A Biomass Fuel Assessment for Duke University's Chilled Water Plant #2

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May 2010

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Duke University is considering utilizing biomass fuel to supply steam for the campus chilled water plant as part of the University's sustainability plan. North Carolina has been cited as having a high potential supply of biomass fuels, however the distribution and costs of these fuels are poorly quantified. This Masters Project identifies the University's biomass fuelshed and locates potential supply sources and probable fuel quantities. An Excel workbook couples user-defined transportation, processing, collection and handling, and purchase premium expenses within fuel classes to establish probable purchase costs for each supply source. Results are optimized for a lowest cost fuel mix to meet modeled plant demand based on user defined plant parameters. Finally, total biomass fuel costs are compared to fossil options to determine if biomass is a financially justifiable fuel for Duke to pursue.

The results of this study indicate that the university fuelshed likely contains supply for more than 4 times the steam plants fuel requirements. The cost per million British thermal units combusted within the fuelshed is highly variable, ranging from approximately $1.01 for construction / demolition material to over $29 for forest thinnings. Several fuel classes are more economic than current prices for natural gas, ranging from less than a quarter to three quarters of the price of natural gas.

The preliminary assessments of purchasing biomass fuel for use in the plant resulted in costs significantly lower than natural gas, and even potentially lower than coal. It is anticipated that the annual fuel costs for a biomass plant could be met for around $2.25 million based on plant parameters modeled and the estimated biomass characteristics (collection, base cost, etc.). Fuel costs are demonstrated to be highly sensitive to changes in fuel properties (mainly distance and moisture content) and plant operating parameters. A large portion of the biomass estimates are derived using employee based proxy equations, and the author was unable to confirm the accuracy of these supply estimates. Finally, the cost modeled is for fuel supply only. This paper does not take into consideration storage, operating / maintenance, or capital outlay, all of which are traditionally higher for biomass than fossil fuels. Despite these uncertainties there is a clearly demonstrated opportunity to fuel the plant with biomass at a cost less than natural gas. Additionally, the large and diverse biomass supply will lend resiliency to market fluctuations.

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I. REPORT SUMMARY

Duke University is in the process of fundamentally restructuring their west campus steam plant system. This system is currently fueled by coal and the University has expressed an interest in utilizing biomass fuels as part of the it's long term carbon neutral sustainability initiative [1]. This project undertook the first steps to identify and quantify the university's fuelshed resources and assess the financial viability of purchasing biomass fuel based on modeled fuel and plant parameters as compared to coal alternatives, particularly natural gas.

Unlike most fossil alternatives, biomass fuels have highly variable physical and combustion characteristics [2-6]. The thermal content varies widely across the major fuel classes listed on page 10, and even within individual classes there can be large variations [4, 7, 8]. Fuel moisture has a significant impact on the thermal properties, and higher moisture levels negatively impact boiler efficiency resulting in the need for even greater amounts of fuel [2, 9, 10]. Raw fuel size can range from ready for combustion (i.e. sawdust) to large dimensional lumber (framing, railroad ties) requiring extensive processing prior to combustion. These variables increase the complexity of calculating how much fuel is needed and available. The following components were identified as the starting point to understanding if purchasing biomass fuel is a financially viable option within the Duke University fuelshed.

1. **Identify the university's biomass fuelshed, sources, and quantities.** The cost of transporting biomass limits the size of any potential fuelshed; EPA notes that "the availability of biomass feedstocks in close proximity… is a critical factor in [the] efficient utilization" [2]. Once a fuelshed is identified for the University, it is then

possible to categorize and evaluate potential fuel sources and establish the transportation network distance.

2. **Establish the proposed plant's fuel needs.** Individuals with the University facilities department specified that the plant would be required to deliver 80,000 pounds of steam per hour. The amount of fuel needed to reach this baseload is influenced by plant operating characteristics and the combustion properties of the fuel utilized. For this report a stoker grate boiler was modeled per Duke's desire for low cost coupled with high reliability and flexibility to co-fire coal.
3. **Establish probable fuel costs for each source and optimize purchasing for lowest cost.** Once the biomass fuelshed sources and available quantities are defined it is possible to calculate transportation costs for each fuel source. This can be coupled with published data on processing, harvest / collection, premiums, and base resource cost for each fuel class to determine total and mmBTU cost for each source location. An optimization model designed to meet the monthly steam load at the lowest cost can then be executed to identify purchase points and provide a fuel cost estimate.

This report concentrates on four biomass fuel classes: mills, forestry residues, construction / demolition material, and wood-products manufacturing industries. Other fuel classes including forest thinning, municipal solid waste, and agricultural slash were excluded from consideration due to varying economical, technological, and permitting concerns. Within each of the fuel classes, Standard Industry Classification (SIC) codes sourced from published literature are used to identify applicable potential biomass sources **(**Figure 4**)**. It is possible, and in fact likely, that other sources of biomass exist beyond the industries captured using SIC codes, however these codes provided a strong starting point for analysis. A total of 272 point sources were identified within a 70 mile radius of Duke. This number was subsequently refined down to a total of 238 point sources for inclusion in the network analysis spatial component and optimization model.

This analysis identifies the potential of over four times the amount of biomass fuel needed annual within the Duke fuelshed, excluding refuse derived fuels (RDF), municipal solid waste (MSW), agricultural residues, and tire derived fuels (TDF). Utilizing a conservative natural gas price of $4 per mmBTU, the potential biomass fuel is still nearly double the plant's annual demand. Source fuel quantities varied greatly from less than half a ton of material per month to several thousand tons. Construction / demolition landfills were consistently among the most quantity-concentrated biomass sources, and the majority of these facilities were within 50 network miles of Duke. Using conservative combustion and supply fuel parameters, construction / demolition material alone could likely supply over 80% of the modeled plant fuel requirements with the added benefits of low competition and comparatively homogenous fuel processing and associated characteristics streamlining the handling process.

There is a clear "supply" potential for Duke to utilize biomass fuel for the west campus plant. Likewise, the fuelshed has a relatively large degree of fuel diversity, which provides a degree of resiliency to market fluctuations. Should Duke decide to further pursue biomass as a fuel source, the next consideration is whether University would purchase wood via a fuel broker (guaranteed supply, but with added price premium) or negotiate purchase contracts directly with the sources (lower cost, but greater uncertainty). Should Duke pursue the latter route, the needed next steps are to contact the identified sources directly to ascertain actual monthly delivered quantities and refine the estimated price per ton of fuel from each supplier. Throughout the design process Duke should update the plant assumptions in the fuel purchase model to ensure that fuel quantities are reflective of technological and engineering choices actually made. A final option that Duke may wish to explore to further increase the biomass reliability and decrease fuel price is to evaluate the use of the additional biomass fuels that were not considered in this report per Duke's stated wood based fuel preference. Although MSW, RDF, and TDF all have increased emissions as well as public perception barriers to overcome, they are potentially negative cost fuels that Duke could easily secure access to. TDF in particular has a high heat content (comparable, or higher, to the best coals) and biological rubber composition in the high 20 percent that qualifies as renewable fuel content [11].

II. BIOMASS AND DUKE UNIVERSITY

The definition of what constitutes "biomass" from an energy perspective varies depending on who is being consulted. The EPA classifies biomass as "any organic matter, typically plant-based mater, that is available on a renewable or recurring basis. [2]" This is an expansive definition encompassing many sources; for ease of comprehension it is generally broken into the several overarching classes depicted in Figure 1. With such a large diversity of natural fuel sources, it should come as no surprise that combustion of biomass for heat and power is widely held to be one of the earliest form of energy utilization [12-14]. Throughout the centuries it has progressed from highly inefficient open pit combustion for heat and light to gasification for electric and thermal generation using combined heat and power systems that can operate at an efficiencies in excess of 90% [15].

Although biomass only accounts for a small portion of the total US energy portfolio (around 3%), it has historically been the second largest renewable energy source (48% in 2000) in the US following hydropower [5, 6, 16]. The southeast region of the United States has been cited by the National Renewable Energy Laboratory (NREL) as having a large biomass fuel base. North Carolina in particular is identified as having over 10.2 million pounds of biomass available for combustion – the equivalent of 2,200 MW of capacity [17]. While not all of this capacity is likely to be exploitable due to economic and technological constraints, there are currently only 21 power generating facilities in North Carolina utilizing biomass as a fuel, representing a combined total of only 290 MW of capacity based on 2009 available information[1]. The majority of these facilities produce their own biomass waste onsite (i.e. paper mills, landfills) and collection for power and process heat is a natural fit. Only two facilities are utilizing offsite purchased biomass as their primary fuel (Craven County Wood Energy and Costal Carolina Clean Power) and jointly account for roughly 75 MW of capacity. Biomass power is clearly underutilized in North Carolina.

The benefits of biomass energy, particularly in advanced wood combustion combined heat and power systems have been extensively and well documented [2, 5, 6, 15, 18-20], still it is worthwhile to reiterate the key findings in the context of Duke University. The overarching benefits of biomass energy can be broken into two broad categories: economic and environmental.

Biomass fuels can be more economical per million British thermal units (MMbtu) than fossil fuels, although this is not always the case [19]. Since biomass fuels cover such a large spectrum

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[1] Based on EPA eGRID Files, EIA databases, and a review of North Carolina energy company websites.

the base resource costs can range from negative values (as with MSW) to in excess of 100 or more dollars per ton [2, 3, 5, 21]. Generally though, biomass fuels cost less than 50 dollars per ton. The comparatively low cost of biomass is a result of almost all biomass fuel being a waste byproduct of higher value industries (e.g. dimensional lumber, paper mills) or daily activities (see Figure 1) as opposed to the primary product of an energy extraction operation as with coal or oil.

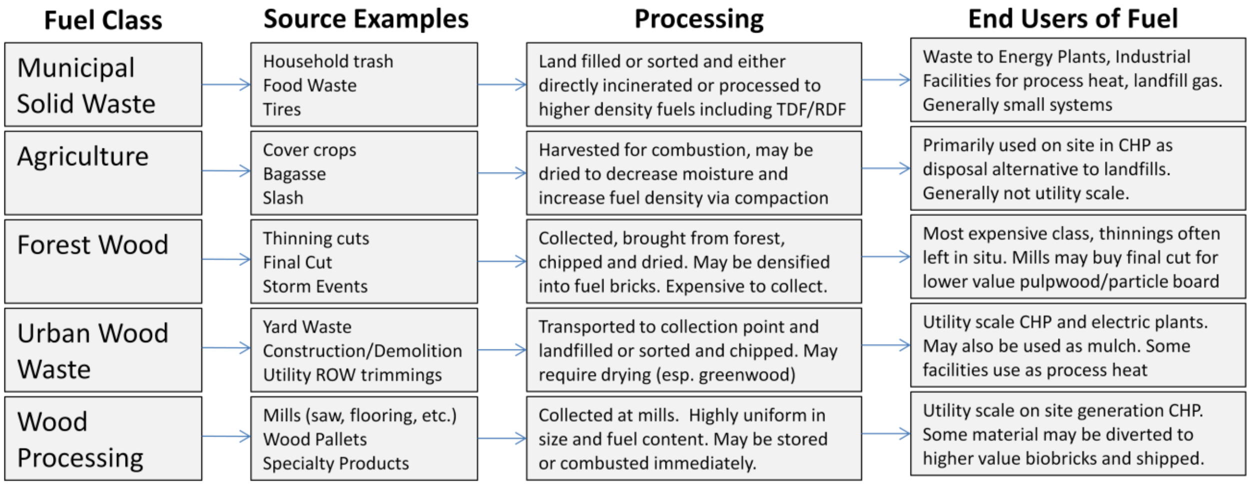

Figure 1. Biomass Fuel flowchart

Due to the large moisture content inherent in biomass, transportation costs can rapidly become a significant economic barrier [22]. Biomass for heat and power is almost exclusively a local product with maximum transit distance rarely exceeding 100 miles, and preferentially remaining under 50 miles. The local, distributed nature of biomass fuels has the added economic value of keeping investment directly in communities surrounding the plant, and creating blue collar jobs (over 4 per MW installed power according to NREL) primarily in the processing and transportation of the fuels. Biomass fuels, when harvested sustainably[2], are considered carbon neutral due to the fact that the carbon emitted during combustion is part of the earth's biological

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[2] The definition of sustainable biomass harvesting is the subject of some debate. For woody biomass, the author recommends using the Union of Concerned Scientist's definition of renewable biomass available online at www.ucsusa.org

cycle and will be reabsorbed by new plant material thus remaining in the biological cycle; in contrast to fossil carbon which is part of the earth's geological cycle and is released into the biological cycle via combustion [23]. With the increasing likelihood of carbon pricing in the near future, biomass as a carbon neutral fuel has significant added economic benefits. Carbon pricing is projected by EPA to start at $15 per ton carbon emitted, and even for a comparatively small plant like the one Duke proposes the value of avoided carbon costs is in the hundreds of thousand dollars.

A key element of biomass power from an environmental standpoint lies in the emissions and landfill reductions. Biomass combustion yields significantly less pollutants across a broad spectrum when compared to coal, especially with regard to sulfur dioxide and heavy metals including Mercury[3] [2, 7, 19, 20]. It is far simpler to control the emissions from controlled biomass combustion than it is from biological decomposition (or historically open air combustion), the usual alternatives to controlled combustion. Studies have shown that biomass decomposition greenhouse gas emissions (notably methane) from gas capture controlled landfills are three and a half times more potent than comparable emissions from combustion of the biomass [6]. In uncontrolled landfills the emission factor increases to over thirteen times more potent than combustion [6]. Finally, the amount of waste diverted to landfills is significantly less after combustion in part to the actual volume reduction from individual materials, but also from the recapture of useful products (e.g. ash) that is otherwise unavailable when material is directly landfilled.

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[3] As with any generation, actual emissions depend largely on systems design and so there may be exceptions to this statement. In particular, Nitrous Oxides and Particulates may be higher in older biomass systems than with a comparable coal unit. Likewise, heavy metals can be influenced by the fuel stream (particularly when using construction / demolition and bedding waste) and Dioxin emissions have historically been a concern, especially in older units.

The current regulatory climate is favorable to biomass energy, particularly when combined heat and power are part of the systems (as is the case with Duke). The end value of relevant incentives would require a paper in itself, however a review of state programs identified seven regulations that directly address biomass and CHP systems with benefits from tax incentives to grants (Figure 2) [24].

North Carolina Incentive Program	Incentive Type
NC Energy Improvement Loan Program	Loan
NC Green Business Fund	Grant
NC Green Power Production Incentive	Rebate
NC Interconnection Standards	Interconnection
NC Net Metering	Net Metering
NC Renewable and Energy Efficiency Portfolio Standard	Environmental Regulation
NC Renewable Energy Tax Credit	Tax

Figure 2. Existing North Carolina CHP and Biomass Energy Incentives that could be used by Duke University

Additional federal incentives exist such as the Open Loop Biomass Production Rebate and the CHP Investment Tax Credit that biomass and CHP systems can take advantage of. Of particular interest in the regulatory world, and valued by Duke University, are the Renewable Energy Credits (RECs) that can be sold to utilities to meet North Carolina's Renewable Energy Portfolio Standards. Finally, looking to the future, in the event that carbon emissions are regulated biomass has a clear advantage over natural gas as it is classified as near carbon and hence likely exempt from any taxes or carbon based regulatory burdens.

Biomass energy, however, is not without limitations including high up-front costs, fuel specific emission concerns, storage systems for fuel and waste ash, fuel availability/reliability, and transportation. These limitations fall into two distinct parts of the biomass power development cycle. The first phase is a fuel availability analysis that identifies likely sources of biomass fuels and addresses the cost of procuring these as well as attempts to provide some indication of fuelshed resiliency (Figure 3). This analysis is essential in deciding whether or not to proceed with a biomass system and is the focus of the remainder of this report.

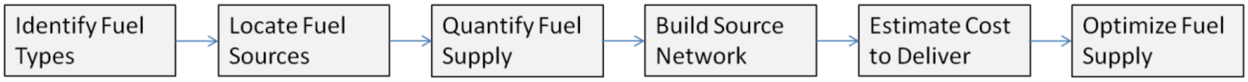

Figure 3. Report scope.

In the event that fuel supply analysis yields positive results, then second part is the actual engineering and site planning (storage, emissions inventory, operation and maintenance costs) which is not addressed in this report as these limitations are directly affected by the site evaluation and the generation system.

Publically available biomass data is often limited to county or regional levels, such as NREL's biomass maps. This data is useful for getting a broad picture of a regions resource base, but due to the high transit costs associated with biomass is of little use in conducting plant specific biomass fuelshed analysis. Reported quantities of biomass generation are generally not available for many industries due in part to the fact that it is a waste byproduct for these industries and that it may give industry competitors proprietary information about manufacturing capabilities. One method of gathering this information is via a survey (time consuming and expensive), while another is to chose a widely available statistic such as sales, square footage, or number of employees as a proxy for biomass estimation. This evaluation used reported quantities when available and employment numbers as a proxy when reported numbers did not exist or couldn't be accessed.

Geographic Information Systems (GIS) have historically been used to model the spatial component of the biomass energy dynamic. The most basic approach has been to use the GIS as a buffering tool to build concentric rings of varying distance around a potential biomass station and then intersect geocoded point source data (such as SIC codes) with the rings to establish fuel potential within a user specified distance. A straight line measure is used to calculate the distance between source and plant locations. The assumption that biomass can be moved in a straight line is the major weakness of this method, as it has a tendency to underestimate the real transport distances and subsequent fuel cost. A fuelshed analysis done for Virginia Tech used essentially this approach, with the GIS portion being indirectly manipulated within the ReferenceUSA database [25]. A second method, which this analysis used, allocates biomass based on a network analysis using some form of restrictions like distance, speed [26-28] or road class [28]. This approach is preferential to the linear buffer as is takes into account natural barriers (e.g. water) and accurately models limitations with the physical infrastructure. An additional benefit is that network analysis has the ability to exclude user specified road classes from routing consideration (e.g. schools, hospitals, community housing); while accurately measuring the additional distance these restrictions can add.

III. <u>METHODOLOGY</u>

Identify Fuel Types: Duke University has indicated that the steam plant must be able to supply 80,000 lbs per hour of high pressure steam. Additionally, they require that the combustion system have a minimal amount of downtime coupled with a high degree of reliability. Finally, the unit must be flexible enough to handle a range of fuels, including coal in an emergency. These requirements restrict both the potential fuels available and exclude emerging technologies as well as gasification as the boiler technology. From the fuel standpoint agricultural residues were excluded as they have a higher rate of slagging than other biomass fuels, which in turn leads to increased maintenance and boiler unit downtime [2]. Municipal solid waste and its derivatives (RDF, TDF) are traditionally a negative cost fuel [2], but were not considered in this analysis based on several factors namely: First, the University has stated that they want to use wood-based fuels whenever possible. Second, there is often a public stigma that accompanies waste combustion, which may lead to increased permitting costs and environmental safeguards, offsetting to some degree the low cost of the fuel [29]. Finally, there are incinerator air quality standards for MSW [29]. From the combustion technology standpoint, this report assumes the use of a stoker grate boiler.   This technology has a comparatively low maintenance costs and downtime and is suited for combustion of coal, the University's preferred backup fuel [2]. Additionally, stoker grate boilers can handle a large range of fuel sizes and moisture content, lowering process costs and increasing fuel options [2].

Locate Fuel Supply: Wood based industry residues were identified using Standard Industry Classification codes (SIC) for business listed in the ReferenceUSA database, and by a review of North Carolina's Department of Solid Waste. In addition to construction / demolition landfills, thirteen relevant industry SIC codes were identified (Figure 4) from a literature review and previous case studies. A 70 mile buffer from the Durham area code 27707 was used to identify local biomass sources. Sources in Virginia were ultimately excluded from the analysis due to the existence of an extremely large biomass facility (Multi-Trade) that is already exploiting most of the large supply sources in the Virginia region of the fuelshed [7].

SIC Code	Description	Employee Multiplier (tons)	Source
2421	Sawmills & planning mills	101	Bogart
2426	Hardwood dimension & flooring mills	45.8	Buggeln & Young
2429	Special product sawmills	562	Bogart
2431	Millwork	54.9	Buggeln & Young
2434	Wood kitchen cabinets	22.3	Buggeln & Young
2435	Hardwood veneer & plywood	75	n/a
2436	Softwood veneer & plywood	75	n/a
2439	Structural wood members	34	Bogart
2448	Wood pallets & skids	120.6	Buggeln & Young
2452	Prefabricated wood buildings & components	7	Bogart
2493	Reconstituted wood products	3	Bogart
2499	Other wood products	3	Bogart
2511	Wood household furniture	50.7	Buggeln & Young

Figure 4. Standard Industry Classification Codes used in the ReferenceUSA database and assigned biomass per employee values based on referenced literature. Plywood was assigned a value based on extrapolation from cited sources.

Quantifying fuel supply: Five year reported quantities were collected for construction / demolition material landfills from the North Carolina Department of Solid Waste. These numbers included all construction / demolition components and needed to be refined. Published data indicates that the immediately combustible[4] amount of wood in construction / demolition material is around 15 percent of the waste stream. Annual amounts were broken into likely monthly quantities in the following manner: ((total amount of construction / demolition material * .15)/12 months). One aspect of construction / demolition that needs to be accounted for is the impact that changes in the building market can have on the volume of material generated. In order to account for this dynamic, conservative quantities from 2008 (economic recession and construction downturn) were used. The ReferenceUSA database does not include any individual site production information that could be used to directly calculate waste wood quantities however it does include site attributes (employees) that could be used as the waste wood proxy.

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[4] Immediately combustible means wood requiring processing for size only (i.e. untreated wood). Other wood material may be combustible with minimal treatments, or may be combustible with additional stack filtration.

A literature review of previous biomass studies from the southeast region of the United States identified likely waste wood produced per employee (Figure 4); this was multiplied by the site employee number to provide a rough estimate of site biomass.

Build Source Network: Source geographic coordinates were imported into ESRI ArcGIS program to establish the physical location of sites in relation to North Carolinas Integrated State Road Network (ISRN)[5]. Addresses were used to verify site locations (as opposed to a mailing address) for construction / demolition facilities, and GPS coordinates from the ReferenceUSA database were used to locate SIC identified facilities. A snap distance of 1/10th of a mile was used to ensure that all sites were located directly on the road network in the GIS system; failure to locate a site directly on the ISRN shapefile would result in that site being excluded from the network analysis. The Network Analyst toolbox was used to build a fuelshed road network with distance attributes based on the "length" property of the ISRN shapefile (Appendix B, Figure 16). Transportation distances were realistically estimated from each source to the biomass site along this network setting the plant as the "facility" layer and the sources as the "incident" layer (Figure 5).

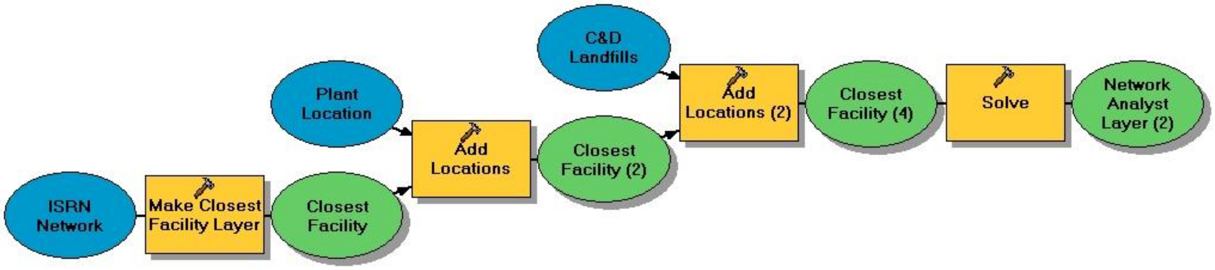

Figure 5. Example of the ArcGIS network models used to establish distances, in this case for construction / demolition landfills.

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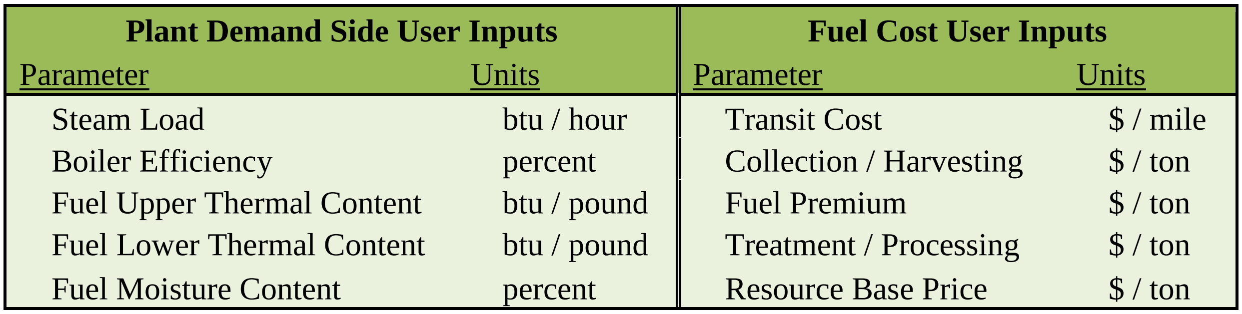
[5] Please see Appendix B for selected GIS figures.

Estimate Delivered Cost: An Excel spreadsheet was built to model fuel prices for each unique source within the fuelshed. This model coupled source distances from the GIS analysis with a hauling cost per mile to establish likely transportation costs. Transportation costs were coupled with the user specified fuel components in Figure 6 to establish a delivered price per ton for each fuel source location. Fuel demand was calculated using a basic stoker-grate boiler biomass plant model that allowed the user to specify key parameters (Figure 6) which automatically adjusted boiler efficiency to account for moisture levels (a non-linear relation [10]) and updated the fuel demand accordingly for each fuel class. The full simplified model is provided in Appendix A.



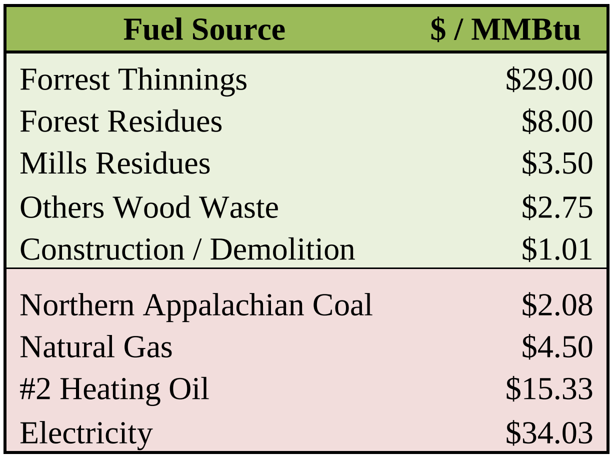
Plant Demand Side User Inputs		Fuel Cost User Inputs	
Parameter	Units	Parameter	Units
Steam Load	btu / hour	Transit Cost	$ / mile
Boiler Efficiency	percent	Collection / Harvesting	$ / ton
Fuel Upper Thermal Content	btu / pound	Fuel Premium	$ / ton
Fuel Lower Thermal Content	btu / pound	Treatment / Processing	$ / ton
Fuel Moisture Content	percent	Resource Base Price	$ / ton

Figure 6. Model user-input parameters derived from literature [2, 21, 22, 30]

Optimize Fuel Supply: An optimization run was executed using the Excel solver to identify the least cost sources of biomass to meet the plants expected monthly steam requirement. Due to the large number of source points, which exceeded Excel's capabilities, a minimum supply threshold of 25 tons per month was set to enable the optimization model to run. The model was constrained so that no site could exceed its monthly supply. Additionally, the model was set as a linear model and constrained so that non-negativity was assured.

IV. ANALYSIS RESULTS

A robust fuel supply exists, both in terms of total biomass quantity and diversity of sources, which could be economically exploited by Duke University (Appendix B, Figure 15). Mill residues, other wood processing industry waste, and construction demolition material are all competitive with natural gas on a mmBTU basis. Forest thinnings and forest residue are not cost competitive (Figure 7). It is possible that Duke can command a lower price than modeled for forest residues since they own the forest parcels (via the Duke Forrest) that would provide the fuel. *Ceteris paribus* a base price below $9 would lower the mmBTU price to less than $5, making forest residues competitive with current natural gas prices.



Fuel Source	$ / MMBtu
Forrest Thinnings	$29.00
Forest Residues	$8.00
Mills Residues	$3.50
Others Wood Waste	$2.75
Construction / Demolition	$1.01
Northern Appalachian Coal	$2.08
Natural Gas	$4.50
#2 Heating Oil	$15.33
Electricity	$34.03

Figure 7. Modeled biomass fuel prices (post combustion, excluding the transportation component) per mmBTU within the University fuelshed.

Within the three competitive fuel classes construction / demolition material has the lowest average cost at $2.28 per mmBTU, once transportation costs are included (Figure 8). One outlier facility was identified ("other wood waste" class, wood shingling manufacture) and excluded from the analysis as it was modeled to potentially supply nearly 200% of the annual fuel needs; a review of the company's web site indicated that this was likely a large overestimate. This is a limitation of the employee proxy, and is addressed at length in the discussion section of this report.

Fuel Class	Minimum	Maximum	Median	Average
Construction / Demolition Material	$1.25	$3.34	$2.49	$2.28
Other Wood Wastes	$2.41	$4.84	$4.15	$3.91
Mills	$2.78	$5.62	$4.49	$4.37

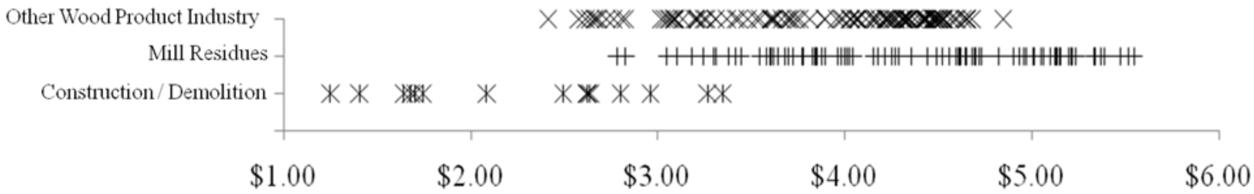


Figure 8. Fuel cost table and range graph per mmBTU, including transportation, for the three competitive fuel classes

The distance distributions across the three competitive fuel classes are relatively homogenous, however the “other wood processing industry” class has a further median distance by about seven miles. The supply volume dynamic is perhaps the most interesting of the results. Construction / demolition material is the most concentrated supply source, with over twice the average monthly fuel amount per site as compared to the next closest category, mills (Figure 10) More telling, the median monthly supply for construction / demolition material was significantly closer to the average than for the mills (Figure 10), indicating that the variation between sites was not nearly as extreme as in other classes. “Other wood product industry” has the most source locations at 130; however these are generally smaller sources (Figure 10 & Figure 11). For both mills and “other wood product industry” several sites calculated at such low delivered quantities that they appeared in the model as zero values (Figure 10). Mills had that largest amount of potential supply with 92 sites with nearly 17,000 lbs per month; this is more than one and a half times the “other wood products industry” and just under three times the amount available from construction / demolition (Figure 10).

Fuel Class	Source Points	Estimated Potential Supply	Class Supply Potential
Construction / Demolition Material	15	5750.6	81%
Other Wood Wastes	130	9331.3	131%
Mills	92	16955.6	187%

Figure 9. Fuel supply category overview

Fuel Class	Minimum	Maximum	Median	Average
Construction / Demolition Material	16.7	1196.9	257.9	383.4
Other Wood Wastes	0.0	1306.5	7.9	71.8
Mills	0.0	3125.0	37.0	184.3

Figure 10. Fuel class supply characteristics (tons).

Finally, the fuel optimization model skewed heavily to construction demolition material (n=12, N=14), with over 83% of the plant's supply coming from this fuel class (Figure 11). The remainder of the thermal needs was filled out by a wood furniture manufacturer (7% of remainder) and a door manufacturer (93% remainder). Monthly delivered fuel costs were slightly over $188,600; and the annual total fuel price was 2.26 million (Figure 11).

Source	Supply (tons)	Cost
Forest Residues	0	$0
Forest Thinings	0	$0
Mill Residues	0	$0
UWW	0	$0
Construction / Demolition	4810.9	$150,972
MSW	0	$0
Other Wood Waste	978.4	$37,690

Figure 11. Monthly fuel least cost optimization results

The majority of the fuel sources from the optimization run were less than 55 miles from the University (average = 35 miles); the closer the supply points the less sensitive the cost to fluctuations in fuel prices. No individual site contributes more than 17% of the fuel supply, although the 4 major contributors provide nearly 59% of the monthly total (Figure 12).

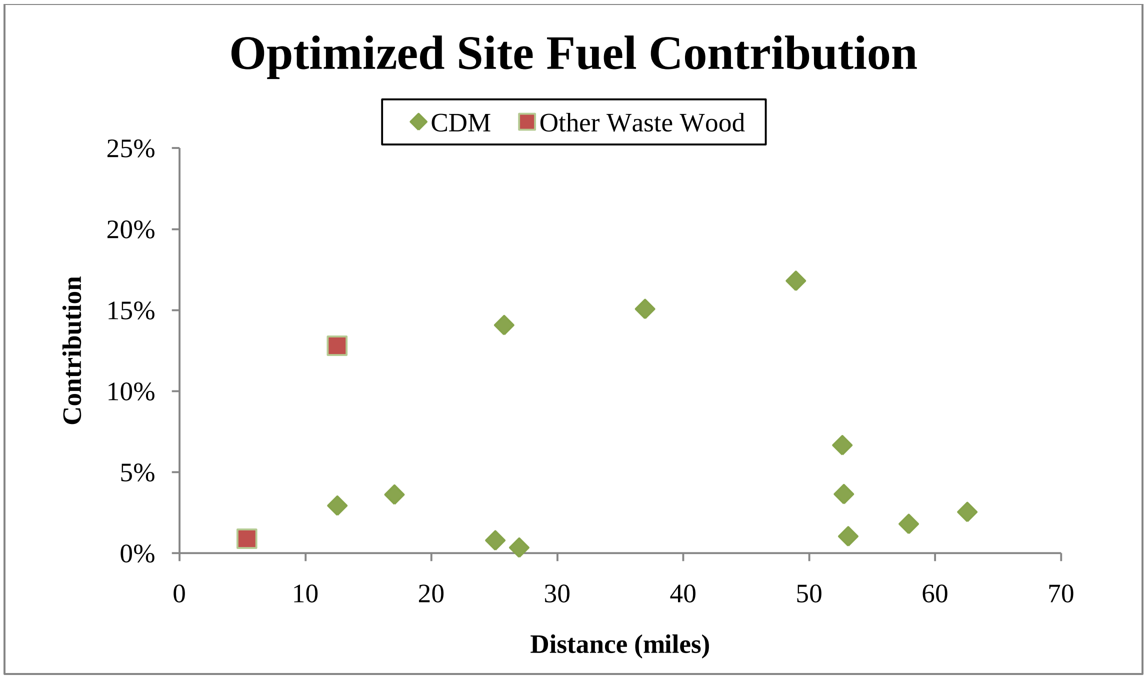


Figure 12. Distance and contribution from sites identified from fuel optimization run.

V. DISCUSSION

This analysis presents the first step in defining and calculating Duke University's biomass fuelshed supply. Prior to discussing the results and implications of this analysis, it is important to couch these findings within limitations of this study. Figure 3 on page 10 is a good reference for categorizing the key areas for potential methodological limitations. The first important methodological limitation stems from the use of SIC codes in ReferenceUSA to identify source points. Although ReferenceUSA is a high quality database, they rely on companies correctly reporting their SIC code. Using construction / demolition as an example, this study identified instances where companies either failed to properly classify themselves by SIC code and hence did not appear in the database despite being listed in North Carolina's Division of Waste Management. Alternatively, several construction / demolition landfills listed in ReferenceUSA have not been active for several years according to the Division of Waste Management. The potential for incorrectly identifying or potentially missing source facilities is a shortcoming of the ReferenceUSA database. The issue of unrepresented facilities could be compounded by the fact that this analysis used facilities' primary SIC code only. Thus it is possible that wood producing facilities may not have been properly identified as a result of their SIC indicated primary business activity.

A second issue was the use of employees as a proxy for biomass production via the ReferenceUSA database. This method has been used historically (Figure 4) but treats each SIC code as a homogonous industry with similar manufacturing capabilities. I believe this may lead to an overestimate of the biomass production at smaller labor intensive facilities while underestimating the production at larger more machine intensive sites, however there was no means to verify this within the scope of this report. A verified issue with employment numbers is that they are self reported by the companies on the many business fillings that ReferenceUSA uses to build their database. There were several examples of companies reporting only one employee which was likely just a placeholder value. For example, Universal Forest Products had two mill locations within the fuelshed, both reporting only one employee. However, a review of their website indicated that these locations are major mills producing everything from I-beams to custom cut lumber and framing. In cases such as this the biomass potential is likely to be significantly underestimated. This however does not adversely compromise the report or the methodology, as the supply estimates were skewed to the conservative side as a result of incidences like Universal Forest Products.

The cost analysis provides a basic estimate of delivered prices and lowest cost purchase mix. It is not a detailed cost analysis of operating a biomass fueled plant, but rather a simplified view of potential fuel purchase costs. This analysis is appropriate primary evaluation of what the University fuelshed has to offer. It is not intended to support an economic-based investment decision in regard to a University biomass plant. Several costs including ash disposal, storage, and operating / maintenance were not considered in this analysis.

This fuelshed analysis found that Duke University likely has access to ample and diverse sources of biomass (Appendix B, Figure 15) to support their combustion needs at cost competitive rate (per MMBtu basis) as compared to natural gas (as seen in Figure 8). The optimization model identified construction / demolition material as the majority fuel type for the plant. A traditional concern with biomass fuels is long term supply and reliability where price fluctuations, competition, and market changes can disrupt or even remove sources of fuel from the purchasing mix [7, 31]. To this end, construction / demolition material is a particularly attractive fuel option. Unlike mill residues, the competition for this fuel source is usually negligible [7]. Construction / demolition fuel requires processing to achieve the required size for the combustion unit, and competitors prefer to utilize mill residues (a more homogonous and clean product) whenever possible. Additionally, construction / demolition landfills may be willing to provide the raw fuel for free as they are in effect a storage site. Once they have the material on hand they have no further use for the majority of it. Ideally, Duke would be able to include a small fuel yard capable of handling raw clean construction / demolition material, subsequently allowing Duke to capture the tipping fee and further reducing the fuel cost. Unlike forest residues and mill residues, construction / demolition fuels have a lower moisture content, generally in the range of 12% to 15% as opposed to 30% to 50% [2]. This has a twofold benefit to the University. First, a lower moisture content mean a high amount of useable thermal content per ton of fuel purchased, in effect lowering the per mmBTU price. This is the dynamic that caused the pre-transport prices for construction / demolition to so low in Figure 7. Second, the decreased moisture allows for a more efficient boiler operation, again increasing the amount of useable thermal content. The quantities associated with construction / demolition material for each site are likely the most accurate of all fuel estimates in this report. This is due to the high quality data available from Waste NC. The likely accuracy of the fuel estimates for construction / demolition material and reduced likelihood of over-estimates further make this fuel class an excellent starting point for Duke. Finally, a review of the eGRID and EIA databases leads me to believe there are currently no facilities in the area competing for these resources. This could enable Duke to achieve a first mover advantage. This may not be the case for long however, as there are proposals on the table to build at least one new biomass power plant within the University's fuelshed. The proposal indicates that the plant will rely on mill residues and forest residues, however the primary stakeholder has previous experience operating construction / demolition material fired plants [32].

Duke has a stated goal to become carbon neutral. Attainment of this goal will requires the on-site generation of renewable energy or the purchase of carbon offsets [1]. Carbon offsets are currently trading for around $2 per ton on the Chicago Climate Exchange (CCX) while the EPA projects initial carbon permit prices under a federally capped program to start at $15 per ton. As it currently stands, biomass fuels are categorized as carbon neutral, hence the cost of carbon emissions to Duke is zero[6]; and there is a potentially significant avoided carbon costs. An estimate of these savings can be found in Figure 13. Assuming the conservative EPA emissions starting price the carbon offset price alone for a plant utilizing natural gas is nearly 33% of the total biomass fuel alternative.

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[6] This assumes that biomass remains classified as a carbon-neutral fuel

	Pounds CO2 per mmBTU	Current CCX Price ($2)	EPA Projected Starting Allowance Price($15)
Biomass	0	$0.00	$0.00
Coal	202.8	$167,202.64	$1,254,019.76
Natural Gas	117.08	$96,529.02	$723,967.62

Figure 13. Potential carbon costs based on plant characteristics

Another benefit to the university is Renewable Energy Credits (RECs). Duke has stated that they will utilize a backpressure turbine on the steam loop, which should be capable of generating several MW electricity per hour based on the technology and anticipated plant size [2]. By using biomass fuel, this electricity would qualify as renewable energy, potentially providing Duke with one REC for every MW energy and MW thermal equivalent generated. The market for RECs is highly volatile with prices ranging from under half a cent per kWh to 5.6 cents per kWh[7], but with North Carolina utilities required to generate or purchase from independent producers the equivalent of 12.5% of the state's energy via renewable energy in the next decade there is clear economic value to REC generators[8]. Duke may be able to leverage its position as a reliable producer of REC (versus solar or wind) to command a market premium and contract with the utilities. There is also value via deferred costs from the electricity generated by the backpressure turbine, regardless of the fuel source. The emissions benefits and REC credits were not intensively modeled in this analysis due to the fact that they are largely influenced by technological choices beyond fuel, however they clearly represent an important financial mechanism that Duke can capitalize on should they chose to use biomass fuels.

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[7] http://apps3.eere.energy.gov/greenpower/markets/certificates.shtml?page=1 (accessed4/20/2010)

[8] http://www.ces.ncsu.edu/forestry/biomass/pubs/WB003.pdf (accessed 4/20/2010)

VI. CONCLUSION

This report provides an initial assessment of Duke's biomass fuelshed by identifying supply points and probable quantities and analyzing this data via a simple purchase cost model. The report's value lies in providing a starting point for Duke to contact key sources directly and refine the supply dynamic and modeled assumptions with facility verified numbers. Based on the results of this analysis the question for Duke is no longer "is biomass fuel a viable option", but rather "is operating a biomass CHP plant a more financially attractive option than the fossil alternatives and the emissions credit open market"?

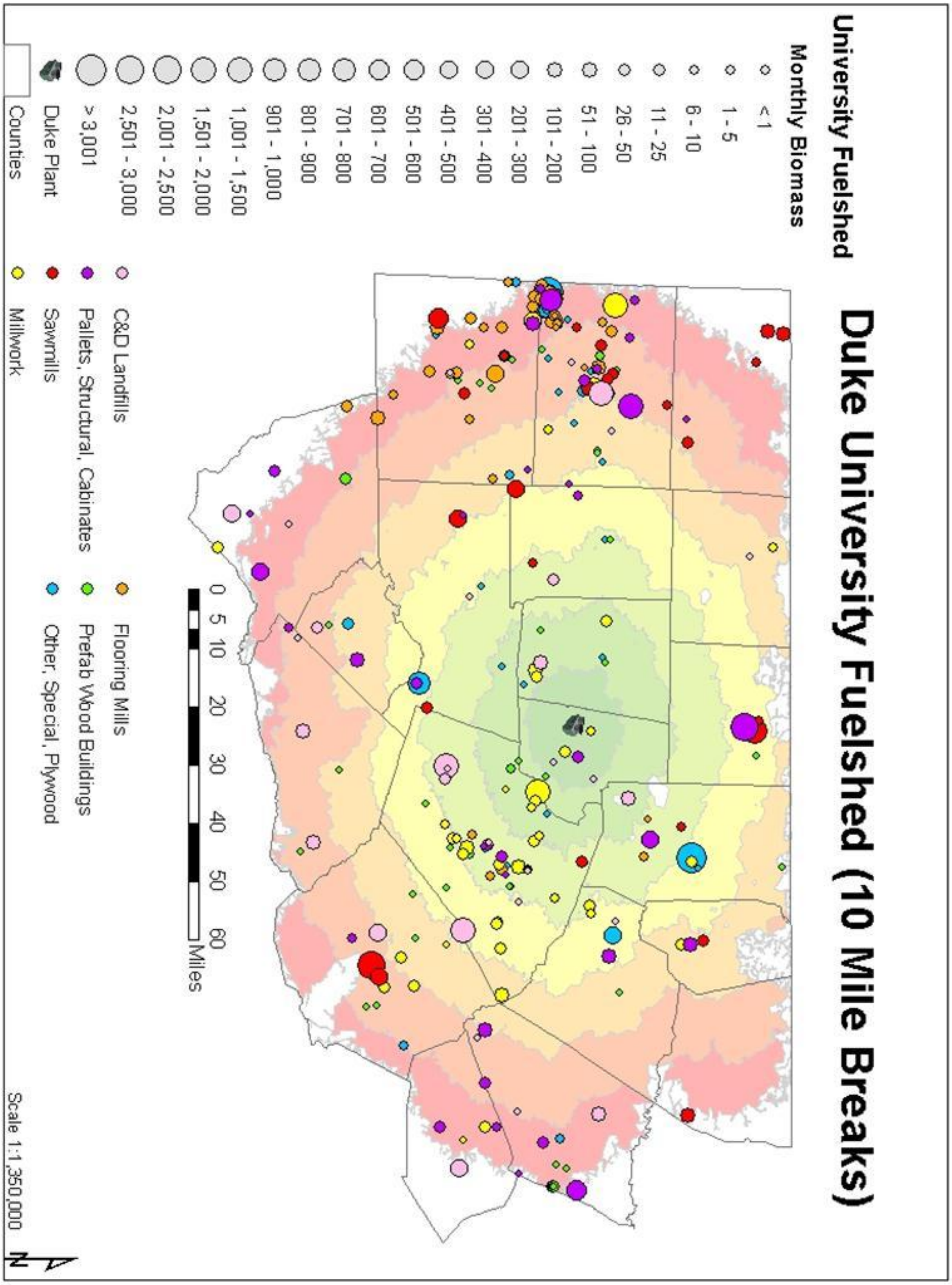
To this end, there are several steps Duke should take to move forward. First, Duke should decide if they want to use a fuel broker (or wood procurement company) to purchase the biomass fuel, or if they prefer to negotiate for themselves on the open market. A fuel broker can help provide long term guaranteed biomass supply, but will come with a price premium in exchange for the reduced uncertainty of the supply / risk. Purchasing fuel on the open market is a lower cost alternative, but likely will require a dedicated plant staff member. The second consideration is for Duke to decide if construction / demolition materials are an acceptable fuel. Previously, Duke indicated they prefer wood based fuels, excluding MSW and derivatives as well as agriculture byproducts. There is the potential for MSW and derivatives to be utilized at an even lower cost than construction / demolition material while providing the surrounding cities with a valuable outlet for their solid waste; much of which is currently trucked to Virginia. MSW has gained good market penetration in European countries (notably in Denmark) and the in the United States are social and political as opposed to supply and technology [33, 34]. By providing an outlet for local use of MSW, Duke could earn additional income disposing of the waste while lessening the economic and environmental burdens of transporting and landfilling the waste out of state. Duke is in a prime position to be a first mover in the Durham area for biomass, and can be a leader in the responsible use of biomass for combined energy generation and heating [18]. Although biomass plants traditionally cost more to operate than natural gas [2], it is possible that with (or even without) the value from emissions and associated savings a biomass power station is a relatively low cost option for the University.

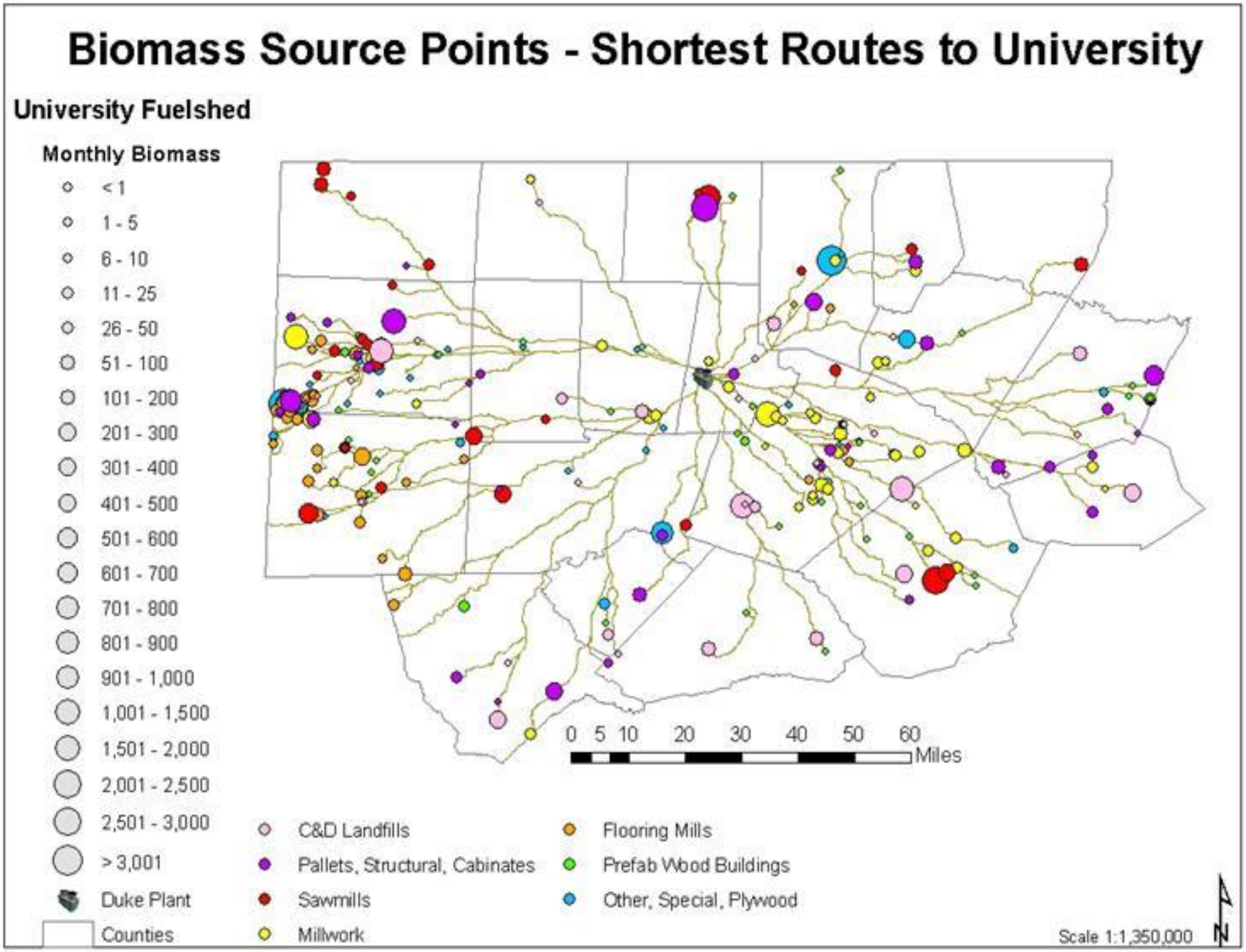
APPENDIX A – Excel powerplant and fuel model parameters

	Forest Residues	**Forest Thinings**	**Mill Residues**	**UWW**	**CDM**	**MSW**	**Other Wood Waste**
Plant Parameters							
Steam Demand (lbs / hr)	80,000	80,000	80,000	80,000	80,000	80,000	80,000
Boiler Efficiency	85.00%	85.00%	85.00%	85.00%	85.00%	85.00%	85.00%
Fuel Needed (BTU/hr)	94,117,647	94,117,647	94,117,647	94,117,647	94,117,647	94,117,647	94,117,647
Moisture Adjusted Boiler Efficiency	61.25%	51.25%	76.88%	73.75%	81.25%	76.88%	81.25%
Actual Fuel Needed (BTU / hr)	153,661,465	183,644,189	122,429,460	127,617,149	115,837,104	122,429,460	115,837,104
Fuel Parameters							
BTU/lb (high)	8570	8570	8570	6150	8598	5000	8568
BTU/lb (low)	8570	8,570	8,570	6,150	8,598	5,000	8,568
BTU/lb (average)	8570	8570	8570	6150	8598	5000	8568
Fuel Moisture Percent	50%	60%	25%	30%	15%	25%	15%
Moisture Adjusted BTU/lb	4285	3428	6428	4305	7308	3750	7283
Combustion BTU w/ all efficiency losses	2625	1757	4941	3175	5938	2883	5917
Efficiency Loss Adjusted from Moisture >50%	*0.00%*	*10.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*	*0.00%*
Efficiency Loss Adjusted from Moisture 50-20%	*15.00%*	*15.00%*	*2.50%*	*5.00%*	*0.00%*	*2.50%*	*0.00%*
Efficiency Loss Adjusted from Moisture <20%	*8.75%*	*8.75%*	*5.63%*	*6.25%*	*3.75%*	*5.63%*	*3.75%*
Total efficiency loss from moisture	*23.75%*	*33.75%*	*8.13%*	*11.25%*	*3.75%*	*8.13%*	*3.75%*
Supply Requirements							
Tons Fuel per Hour	29.3	52.3	12.4	20.1	9.8	21.2	9.8
Tons Fuel per Day	702.6	1,254.4	297.3	482.3	234.1	509.6	234.9
Tons Fuel per Month	21,372.2	38,157.8	9,044.8	14,672.8	7,121.1	15,502.8	7,146.1
Tons Fuel per Year	256,466.0	457,893.2	108,537.7	176,074.1	85,453.5	186,033.5	85,752.7
Transit Components							
Truck Capacity (tons)	30	30	30	30	30	30	30
Trucks per Day	24	42	10	17	8	17	8
Trucks per Month	713	1,272	302	490	238	517	239
Trucks per Year	8,549	15,264	3,618	5,870	2,849	6,202	2,859
Fuel Component Costs							
Additional Transit Cost per Mile	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50
Collection / Harvesting Cost (Ton)	$5.00	$10.00	$0.00	$0.00	$0.00	$0.00	$0.00
Premium to secure resource (Ton)	$7.00	$7.00	$5.00	$0.00	$0.00	$0.00	$0.00
Fuel Processing Cost (Ton)	$5.00	$5.00	$4.00	$12.00	$12.00	$12.00	$10.00
Literature Purchase Cost per ton (low)	$15.00	$50.00	$8.00	$3.00	-$24.00	-$24.00	$15.00
Literature Purchase Cost per ton (high)	$30.00	$100.00	$50.00	$24.00	$15.00	$15.00	$30.00
Modeled Onsite Purchased Cost	$25.00	$80.00	$25.00	$13.50	$0.00	$0.00	$22.50
Total Cost ex. Transportation (per Ton)	$42.00	$102.00	$34.00	$25.50	$12.00	$12.00	$32.50
Per MMBtu raw fuel	***$4.90***	***$14.88***	***$2.64***	***$2.96***	***$0.82***	***$1.60***	***$2.23***
Per MMBTU post combustion	***$8.00***	***$29.03***	***$3.44***	***$4.02***	***$1.01***	***$2.08***	***$2.75***

(Fields in yellow indicate user input parameters)

APPENDIX B


Duke University Fuelshed (10 Mile Breaks)
University Fuelshed
Monthly Biomass
< 1
1 - 5
6 - 10
11 - 25
26 - 50
51 - 100
101 - 200
201 - 300
301 - 400
401 - 500
501 - 600
601 - 700
701 - 800
801 - 900
901 - 1,000
1,001 - 1,500
1,501 - 2,000
2,001 - 2,500
2,501 - 3,000
> 3,001
Duke Plant
Counties
C&D Landfills
Pallets, Structural, Cabinates
Sawmills
Millwork
Flooring Mills
Prefab Wood Buildings
Other, Special, Plywood
0 5 10 20 30 40 50 60
Miles
Scale 1:1,350,000
N


Biomass Source Points - Shortest Routes to University

Appendix C Literature Cited

1. Anon., *Going Green: Becoming a Carbon Neutral Campus*, in *Duke University Climate Action Plan*. 2009, Duke University: Durham, NC. p. 123.
2. Energy and Environmental Analysis Inc., *Biomass Combined Heat and Power Catalog of Technologies*, in *Combined Heat and Power Partnership*. 2007, U.S. Environmental Protection Agency: Washington, DC. p. 113.
3. Bergman, R. and J. Zerbe, *Primer on Wood Biomass for Energy*. 2008, USDA Forest Service: Madison, Wisconsin. p. 10.
4. Domaiski, E.S., T.L. Jobe Jr., and T.A. Milne, *THERMODYNAMIC DATA FOR BIOMASS CONVERSION AND WASTE INCINERATION*. 1986, National Bureau of Standards: Golden. p. 1-326.
5. Haq, Z., *Biomass for Electricity Generation*, in *Biomass for Electricity Generation*. 2003, Energy Information Administration. p. 18.
6. Morris, G., *The Value of the Benefits of U.S. Biomass Power*. 1999, Green Power Institute: Berkeley, California. p. 24.
7. Wiltsee, G., *Lessons Learned from Existing Biomass Power Plants*. 2000, National Renewable Energy Laboratory: Golden. p. 1-149.
8. Frombo, F., et al., *Planning woody biomass logistics for energy production: A strategic decision model.* Biomass and Bioenergy, 2009. **33**: p. 372-383.
9. Good, J., et al., *Determination of the efficiencies of Automatic Biomass Combustion Plants*, Verenum, Editor. 2006, International Energy Agency. p. 33.
10. Liang, T., M.A. Kahn, and Q. Meng, *Spatial and temporal effects in drying biomass for energy.* Biomass and Bioenergy, 1996. **10**(5, 6): p. 353 - 360.

11. ASTM International, *Standard Practice for Use of Scrap Tire-Derived Fuel*. 2006.

12. Ristinen, R.A. and J.J. Kraushaar, *Energy and Environment*. 2006, Hoboken: John Wiley and Sons, Inc. 1-361.

13. Smil, V., *Energy at the Crossroads: Global Perspectives and Uncertainties*. 2005, Cambridge: MIT Press. 428.

14. Jaccard, M., *Sustainable Fossil Fuels: The Unusual Suspects in the Quest for Clean and Enduring Energy*. 2005, Cambridge: Cambridge University Press. 382.

15. Richter, D., et al., *Wood Energy in America.* Science, 2009. **323**: p. 2.

16. Perlack, R.D., et al., *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of A Billion-Ton Annual Supply*, ORNL, Editor. 2005, US Department of Energy: Oak Ridge.

17. Anon., *Charting a New Path for North Carolina's Electricity Generation*, National Wildlife Federation, Editor. 2008. p. 2.

18. Richter, D., *Good Wood Energy*, in *The News & Observer*. 2010: Durham, NC.

19. Maker, T., *Fueling District Energy and CHP with Local BIomass: U.S. Policy Considerations*, Energy Efficiency Associates: Calais, VT. p. 1 -10.

20. Madlener, R. and S. Vogtil, *Diffusion of bioenergy in urban areas: A socio-economic analysis of the Swiss wood-fired cogeneration plant in Basel.* Biomass and Bioenergy, 2008. **32**: p. 815 - 828.

21. Badger, P., *Processing Cost Analysis for Biomass Feedstocks*, U.S. Department of Energy, Editor. 2002, General Bioenergy, Inc.: Florence, AL. p. 53.

22. Beccali, M., et al., *Assessment of bioenergy potential in Sicily: A GIS-based support methodology.* Biomass and Bioenergy, 2009. **33**: p. 79-87.

23. Markewitz, D., *Fossil fuel carbon emissions from silviculture: Impacts on net carbon sequestration in forests.* Forest Ecology and Management, 2006. **236**: p. 153 - 161.

24. Environmental Protection Agency, *Combined Heat and Power Partnership - Funding Resources*, in *Combined Heat and Power Partnership*, EPA, Editor. 2009, http://www.epa.gov/chp/funding/funding.html.

25. Smith, R. and O. Parhizkar, *Appendix C - Fuel Assessment Report*, in *Biomass Fuel Analysis for Virginia Tech*, M. Spurr, Editor. 2005, Department of Wood Science and Forest Products: Blacksburg, Virginia. p. 28.

26. Perpiñá, C., et al., *Methodology based on Geographic Information Systems for biomass logistics and transport optimization.* Renewable Energy, 2009. **34**: p. 555-565.

27. Ranta, T., *Logging residues from regeneration fellings for biofuel production - a GIS based availibility analysis in Finland.* Biomass and Bioenergy, 2005(28): p. 171-182.

28. Panichelli, L. and E. Gnansounou, *GIS-based approach for defining bioenergy facilities location: A case study in Northern Spain based on marginal delivery cost and resources competition between facilities.* Biomass and Bioenergy, 2008(32): p. 298-300.

29. Kaplan, P.O., J. Decarolis, and S. Thorneloe, *Is it Better to Burn or Bury Waste for Clean Electricity Generation.* Environ. Sci. Technol., 2009. **43**: p. 1711 - 1717.

30. Foley, T., *Energy Models and Modeling, Biomass Trasport Optimization Model Planning Meeting*, R. Crowley, Editor. 2009: Duke University Durham, ND. p. Tim aquired the MPG number through his conversations with industry participants, and the 100 gallon tank is about the size of the average heavy load tractor trailor.

31. Buchholz, T.S., T.A. Volk, and V.A. Luzadis, *A participatory systems approch to modeling social, economic, and ecological components of bioenergy.* Energy Policy, 2007. **35**: p. 6084 - 6094.

32. Anon., *Alternatives Evaluation and Site Selection Study for the Proposed Hertford Renewable Energy, LLC Biomass Power Plant, Hertford County, North Carolina*, Decker Energy International, Editor. 2008: Winter Park, FL. p. 1 - 28.

33. Vehlow, J., et al., *European Union waste management strategy and the importance of biogenic waste.* Journal of Material Cycles and Waste Management, 2007. **9**(2): p. 130 - 139.

34. Rosenthal, E., *Europe Finds Clean Energy in Trash, but U.S. Lags*, in *New York Times*. 2010: http://www.nytimes.com/2010/04/13/science/earth/13trash.html?pagewanted=3&ref=earth. p. 3.