THE PROMISE OF BIOMASS

Clean Power and Fuel—If Handled Right

CLEAN, RENEWABLE ENERGY RESOURCES for electricity and transportation are an important part of the solution to the climate, economic, environmental, and security challenges posed by our fossil fuel use. Together with energy efficiency and other strategies, bioenergy—including biofuels for transportation and biopower for electric generation—can, if produced from appropriate sources, provide a clean, low-carbon alternative to fossil fuels that allows communities to benefit from locally available resources.

The key to using biomass resources in a beneficial way is to focus on the *right* resources, and use them at an appropriate scale. To help identify sustainable sources and scales, the Union of Concerned Scientists (UCS) has conducted an assessment of bioenergy production that carefully balances the energy and environmental tradeoffs. For example, we found that biomass resources totaling just under 680 million tons could be made available, in a sustainable manner, each year within the United States by 2030. This is enough biomass to produce more than 54 billion gallons of ethanol by 2030 (four times as much corn ethanol as the United States produced in 2010) or 732 billion kilowatt-hours of electricity (19 percent of total U.S. power consumption in 2010).

Bioenergy is one of several elements in a comprehensive climate strategy that could cut projected oil use in half by 2030 and phase out the use of coal in the electricity sector. It has the potential for rapid growth, and the fact that it can be produced from a variety of resources distributed around the country represents a significant opportunity for local and regional economies (Figure 1). Developing the technologies, practices, and policies needed to use these resources responsibly, while avoiding the pitfalls associated with unsustainable development, will ensure that communities across America benefit both financially and environmentally.

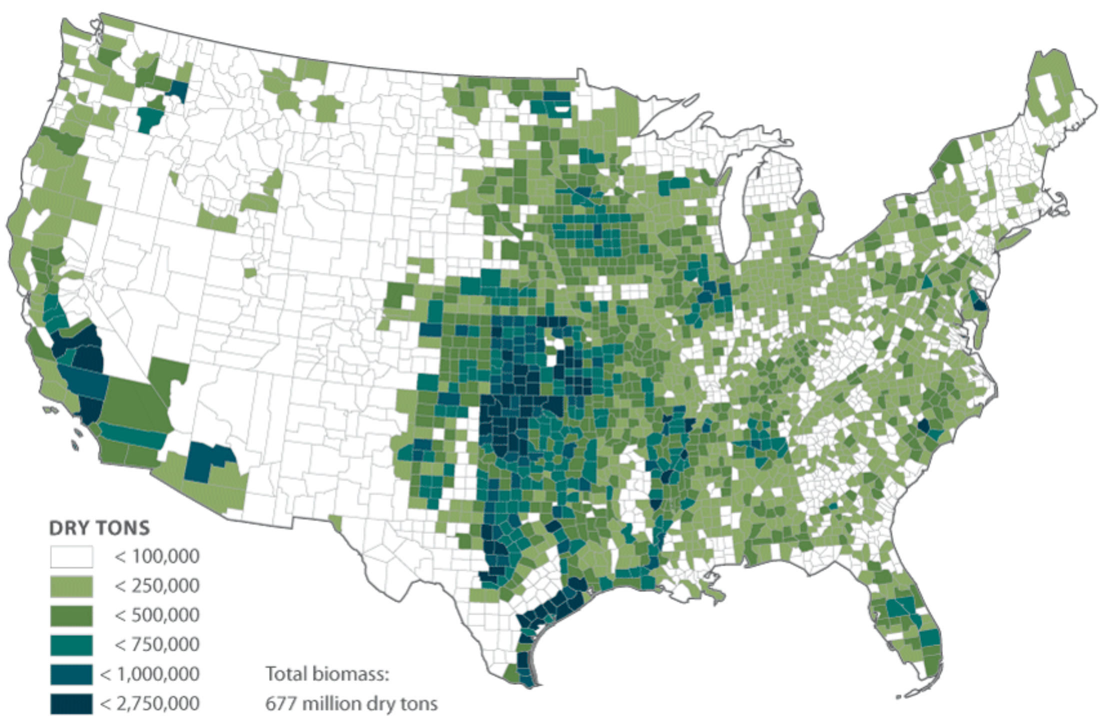

FIGURE 1 Biomass Availability across the Continental United States

Though biomass production is generally widespread, it is most concentrated in the Southern Plains, California, the Corn Belt, and along the Mississippi River. Counties that are not shaded may have biomass available, but in comparatively small amounts.

What Is Bioenergy?

Biofuels

Biofuels are transportation fuels made from biological materials, including **ethanol** made from corn or sugar and **biodiesel** made from vegetable oil or waste fats. To date, food crops—corn, sugar, and vegetable oil—have been the primary source of biofuels, but increased use of these fuels has created more problems than solutions: rising food prices and food price volatility, and accelerated expansion of agriculture in the tropics. The future of biofuels therefore depends on making a transition to non-food biofuels such as **cellulosic biofuel**, which is made from waste materials and environmentally friendly perennial grasses. The scale of the biomass resources we can make available (as described in this report) shows that biofuel growth need not threaten food production if we shift from food crops to better sources.

Biopower

Biopower is electricity generated from biological materials, such as the burning of biomass to run steam turbines; it is the third-largest source of renewable energy for electricity generation after hydro and wind power, accounting for nearly 11 percent of renewable power in 2011 (EIA 2012). About half of all biopower generation occurs within the forest products industry, where mills use their own nonmarketable waste biomass to provide power and heat for their operations. Landfill gas, anaerobic digesters, and other biological sources of methane account for more than a quarter of biopower; this resource represents a win-win solution because the captured methane—a potent heat-trapping pollutant—would otherwise contribute to global warming.

More controversial is the expanding use of whole trees to generate electricity. The loss of carbon stored in forests and other ecosystem services that trees provide take decades to recover, and for this reason several recent analyses have found that this is not an effective way to provide low-carbon electricity (BERC 2012; Manomet 2010). Moreover, other ample, low-cost resources make harvesting whole trees unnecessary.

The Indian River BioEnergy Center, near Vero Beach, FL, will use waste biomass to produce 8 million gallons of cellulosic biofuel and to generate biopower to run the plant and for export to the local market.

Competition for Finite Resources

The same farms, forests, and fields that could provide bioenergy currently provide other essential goods such as food and wood products, plus “ecosystem services” such as clean air, clean water, carbon sequestration, wildlife habitat, and places for recreation. To protect these essential goods and services we must limit the amount of land devoted to producing biomass. Exceeding the limits of sustainable biomass utilization will trade our current fossil fuel problem for problems in our food system and forests, and will do nothing to reduce heat-trapping emissions. So, while the economic and environmental benefits of bioenergy are often measured in terms of its displacement of fossil fuels, a more realistic assessment must include its impact on our farms, forests, water, wildlife, and soils.

First-generation sources of bioenergy including corn, sugarcane, soybeans and palm oil have accelerated the global expansion and intensification of agriculture—and its adverse environmental impacts (Foley 2011). Beneficial sources of biomass, on the other hand, can complement food production and enhance agriculture. Waste materials, for example (including sustainably harvested agricultural and forest residues, wastes from construction and demolition, unrecyclable garbage, and manure), can supply biomass without expanding the footprint of agriculture (Tillman 2009). And perennial crops including tall grasses and fast-growing trees can provide a large supply of biomass while reducing the environmental impact of intensively managed annual crops like corn (UCS 2011).

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A Billion Tons of Biomass?

For more than a decade, researchers at the U.S. Department of Energy's Oak Ridge National Laboratory (ORNL) have been studying available biomass resources to determine the scale and cost of potential bioenergy sources. Their most recent analysis includes county-by-county assessments of the availability of more than 30 potential sources of biomass ranging from tall prairie grasses to construction and demolition debris. The purpose of their analysis was to determine whether a billion tons of biomass is available to produce bioenergy (ORNL 2011). UCS based its assessment on ORNL's sophisticated modeling efforts, in some cases adopting its results directly, and in others making changes that reflect our best judgment of the appropriate sources and scale of biomass available for energy use.

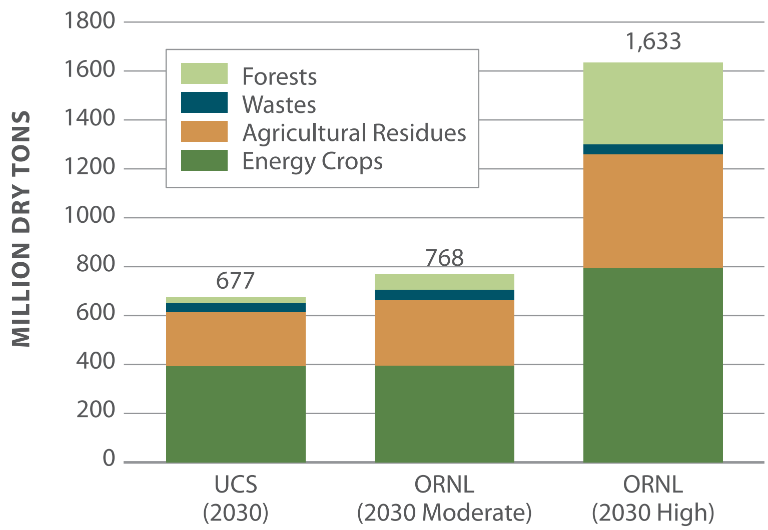

FIGURE 2 Biomass Resource Availability

The ORNL study showed a wide range in biomass resources depending on crop yields and tillage practices. Our results are significantly lower than that study due to stricter sustainability criteria and less optimistic assumptions regarding the adoption of no-till agriculture and increases in crop yields.

After a thorough review of ORNL's assumptions and sustainability thresholds, we concluded that its analysis is too optimistic in some areas, and lacks adequate safeguards to protect the environment. For example, in setting thresholds for the use of agricultural residues, ORNL allowed removal of residues right up to the threshold of causing unacceptable soil erosion or degradation. We opted for a stricter threshold that would protect the fertility of agricultural soils, and also excluded certain categories of biomass, such as whole trees, that are unlikely to result in low-carbon power or fuel production.

Our criteria are designed to establish a level of biomass utilization consistent with protecting land needed to grow food, and supporting healthy farms and forests. The totals shown in the figures and noted in the text below, as well as the underlying data for the maps, reflect total resource availability in 2030, based on our adjustments to ORNL's underlying data set; for more detail on our methodology, see the appendix (page 9). In short, our total is 12 percent lower than ORNL's moderate scenario based on similar assumptions, and almost 60 percent lower than its optimistic scenario (Figure 2).

Energy Crops

The largest long-term opportunity to expand bioenergy production in the United States comes from so-called energy crops including tall grasses like switchgrass and miscanthus, and fast-growing trees like hybrid poplar and willow. As much as 400 million tons of these crops could be produced each year by 2030.

Energy crops are attractive because they produce energy efficiently, requiring only modest amounts of fertilizer and pesticide, and less fertile soil than is needed for other types of agriculture. Most are perennials, which can be harvested for many years after planting, and expanding the role of perennial crops in agriculture can provide important environmental benefits compared with the food crops currently used for biofuels (primarily corn and soybeans).

Energy crops can be integrated into the agricultural system in various ways: as buffer strips or wind breaks, on highly erodible soils or floodplains, or on land being cycled through longer planting rotations. All these techniques can have a positive impact on the sustainability of food and energy production (Schulte 2006).

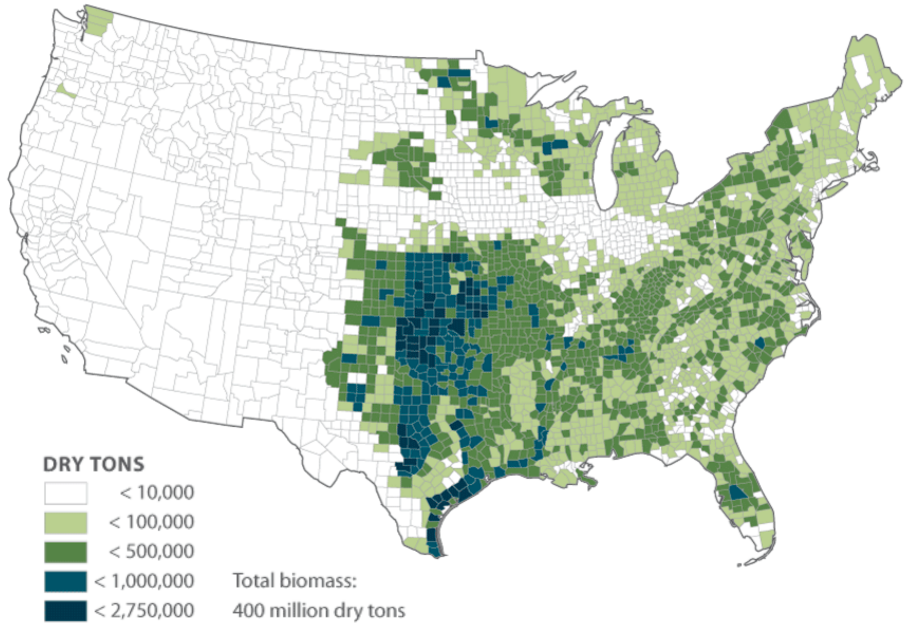

FIGURE 3 Potential Biomass Resources from Energy Crops

Energy crops could be the largest source of biomass, but time and significant changes in agricultural practices will be needed to produce these crops on the scale shown here.

However, energy crops, like all crops, depend on scarce resources including fertile land and water, and as energy crop production expands it will inevitably compete with other land uses such as growing food, producing wood, and protecting natural habitat for recreation and other ecosystem services (see box, "What About Land Use Changes?"). Producing 400 million tons of energy crops would require more than 60 million acres of existing cropland and pastureland. According to ORNL, energy crops are likely to be grown primarily in Kansas, Missouri, Oklahoma, Texas, and to a lesser extent, Arkansas, Kentucky, North Carolina, and Virginia. Approximately two-thirds of the land that would be converted to energy crop production is currently pastureland; the other third is cropland producing wheat, soybeans, and other food or animal feed crops (ORNL 2011).

Production of ethanol from corn and biodiesel from soybeans has already changed agricultural land use: between 2000 and 2010, the share of the U.S. corn crop being used for ethanol grew from 6 percent to 40 percent, leading to expanded corn acreage at the expense of other crops and land uses. In 2010, ethanol's share of corn acreage amounted to 35 million acres versus just 5 million acres a decade before (ERS 2012). The transition to perennial energy crops is likely to be more gradual and less environmentally damaging than the expansion

Researchers at the State University of New York College of Environmental Science and Forestry are developing varieties of willow along with the cultivation and harvesting techniques to make this an economically attractive source of biomass. Willow grows well in the northeastern and upper midwest portions of the United States.

What About Land Use Changes?

Using crops to produce fuel or energy can expand agriculture's already large environmental footprint. This expansion can take the form of obvious changes in land use when, for example, forests are cleared or peat swamps are drained to make way for palm trees (for palm oil production) or soybeans (for biodiesel production) (May-Tobin 2012). But land use changes can also happen indirectly, as when increased use of corn to make ethanol in the United States or rapeseed to make biodiesel in Europe accelerates the expansion of other crops in Brazil or Indonesia to make up for lost food production capacity.

Globally, agriculture is expanding most rapidly in the tropics, where it often occurs at the expense of forests (Gibbs 2010). Clearing forests releases a huge amount of carbon into the atmosphere, and when these emissions resulting from indirect land use changes are included in the environmental footprint of biofuels, the climate benefit of replacing fossil fuels with biofuels is reduced or even eliminated (ERS 2011).

Indirect land use emissions are a significant component of crop-based bioenergy's total life-cycle emissions, but not the only one. The efficiency with which crops are converted to bioenergy is also important, as is the type of crop, where it is grown, and the other environmental impacts associated with its production and use. Nevertheless, energy crops are expected on balance to be a lower-carbon energy source than fossil fuels because they compete for land largely used for pasture rather than corn or soybeans, they require low inputs of fertilizers and pesticides, they increase soil carbon, and they can be converted to fuel or power without additional fossil fuel.

Switchgrass and other perennial grasses can produce high yields with minimal use of fertilizer and pesticide, protect soil from erosion, and reduce water pollution. The image above is from central Pennsylvania, but different varieties are suitable for a wide range of habitats and climates across the central and eastern United States.

The scale of the biomass resources we can make available shows that biofuel growth need not threaten food production if we shift from food crops to better sources.

of food crops to produce first-generation biofuels, because it will occur across a larger area of the country and on less productive land—in other words, outside the Corn Belt that currently supplies the vast majority of the United States' first-generation biofuels.

Large-scale cultivation of energy crops can ease some of the environmental problems associated with our current reliance on a handful of commodity crops including corn and soybeans. More acreage devoted to perennial energy crops would reduce erosion, improve water quality, and enhance soil carbon, benefiting both the climate and crop yields. And these benefits can be more pronounced if perennial crops are grown in areas with highly erodible soil or in watersheds where pollution from corn production is especially intense (Jha 2010). To ensure energy crops complement existing agricultural production, the risk of invasive species must also be taken into consideration (Glaser 2012).

Agricultural Residues

Agricultural residues left behind after harvest—corn stover (i.e., stalks and leaves) and wheat straw—are a potential source of up to 155 million tons of biomass for bioenergy production. Since these residues are a natural by-product of the primary crop, they can be used to generate energy without reducing the availability of food crops or expanding the footprint of agriculture. However, only a portion of the residues can be removed, because some must be left behind to protect the soil from erosion and degradation. Our assessment relies on the same data used by ORNL, but we set a stricter threshold for acceptable erosion and required that residues be removed at a rate that allows soils to maintain their organic matter (also called soil carbon), which is a key contributor to long-term soil productivity.

The extent of acceptable residue removal varies from field to field or even within a field, depending on the soil conditions, climate, slope, and management practices (Muth et al. 2012a). Sustainable use of crop residues at the scale described here will require the adaptation of farm management techniques to minimize potential environmental harm. Cover crops, for example, can expand the amount of residues available for bioenergy beyond what we have described, while reducing erosion and water pollution and enhancing agricultural productivity (Wiggins 2012)

Agricultural residues can supply biomass without expanding the footprint of agriculture.

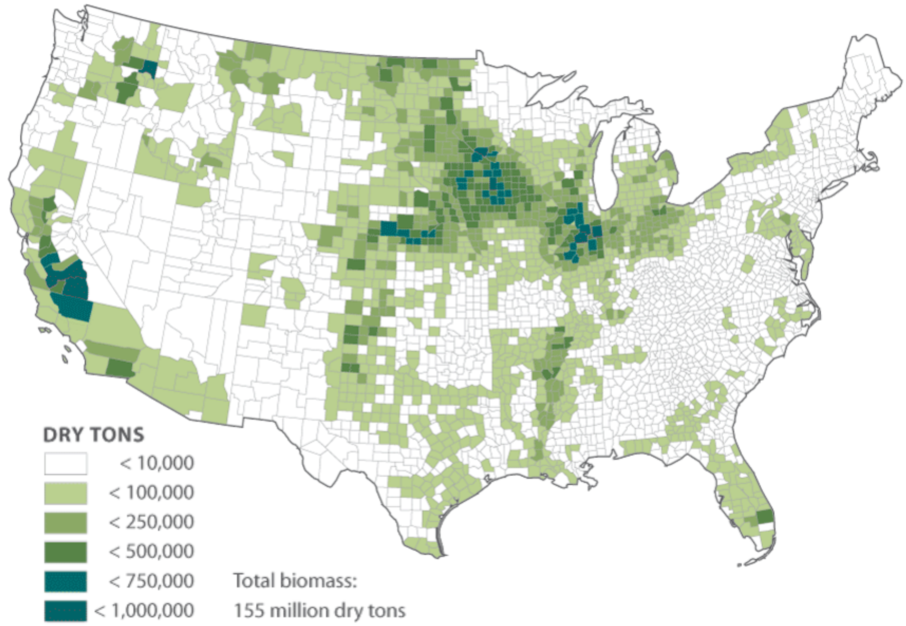

FIGURE 4 **Potential Biomass Resources from Agricultural Residues**

This category is comprised of both primary and secondary residues from corn and small grains, as well as cotton, orchard prunings, and other parts of the plant not needed for food or other uses. Slightly less than 25 percent of our biomass estimate is supplied by agricultural residues.

Waste Materials

Waste resources are smaller in scale compared with agricultural resides and energy crops, but they may be among the first biomass resources to be used for bioenergy production, as in many cases there is already an existing infrastructure to collect them, and they can be made available at a low cost. Each type of available waste material presents its own opportunities and challenges:

Household garbage, vegetative waste (lawn clippings and tree trimmings), and construction and demolition debris. These materials are already collected for disposal and, even after recycling, can provide 35 million tons of biomass close to urban centers where large quantities of fuel are required. Tapping into this waste stream can extend the life of existing landfills, postpone the need to find additional landfill capacity, and reduce waste disposal costs and impacts—but care must be taken when integrating this form of bioenergy with competing uses of waste materials, such as existing recycling and composting systems. Many sources of waste biomass are mixed with recyclable materials and potentially dangerous contaminants, so sorting and pollution control technologies are needed to ensure bioenergy is produced in a safe and environmentally responsible manner.

Manure. Properly managed, manure—almost 60 million tons of which is currently available in the United States—can provide benefits to agriculture because it contains valuable nutrients. Improperly managed, it becomes a significant source of water pollution in many parts of the country. Smart practices such as locating livestock in close proximity to crop production (ideally on an integrated farm with both crop and livestock operations), and using anaerobic digesters that extract bioenergy (in the form of biogas) from manure while minimizing methane emissions, can provide electricity while improving water quality and returning nutrients to the farm.

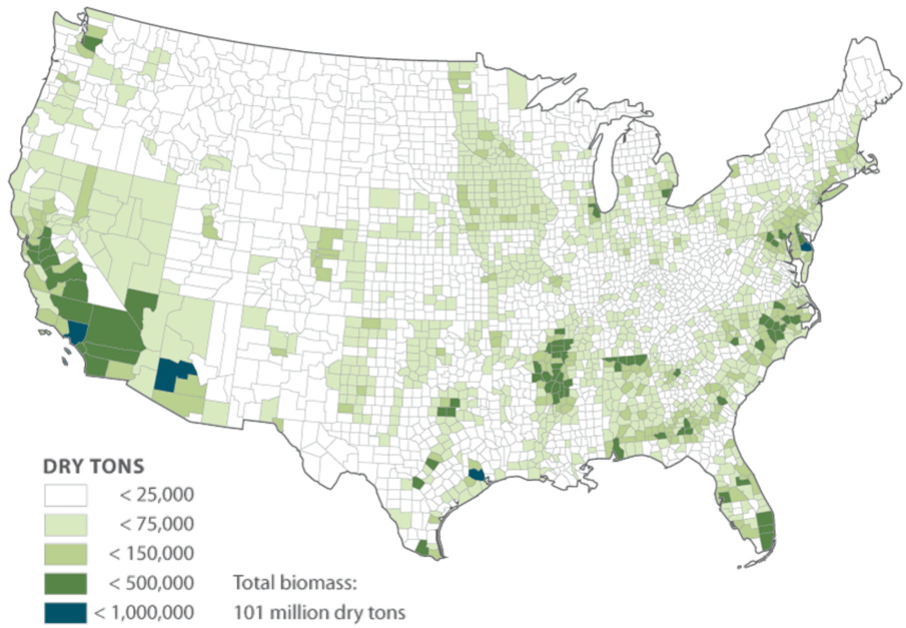

FIGURE 5 Potential Biomass Resources from Waste Materials

Evident from this map is the concentration of resources in urban centers and certain rural areas where animal agriculture is prevalent. About 15 percent of our total biomass estimate is derived from waste streams.

The anaerobic digester component of the waste management system at Pennwood Dairy Farms in Pennsylvania captures biogas for energy production, manages odors, reduces net global warming emissions, and reduces pathogens.

Forest Biomass

This is one of the largest sources of biomass already in use, as lumber mills and paper plants convert the waste from their operations into heat and power. But because these are existing uses of biomass, they were not included in our assessment of new biomass resources. Unused mill residues are included in our assessment of waste materials described above.

Waste wood in the form of sawdust or wood chips is often made into pellets that are then burned to generate electricity. Demand for these pellets has been growing so rapidly, especially in European markets, that it is outstripping the supply of sawdust and other waste wood sources, leading producers to start using whole trees to make pellets (IEA 2011). Though pellets made from waste wood are a low-carbon source of energy, recent science has raised significant doubts as to whether the same can be said for pellets made from whole trees, since increasing the amount of wood harvested from a forest reduces the forest's capacity to store carbon in its trees and soil (Mitchell 2012; Clark 2011; Hudiberg 2011). In the absence of a clear emissions benefit, we have chosen to exclude wood from whole trees, including pulpwood and forest thinnings, from our assessment (recognizing that this oversimplifies matters given the rapidly evolving state of the science and the varying sources of forest biomass and circumstances of their use). We did, however, include tree tops and limbs collected during logging operations.

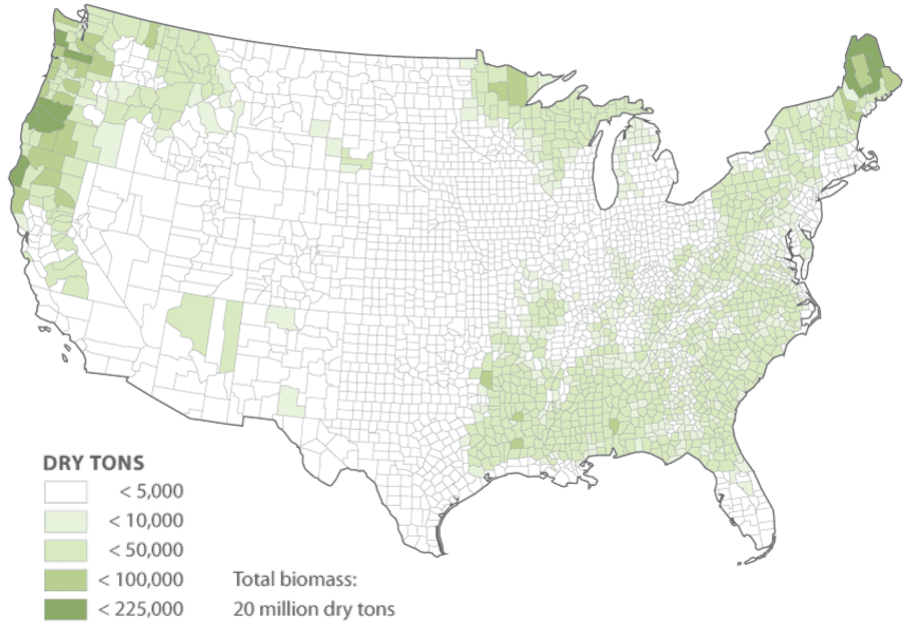

FIGURE 6 **Potential Biomass Resources from Forests**

Tree tops and limbs made up a small but important component of our biomass supply.

Continued on page 12

Because the loss of carbon stored in forests—and other ecosystem services that trees provide—take decades to recover, several recent analyses have found that harvesting whole trees is not an effective way to provide low-carbon electricity.

Technical Assumptions

This report primarily relied on data from ORNL's updated "Billion Ton" study under the baseline yield scenario, which assumed a 1 percent increase in yield for energy crops and baseline tillage practices. This was the most conservative scenario; other scenarios assumed a 4 percent per year increase in energy crops and high corn yields with high no-till agriculture. We chose the baseline scenario and only evaluated those resources for which we could clearly determine there was no current use. The table at right shows the amounts of biomass available based on our assumptions and the ORNL baseline yield scenario.

Feedstock	Available Biomass (million dry tons)	
	UCS Analysis	Updated ORNL Analysis (base case 1% yield increase)
Energy Crops	400	400
Agricultural Residues: Primary	129	180
Agricultural Residues: Secondary	25.5	25.5
Waste Materials: Urban and Mill Wastes	43.4	43.4
Waste Materials: Manure	58.9	58.9
Forest Biomass: Integrated Operations	20.5	40.9
Forest Biomass: Other Removals	0	12.6
Forest Biomass: Pulp	0	3.4
Forest Biomass: Thinnings	0	3.2
Total	**677**	**767**

Detailed assumptions for each biomass category are described below:

Energy crops. This category was a mix of annual crops, perennial grasses, and woody energy crops that would be available for a farm gate price of $60 per dry ton. The data on energy crops are drawn directly from the ORNL study without modification, and reflect the baseline yield scenario including the assumption of a 1 percent per year increase in energy crop yields. Perennial grasses were modeled as a single category, but actual cultivation will include a variety of species. The actual breakdown of species will depend on agronomic and economic factors, and should also include careful consideration of the risk from invasive species (Glaser 2012). In our analysis, perennial-grass energy crops comprised 64 percent of the biomass. Woody energy crops including poplar, willow, pine trees, and eucalyptus comprised 32 percent of the total biomass. These energy crops are also referred to as short-rotation woody energy crops and tend to be harvested every 5 to 10 years. These types of woody biomass were separated from the woody biomass coming from the forest sector, primarily because they are planted on agricultural land rather than harvested from existing forests, so their use does not cause a reduction of stored forest carbon. Annual energy crops such as different varieties of sorghum made up the remaining 4 percent.

Primary agricultural residues. This category included corn stover and the straw or stems left over from harvesting barley, oats, and wheat. Corn stover was by far the largest category of crop residue available for bioenergy. We assumed baseline tillage practices and corn yields. In collaboration with researchers at Idaho National Labs we were able to use the same analysis developed for ORNL, but applied more stringent criteria to limit erosion and soil carbon thresholds, which reduced the amount of crop residues that could be removed. In particular we only included residue removals in circumstances where erosion was predicted to be less than half the maximum amount of soil loss that can be tolerated and still permit a high level of crop productivity to be sustained economically and indefinitely (referred to as T), and adopted a more stringent threshold for soil carbon accumulation, requiring soil organic matter to remain constant rather than the overall soil conditioning index. For details of the methodology see Muth et al. 2012b. This approach provided an enhanced safety margin to ensure residue removals did not interfere with the long-term productivity of the soil, but did reduce potential biomass from the ORNL study by more than 50 million dry tons.

Secondary agricultural residues. Comprised of cotton gin trash and residues (33 percent), orchard and vineyard prunings (22 percent), rice straw and hulls (38 percent), sugarcane trash (4 percent), and wheat dust (2 percent), and given at the state level. To develop the county-level maps we disaggregated the state totals based on the amount of farm acreage in a given county relative to the total state farm acreage. The total biomass remained unchanged. Each type of residue's share of the total for this category is given in parentheses.

Waste materials (urban and mill wastes). We only considered the unused portion of mill residues, which comprised 17 percent of this category. Urban wood waste, including construction and demolition materials, made up 57 percent of this category. Some sources of wood waste are contaminated with pollutants that make them unsuitable for direct combustion to generate electricity. However, we have included these sources because there are conversion technologies that can utilize these materials for bioenergy purposes without pollution problems (for example, gasification and conversion to liquid fuel).

Waste materials (manure). Manure estimates in our summary are based on ORNL's baseline estimate for 2030 at a price of $60 per ton.

Forest biomass. As a general rule we have attempted to exclude whole trees from our assessment because of a concern that the associated loss of carbon stored in forests will offset beneficial emissions reductions associated with substituting bioenergy for fossil fuels. We recognize that the science in this area is rapidly developing, and that the details of different forest types, management practices, harvest regimes, and carbon accounting methodologies will affect this result. Our decision to exclude these resources from our assessment does not represent a definitive conclusion, but a lack of confidence in the available data on the quantity of forest biomass that would reliably provide a low-carbon source of biomass.

Forest (integrated operations). Integrated operations is a category that is a 50/50 split between tree tops or limbs and thinnings. We have excluded the thinnings from our resource assessment, consistent with our efforts to exclude whole trees. There are likely circumstances under which thinnings could be an environmentally responsible and low-carbon source of biomass, but we were unable to distinguish these cases from others in which the thinnings would not be low-carbon, so we have excluded them. After removing thinnings, this category comprised just under 20 million dry tons.

Forest (other residue removals). This category was defined in the ORNL study as "Unutilized wood volume from cut or otherwise killed growing stock from cultural operations, such as precommercial thinnings or timberland clearing" (ORNL 2011). We excluded this category because it was not possible to distinguish between biomass from land clearing and thinning operations, and as in the integrated operations category, the carbon benefits are unclear. Although not included in our results, this category comprised about 12.6 million dry tons, or just under 2 percent of the biomass identified by ORNL.

Forest (pulp). This category represents conventional pulp-sized wood harvested purely for bioenergy, and was not included in the original ORNL study. We excluded this category because the carbon benefits are unclear and would likely take decades to begin to occur. At a price of $60 per dry ton, less than 1 percent of the total biomass identified by ORNL would be available from this category.

Forest (thinnings). We excluded this category from our assessment following our decision to exclude the use of whole trees. There are circumstances in which the use of certain forest thinnings can produce a low-carbon source of energy, as when the rate of forest carbon accumulation drops because of insect infestation or increased fire emissions (Hudiberg 2011), but because we were unable to segregate thinnings that meet this condition from others that do not, we excluded the whole category.

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Sound Policies for Expanding Biomass

> ***The key to using biomass resources in a beneficial way is to focus on the right resources, and use them at an appropriate scale.***

Sustainable biomass resources provide a valuable opportunity for all regions of the country to move from polluting fossil fuels to cleaner, renewable sources of power and fuel. Though the scale of these biomass resources is large, it is finite, so their development must be balanced with the necessity of preserving land for food production and ecosystem services. Smart policies are therefore required to accelerate bioenergy production while protecting our food system, water quality, climate, and land.

In the transportation sector, for example, the federal Renewable Fuel Standard (RFS) created in 2007 encourages greater biofuels use, supports a shift away from food-based biofuels toward cellulosic biofuels, prohibits biomass from being produced in sensitive areas, and requires life-cycle accounting (including indirect land use changes) to ensure that eligible biofuels actually reduce carbon emissions. While these are noble goals, and the RFS *has* expanded biofuels use, it has not yet succeeded in creating a commercial-scale cellulosic biofuels industry. More time and additional policy support (e.g., research support and incentives for investment) are needed to fully realize its ambitions (Martin 2010). Another policy approach, the California Low Carbon Fuel Standard, casts a broader net, supporting low-carbon biofuels, electricity, and other fuels, and reserves its largest incentives for those fuels with the lowest life-cycle carbon emissions.

In the electricity sector, state and federal renewable energy policies have supported the expanded use of biomass to generate electricity, along with wind, solar, and other renewable resources. For example, 29 states and the District of Columbia have adopted renewable electricity standards (RES), which require utilities to increase their use of renewable energy to a certain percentage of their total power supply over time. Federal production tax credits have also been a key driver for developing renewable energy. State RESs should be expanded and a strong federal standard should be adopted, but it is important that these policies include sustainability standards to ensure they support only beneficial sources of biomass (UCS 2009). Life-cycle analysis has not been required by renewable energy policies to date, but the Environmental Protection Agency and a panel of scientific experts are working together on an approach that will account for all CO_2 emissions from biomass (SAB 2011).

As biomass production grows, the U.S. Department of Agriculture will need to support farmers and protect ecosystem services by developing best practices for biomass cultivation and harvesting. Policies like the Biomass Crop Assistance Program can help, but other agricultural policies (such as conservation policies) and economic supports (such as crop insurance) should be adapted in ways that take advantage of the market opportunities without harming our food system or environment.

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