Appendix G. Biomass Energy Supply and Land-Use Assumptions

This appendix describes the cellulosic biomass energy supply curves for the United States that we used in our Reference and Blueprint cases. It also describes our assumptions for estimating the land-use impacts of using biomass to produce electricity and biofuels, other renewable energy technologies to produce electricity, and from avoided surface and mountaintop removal coal mining under the Blueprint.

G.1. Biomass Energy Supply Assumptions

The supply curves include the amount of biomass that is potentially available for energy use in the United States at different prices. We developed separate supply curves for each of the main biomass feedstocks in the model—energy crops (switchgrass), agricultural residues (corn stover and wheat straw), forestry residues, and urban wood waste and mill residues—and then added the data from those curves together to get a total biomass supply curve.[1] The National Energy Modeling System (NEMS) includes a supply curve for each biomass feedstock for every year through 2030 and for 13 different regions of the United States.

In developing our supply curves we worked extensively with Marie Walsh, an agricultural economist with the University of Tennessee and formerly with the Oak Ridge National Laboratory (ORNL). Walsh and her colleagues at ORNL developed most of the original biomass supply curves used in NEMS.

G.1.1. Energy Crops

Walsh and her colleagues at the University of Tennessee recently updated the energy crop supply curves for Energy Information Administration's (EIA's) 2007 analysis of producing 25 percent of U.S. electricity and transportation fuel with renewable energy by 2025 (EIA 2007). These estimates were based on new runs conducted in an economic forecasting model for agriculture called POLYSYS. Starting with the U.S. Department of Agriculture (USDA) 2006 baseline forecast, the model projects all the major crops and calculates changes in land use based on the price of biomass and corn in each of 305 agricultural statistical districts in the United States.

This updated supply curve developed for the EIA includes about 67 percent more biomass from energy crops than the previous estimate used by the EIA. Most of the increase is due to assumed increases in energy crop yields over time and increases in the amount of land (mostly pasture lands) available for energy crop development. Switchgrass yields were updated to better reflect more recent data compiled from summary reports by switchgrass researchers and some machinery limitations not included in the original analysis (McLaughlin and Kszos 2005; Ocumpaugh et al. 2003; Parrish et al. 2003; Taliaferro 2002; Taliaferro, Vogel, and Bouton 2002; Vogel and Jung 2000). The resulting increases in switchgrass yield for different parts of the country are shown in

[1] Note that the supply curve for corn is separate from the cellulosic biomass supply curve, but these resources compete with each other for producing biofuels in the transportation sector.

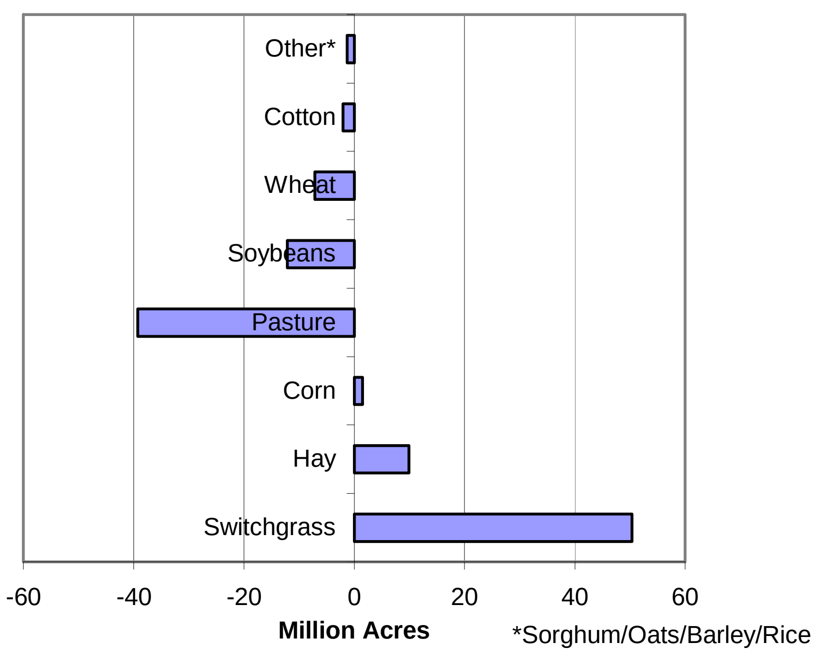
Table G.1. We used similar assumptions for yield increases in the 2007 UCS study, *Cashing In on Clean Energy* (UCS 2007).

The POLYSYS model also accounts for the direct land-use changes in the United States when a value is assumed for using switchgrass. As shown in Figure G.1, most of the switchgrass will likely be grown on converted pastures, not croplands. At $50 per dry ton, the model estimates that it would be economically viable to plant more than 50 million acres of switchgrass in the United States by 2025, with 39 million acres (78 percent of the switchgrass acres or 64 percent of the total acres displaced) converted from pastures and the remainder coming mainly from displacing soybeans and wheat acres. The acreage assumed to be planted in switchgrass represents just over 5 percent of total agricultural land in the United States; however, as described below, we are only including half of this amount in the analysis.

Table G.1. Changes in Switchgrass Yield through 2025

REGION	Base Yield	Annual Breeding Gains	Projected Yields 10 Years	Projected Yields 20 Years
		Tons/Acre		
North East	4.87	1.5%	5.6	6.3
Appalachia	5.84	5.0%	8.8	11.7
Corn Belt	5.98	3.0%	7.8	9.6
Lakes States	4.8	1.5%	5.5	6.2
Southeast	5.49	5.0%	8.2	11.0
Southern Plains	4.3	5.0%	6.5	8.6
North Plains	3.47	1.5%	4.0	4.5

Figure G.1. Change in Harvested Acres from Growing Switchgrass in the United States in 2025 (at $50/dry ton)



The analysis also projects acreage for hay production increasing by almost 10 million acres in 2025. The POLYSYS model assumes that any loss in regional forage production on pasture acres must be replaced by new regional hay production. The additional acreage planted in hay is less than the displaced pasture acres because the hay acres are more intensively managed. The analysis also shows a slight increase in corn acreage as growing markets for cellulosic biomass will also increase the value of corn stover.

Recent indirect land-use impact analysis has cast doubt on the purported benefits of growing biomass energy crops on croplands. Searchinger and Fargione have shown that diverting croplands to grow corn and other energy crops, such as switchgrass, can result in significant indirect land-use impacts and increases in global warming emissions (Searchinger et al. 2008; Fargione et al. 2008).

However, Fargione finds that growing switchgrass on abandoned or marginal agricultural land, where it does not displace crops, has little or no indirect land-use impacts and has immediate benefits in reducing global warming emissions. Searchinger claims little is known about where switchgrass will be grown. For the purposes of his analysis, he assumes that it will be grown entirely on croplands, resulting in significant indirect land-use impacts.[2]

To minimize the potential indirect land-use effects that could occur from growing switchgrass on cropland, our Climate 2030 Blueprint analysis applied a fairly rough and conservative exclusion of 50 percent to the energy crop (switchgrass) supply used in the EIA 25x25 analysis. It will also allow for most switchgrass production to occur on pasture land and marginal agricultural lands, providing much greater life cycle carbon dioxide reductions. Based on this exclusion, we assume that 121 million dry tons of switchgrass is available for energy production (see Figure G.2).

Searchinger and Fargione considered switchgrass only as a feedstock for ethanol. In NEMS, switchgrass and other cellulosic biomass are also available to produce electricity in either dedicated power plants or by co-firing it in existing coal plants, thereby displacing coal and potentially some natural gas. Because coal has approximately 34 percent higher carbon emissions than gasoline on a per unit of energy basis, using switchgrass to displace coal-fired electricity will have greater heat-trapping emissions reduction benefits than using it to displace gasoline. Coal mining also has greater land-use impacts than oil drilling.

G.1.2. Agricultural Residues

We assume 158 million dry tons of corn stover and wheat straw are potentially available for energy production based on the estimate developed by Walsh's colleagues at the University of Tennessee for the EIA's 25x25 study using the POLYSYS model. This new estimate is a significant improvement over the earlier analysis because it uses a much

---

[2] Searchinger also assumes that growing switchgrass on cropland will result in greater indirect land-use impacts than corn because he assumes switchgrass ethanol will not have an animal feed by-product. He assumes dried distillers grains from corn ethanol will reduce diverted land by one-third, whereas each acre of switchgrass is assumed to displace an acre of cropland.

more rigorous approach to estimate the residues that must remain on the field to prevent erosion and maintain soil quality based on the research by Nelson (Nelson 2002; Nelson et al. 2003). This research considers a number of environmental and best-management practices (e.g., transition to reduced tillage, no tillage practices over time) by soil type, soil topography, and geographic location (Nelson 2002).

G.1.3. Forestry Residues

Walsh estimates that 63 million dry tons of logging residues and nearly 25 million dry tons of other removals are potentially available for energy production in 2007, based primarily on data from the USDA Forest Service.[3] Future year logging residue quantities are estimated using a multiplier based on the projected timber harvests contained in the base case analysis of the most recent Resource Policy Act (RPA) Update by the Forest Service (Haynes et al. 2007). The estimation of future year quantities of other removals uses a different approach than is used for logging residues. Specifically, since a substantial portion of other removals is a result of land clearing for urban development (mainly housing), a multi-step approach is used based on estimated increases in housing units.

This overall estimate for forestry residues is lower than what we used in our 2001 *Clean Energy Blueprint* (Clemmer et al. 2001) and our 2007 *Cashing In on Clean Energy* study (UCS 2007). In these two studies, we applied a 50 percent exclusion to the forest residue supply the EIA was using in NEMS to account for additional sustainability criteria. Walsh's estimates are conservative in that they do not include other potential sources of forest materials such as fuel wood, fuel treatment removals to limit catastrophic fires and improve productivity, and changes in the management of pine plantations.

Like agricultural residues, forest residues have ecological value for soil quality and habitat. While the Walsh analysis does not explicitly include any sustainability criteria, it does apply some constraints on the removal of forestry residues such as excluding old-growth forests, roadless areas, and steep slopes; equipment limitations for gathering small pieces of wood (approximately 65 percent of material is assumed to be retrieved); and limiting the quantities of other removals to 50 percent of the total generated to account for harvest limitations and alternative uses.

G.1.4. Urban and Mill Residues

We assume 27 million dry tons of urban and mill residues are available for energy production. This is based on Walsh's estimate of urban residues, which exclude contaminated materials and are based on a more rigorous analysis than the data the EIA is using.

---

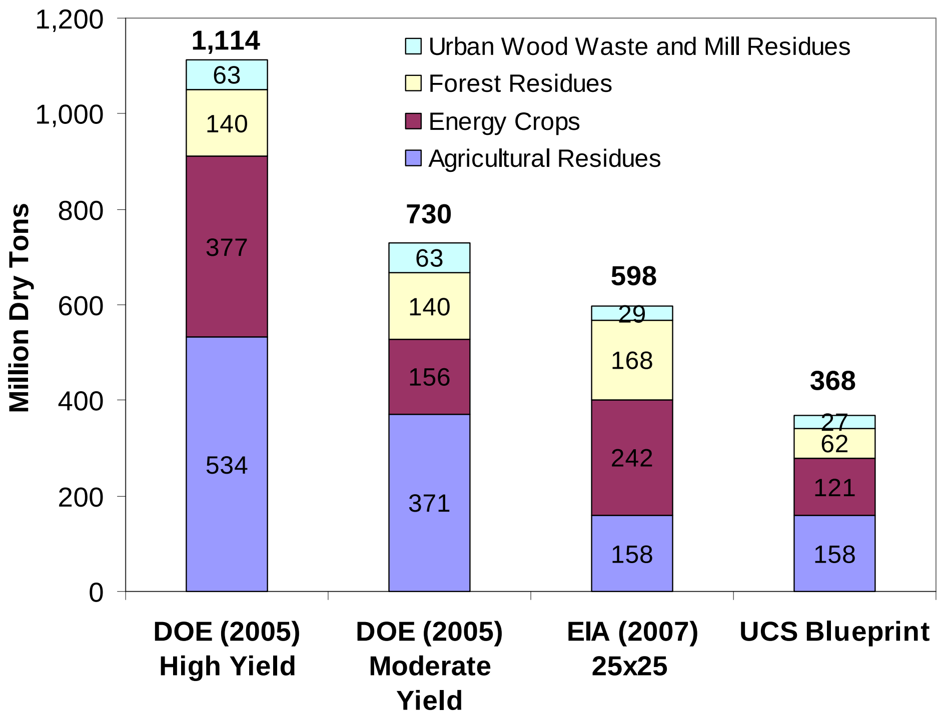
[3] Walsh defines logging residues as the unused portion of growing stock trees (commercial species with a diameter breast height of at least five inches, excluding cull trees) cut or killed by logging and left behind. She defines other removals as unutilized wood volume from cut or otherwise killed growing stock, from cultural operations such as pre-commercial thinning, or from timberland diversion to other uses such as crop land, roads, urban development, parks, etc.

Walsh's mill residue estimates are based on 2007 data from the USDA Forest Service's Forest Inventory Analysis Timber Product Output database. According to the database, 88.7 million dry tons of primary mill residues were produced in the 2007 survey year, but only 1.3 million tons were not used. Her original estimates included both used and unused residues, assuming that the residues currently being used could potentially become available with higher demand and higher prices for biomass. While this is a reasonable assumption, we decided to take a conservative approach and not include the residues currently being used because they would need to be replaced either with additional biomass removals or with fossil fuels. This could increase emissions and potentially have negative impacts on forest health and there is no easy way to account for these impacts in NEMS.

G.1.5. Total Biomass Supply

Across the board our decisions in creating the supply curves for cellulosic biomass have been conservative, especially when compared with recent Department of Energy and EIA analyses. Overall, our analysis includes only one-third of the available supply cited in the high-yield scenario of the Department of Energy's Billion Ton study (DOE and USDA 2005), half of the supply included in the study's moderate-yield scenario, and about 60 percent of the available supply included in the EIA's 25x25 analysis (EIA 2007).

Figure G.2. Comparison of Bioenergy Potential Used in Various Studies



Sources: DOE and USDA 2005, and EIA 2007.
Note: EIA 25x25 and our Climate 2030 Blueprint numbers reflect supplies from the year 2030 at $5.25 (2005$)/MMBtu.

G.2. Land-Use Assumptions

This section describes the assumptions we used in box 7.3 and section 7.7 of the report to estimate the land-use impacts from renewable electricity, biofuels, and avoided coal mining under the Climate 2030 Blueprint.

Estimates of the number of acres of biomass required to achieve Blueprint projections are from Oak Ridge National Laboratory (ORNL 2009). The number of biomass acres needed was calculated by applying a crop yield to energy content ratio (energy per pound divided by pounds per acre) to the projected increase of biomass generation under the Blueprint.

Assumptions for the land area used by solar photovoltaics (PV) are based on National Renewable Energy Laboratory data (NREL 2004). The estimated acreage used by PV in the Blueprint is calculated by applying a land area to power ratio to the projected increase of PV generation under the Blueprint.

Wind turbine land use data are based on data from the Department of Energy's report on generating 20 percent of U.S. electricity from wind (EERE 2008). The estimated total land area needed for wind generation was calculated by applying an area to power ratio to the projected wind capacity under the Blueprint. The footprint land area was estimated as 2 to 5 percent of total land area based on capacity, also based on data from EERE 2008.

Estimates of the number of acres needed for concentrating solar power (CSP) are also based on data from NREL 2004. The estimated acreage used by CSP in the Blueprint is calculated by applying a land area to power ratio to the projected increase of CSP generation under the Blueprint.

Miles of Appalachian ridgeline saved from mountaintop removal mining under Blueprint policies are based on data from the Environmental Protection Agency (DOI 2005). The estimated number of miles of mountaintop saved was calculated by applying a ratio of miles of mountaintop removed to coal produced (miles per short ton) to the projected coal production savings in Appalachia under the Blueprint.

Assumptions for mining acreage savings are based on data from the Office of Surface Mining's annual report (OSM 2006). The acres saved from surface mining was calculated from the ratio of number of new acreage permitted each year for surface mining (OSM 2006) to the amount of coal produced from surface mines yearly (EIA 2007).

References

Clemmer S., D. Donovan, A. Nogee, and J. Deyette. 2001. *Clean energy blueprint: A smarter national energy policy for today and the future*. Cambridge, MA: Union of Concerned Scientists with American Council for an Energy Efficient Economy and

Tellus Institute. October. Online at *http://www.ucsusa.org/clean_energy/solutions/big_picture_solutions/clean-energy-blueprint-a.html*

Department of Energy (DOE) and Department of Agriculture (USDA). 2005. *Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply*. Oak Ridge, TN: Oak Ridge National Laboratory. Online at *http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf.*

Department of the Interior (DOI). 2005. *Mountaintop mining/valley fills in Appalachia: Final programmatic environmental impact statement*, EPA 9-03-R-05002. Washington, DC: U.S. Environmental Protection Agency.

Energy Information Administration (EIA) 2008. *Coal production 1949–2007*. Online at *http://www.eia.doe.gov/emeu/aer/txt/ptb0702.html.*

Energy Information Administration (EIA). 2007. *Energy and economic impacts of implementing both a 25-percent renewable portfolio standard and a 25-percent renewable fuel standard by 2025.* Washington, DC: U.S. Department of Energy. Online at *http://www.eia.doe.gov/oiaf/servicerpt/eeim/pdf/sroiaf(2007)05.pdf*

Fargione, J., J. Hill, D. Tillman, S. Polasky, and P. Hawthorne. 2008. Land clearing and the biofuel carbon debt. *Science* 319(5867). Online at *http://www.sciencemag.org/cgi/content/abstract/319/5867/1235*.

Haynes, R.W., D.M. Adams, R.J. Alig, P.J. Ince, J.R. Mills, and X. Zhou. 2007. *The 2005 RPA timber assessment update.* General technical report PNW-GTR-699. Portland, OR: U.S. Forest Service, Pacific Northwest Research Station.

McLaughlin, S.B., and L.A. Kszos. 2005. Development of switchgrass (*Panicum virgatum*) as a bioenergy feedstock in the United States. *Biomass and Bioenergy* 28:515–535.

National Renewable Energy Laboratory (NREL). 2004. *PV FAQs*. Washington, DC: U.S. Department of Energy. Online at *http://www.nrel.gov/docs/fy04osti/35097.pdf*.

Nelson, R.G., M.E. Walsh, J.J. Sheehan, and R. Graham. 2003. Methodology to estimate removable quantities of agricultural residues for bioenergy and bioproduct use. *Applied Biochemistry and Biotechnology* 113(1–3):0013-0026.

Nelson, R.G. 2002. Resource assessment and removal analysis for corn stover and wheat straw in the Eastern and Midwestern United States—rainfall and wind-induced erosion methodology. *Biomass and Bioenergy* 22:349–363.

Oak Ridge National Laboratory (ORNL). 2009. *Bioenergy feedstock conversion factors*. Online at
http://bioenergy.ornl.gov/papers/misc/energy_conv.html.

Ocumpaugh, W., M. Hussey, J. Read, J. Muir, F. Hons, G. Evers, K. Cassida, B. Venuto, J. Grichar, and C. Tischler. 2003. *Evaluation of switchgrass cultivars and cultural methods for biomass production in the South Central U.S.* Consolidated report 2002. ORNL/SUB-03-19XSY091C/01. Oak Ridge, TN: Oak Ridge National Laboratory.

Office of Energy Efficiency and Renewable Energy (EERE). 2008. *20% wind energy by 2030: Increasing wind energy's contribution to U.S. electricity supply*. DOE/GO-102008-2578. Washington, DC: U.S. Department of Energy.

The Office of Surface Mining (OSM). 2006. *2006 annual report.* Washington, DC: U.S. Department of the Interior.

Parrish, D.J., D.D. Wolf, J.H. Fike, and W.L. Daniels. 2003. *Switchgrass as a biofuels crop for the Upper Southeast: Variety trials and cultural improvements*. Final report for 1997 to 2001. ORNL/SUB-03-19XSY163/01. Oak Ridge, TN: Oak Ridge National Laboratory.

Searchinger, T., R. Heimlich, R.R. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, and T. Yu. 2008. Use of U.S. croplands for biofuels increases global warming pollution from land-use change. *Science* 319(5867):1238–1240.

Taliaferro, C.M. 2002. *Breeding and selection of new switchgrass varieties for increased biomass production*. ORNL/SUB-02-19XSY162C/01. Oak Ridge, TN: Oak Ridge National Laboratory. Online at
http://www.ornl.gov/info/reports/2002/3445605360105.pdf.

Taliaferro, C.M, K.P. Vogel, and J.H. Bouton. 2002. *Scale-up and commercialization of new switchgrass cultivars*. Unpublished manuscript. Oak Ridge, TN: Oak Ridge National Laboratory.

Union of Concerned Scientists (UCS). 2007. Cashing In on Clean Energy (updated October 2007). Online at
http://www.ucsusa.org/clean_energy/solutions/renewable_energy_solutions/cashing-in-on-clean-energy-a.html.

U.S. Department of Energy (DOE). 2005. *Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply.* April. Online at *http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf*.

Vogel, K.P., and H.G. Jung. 2000. *Genetic improvement of switchgrass and other herbaceous plants for use as a biomass fuel feedstock*. Final report. ORNL/SUB/90-90OR21954/1. Oak Ridge, TN: Oak Ridge National Laboratory.