Potential of using forest residue to offset coal use in co-fired coal power plants in the eastern United States

Jason Parent[1], Marcello Graziano[2], Xiusheng Yang[1*]

(1. *Department of Natural Resources and the Environment, University of Connecticut, Storrs, CT 06269-4087, USA*;
2. *Department of Geography, University of Connecticut, Storrs, CT 06269-1063, USA*)

Abstract: The global transition from fossil fuel-based energy sources to renewable energy sources will be most effective, for at least the near future, by utilizing local resources and existing infrastructure. In many areas of the eastern United States, forest residue is abundant and can be used in existing facilities to supplement coal in coal-fired power plants. Thus forest residue has potential as a renewable energy source that could be effectively utilized in the near future. This study uses GIS to estimate the potential quantity of forest residue available for use in coal-fired power plants in the eastern United States. Transportation costs limit the distance over which it is feasible to transport forest residue to the power plants and these costs may fluctuate depending on economic conditions. Thus, we consider three scenarios in our analysis assuming the maximum feasible transport distances to be 60, 80, and 100 km. In the eastern U.S., the total annual forest residue available to coal plants is approximately 29.4, 40.2, and 48.2 million dry tons, respectively, for maximum transport distances of 60, 80, and 100 km. Assuming an 80 km transport distance, forest residue has the potential to reduce coal consumption by 22.3 million tons per year. Under this scenario, greenhouse gas emissions would be reduced by almost 58.1 million tons per year, and NO_x and SO_x emissions would be reduced by 69.3 and 122.6 thousand tons respectively. This analysis suggests that by offsetting coal use, forest residue has the potential to substantially reduce power plant emissions.

Keywords: forest residue, coal, biofuel, co-firing, GIS, alternative energy
DOI: 10.3965/j.ijabe.20140704.011

Citation: Parent J, Graziano M, Yang X S. Potential of using forest residue to offset coal use in co-fired coal power plants in the eastern United States. Int J Agric & Biol Eng, 2014; 7(4): 99－105.

1 Introduction

The use of fossil fuels has been linked to many issues including global climate change, air and water pollution, environmental degradation from resource extraction, and national security. As energy demands increase, these problems will become further exacerbated unless alternative energy sources can be found and exploited. Although numerous renewable energy sources have been identified, no single source is likely to be sufficient to replace fossil fuels and energy sources will likely need to be varied to make efficient use of the resources of a given region. Exploiting new sustainable energy sources that can utilize existing infrastructure, with minimal additional investment, may be the most cost-effective strategy of significantly reducing fossil fuel use in the near future. This study investigated and quantified the potential of using forest residue in the eastern United States as a renewable energy source that could result in substantial reductions in fossil fuel use with only modest investments in currently available technology.

Forest residue, consisting of tree tops, branches, and culled or damaged trees, has potential as a sustainable energy source in forested regions. Forestry operations generate large amounts of woody biomass that are of not

Received date: 2014-05-23 **Accepted date:** 2014-08-10
Biographies: Jason Parent, PhD candidate, Graduate Research Associate, research interests: natural resources and the environment. Email: jason.parent@uconn.edu. **Marcello Graziano,** PhD candidate, Graduate Research Associate, research interests: geography. Email: marcello.graziano @uconn.edu.
***Corresponding author: Xiusheng (Harrison) Yang,** PhD, Professor, research interests: natural resources and the environment. Mailing Address: Department of Natural Resources and the Environment, University of Connecticut, 1376 Storrs Road, Storrs, CT 06269-4087, USA. Tel: +1-860-486-0135; Fax: +1-860-486-5408; Email: Xiusheng.Yang@uconn.edu.

of sufficient quality to use as lumber or paper. Forest residue, or logging slash, accounts for 20%-30% of the biomass cut in forestry operations[1]. In the northeastern and southeastern regions of the United States, the forest industry generates an estimated 710 000 and 520 000 cubic feet of forest residue, respectively, each year[2]. This forest residue is typically left in the forest or removed by burning[3] as a result of the undeveloped market for this resource. The recent push for renewable energy has motivated efforts to overcome the economic obstacles associated with collecting forest residue and find ways to make it a viable energy source at a commercial scale[4-7].

Fuels derived from woody biomass can take either liquid or solid form. Conversion of forest residue to liquid biofuel typically involves acid pretreatments and fermentation as well as heating the material to temperatures as high as 600 degrees Celsius[8]. This process generates liquid fuel, which can be used to power transportation fleets, and a charcoal solid waste that can itself serve as a fuel. However, the technologies required to derive liquid fuel from woody biomass have yet to be fully scaled up for commercial use. In addition, the process requires specialized facilities and substantial energy inputs making it unlikely to see large scale commercial use in the near future. Solid woody fuels (i.e. wood chips) on the other hand require no additional inputs of energy, beyond the harvest and transport, and do not require specialized infrastructure for large scale use. Conventional coal power plants are capable of using woody biomass for power generation with only modest costs for the upgrade[6]. The technology required to co-fire coal and biomass has been proven in some 150 power plants in Europe, the United States, and Australia with investment costs recovered in as little as two years [6]. Although dedicated biomass power plants are limited in size by the availability of feedstock, co-fired power plants have no such limitations and can have power outputs 10 times that of a biomass power plant[6].

Coarse woody debris has an important ecological function in natural ecosystems providing substrate, shelter, and habitat for many forest species; retaining organic matter and nutrients in the soil; and reducing soil erosion[9]. Large-scale removal of forest residue therefore could have adverse effects on certain species and on nutrient cycling within the forests. However, the literature suggests that if proper harvesting practices are followed, then the removal of forest residue can have neutral or even positive ecological effects. Positive impacts of forest residue harvest include removal of excess nitrogen and reduction of soil acidity[4,10], increase in abundance and diversity of certain groups of species[11,12], and decreasing fire loads[13]. To reduce soil nutrient depletion and provide wildlife habitat, 0.8 – 2.2 tons of forest residue per acre may be spread throughout the harvest area[5]. Soil nutrients may be replenished by spreading recycled wood ash over harvested areas at a rate of 0.7 – 2 tons per acre[4,10]. Soil nutrients may be conserved by foregoing forest residue harvest at regular intervals[12] to reduce soil nutrient loss and provide wildlife habitat. Ecologically-sensitive forest areas could be excluded from forest residue harvest altogether[4,7].

The purpose of this study was to assess the potential of using forest residue for commercial scale power generation in the eastern United States. Specifically, we use Geographic Information Systems (GIS) to estimate the quantity of forest residue that can be substituted for coal in co-fired power plants and the corresponding reduction in emissions of greenhouse gases and other pollutants. The use of forest residue as a fuel would give economic value to a forestry waste product thereby providing benefits to local economies. Forest residue has the potential to be an environmentally-sound and cost-effective energy source that could significantly lower fossil fuel use in the eastern United States in the near future.

2 Methods

2.1 Data acquisition and preparation

The study area for this project was bounded by Minnesota to the west, Maine to the north, and Florida to the south (Figure 1). This region covers an area of more than 3 million km^2 and contains numerous coal-fired power plants and extensive forest lands. The following GIS datasets were gathered from the appropriate agencies:

1) maps of annually available forest residue by county for the United States[14], 2) National Land Cover Dataset (NLCD) land cover[15], 3) power plant type and location in the United States[16], 4) road network[17], 5) state boundaries[17], and 6) protected lands[18]. The commercial software ArcGIS 9.3, augmented with Python scripts, was used for all GIS analyses.

Data required for the analyses were extracted from the primary datasets listed above. Forest land cover (deciduous, coniferous, and mixed forest) was extracted from the NLCD land cover map with a spatial resolution of 30 meters. Locations of coal-fired power plants were obtained from the EPA power plant dataset. Protected areas (GAP status 1 and 2) were extracted from the Protected Areas Database of the United States. Forest land cover within protected areas was excluded from analysis since harvest is restricted in these areas. States in the study region were extracted from the ESRI data and were used to clip all datasets to the boundaries of the study area. Data were projected into the North American Lambert Conformal Conic projection system. Figure 1 shows the forest land and coal-fired power plants in the study area.

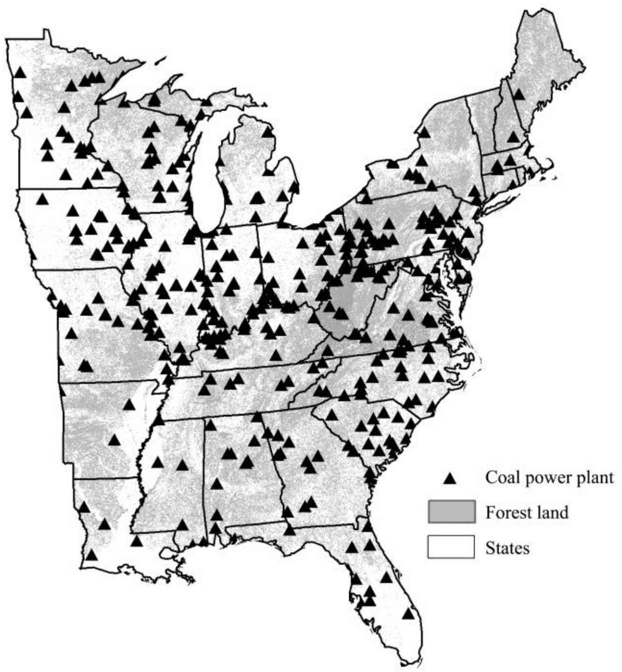

Figure 1 Map of study area, forestland, and coal-fired power plant locations

2.2 Forest residue source area

The source area of forest residue for a given location is constrained by travel distance. The maximum distance over which it is economically feasible to transport forest residue was estimated to be 80 kilometers[1] but it could vary significantly depending on fuel costs and feedstock value. To account for the variability in the maximum viable transport distance, we performed analyses for three scenarios assuming maximum transport distances of 60, 80, and 100 km respectively.

Many studies create feedstock source areas by approximating the maximum transport distance as being a straight-line distance[1,5]. However, more accurate source areas could be generated if they were defined using travel distances (Figure 2). Roads are the primary means by which forest residue is transported and therefore we used measurements along ESRI's StreetMap road network as transport distances. This dataset contains all classes of roads including logging and fire roads. The ESRI's StreetMap road network was converted to a raster dataset with a pixel resolution of 100 meters. The *Cost Distance* tool[17], in ArcGIS's Spatial Analyst extension, was used to measure distances in the road network, along a contiguous path, outward from a given coal power plant until the maximum transport distance for each path was reached. A Python algorithm was used to delineate the *convex hull* (A convex hull is the smallest convex polygon that fully encompasses a given set of points) of the road pixels within the maximum transport range. The convex hull was considered to be the source area for a given power plant.

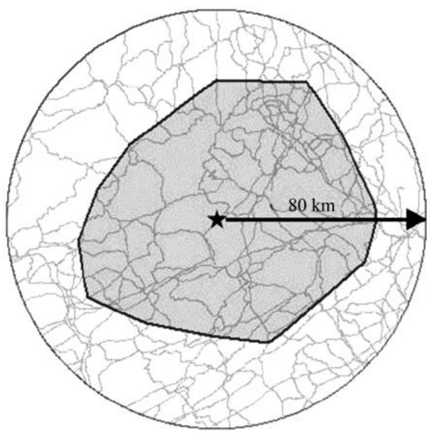

Figure 2 Feedstock source area based on a straight-line distance approximation (circle) versus the source area based on actual travel distances (gray polygon) along roads (gray lines). The actual source area is considerably smaller than the source area based on a straight-line distance

Source areas were delineated for all coal power plants in the study region.

The feedstock source areas for many power plants overlapped. However, this study does not seek to allocate resources to power plants – we only investigate the overall potential of forest residue feedstock. Consequently, we dissolved all power plant source areas into a single polygon with no overlapping parts. The source area polygon was then split along state boundaries to allow state level analyses to be conducted.

2.3 Source area forest residue

The total forest residue available annually in the source areas was calculated for each state. U.S. Forest Service data, available through the National Renewable Energy Laboratory (NREL), provided estimates of the annual forest residue available at the county level[14]. Since the NREL data are based on actual logging statistics, we assume that these data correspond only to forest areas that do not have protected status. From the NLCD, we extracted deciduous, coniferous, and mixed forest land cover pixels that did not fall within protected areas (Protected forest areas include locations with Gap 1 or Gap 2 status in the Nature Conservancy's protected lands dataset. Areas with this designation are managed primarily for wildlife habitat). Annual forest residue per pixel was calculated, for each county, by dividing the total forest residue by the number of unprotected forest pixels We calculated total annually available forest residue, for the source areas of each state, by summing the quantities of per pixel forest residues using ArcGIS's *Zonal Statistics* tool.

2.4 Estimation of coal and emission reductions

The heat values of coal and forest residue were used to calculate the amount of coal needed to generate the same energy as the total annually available forest residue in the feedstock source area of the coal power plants. Logging residue has an average heat value of 15 GJ/ton whereas bituminous coal, the grade typically used in power plants, has an average heat value of 27 GJ/ton[19]. Therefore, we assume that the heat content of one dry ton of forest residue is equal to 0.56 tons of coal.

The emission rates from burning coal were obtained from the literature. One ton of coal emits approximately 2.86 tons of carbon dioxide[20]. Emissions of nitrous oxides (NO_x) and sulfur oxides (SO_x) are roughly 7 tons per kiloton of coal[21]. Greenhouse gas emissions are 91% lower for wood biomass than for coal[22]. Average emissions of NO_x and SO_x from wood biomass are 43.5% and 78.5% lower, respectively, than emissions from coal[22]. Coal usage in the study area, in 2007, was obtained from the Energy Information Administration[23].

3 Results

3.1 Forest residue availability

Forest residue in extensive areas of the eastern U.S. is within the maximum feasible transport range for coal power plants (Figure 3). The total annual forest residue available to coal plants in the region was 29.4, 40.2, and 48.2 million dry tons for maximum transport distances of 60, 80, and 100 km respectively. The Southeast region had the greatest quantities of forest residue available to coal plants (Figure 4). Midwestern states, especially Wisconsin and Minnesota, tended to have substantial quantities of available feedstock. The Northeast region, with the exception of Pennsylvania, has the lowest potential for offsetting coal use with forest residue.

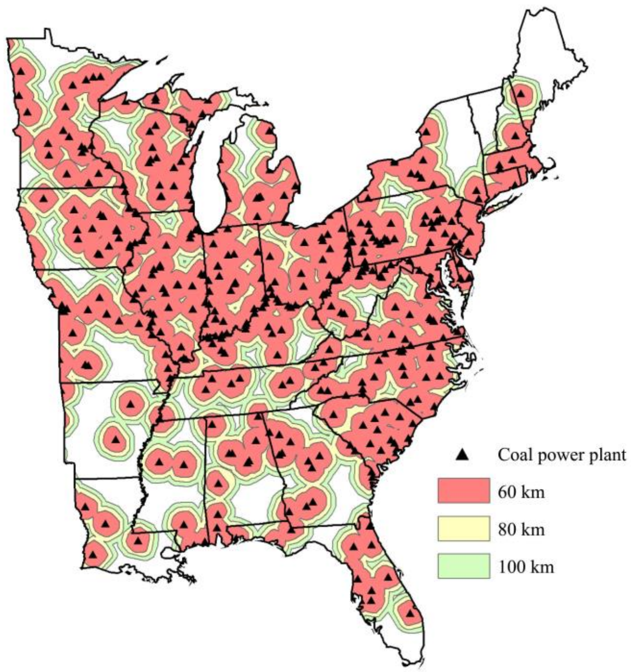

Figure 3 Map of forest residue source areas, for coal-fired power plants, assuming transport distance thresholds of 60, 80, and 100 km

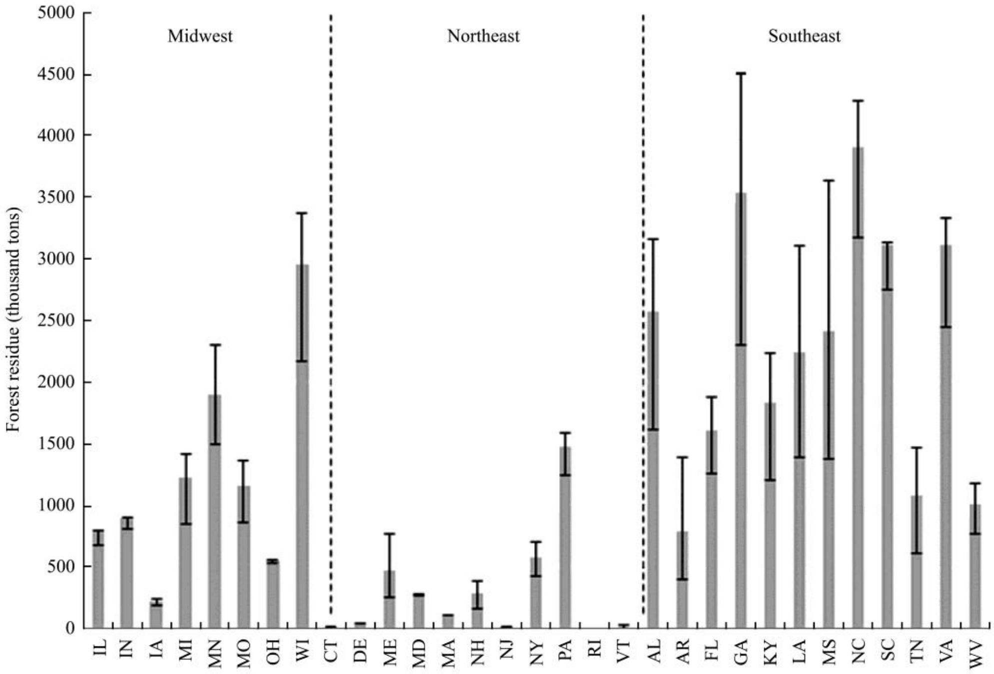

Figure 4 Total forest residue available, by state, to coal-fired power plants assuming a maximum transport distance of 80 km. Error bars indicate the residue available in the 60-100 km transport range

3.2 Greenhouse gas emission reductions

It was estimated that the eastern U.S. would have the potential to reduce coal consumption by 22.3 million tons per year - assuming that forest residue is used as wood chips in electricity generation and that the maximum feasible transport distance for forest residue is 80 km. Therefore, offsetting coal use with forest residue could reduce greenhouse gas emissions by 58.1 million tons per year (Figure 5), or by 2.5% of 2007 coal power plant emissions (Figure 6). In addition, NO_x and SO_x emissions would be reduced by 69.3 and 122.6 thousand tons respectively (Figure 5). This would be equivalent to a reduction of 1.2% and 2.2% of 2007 NO_x and SO_x coal power plant emission levels (Figure 6).

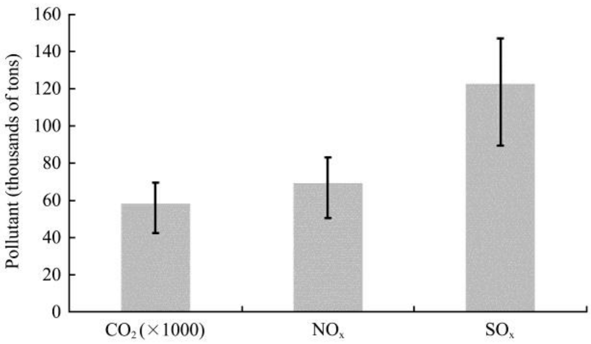

Figure 5 Total reductions of emissions using forest residue to offset coal use assuming an 80 km maximum transport distance. Error bars indicate quantities for the 60-100 km transport range. Carbon dioxide (CO_2) emissions are in millions of tons; nitrous oxides (NO_x) and sulfur oxides (SO_x) emissions are in thousands of tons

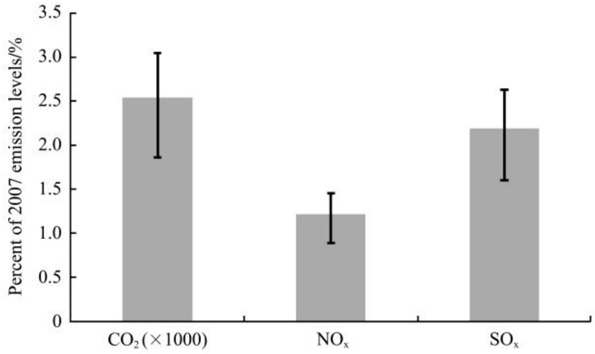

Figure 6 Emission reductions, as the percent of 2007 coal emissions, using forest residue to offset coal use in the study area. Gray bars indicate quantities for the 80 km transport distance; black error bars indicate quantities for the 60-100 km transport range

4 Discussion

The eastern United States has substantial amounts of forest residue available for use in coal power plants. Coal usage in the region could be reduced by 2.0%–3.4% of 2007 levels depending on the maximum viable transport distance of forest residue. The reduced coal use would lower greenhouse gas emissions by 1.9%–3.1%, NO_x emissions by 0.9%–1.5%, and SO_x emissions by 1.6%–2.6%. Although these reductions are small fractions of current levels, they are far from inconsequential given the current coal consumption and emission levels. A sustainable energy grid will need to be drawn from many different sources with each source likely providing a small but significant source of energy. Forest residue may be considered as one component of this future energy grid. Given the relative ease of adapting current technology and infrastructure to using forest residue in power generation, it is likely to be an energy source that can be tapped throughout the eastern U.S. in the near future.

In regions that have few coal plants and abundant forest land, such as New England, there are substantial amounts of available forest residue that are too remote to be feasible for use in co-fired coal power plants. These areas have potential for alternative uses of forest residue such as conversion to a liquid biofuel or use as a solid fuel in a biomass power plant. These alternative uses would likely require substantial investments in infrastructure but may provide an effective strategy for expanding renewable energy use in these regions.

Previous studies assessing forest residue availability have used a straight-line distance approximation of the maximum viable transport distance of forest residue to a receiving location. This simplification overestimates the forest residue that is available within a given distance threshold since straight-line distances can be considerably shorter than the actual travel distance. This study developed a technique using GIS capabilities, in a Python script, to delineate source areas based on actual travel distances. The tool allows the source areas to be automatically generated for a set of points given the maximum travel distances and the road network. The tool can be easily adapted to delineate source areas based on travel times provided the road dataset contains information on speed limits or route classes. Travel time may provide a more accurate delineation of the source area since it would account for road conditions. However, travel times were not used in this analysis as we were unable to find literature that provided estimates of the maximum viable transport time for forest residue delivered to a receiving location.

Coarse woody debris has an important ecological role in forestland. The harvest of forest residue, however, would not necessarily have adverse consequences. The widespread use of fossil fuels and synthetic fertilizers has resulted in excess nitrogen deposition in many parts of the world including the eastern United States[25]. The excess nitrogen results in soil acidification and in the leaching of nutrient cations, such as calcium and potassium, from forest soils[25]. Removal of forest residue may benefit soils in areas affected by nitrogen deposition. In regions where nutrient depletion is a potential problem, various practices may be employed to restore soil nutrients. These practices include spreading a percentage of the available forest residue across the harvest area, spreading wood ash in the harvest area, or foregoing residue harvest at regular intervals. Leaving some forest residue in the harvest area would have the added benefit of providing habitat for forest species requiring coarse woody debris. By employing appropriate practices, forest residue can be harvested in many forested areas in a manner that minimizes ecological impacts.

5 Conclusions

The transition from fossil fuel dependence to a renewable energy economy requires significant financial support and public resolve. The latter requirement can be obtained more readily by using the most cost-effective strategies of developing alternative energy sources and by exploiting local resources. Forest residue is a local resource that is abundant in the eastern United States and can be effectively used to generate power in an environmentally sustainable manner. Solid wood fuel derived from forest residue could be used to supplement the coal used in power plants with only modest investments in infrastructure. The low start-up costs could make the use of forest residue in coal power plants an appealing sustainable energy source that has potential to effectively reduce fossil fuel consumption in the near future.

[References]

[1] Blackwelder D B, Wilkerson E. Supply system costs of slash, forest thinnings, and commercial energy wood crops. Idaho National Laboratory. Technical Memorandum. Sept. 2008.

[2] SmithW B, Miles P D, Vissage J S, Pugh S A. Forest Resources of the United States, U.S. Department of Agriculture Forest Service, 2002.

[3] Perez-Verdin G, Grebner D L, Munn I, Sun C. Grado S.

Economic impacts of woody biomass utilization for bioenergy in Mississippi. Forest Prod J, 2008; 58: 75–83.

[4] Ranta T. Logging residues from regeneration fellings for biofuel production- a GIS-based availability and supply cost analysis. PhD dissertation. Lappeenranta University of Technology, 2002.

[5] Perez-Verdin G, Grebner D L, Sun C, Munn I A, Schultz E B, Matney T G. Woody biomass availability for bioethanol conversion in Mississippi. Biomass Bioenergy, 2009; 33: 492–503.

[6] International Energy Agency (IEA). Biomass for Power Generation and CHP. No.3 2007. http://www.iea.org/techno/essentials.htm [2010-04-28].

[7] Schulte L, Tyndall J, Hall R B, Grubh K. Rapid assessment of woody biomass capabilities in three regions of the U.S. Midwest. Report, Iowa State University, Department of Natural Resource Ecology and Management, 2008.

[8] Huber G W, Dale B E. Grassoline at the pump. Sci Am, 2009; 301: 52–59.

[9] McIverJ D, Starr L. A literature review on the environmental effects of postfire logging. W J of App For, 2001; 16: 159–168.

[10] Börjesson P. Economic valuation of the environmental impact of logging residue recovery and nutrient compensation. Biomass Bioenergy, 2000; 19: 137–152.

[11] Fleming R L, Powers R F, Foster N W, Kranabetter J M, Scott D A, Ponder F, et al. Effects of organic matter removal, soil compaction, and vegetation control on 5-year seedling performance: a regional comparison of Long-Term Soil Productivity sites. Can J For Res, 2006; 36: 529–550.

[12] Nitterus K, Astrom M, Gunnarsson B. Commercial harvest of logging residue in clear-cuts affects the diversity and community composition of ground beetles (*Coleoptera: carabidae*). Scand J For Res, 2007; 22: 231–240.

[13] Brown J K, Reinhardt E D, Kramer K A. Coarse woody debris: managing benefits and fire hazard in the recovering forest. Gen. Tech. Rep. RMRSGTR- 105. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 2003.

[14] National Renewable Energy Laboratory (NREL). Biomass Resources in the United States. 2009. http://www.nrel.gov/gis/data_analysis.html [2010-04-28].

[15] Homer C, Huang C, Yang L, Wylie B, Coan M. Development of a 2001 national landcover database for the United States. Photogramm Eng Remote Sens, 2004; 70: 829–840.

[16] United States Environmental Protection Agency (US EPA). The Emissions and Generation Resource Integrated Database for 2007. eGRID2007. Technical support document. 2007.

[17] Environmental Systems Research Institute (ESRI). Cost Distance. ArcGIS Desktop 9.3 Help. 2010. http://webhelp.esri.com/arcgisdesktop/9.3/index.cfm?id=6198&pid=6193&topicname=Cost_Distance. [10-04-28].

[18] Protected Areas Database of the United States. http://www.protectedlands.net/ [2010-9-17].

[19] Oak Ridge National Laboratory. Bioenergy Conversion Factors, Biomass. http://bioenergy.ornl.gov/papers/misc/energy_conv.html. [2010-10-20].

[20] Hong B D, Slatick E R. Carbon Dioxide Emissions Factors for Coal. U.S. Energy Information Administration: Independent Statistics and Analysis. 1994. http://www.eia.doe.gov/cneaf/coal/quarterly/co2_article/co2.html [2010-04-28].

[21] Union of Concerned Scientists (UCS). How Coal Works. 2009. http://www.ucsusa.org/clean_energy/coalvswind/brief_coal.html [2010-04-28].

[22] Zhang Y, Mckechnie J, Cormier D, Lyng R, Mabee W, Ogino A, et al. Life cycle emissions and cost of producing electricity from coal, natural gas, and wood pellets in Ontario, Canada. Environ Sci Technol, 2010; 44, 538–544.

[23] Energy Information Administration (EIA). August 2009. State Energy Consumption Estimates 1960 through 2007. (p. 4) http://www.eia.doe.gov/emeu/states/sep_use/notes/use_print2007.pdf.

[24] Energy Information Administration (EIA). Form EIA-5, and Bureau of the Census, U.S. Department of Commerce, Monthly Report EM 545. 2009.

[25] Vitousek P M, Aber J D, Howarth R W, Likens G E, Matson P A, Schindler D W, et al. Human alteration of the global nitrogen cycle: sources and consequences. Ecol Appl, 1997; 7: 737–750.