenarios described in Chapters 2 and 4 were further analyzed to predict changes in forest biomass. As with the forest changes analyzed in other chapters, the primary focus here is on storylines A1B, A2, and B2 as well as variants of those storylines assuming increased biomass utilization. For consistency with other chapters of this document, biomass is reported in United States short tons (2,000 pounds) and acres rather than in metric tons and hectares, as is typical for international reporting. Because carbon constitutes about half the dry weight of biomass, or roughly a quarter the green weight of biomass, readers may prefer to visualize tons of woody biomass in the form of boles, limbs, branches, bark, roots, or residue; and to think of carbon as a proportion of that biomass (Fig. 7.3).



Although woody biomass is a collective term for the mass (weight) of all the material in trees, it is often used to summarize the components that are relevant to wood harvesting and merchandising: boles above stump height, tops and limbs, cull trees versus those that can be utilized for wood products, and composition by species or diameter class. Biomass can be reported in green tons or in equivalent dry weight, which is used to compute the energy value in wood and to compare biomass yields among different harvesting treatments or different geographic locations. Total biomass per tree is often computed using an equation that is based on tree diameter, with the biomass of various tree components estimated as a proportion of total biomass. Aboveground woody biomass per acre is usually proportional to the cubic volume of wood or the basal area per acre.

FIGURE 7.3
Schematic of the combined forest tree components that constitute woody biomass and the elemental carbon that is contained therein (stump, bole, branches).

Coinciding with the slight increase (4 percent) projected for aboveground sequestered carbon (Fig. 7.1) is a projected 4-percent increase in aboveground northern forest biomass from 2010 to 2060 for scenario A2-C (Fig. 7.4, Table 7.1). The variations among predictions of aboveground biomass are small; the largest difference of 277 million dry tons in 2060 is only 3.3 percent of the 2010 estimate (Fig. 7.4, Table 7.1). But the contrast between the expected increase in aboveground biomass and the expected decrease in the total amount of carbon sequestration merits further discussion. Total timberland[1] in the North is expected to decrease by nearly 6 percent by 2060 (Chapter 4). Because aboveground biomass and soil (with its considerable quantity of sequestered carbon) are considered "removed" from the forest when forest land is converted to other uses, gradual losses of forest land can result in a net decrease in total sequestered carbon—due primarily to removal of the carbon in the associated forest soils—even though aboveground biomass and aboveground carbon sequestered increases.

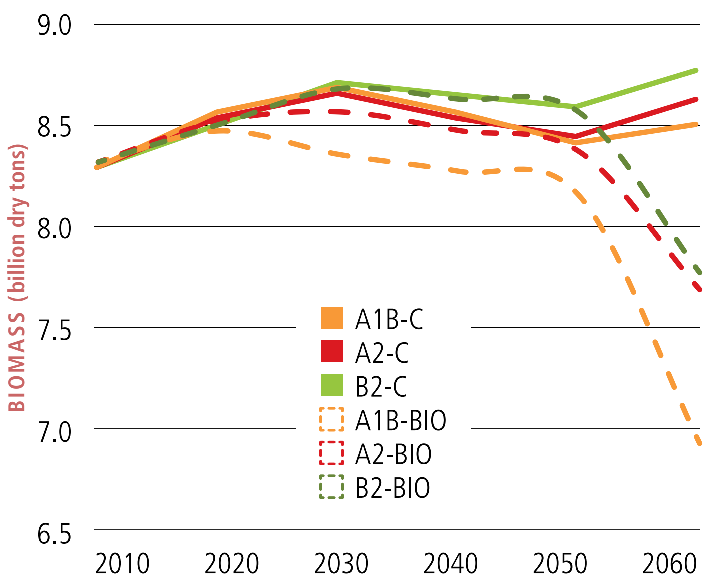


FIGURE 7.4

Projected total aboveground biomass on forest land in the North, 2010 to 2060, under six scenarios, each representing a global greenhouse gas storyline (IPCC 2007) paired with a harvest regime. Storyline A1B assumes moderate greenhouse gas emissions, moderate gains in population, and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio); A2 assumes high greenhouse gas emissions, large gains in population and energy consumption, and moderate gains in income; and B2 assumes low greenhouse gas emissions with moderate gains in population, income, and energy consumption. Scenario projections assume harvest will continue at recently observed levels (labeled –C) or increase to reflect increased harvest for bioenergy production (labeled –BIO).

[1] *Timberland is defined as forest land that maintains a minimum potential for growth of 20 cubic feet per acre per year and is not restricted from active forest management by statute or regulation.*

Lichen on stump

A closer examination of aboveground woody biomass estimated for 2010 (Fig. 7.5) and projected for 2060 (Fig. 7.6) reveals substantial variation among the Northern States. Under scenario A2-C, aboveground woody biomass is expected to decrease in several of the States along the Atlantic seaboard (Table 7.1). New Jersey, Maryland, Delaware, and Rhode Island are all projected to experience decreases of >15 percent. Additionally, the increase of aboveground forest biomass for the region does not completely reflect some of the interim trends that occur within the 50-year time period. Under all three scenarios (A2-C, A1B-C, B2-C), total aboveground forest biomass would actually decrease from 2030 to 2050, and then increase again in the last decade of the projection period (Fig. 7.4). This is a sharp contrast to the enhanced biomass-utilization scenarios (A1B-BIO, A2-BIO, and B2-BIO), which all show an overall decrease in aboveground forest biomass from 2030 to 2060 (Figs. 7.4, 7.6). The large decreases in aboveground forest biomass for the enhanced biomass utilization scenarios are projected to take place primarily from 2020 to 2030 and from 2050 to 2060. This trend reflects both the current rise in woody biomass utilization for energy and the assumption that limited supplies and higher costs of fossil fuels (peak oil) will result in increased biomass utilization in about 40 years. From 2010 to 2060, aboveground forest biomass is expected to increase in 11 Northern States under scenario A2-C compared to only two States (Missouri and New York) under A2-BIO (Appendix 7).

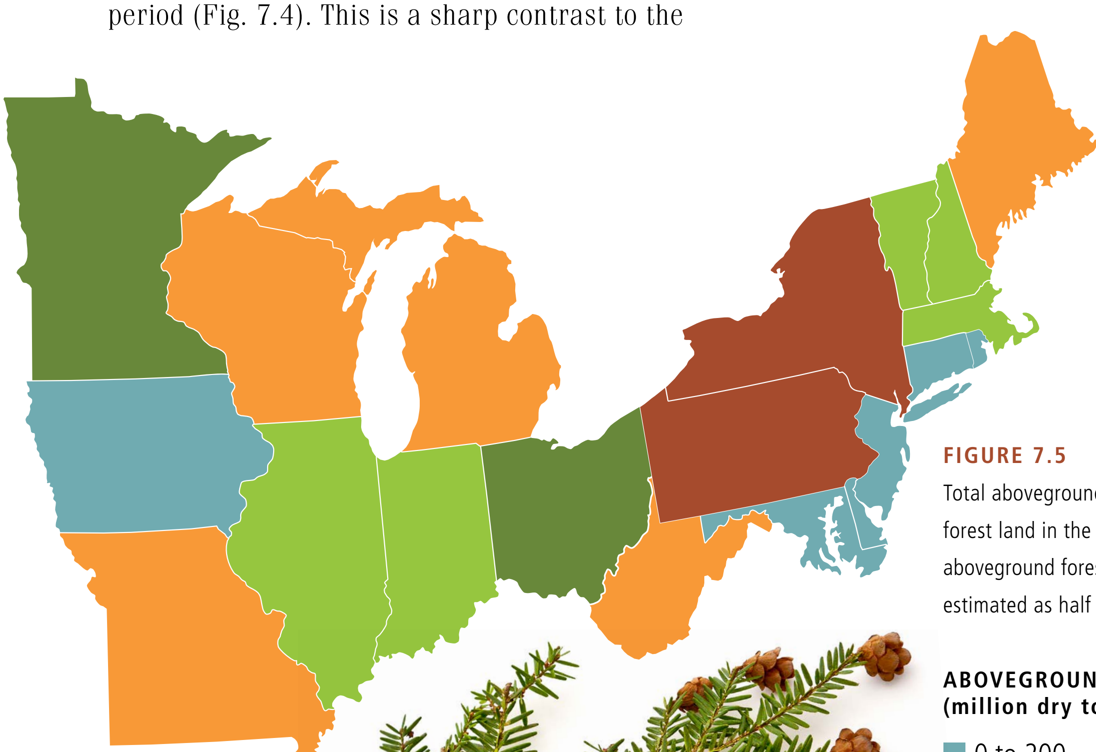
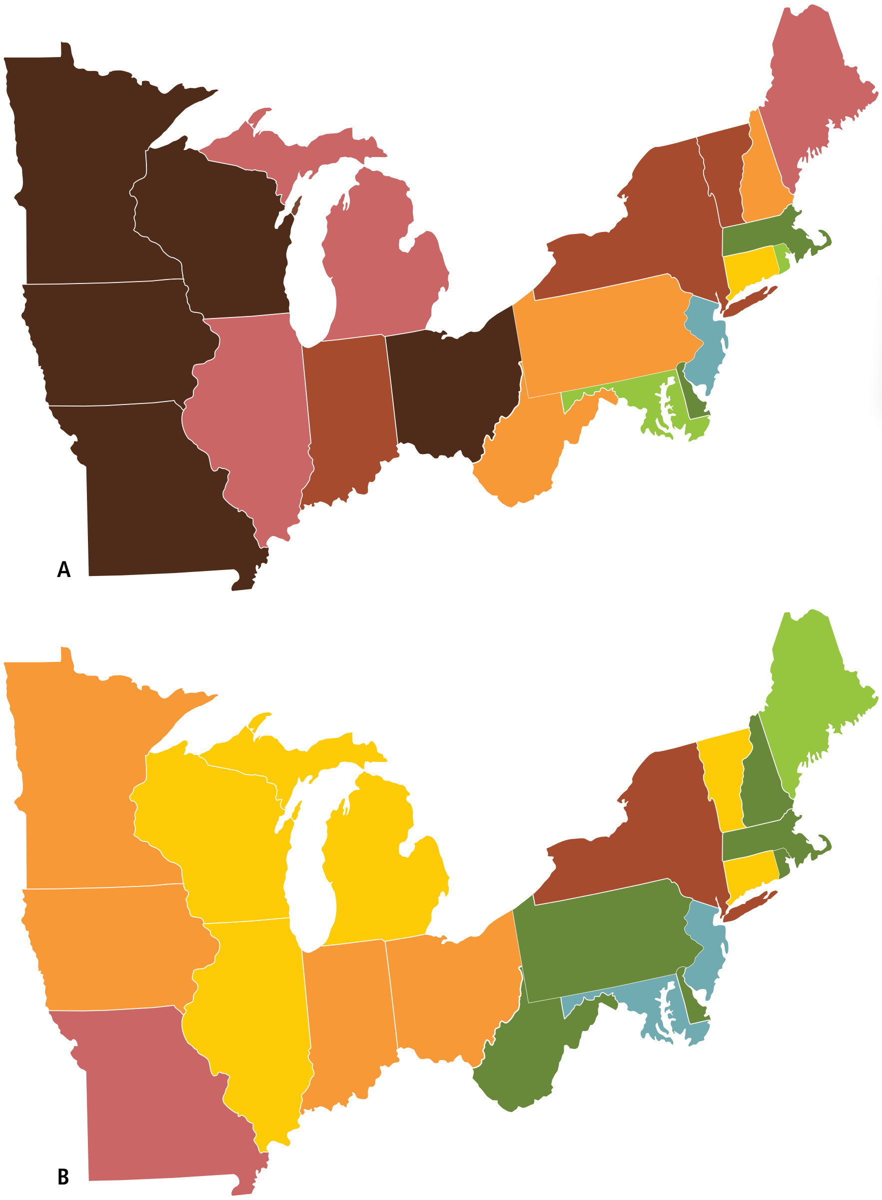


FIGURE 7.5

Total aboveground live-tree biomass on forest land in the North, 2010; note that aboveground forest carbon in million tons is estimated as half the biomass dry weight.

ABOVEGROUND BIOMASS (million dry tons)

- 0 to 200
- 200 to 400
- 400 to 600
- 600 to 800
- 800 to 1,000
- Over 1,000



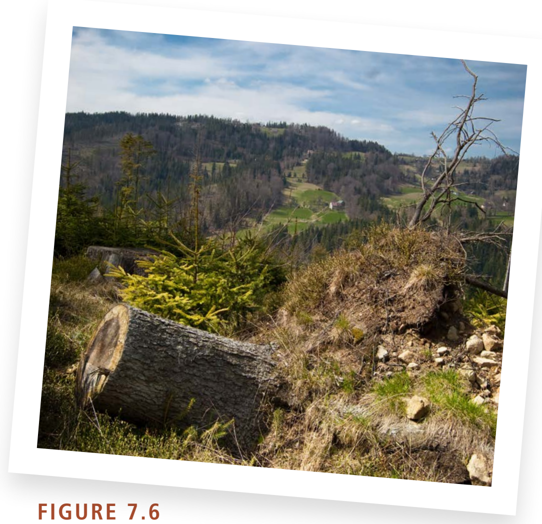


FIGURE 7.6

Change in total aboveground live tree biomass on timberland for the North, 2010 to 2060, under greenhouse gas emissions storyline A2 that assumes high levels of greenhouse gas emission associated with moderate urbanization gains (rapid population growth and moderate income growth) combined with high energy consumption under the assumption of (A) harvest rates continuing to follow historical trends (scenario A2-C), or (B) increasing harvest rates to satisfy demands for bioenergy (scenario A2-BIO).

CHANGE IN ABOVEGROUND BIOMASS (percent)

-40 to -30
-30 to -20
-20 to -10
-10 to -5
-5 to 0
0 to 5
5 to 10
10 to 20

In a few Northern States, the conversion of forest land to other uses would decrease both total aboveground woody biomass and timberland area from 2010 to 2060; however, for most States, average aboveground biomass per acre is expected to increase on the forested acres that remain after conversion. Aboveground woody biomass per acre of retained forest would increase for almost every State in the region, even though total aboveground woody biomass would decrease in nine States (Fig. 7.7) primarily due to a decline in total forest area. This is an indication of the large influence that projected land-use change has in projections of woody biomass. The increase in woody biomass for acres that remain forested is also an important factor for the future of energy from woody biomass in the region, as discussed below.

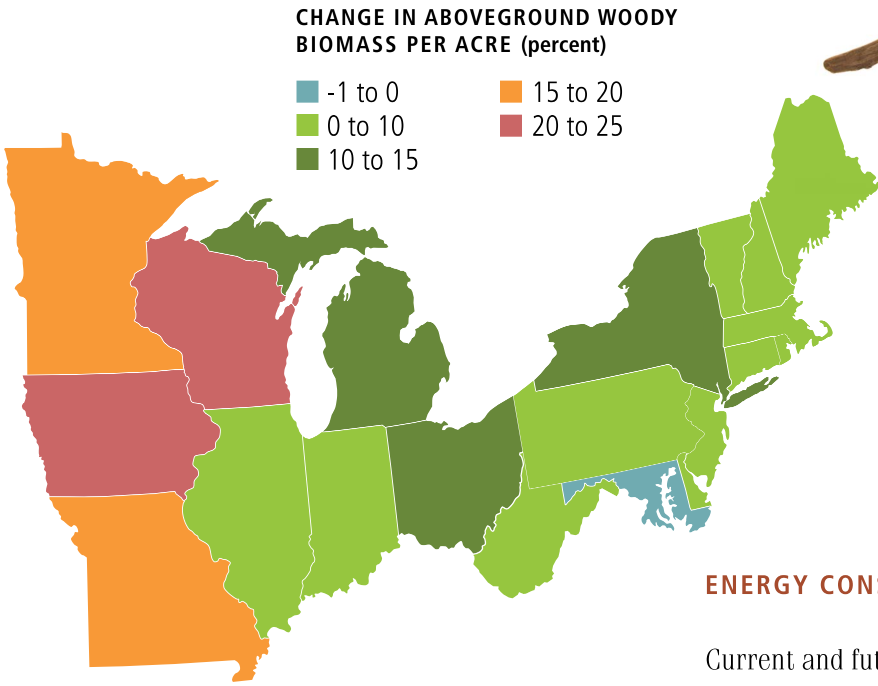


FIGURE 7.7

Change in aboveground woody biomass per acre of timberland, 2010 to 2060, in the North under scenario A2-C, which assumes high greenhouse gas emissions, large gains in population and energy consumption, moderate gains in income, and harvest rates that continue at recently observed levels.

Projections of biomass increases for northern forests under scenario A2-C are expected to differ from national-level projections (USDA FS 2012a, USDA FS 2012c), with aboveground volume of growing stock (a surrogate for aboveground biomass or carbon) increasing more slowly than the national rate from 2020 to 2030 and then continuing to increase from 2050 to 2060 in contrast to a national trend of growing-stock volume decreases. Over the 50-year period, the result would be a small decrease in growing-stock volume at the national scale but a modest increase for the Northern States.

ENERGY CONSUMPTION

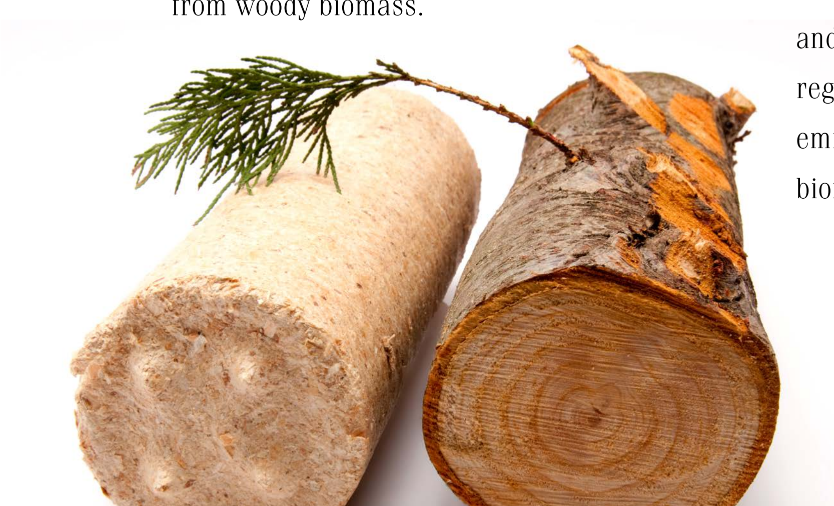
Current and future patterns of energy consumption affect the quantity of carbon emissions and the quantity of biomass utilized for energy. Patterns of biomass utilization affect rates of forest harvesting, forest age structure, and the associated capacity of forests to sequester carbon.

Annual energy consumption per capita in the United States is expected to decrease by 9 percent, from 318 million Btu in 2010 to 290 million Btu in 2030 (USDOE EIA 2012). However, population in the North (based on storyline A2) is expected to increase by 16 million from 2010 to 2030 and by 36 million by 2050 (Appendix Table A2.1). Thus, even with declining per capita energy consumption, total energy consumption in the region is likely to increase from 41 quadrillion Btu in 2010 to 42 quadrillion Btu in 2030 and would continue to increase because the projected rate of population increase exceeds the rate of decrease in per capita energy consumption (USDOE EIA 2012, USDA FS 2012a).

In 2010, about 4 percent of all U.S. energy consumption came from wood combustion. Less than 1 percent of electrical power consumed in the United States comes from wood or wood byproducts (USDOE EIA 2010). In the North, this percentage is slightly higher (Fig. 7.8), with electric utilities throughout the region using wood for part of their energy (USDA FS 2011).

Electricity consumption alone makes up approximately 41 percent of the annual national energy consumption, with the Northern States accounting for 40 percent of the national electricity consumption total. About 55 percent of northern electricity consumption is fueled by coal, followed by 27 percent fueled by nuclear energy (Fig. 7.8, Table 7.2). Individual States vary greatly in the source of the electricity consumed, with coal-generated electricity ranging from 0 to 97 percent and nuclear energy ranging from 0 to 66 percent (Table 7.2).

Two percent of total annual electricity consumption in the region is derived from a combination of woody and herbaceous biomass (Fig. 7.8); this is about 25 percent of total annual electricity consumption from all renewables including hydroelectric and wind sources (Table 7.2). Among the different biomass feedstocks for electricity, woody biomass accounts for the largest share (53 percent), meaning that about 1 percent of all electric production is from woody biomass.



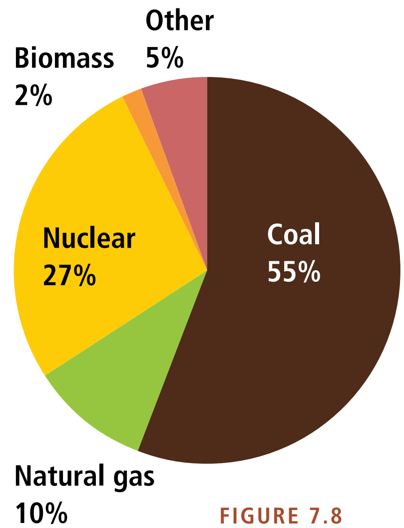


FIGURE 7.8

Electricity consumption in 2010 by source in the North; note that wood and wood residue constitute about half of all biomass, or about 1 percent of all electricity consumption.

USING WOODY BIOMASS FOR ENERGY

Burning fossil fuels to produce energy releases carbon dioxide that was previously sequestered for millennia as carbon in coal, oil, or natural gas. By converting to woody biomass, society may be able to reduce the amount of carbon emissions from fossil fuels. Burning woody biomass also releases carbon into the atmosphere, but when forests harvested for biomass regenerate and regrow, carbon is again sequestered in the trees growing in the regenerated forest. Thus, some carbon would be cycled from the forest to the atmosphere and eventually sequestered back into forest regrowth. Methods to account for carbon emissions and sequestration when using woody biomass for energy are still evolving.

Table 7.2—Electricity consumption by source in the North, 2010 (USDOE EIA 2010).

State	Energy source							
	Coal	Natural gas	Petroleum	Nuclear	Hydroelectric	Biomass[a]	Wind	Total consumption
	(percent)							(trillion Btu)
Pennsylvania	49.3	10.0	0.4	37.2	1.2	1.3	0.5	2,172
Illinois	46.6	1.7	0.1	49.7	0.1	0.5	1.4	2,009
Ohio	84.2	2.8	1.0	11.4	0.4	0.2	0.0	1,390
New York	9.8	27.9	2.0	33.8	20.0	2.3	1.6	1,344
Indiana	95.0	3.1	0.1	0.0	0.4	0.3	1.1	1,193
Michigan	64.6	8.0	0.3	21.6	1.2	2.1	0.3	1,057
Missouri	81.9	3.3	0.1	11.8	1.9	0.1	0.5	909
West Virginia	97.2	0.2	0.3	0.0	1.4	0.0	1.0	716
Wisconsin	64.6	6.9	1.1	22.0	2.1	1.6	1.7	602
New Jersey	9.9	28.2	0.1	59.9	0.1	1.8	0.0	600
Minnesota	54.2	4.2	0.1	23.0	1.2	3.7	8.8	563
Iowa	73.1	1.9	0.2	9.3	1.8	0.3	13.7	528
Maryland	54.9	4.3	0.9	34.2	4.1	1.7	0.0	445
Massachusetts	25.2	43.2	2.5	15.7	3.2	5.8	0.0	360
Connecticut	8.7	23.7	1.1	57.6	1.7	4.5	0.0	302
New Hampshire	16.1	19.3	0.9	45.2	8.0	8.5	0.3	204
Maine	0.8	33.1	2.8	0.0	29.0	26.0	2.5	116
Vermont	0.0	0.1	0.0	66.1	16.8	6.7	0.1	85
Rhode Island	0.0	92.6	0.2	0.0	0.0	2.9	0.0	61
Delaware	70.5	23.8	2.3	0.0	0.0	3.4	0.0	47
Total for North	55.3	9.9	0.6	26.9	3.2	1.6	1.5	14,702
U.S. total	47.8	18.5	1.0	21.9	7.0	1.2	1.9	38,094

[a] *All biomass*

The carbon and energy balance associated with broader use of woody biomass and other plant-derived biomass for energy production depends on numerous assumptions used in the computations (Malmsheimer et al. 2008).

Because feedstocks are relatively abundant and infrastructure for utilization is already in place, woody biomass represents an opportunity for replacing some portion of fossil fuels used for energy production in the Northern States.

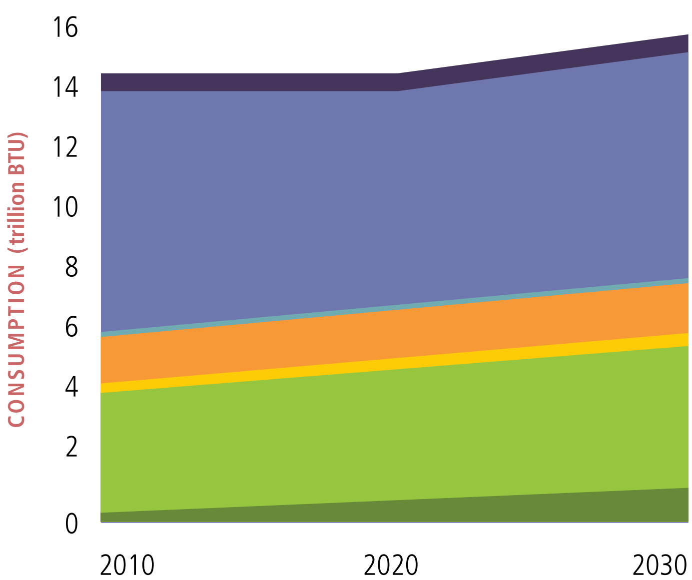


FIGURE 7.9

Projected annual electricity consumption in the North, 2010 to 2030, based on national-level rates of change (USDOE EIA 2014).

Nevertheless, long-term projections by the U.S. Department of Energy's Energy Information Administration (EIA) indicate the vast majority of electricity generation will continue to come from coal, natural gas, and nuclear fuels. These projections indicate that biomass from all sources will continue to be only a small part of the total energy profile (USDOE EIA 2010), but also that total electricity derived from biomass will increase from 2010 to 2030 (Fig. 7.9). Although small in absolute terms compared to other feedstocks, this would represent a 350-percent increase in biomass utilization from 2010 to 2020, the greatest percentage increase of any electricity source (Fig. 7.10).

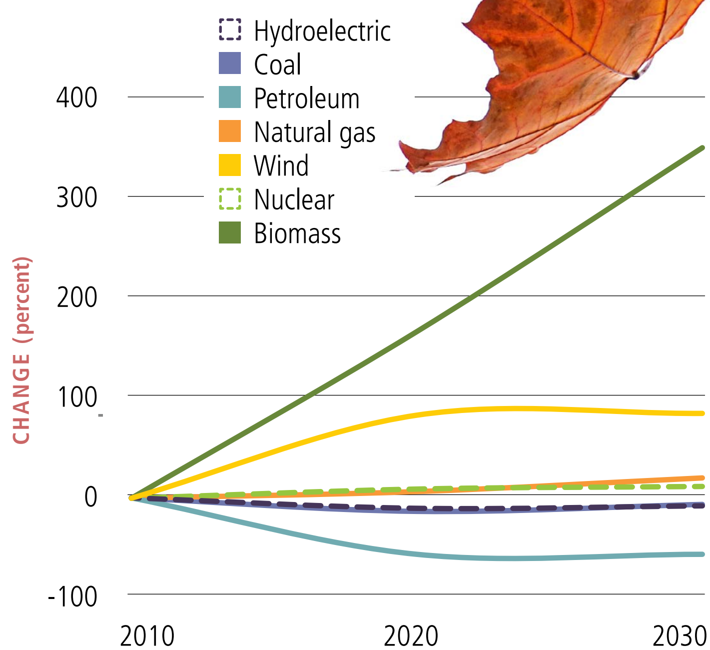
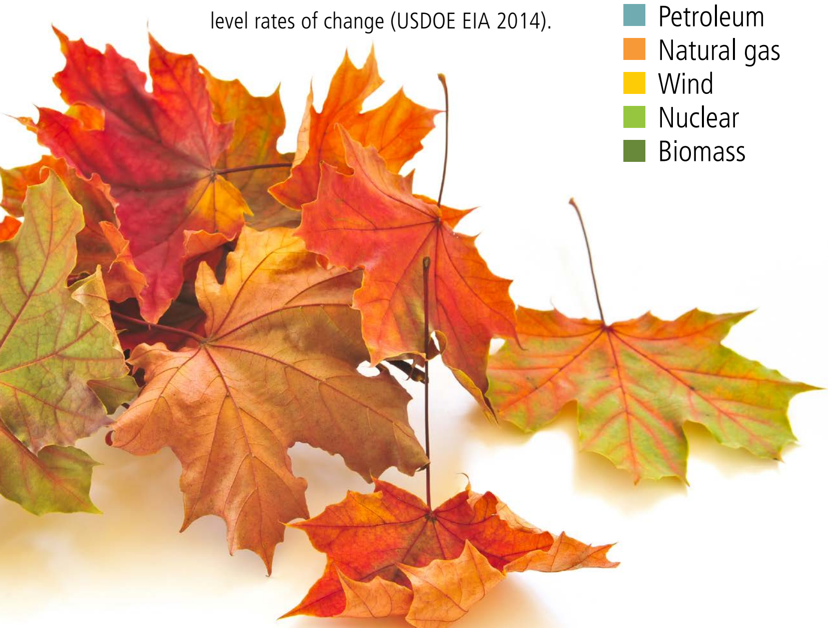


FIGURE 7.10

Projected change in annual electricity consumption by electricity source, 2010 to 2030, in the United States; note that the projections were derived using national-level projections and adjustment factors that were based on 2010 proportions of electricity consumption (USDOE EIA 2014).



The increase in biomass utilization for electricity production is part of a more gradual overall increase in bioenergy consumption that started at the turn of this century in response to a developing market for corn-based ethanol (USDOE 2011). However, unlike ethanol producers, which primarily serve the transportation sector, the forest products industry has traditionally been both the primary supplier and the primary consumer of woody biomass for energy production (USDOE 2011). In 2010, annual consumption of harvested roundwood fuelwood was 1.6 million cubic feet, and consumption is expected to increase by 230 percent in 2060 (Ince et al. 2011, USDA FS 2012a). Fuelwood utilization extends beyond electricity production to include industrial production of steam and heat in paper and wood-processing mills and residential heating.

CO-FIRING OF BIOMASS FOR ELECTRICITY

Because wood biomass is likely to remain a relatively small component of total energy production through 2030, future increases in its use for electrical energy could be clustered around locations that have a comparative advantage in the quantity of raw materials, the transportation network, or existing energy infrastructures. Spatial analyses were used to identify places where an increase in the use of biomass may be practical in co-firing boilers that combine wood with coal.

The use of biomass with coal during electric generation could be a low-risk, short-term option for rapidly increasing renewable energy production because adding wood as a feedstock to existing coal-fired electric plants would be relatively inexpensive. Furthermore, unlike wind and solar energy, woody biomass can be readily stored as chips or on the stump until needed. With an abundant, widely dispersed biomass resource base, a large number of coal-fired power plants (360), and a long history of woody biomass use, the North has a relatively high potential for future utilization of biomass for electricity production (USDOE 2011).

One way to assess the feasibility of replacing fossil fuels with biomass is to examine the regional electric energy footprint with respect to biomass resources. Clearly, total replacement of fossil fuels with biomass would not be feasible. Doing so would consume 11 percent of all standing woody biomass in the North to generate the electricity consumed in a single year (Table 7.3); after 9 years, virtually all the wood in the region would have been used to generate electricity. However, increasing woody biomass used for electricity production above the 0.2 percent level would not have dire ecological consequences (Table 7.3).

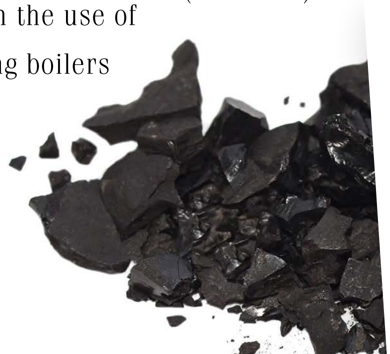


Table 7.3—Proportion of electricity produced from coal and biomass by State with the proportion of the State's total aboveground woody biomass that would be required annually to instead generate electricity from woody biomass.

State	Electricity produced from coal	Electricity produced from biomass	Proportion of State's total aboveground woody biomass needed annually to replace:	
			All coal-generated electricity	Electricity from all sources
	(percent)			
Rhode Island	0.0	0.5	0	16
Vermont	0.0	0.1	0	2
Maine	0.8	0.3	< 1	1
Connecticut	8.7	0.7	2	15
New Jersey	9.9	0.8	6	36
New York	9.8	0.2	1	10
New Hampshire	16.1	0.4	1	5
Massachusetts	25.2	0.6	3	12
Illinois	46.6	0.2	25	153
Pennsylvania	49.3	0.2	7	13
Minnesota	54.2	0.2	5	8
Maryland	54.9	0.3	10	17
Wisconsin	64.6	0.1	4	6
Michigan	64.6	0.2	5	9
Delaware	70.5	0.5	15	19
Iowa	73.1	<0.1	22	28
Missouri	81.9	<0.1	7	9
Ohio	84.2	<0.1	17	20
Indiana	95.0	<0.1	30	31
West Virginia	97.2	0.0	7	7
All States	55.0	0.2	6	11

Although energy footprints are a good way to calculate the limitations of woody biomass as an energy source based on energy consumption, they are relatively uninformative as indicators of the actual resource potential for woody biomass as an energy feedstock in the Northern States. Annual net forest inventory change is more informative because it accounts for annual growth minus annual removals from harvesting, mortality, and land-use change, thus showing which States have (or will have) annual woody-biomass increases (after accounting for removals) that could satisfy energy demands without perpetually depleting existing forests. The projected mean annual net inventory change over the preceding decade was calculated for 2020, 2030, 2040, and 2050 for multiple scenarios (Table 7.4). At 2060, mean annual net inventory change was calculated for the 2050 to 2060 interval, and over the entire 50-year interval (2010 to 2060) for comparison.

Lake and midwestern States would generally have the highest positive net inventory change from 2010 to 2060 under all scenarios (Table 7.4). In one 20-year period (2030 to 2050) all States in the North are expected to have a net annual decrease in aboveground biomass. States along the Atlantic seaboard (such as Maryland, New Jersey, and Massachusetts) would have negative values throughout most of the projection period, reflecting an expected decrease in total aboveground biomass over the next 50 years. However, this does not imply that these States have no potential for biomass energy. Most of the projected 6-percent loss of timberland in the region (Chapter 4) is expected to take place in the States farthest east, which are projected to experience net annual decreases in woody biomass due to loss of forest through urbanization. However, most of these States would also experience increases in average aboveground woody biomass per acre of forest land retained as forest (Figure 7.7). Therefore, negative values for annual inventory change do not necessarily mean that woody biomass will not be available from existing timberland in the future.

Nevertheless, increases in demand for woody biomass for energy could potentially lead to decreases in available woody biomass on timberland. The enhanced woody biomass utilization scenarios offer a hypothetical assessment of this contingency based on two primary assumptions: (1) the adjustment for harvesting probability was applied using the same predetermined proportions across the entire region, and (2) conversions from forest/timberland into other land uses were not reflected, but rather higher utilization on timberland currently existing and expected to exist in the future was simulated.

Overall, the enhanced biomass utilization scenarios (A1B-BIO, A2-BIO, B2-BIO) predict decreases in woody biomass from 2010 to 2060 when compared to the non-enhanced counterparts (Fig. 7.4). With northern timberland projected to decrease by about 6 percent from 2010 to 2060, levels assumed by the enhanced biomass utilization scenarios in eastern States could perpetually reduce the amount of available woody biomass from timberland (Appendix 7).

Table 7.4—Annual net forest biomass change for the North under three scenarios— A1B-C assumes moderate levels of greenhouse gas emissions associated with moderate gains in population growth and large gains in income and energy consumption (but with a balanced renewable/fossil fuel portfolio), A2-C assumes high levels of greenhouse gas emissions associated with large gains in population growth and energy consumption with moderate gains in income, and B2-C assumes low levels of greenhouse gas emissions associated with moderate gains in population growth, income, and energy consumption—combined with the assumption that harvesting will continue at rates observed from 1995 to 2005 and not increase substantially to meet future demand for bioenergy.

State	Estimated for 2010[a]	Projected mean annual changes (A2-C only)				Projected mean annual changes (all scenarios)					
		2010 to 2020	2020 to 2030	2030 to 2040	2040 to 2050	2050 to 2060			2010 to 2060		
						A1B-C	A2-C	B2-C	A1B-C	A2-C	B2-C
	(thousand dry tons)										
Maryland	3,406	-772	-1,333	-1,076	-955	-630	-891	5	-953	-1,006	-826
New Jersey	2,155	-1,232	-27	-692	-683	-494	-547	698	-626	-636	-387
Pennsylvania	10,095	-1,795	1,018	-1,522	-1,816	-683	1,186	4,433	-960	-586	64
West Virginia	9,013	-1,047	-770	-653	-801	-1,994	999	1,661	-1,053	-454	-322
Massachusetts	3,465	-376	48	-508	-538	-1,172	-614	-34	-509	-398	-282
Connecticut	459	449	-34	-292	-346	-334	-941	-402	-112	-233	-125
Rhode Island	565	-6	-245	-105	-116	-4	-87	196	-95	-112	-55
New Hampshire	2,708	1,116	86	-450	-505	-796	-690	107	-110	-89	71
Delaware	772	-39	-61	-85	-95	-60	-4	141	-68	-57	-28
Illinois	5,612	751	-233	-164	-186	-743	95	1,071	-115	53	248
Vermont	1,184	179	1,231	-223	-256	-832	480	-263	20	282	134
Maine	-930	2,286	865	-242	-290	-2,285	-749	-179	67	374	488
Indiana	6,930	1,101	7	-357	-432	594	1,792	1,479	183	422	360
Iowa	2,274	1,479	268	-67	-80	-224	657	724	275	452	465
Michigan	9,713	1,970	291	-772	-919	2,566	3,248	6,037	627	764	1,322
Ohio	7,555	4,054	375	-448	-560	3,891	1,859	3,465	1,462	1,056	1,377
Minnesota	4,166	1,510	2,827	-359	-390	1,632	2,293	706	1,044	1,176	859
Missouri	11,209	3,394	765	-477	-576	3,086	3,743	5,191	1,238	1,370	1,660
New York	10,362	5,592	1,911	-616	-740	2,114	2,042	4,413	1,652	1,638	2,112
Wisconsin	6,784	4,441	2,407	-440	-528	2,211	3,553	3,661	1,618	1,887	1,908
Total for region	97,497	23,056	9,396	-9,549	-10,814	5,843	17,425	33,111	3,586	5,903	9,040

[a] *Calculated using volume growth and removals from the most current data from Forest Inventory and Analysis (FIA).*

Net annual change in forest inventory is only one of many factors to consider when assessing resource potential for woody biomass as a feedstock. Another way is net annual woody biomass increase, which simply assumes a value of zero for negative estimates of net annual inventory change (Goerndt et al. 2012) and focuses purely on the extra woody biomass that is available every year (if any) after accounting for growth and removals.

Other forest-derived sources of woody biomass for bioenergy include residues from wood processing mills and logging residues (tops and limbs) from roundwood, snags (standing dead trees), harvesting, and downed woody material from natural mortality or human activity. Volume of logging-residue availability was calculated as 30 percent of the harvesting removals reported by Forest Inventory and Analysis (USDOE 2011). Of the total logging residue, it is assumed 35 percent will be retained on site (USDOE 2011) as coarse woody material providing ecological values.

Figure 7.11 shows 2010 estimates for potential sources of woody biomass feedstocks including annual woody biomass increase, logging residues, standing dead trees, and mill byproducts that are currently unused (Miles 2010, USDA FS 2012d). Unused mill byproducts are the smallest component of available woody biomass for bioenergy (Figs 7.11, 7.12)—primarily because most are already being used, often as a feedstock to supplement power for wood-processing mills. Annual woody biomass increase is the largest (Fig. 7.12). Even assuming a 35 percent retention rate, the biomass of dead standing material is only slightly larger than logging residues, probably because salvaging standing dead trees is traditionally rare in northern forests. However, if an energy-driven market develops for such material and if procurement regimes such as integrated harvesting of roundwood and biomass are implemented, standing dead trees could become an available source of woody biomass.

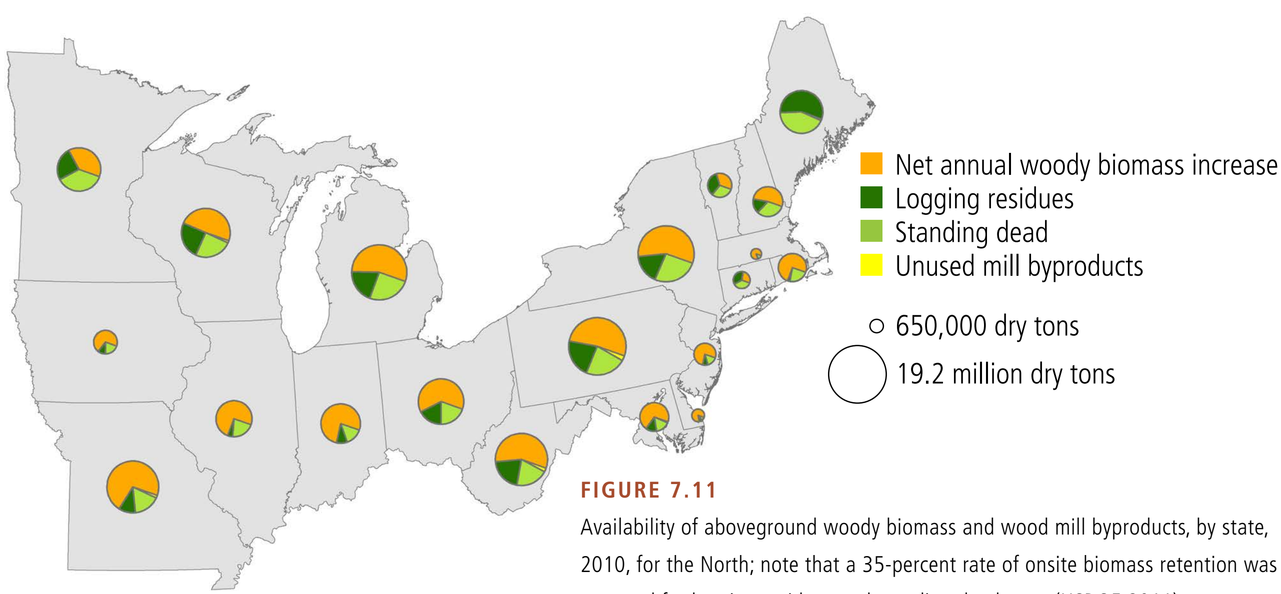


FIGURE 7.11

Availability of aboveground woody biomass and wood mill byproducts, by state, 2010, for the North; note that a 35-percent rate of onsite biomass retention was assumed for logging residues and standing dead trees (USDOE 2011).

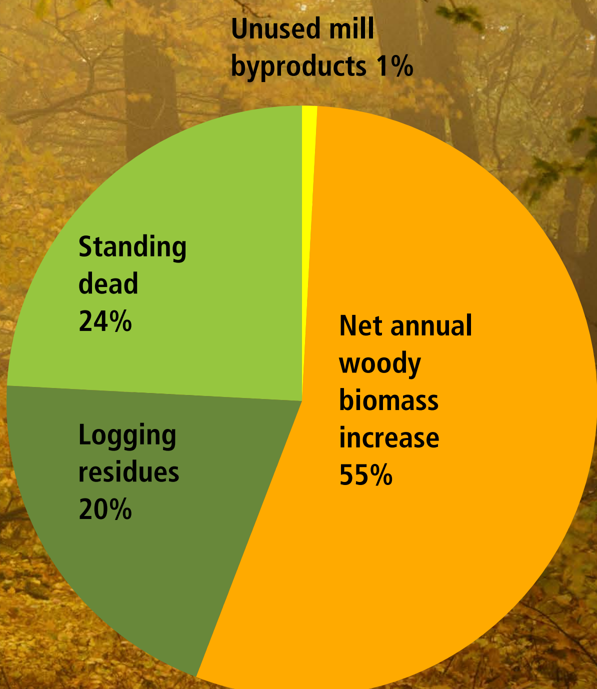


FIGURE 7.12

Availability of aboveground woody biomass and wood mill byproducts for the North in 2010; note that a 35-percent rate of onsite biomass retention was assumed for logging residues and standing dead trees (USDOE 2011).

States with the highest availability of logging residues also tend to have higher estimates for mill byproducts and lower estimates for annual woody biomass increase (Appendix Table A7.3). This illustrates the symbiotic relationship between wood processing and harvesting, as well as the reduction in extra available timberland biomass in States with intensive harvesting. Based on the 35 percent retention rate for both logging residues and dead standing material, the northern region would have a combined potential to generate approximately 303 million megawatt hours of electricity annually from all sources of woody biomass feedstock.

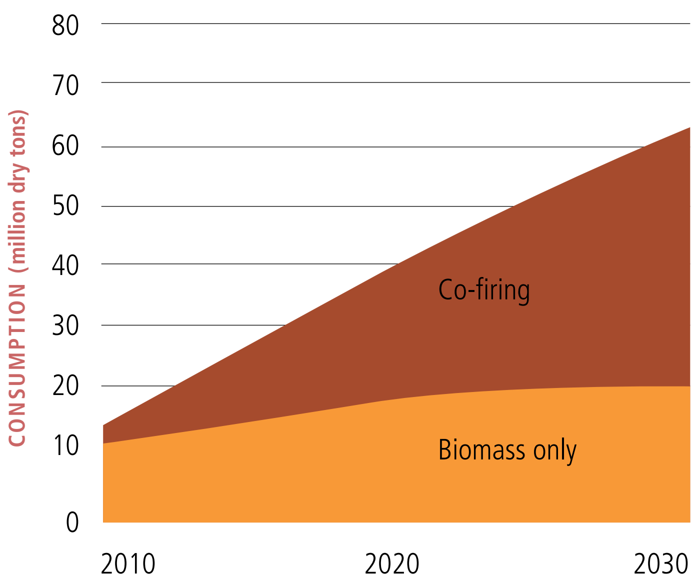


FIGURE 7.13

Electricity consumption by co-firing plants and plants that burn biomass only in the North, 2010 to 2030, based on national-level rates of change (USDOE EIA 2012); note that in 2010, biomass burned in co-firing plants accounted for 17 percent of the total.

Opportunities for co-firing of coal and woody biomass for electricity production appear to be abundant in the Northern States. Of the electricity currently produced from biomass (Fig. 7.13), approximately 83 percent comes from dedicated plants compared to only 17 percent from co-firing plants (USDOE EIA 2010). However, Figure 7.13 shows that biomass electricity production is expected to increase dramatically; moreover, co-firing is likely to be the primary means of biomass-fuel electricity production by 2020 (USDOE EIA 2014). A key consideration is the location of exising coal-fired plants that could incorporate woody biomass as a fuel. This is a first step in identifying northern locations that would have a relative advantage for co-firing.

We evaluated the effects of several physical, environmental, and socioeconomic factors that would influence adoption of co-firing of biomass and coal in the North. The analysis was performed using logistic regression models that accounted for location of existing coal-fired power plants, condition of infrastructure such as roads and railways, implementation of renewable energy portfolio standards, and available biomass feedstocks (such as wood processing residues). Data consisted of projected energy consumption values from the U.S. Energy Information Administration (USDOE EIA 2012) and projected biomass resources under scenario A2-C. Results from the analysis were summarized at the county level (Aguilar et al. 2012) for 2010 and 2030 (Fig. 7.14).

Many of the counties that appear to have high potential for biomass and coal co-firing are in the Lake States (Wisconsin, Minnesota, and Michigan) and in the mid-Atlantic States of West Virginia and Pennsylvania. This is not surprising, as these States tend to have either a large amount of available woody biomass, a large number of coal-fired power plants, or both. Total co-firing probability would not increase dramatically across the region from 2010 to 2030. The States that in the future are expected to have more counties with a high probability of co-firing are primarily in the Midwest (Aguilar et al. 2012), and that increase is attributable to projected increases in available woody mill residues. The overall number of counties with high probability of co-firing is not expected to increase significantly from 2010 to 2030.

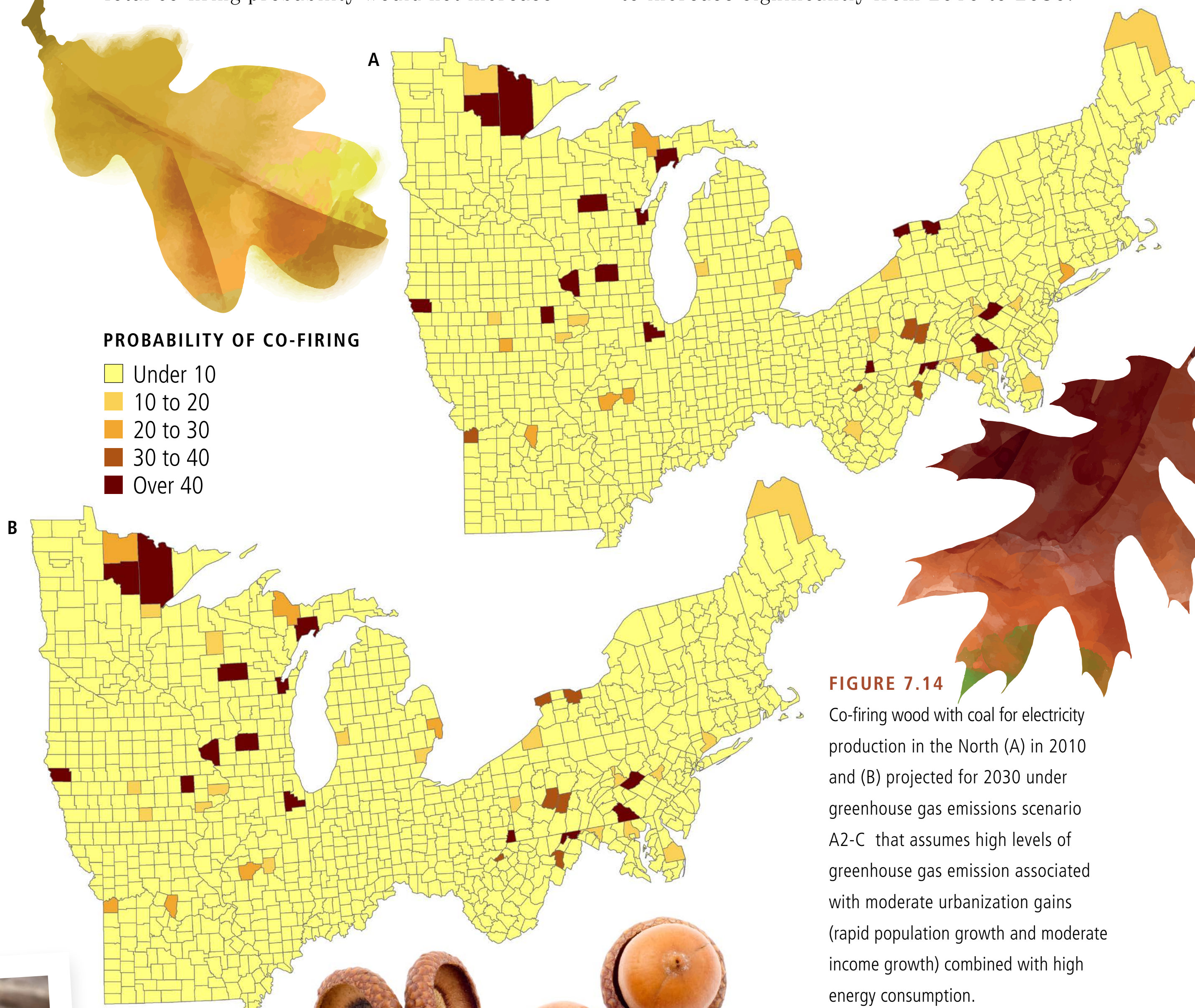


FIGURE 7.14

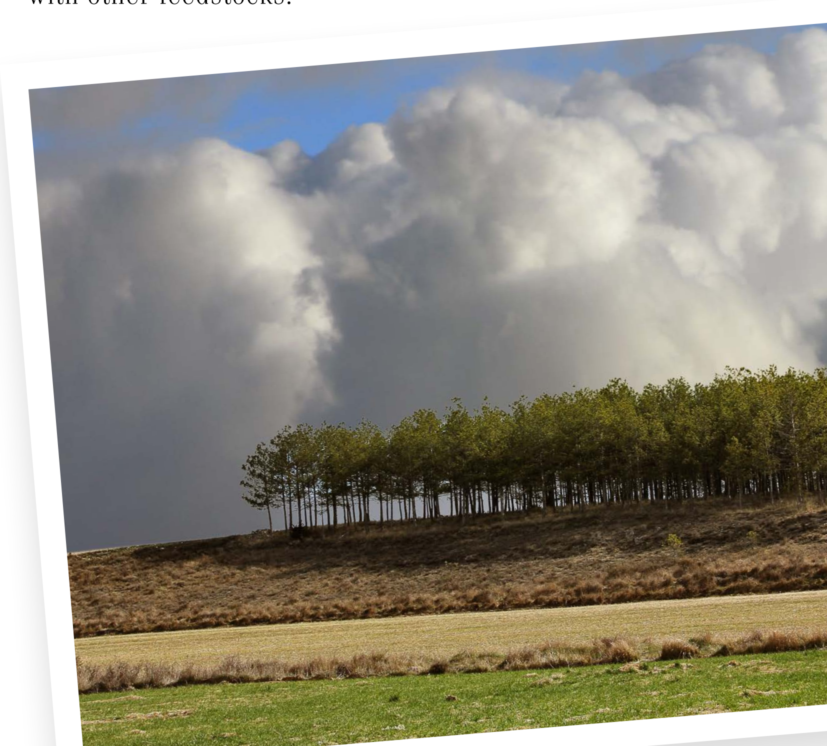
Co-firing wood with coal for electricity production in the North (A) in 2010 and (B) projected for 2030 under greenhouse gas emissions scenario A2-C that assumes high levels of greenhouse gas emission associated with moderate urbanization gains (rapid population growth and moderate income growth) combined with high energy consumption.

Although increases in population and electricity demand in the States farther east would lead to increased probability of co-firing, projected decreases in timber harvesting, and therefore wood mill byproducts, would counteract this effect. Though projected increases in potential of co-firing in the North are relatively low, this could change with the conversion of some power plants to higher efficiency of woody biomass use through co-generation of both heat and electricity.

CONCLUSIONS

The total amount of carbon sequestered in forest biomass and forest soils in the United States is about 27 times the total annual carbon emissions from energy production. However, the carbon sequestered annually by tree growth is only about 13 percent of total annual U.S. carbon emissions (USDA FS 2011, Vose et al. 2012). Thus, the capacity of forests to offset greenhouse gas emission through carbon sequestration, though important, is relatively small compared to the total quantity of emissions. In the Northern States, this shortfall represents an ecological carbon footprint (biomass equivalent of atmospheric carbon) of approximately 24 million acres or 14 percent of existing forest land. For perspective, consider that to sequester enough carbon to offset northern carbon dioxide emissions from fossil fuels, northern forest land would have to increase by 14 percent every year (i.e., double every 7 years). Total fossil fuel emissions will continue to increase with increasing population even though per capita emissions will decrease, both for the United States as a whole and for the Northern States.

In the past, woody biomass has been a relatively small part of the total energy profile for the United States and likely will remain small, but increase proportionally. Nevertheless, as a percentage of current levels of utilization, woody biomass is expected to experience the largest relative increase in use of any power source (350 percent) by 2030 (USDOE EIA 2014). Assuming a future of moderate urbanization (high population growth and moderate income growth) combined with high energy consumption (storyline A2), use of forest-derived roundwood fuelwood as the sole energy source (for heat and power at pulp mills, residences, and other venues) is projected to increase by 230 percent from 2010 to 2060. One form of woody biomass energy that will likely see a dramatic increase is electricity produced in power plants that co-fire coal and wood. This is the result of advances in biomass energy technology as well as a shift from viewing biomass as a localized fuel source (primarily for energy at pulp and paper mills or primary wood processing plants) to a more universally accepted biofuel that can be combined with other feedstocks.



Making biomass utilization feasible for the North would require resolution of barriers associated with infrastructure, economics, and compatibility with other conservation goals. An example is efforts to find markets for small diameter trees that must be removed during savannah and woodland restoration. Residential fuel wood and other biomass energy used by individuals could also have a measurable impact on the future energy profile of the region. Residential heating with wood can be highly efficient, and the potential users (demand) are widely dispersed among the abundant woody biomass resource (Song et al. 2012). Additionally, increased use of urban wood waste can provide an additional source of fuel for bioenergy in the future.

Although the projections used to describe future trends in both carbon and woody biomass for the Northern States are based on intensive study of past trends, the projected energy future of the region is subject to alterations from unpredictable—and unknowable—factors. A recent example is the sharp increase in availability of natural gas that could lead to falling energy prices and thereby reduce economic incentives for biomass use. As assumed in all scenarios that are based on enhanced woody biomass utilization, demand for woody biomass energy feedstocks could increase dramatically if fossil fuels become scarce or cost prohibitive. Implementation of practical cellulosic ethanol technologies would be a game-changer, leading to increased consideration of woody biomass beyond the realm of fuelwood and co-firing and thereby increasing the market base, but perhaps also placing unsustainable demand on the northern woody biomass resource. Carbon emissions regulations will also be influential. Decisions about the carbon or bioenergy future of the North will need to address the woody biomass resource situation within the context of larger energy issues.

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