DISTRIBUTED CELLULOSIC ETHANOL: A COUNTY LEVEL INVESTIGATION OF SUSTAINABLE PRODUCTION POTENTIAL

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by
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ABSTRACT

Development of ethanol from cellulosic biomass may present significant opportunities for areas and regions not currently engaged in starch based ethanol production. The diversity in potential feedstocks for this second generation, bio-based ethanol may enable communities with significant wood based resources, biogenic wastes and agricultural residues to enter into this growing industry. Though there have been numerous efforts to characterize the nation’s cellulosic ethanol production potential, there is little information available for local communities to gauge local resource availability for fuel production. Furthermore, there have not been significant investigations into sustainable cellulosic fuel production at a local level based upon local site characteristics.

This study developed a methodology for assessing cellulosic resource potential at a local level through spatial analysis of current land use patterns and agricultural practices, application of sustainability criteria based upon local conditions, and a biofuel calculator designed to accommodate this data. Five cellulosic resource categories were considered during this study and the process for determining local fuel production potential were illustrated with a case study of Centre County, Pennsylvania. Land based resources for which spatial analysis was performed included: 1) forest products; 2) agricultural residues; and 3) dedicated energy crops. Non-land based feedstocks were also considered and included: 1) primary wood industry waste; and 2) secondary wood products manufacturing waste. ArcGIS technology, current land use and land cover maps for the Commonwealth of Pennsylvania and Natural Resources Conservation Service soil maps were used to determine the total harvestable area for forest and agricultural...
feedstocks. Sustainability criteria based upon soil types, associated harvesting limitations and proximity to riparian areas were applied to the total land area within each of the land cover categories considered, effectively reducing the total harvestable area for cellulosic ethanol feedstock collection. Two levels of sustainability (low and high) were calculated, and differed in the level of protection applied to riparian areas as well as in the removal rates of biomass material from forest and agricultural ecosystems. A cellulosic biomass total from all five resource categories was ultimately converted into a local ethanol fuel potential and compared against local fuel demand to assess the degree to which local cellulosic resources might offset local fuel demand.

The case study of Centre County, PA demonstrated that ethanol production potentials increased from a level capable of meeting just under 10 percent of the county’s fuel demand under the high sustainability scenario encompassing only forested land within 50 meters of roads up to a maximum of over 25 percent of consumption for the low sustainability scenario encompassing all harvestable forestland in the county. This thesis and calculator show that, though local biofuel potential can not fully meet total liquid fuel demand for the study site with the sustainability criteria applied in this calculator, there is a considerable resource potential present. Economic development opportunities may be realized through the sustainable collection local cellulosic resources and the production of a value added product such as ethanol.

Through the creation of a calculator, this study provides a tool for local communities to better understand local resource collection potential under a sustainably paradigm for liquid fuel production. The biofuel calculator is a flexible tool which can be easily updated to keep pace with new technological specifications for the ethanol
industry, as well as potential changes in biomass yields, consumption rates and land use patterns at the study site level. Moreover, the calculator may be used as a comparative analysis tool for local, regional or other scaled applications.
# TABLE OF CONTENTS

LIST OF FIGURES ................................................................................................. viii

LIST OF TABLES ................................................................................................... xi

ACKNOWLEDGEMENTS ......................................................................................... xii

Chapter 1  Introduction .......................................................................................... 1

Chapter 2  Biomass for Fuel .................................................................................... 7

Sugar and Starch Based Ethanol ........................................................................... 7
Starch and Sugar Based Ethanol Technology ...................................................... 8
Benefits of Starch and Sugar Based Ethanol ....................................................... 9
Disadvantages of Sugar and Starch Based Ethanol ............................................. 9
Cellulosic Ethanol ............................................................................................... 11
Cellulosic Ethanol Feedstocks .......................................................................... 12
Agricultural Feedstocks ..................................................................................... 12
Dedicated Energy Crops ...................................................................................... 13
Forestland Feedstocks ....................................................................................... 14
Industrial Feedstocks ......................................................................................... 15
Solid Waste Feedstocks ..................................................................................... 16
Cellulosic Ethanol Technology .......................................................................... 16
Benefits of Cellulosic Ethanol .......................................................................... 18
Disadvantages of Cellulosic Ethanol ................................................................. 19

Chapter 3  Cellulosic Biomass Resource Assessments .......................................... 21
National Assessments .......................................................................................... 22
State and Regional Assessments ...................................................................... 23

Chapter 4  Sustainability ..................................................................................... 26
Sustainability Criteria .......................................................................................... 30
2. Water Quality and Local Hydrology .............................................................. 32
3. Proximity of Resource to Road Infrastructure ............................................. 33
4. Competing Uses for Resources .................................................................. 34

Chapter 5  Methods and Procedure .................................................................... 36
1. Cellulosic Biomass Resources ....................................................................... 37
2. Harvestable Land Area: Spatial Analysis of Land Based Resources .......... 38
Forestland Area Removals .............................................................................. 39
Agricultural Land Area Removals ......................................................... 41
Riparian Buffers .................................................................................. 42
Distance to Roadways .......................................................................... 44
3. Biomass Calculator ............................................................................ 47
4. Case Study Site Selection .................................................................. 51
Centre County, Pennsylvania ............................................................... 52

Chapter 6 Results and Discussion .............................................................. 54

Harvestable Forestland ........................................................................... 56
   All Forests ....................................................................................... 56
   Forestland Within 500 meters of Roads .......................................... 59
   Forestland Within 100 meters of Roads .......................................... 61
   Forestland Within 50 meters of Roads ........................................... 63
Forest Biomass ..................................................................................... 66
Harvestable Agricultural Land ............................................................... 69
   Conventional Crop Area ............................................................... 70
   Dedicated Energy Crop Area ........................................................ 72
Agricultural Residues from Conventional Crops ................................... 75
Biomass from Dedicated Energy Crops .................................................. 77
Industrial Residue ............................................................................... 79
Municipal Solid Waste .......................................................................... 80
Biomass Total For Centre County, Pennsylvania .................................... 82
Ethanol Production Potential ............................................................... 85
Comparison of Ethanol Production Potential to Centre County Gasoline
   Consumption ................................................................................... 87
Discussion .......................................................................................... 91

Bibliography .......................................................................................... 95

Appendix A Biomass Calculator Model Assumption ................................. 104
   Agricultural Residue ....................................................................... 105
   Dedicated Energy Crops ............................................................... 105
   Forest Resources .......................................................................... 107
   Forest Products Industry .............................................................. 107
   Municipal Solid Waste ................................................................. 108
   Fuel Production Potential and Local Fuel Consumption ................. 109

Appendix B Biofuel Calculator Pages ..................................................... 110
LIST OF FIGURES

Figure 2-1: Ethanol production steps for sugar and starch technologies compared to cellulosic ethanol production.................................................................17

Figure 6-1a: Map of Harvestable Forest Area in Centre County, Pennsylvania. Map insert shows forested area falling within 50 m and 100 meters of existing roadways. ...........................................................................................................57

Figure 6-1b: Harvestable Forest area in Centre County by sustainability class and proximity to roadway..........................................................................................57

Figure 6-2: Total harvestable area for all forestland in Centre County by sustainability class. ........................................................................................................58

Figure 6-3a: Harvestable forestland in Centre County, Pennsylvania within 500 meters of roadways. Gray areas are beyond 500 m from roadways. .................60

Figure 6-3b: Harvestable forestland within 500 meters of roads by sustainability class..................................................................................................................60

Figure 6-4a: Harvestable forestland in Centre County, Pennsylvania within 100 meters of roads........................................................................................................62

Figure 6-4b: Harvestable forestland in Centre County, Pennsylvania within 100 meters of roads by sustainability class........................................................................62

Figure 6-5a: Harvestable forestland in Centre County, Pennsylvania within 50 meters of roads........................................................................................................64

Figure 6-5b: Harvestable forestland in Centre County, Pennsylvania within 50 meters of roads by sustainability class........................................................................64

Figure 6-6: Harvestable forestland within each forest category by sustainability class..................................................................................................................65

Figure 6-7: Total biomass for harvestable forestland within 500 meters of roads by yield category....................................................................................................67

Figure 6-8: Total available biomass for Centre County, Pennsylvania for each forest category by sustainability class. .................................................................68

Figure 6-9: Total harvestable agricultural land in Centre County, Pennsylvania by soil class.............................................................................................................69
Figure 6-10a: Harvestable arable land in Centre County by soil class and riparian buffer sustainability class. ................................................................. 71

Figure 6-10b: Total harvestable arable land for Class I-III soils in Centre County by sustainability class. ............................................................................. 71

Figure 6-11: Harvestable acres in Centre County for Class IV e/s soils by sustainability class. ..................................................................................... 72

Figure 6-12: Harvestable acres in Centre County for Class IV w soils by sustainability class. ..................................................................................... 73

Figure 6-13a: Total harvestable arable land in Centre County for all soil and sustainability classes. ............................................................................. 74

Figure 6-13b: Harvestable acres of Class IV agricultural land in Centre County by sustainability class. ............................................................................. 74

Figure 6-14: Relative percentage of acres of conventional crops generating residue relative to total harvested acres for all Centre County crops. ............. 75

Figure 6-15: Relative percentage harvested acres of conventional crops generating biomass residue within Centre County ..................................................... 76

Figure 6-16: Available biomass from conventional crop residue in tons per acres per year from each crop type. ................................................................. 76

Figure 6-17: Fraction of harvestable CIV land in Centre County allocated to switchgrass and willow. ............................................................................. 77

Figure 6-18: Total available biomass from dedicated energy crops by sustainability class ................................................................................................. 78

Figure 6-19: Total Biomass Residue Generated from Mills and Secondary Manufacturers ................................................................................................. 79

Figure 6-20: Total Available Biomass from Mills and Secondary Manufacturers ........................................................................................................... 80

Figure 6-21: Existing Biomass from Municipal Solid Waste for Centre County ..................................................................................................................... 82

Figure 6-22: Relative contribution of each cellulosic biomass category to Centre County’s biomass total under the low sustainability class. ......................... 83

Figure 6-23: Relative contribution of each cellulosic biomass category to Centre County’s biomass total under the high sustainability class. ......................... 84
Figure 6-24: Relative contribution of each biomass category to Centre County’s ethanol production potential under the high sustainability class .................. 86

Figure 6-25: Relative contribution of each biomass category to Centre County’s ethanol production potential under the high sustainability class .................. 86

Figure 6-26: Total ethanol production for Centre County by forest use level and sustainability class. ................................................................. 89

Figure 6-27: Percent of gasoline consumption of Centre County’s cellulosic ethanol production potential .......................................................... 90

Figure 6-28: Percent of ethanol available to meet E10 fuel blends for Centre County, by sustainability class and forest use category. ......................... 90

Figure 2-1: Production Comparison Page ................................................................. 110

Figure 2-2: Production Potential Page .................................................................... 111

Figure 2-3: Forest GIS Spatial Analysis Data Entry Page ....................................... 112

Figure 2-4: Agricultural GIS Spatial Analysis Data Entry Page ......................... 113

Figure 2-5: Forest Variables Page ......................................................................... 114

Figure 2-6: Agricultural Variables Page ................................................................. 115

Figure 2-7: Yield Assumptions Page ...................................................................... 116

Figure 2-8: Industrial Residues Page .................................................................... 117

Figure 2-9: Municipal Solid Waste Page ............................................................... 118
LIST OF TABLES

Table 1: Land-based resources and the applied sustainability criteria impacting total harvestable land area and associated assumptions. .............................................. 46

Table 2: Harvestable Forestland in Centre County, Pennsylvania .......................... 56

Table 3: Total harvestable forest biomass by yield category for forestland within 500 meters of roadway ........................................................................... 67

Table 4: Total forest biomass in Centre County, Pennsylvania for each forest category by sustainability class. ................................................................. 68

Table 5: Total agricultural area in Centre County, Pennsylvania by soil class. ........ 69

Table 6: Total arable agricultural land in Centre County, Pennsylvania by soils class with associated riparian buffer removals by sustainability class. .......... 70

Table 7: Total Available Biomass for Centre County by Crop Type and Sustainability Class ........................................................................................................ 77

Table 8: Total Available Biomass (tons/acre/year) from Dedicated Energy Crops for CIV Agricultural Land ........................................................................ 78

Table 9: Total disposed waste and waste composition for biogenic/cellulosic materials for Centre County, 2006 ................................................................. 81

Table 10: Biomass Totals (tons/ year) for Centre County for Forests within 500 m of Roads by Sustainability Class .............................................................. 83

Table 11: Total production potential by resource category for Centre County, PA ... 85

Table 12: Ethanol Production Potential (in gallons of gasoline equivalent) for Centre County Relative to Local Gasoline Consumption ......................................... 88
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Chapter 1
Introduction

Current levels of alternative fuel development are a direct response to the environmental, economic, social and political consequences of fossil fuel consumption. Environmental concerns stemming from fossil fuel combustion include contributions to global warming, air and water quality impacts from particulates, as well as damage from mining and drilling to obtain the raw resources. A major fraction domestic fossil fuel consumption is used in the transportation sector, for which oil is the primary fuel. The heavy dependence upon oil, both domestically and internationally is not without economic and social consequence, either. Disproportionate resource consumption and production patterns within and between societies across the globe are generating serious concerns in terms of long term economic stability. Also, social and political impacts resulting from conflict over resource access and control are increasing, and include international conflicts between oil producing versus consuming nations as well as intranational conflicts stemming from disparate distribution of development benefits.

The gravity of these problems are motivating the development of numerous and highly varied alternatives to oil as a primary fuel source. Some alternatives rely upon behavioral changes, such as the use of non-motorized or public forms of transportation. Urban planning and smart growth policies designed to reduce per capita vehicle miles traveled may also help in reducing dependence upon oil. However, behavioral changes
have largely been eclipsed by the pursuit of technological advancements aimed at delivering substitutes for oil into the market. For better or worse, the rate of personal vehicle ownership in developed economies and the rapid economic growth in areas such as China and India indicate that individual vehicular transportation will continue to grow in the near-term. Pursuit of hydrogen fuel cell and electric vehicles, powered by renewable energy, are two examples of technological alternatives to oil combustion. However, of the alternatives pursued domestically, biofuels such as ethanol currently have the greatest momentum in terms of deployment within the market.

Suitable for combustion in a conventional engine, fuel blends containing ethanol are now common, particularly as a fuel oxygenating agent. Today, fuel derived from corn is virtually synonymous with ethanol in the United States, the largest global producer of this form of energy. Brazil is a close second, producing ethanol from its largest agricultural commodity, sugar cane. These blends are derived from simple sugars and starches, for which the conversion technologies to create ethanol are mature and commercially available.

A 10 percent ethanol to petro-gasoline blend can be burned in virtually all gasoline engines, and in 2005 over 5 million cars in the U.S. were qualified as “flexible-fuel,” capable of burning 85 percent ethanol to gasoline (RFA, 2006). By 2006, over 30 percent of the gasoline in the U.S. contained some fraction of starch-based ethanol (RFA, 2006). As a result of ethanol’s broad commercial availability and technological compatibility with existing transportation infrastructure, the United States is increasing ethanol production aggressively and the industry is expected to expand significantly in the future. For example, the 2005 Federal Renewable Fuels Standard (RFS) set a
production target for the nation of 36 billion gallons of ethanol by the year 2022, over 10 times greater than total production in 2004 (RFA, 2007). Just two years later, in 2007, the Environmental Protection Agency announced an even larger non-statutory national goal of 35 billion gallons by 2017.

Yet, concerns are growing regarding the large-scale development of this form of fuel as the only, or even single largest alternative to oil (Soloman, 2007; Lang, 2007; Giampietro, 1997; Pimentel, 1991). Environmental impacts of large-scale agriculture are immediately relevant, from its reliance upon petro-chemical inputs for productivity, often referred to as energy intensiveness, to its surface erosion and water quality impacts. Additional concerns exist regarding the lack of feedstock diversity and potential negative distributional impacts stemming from the concentration of ownership and production by dominant firms in the agricultural industry. Finally, there are unknown ramifications of diverting agricultural products from our food supply to produce fuel, leading to inevitable competition for both food commodities and arable land. Already the market is reflecting the impacts of increased corn ethanol production; the price for corn is higher in in the 2007-2008 year than it has at any point in the last ten years (MSU, 2007; New York Times, 2007; CNN, 2007; Birur, et.al., 2007; Marketplace, 2008). This price is increasing the cost of all downstream corn-derived products including beef, poultry and milk due to increasing costs of animal feed. In a related fashion, farmers shift production into high priced corn resulting in price increases in other agricultural commodities, such as soybeans and their downstream products, due to lower levels of crop production.

While corn ethanol undoubtedly has the greatest momentum now, it is not the only feedstock that can be converted into ethanol. Beyond the grain portion of the plant
used to make corn ethanol, stems, stalks and leaves also have the potential to be converted into fuel and are far more prolific in volume. Plant material can be broken into three broad categories: simple sugars (e.g. fruit); starches or complex carbohydrates (e.g. grains, corn and roots); and lignocellulosic material (i.e. fibrous stems, stalks, and seed casings) (Demirbas, 2005). The third category, lignocellulosic, or “cellulosic”, biomass exists in much higher quantities than starch based material and can be derived from many vegetation sources in many regions of the world.

The limitation facing lignocellulosic feedstock processing, and therefore fuel production from this source, is the accessibility of the fermentable sugars. For this reason, cellulosic ethanol is still primarily in the pre-commercial phase of development, although in late 2007, the Department of Energy announced funding for six pilot-scale cellulosic ethanol facilities in the United States (Pu, et.al., 2007).

Though cellulosic ethanol production is not yet available commercially, it is predicted that this technology will become competitive with starch-based ethanol within the next decade. Above and beyond technology advancements required to transition from a corn to a cellulosic-based ethanol industry, uncertainty remains regarding feedstock availability and the environmental implications of its harvesting. As a land based resource, the distribution and magnitude of the cellulosic biomass must be quantified during early stages of development for both the overall cellulosic ethanol industry as well as for plant-scale planning at the local level. As part of this early assessment, the impacts of harvesting and processing large quantities of cellulosic biomass must be explored in order to avoid environmental degradation, such as topsoil loss through erosion, pollution of water resources through runoff, and nutrient loss as organic material is removed from
diverse ecosystems. Similarly, developing an assessment process at a scale appropriate for local communities can enable development of local resources for local consumption to increase efficient fuel use as well as distribute benefits of resource development across a broader social and economic base.

Due to cellulosic ethanol’s relatively nascent stage of development, there is an opportunity to assess its ability to be produced through mechanisms that might alleviate concerns around the development of its closely related cousin, starch-based ethanol. Prior to full-scale deployment of cellulosic technology, it is important to determine the capacity for cellulosic ethanol to be produced through sustainable and equitable practices.

This project explores the production potential of cellulosic ethanol at a local level using a tool that models the volume of available feedstock collected through sustainable practices and converts the total into an ethanol production potential. Resource availability will be based on local land use patterns, topography, soil, climate, and transportation infrastructure in conjunction with sustainability criteria that protect ecosystems from erosion, water pollution and nutrient loss. The biofuel calculator created for this project can be utilized not only to assess the potential for sustainable, decentralized development but can also provide local communities, land owners, resource managers and developers with tools and information to enable environmentally sound development and adaptable management of this resource.

In chapter 2, I set the stage for contemporary interests in cellulosic biofuel and provide a description of both conventional and cellulosic ethanol. In chapter 3, I summarize current efforts to quantify the magnitude of existing cellulosic resources, from the national level down to individual farms. This summary exposes the current gaps in
information available to parties interested in developing cellulosic ethanol from local sources. Situated within this gap is the concept of sustainable development of cellulosic ethanol, and the ability of communities to gauge local production potential based upon local site characteristics according to defined sustainability parameters. In chapter 4, the concept of sustainability is explored and the environmental criteria built into the biofuel calculator are described.

Using a case study of Center County, Pennsylvania I demonstrate the application this methodology, inputting spatial analysis results based upon local site characteristics into the biomass calculator created for this project. In chapter 5, I outline the procedures used to perform spatial analysis and calculate fuel production potentials. Finally, in chapter 6, I present and discuss the results of this analysis. Appendix A specifies the assumptions embedded in the biomass calculator model and Appendix B provides images of each worksheet of the calculator.
Chapter 2

Biomass for Fuel

Starch based ethanol has proved itself a viable transportation fuel over the last century, yet its future as a long term energy source remains dubious. This is primarily due to its primary feedstock and the manner in which corn is grown and utilized in the marketplace. This chapter does two things. First, it describes the feedstocks, conversion technology, benefits and disadvantages of sugar and starch based ethanol. Second, it presents analogous information for cellulosic ethanol, describing the feedstocks, conversion technology, advantages and disadvantages.

Sugar and Starch Based Ethanol

Starch based ethanol involves the chemical conversion of sugar based polysaccharides into an alcohol. Starch based polysaccharides come from the fruits, seeds and roots of plants that are the primary food components for people and constitute a very low fraction of global vegetable matter (McAlloon, et.al, 2000). Over 90 percent of conventional ethanol today is carbohydrate or starch based, refined from the simple sugars of sugar cane to the more complex starches in grain crops including corn or sorghum (Demirbas, 2005). Domestically, over 95 percent of ethanol is produced from corn, with the remaining 5 percent produced from feedstocks including wheat, barley, milo, cheese whey and beverage residues (Soloman, et.al, 2007).
Starch and Sugar Based Ethanol Technology

The production of ethanol from grain based feedstocks involves a seven step process, described by Solomon et al. (2007) and includes: milling, liquification, saccharification, fermentation distillation, dehydration, and denaturing of the alcohol.

The US Department of Energy’s (DOE) Energy Efficiency and Renewable Energy (EERE) Biomass program defines biofuel fermentation as:

“...a series of chemical reactions that convert sugars to ethanol. The fermentation reaction is caused by yeast or bacteria which feed on the sugars. Ethanol and carbon dioxide are produced as the sugar is consumed.”

The EERE provides the following “simplified” fermentation reaction equation for the 6-carbon sugar, glucose: as:

Eq. 1

\[ \text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 2 \text{CH}_3\text{CH}_2\text{OH} + 2 \text{CO}_2 \]

Glucose Ethanol Carbon Dioxide

The process for producing ethanol from sugar cane is slightly simpler and involves five of the seven steps listed above. Two steps are eliminated in processing simple sugars, the liquification and saccharification of the feedstocks (Soloman, 2007).
Benefits of Starch and Sugar Based Ethanol

One of the distinct benefits of ethanol relative to other alternative technologies such as hybrid electric vehicles is that it can substitute for oil as a product rather than simply reduce demand. Also, though debated heavily, it can be argued that conventional ethanol does result in a “positive energy return on investment” (Solomon, 2007, DOE, 2007). In this capacity, conventional starch-based ethanol results in a net reduction in greenhouse gases compared to oil combustion. Currently, oil-based transportation fuel is responsible for roughly one-third of U.S.-based greenhouse gas (GHG) emissions. The US Department of Energy calculates that starch based ethanol combustion is 18-29 percent less greenhouse gas intensive than oil (DOE, 2007). Actual reductions in GHGs, however, are sensitive to the manner of crop production and the volume of oil needed for planting and harvesting operations, discussed in the next section.

Disadvantages of Sugar and Starch Based Ethanol

Despite the benefits of starch-based biofuels described above, life-cycle impacts of this form of ethanol are heavily debated in the literature (Pimentel, 1991; Giampietro, et.al., 1997; Soloman, 2007; Lang, 2007). Environmental concerns are growing in regard to the long-term sustainability of starch based ethanol and stem largely from the fossil
energy and fertilizer inputs required for contemporary feedstock yields. Production of corn and grains for energy currently rely upon intensive, large scale, agricultural practices linked to reduced water quality, topsoil erosion and nutrient depletion.

As a result of the low diversity of feedstocks, conventional ethanol is primarily produced in the Midwest region of the U.S., thereby concentrating much of the economic benefits within this region while the produced fuel must be transported long distances to meet demand outside of the region of production. As a result, there are growing concerns regarding the reinforcement of this particular form of centralized production and ownership, from both an ecological and economic standpoint.

Finally, attention has been steadily increasing in regard to the inherent conflict between land and resources dedicated to crops for food versus land and resources dedicated to crops for fuel (Pu, et.al. 2007; Lang, 2007). This conflict is likely to become more pressing as demand for ethanol increases, and competition for the most productive arable land increases.

These concerns are not going unanswered, however, and ever greater attention and resources are now paid to other suitable technologies for ethanol production, including cellulosic ethanol and growing interest in algae based ethanol production. Many who advocate ethanol as a long term solution to the environmental and social impacts of oil use consider starch based ethanol as a short term necessity which can pave the way for more sustainable forms of biofuel in the future.
Cellulosic Ethanol

As mentioned, starch based feedstocks are not the only biomass material that can be processed into ethanol. Lignocellulosic biomass can also be used as an ethanol feedstock. Often referred to simply as cellulosic ethanol, this form of liquid fuel can be produced from numerous types of herbaceous and woody vegetation. In fact, the lignocellulosic fraction of plant material comprises over 90 percent of globally produced plant biomass (Szczodrak, et.al. 1995). In comparison, starch based polysaccharides from the fruits, seeds and roots of plants constitute less than 10 percent of global vegetable matter the cellulose biomass (McAloon, et.al.,2000).

As the name suggests, lignocellulosic ethanol is derived from plant based cellulose, a polymer of the disaccharide molecule found in the cell walls of mosses, seaweeds, annual and perennial plants and trees. There are three primary components to lignocellulose: 1) cellulose, a longer, higher weight disaccharide polymer comprising approximately 40 percent by weight of lignocellulose; 2) hemicellulose, a shorter polymer that holds the cellulose fibers together and comprises approximately 25 percent of lignocellulose; and 3) lignin, a polymer of propyl-phenol that provides cell walls with the rigidity they need to keep their form, is bound into the hemicellulose and is approximately 20 percent of lignocellulose by weight (Demirbas, 2005; Lange, 2007).
Cellulosic Ethanol Feedstocks

Potential feedstocks for cellulosic ethanol range from agricultural crops and residues to forest material to municipal and urban wastes to industrial byproducts. Cellulosic resources are often categorized as primary sources produced directly from the land; secondary sources in the form of byproducts from an industrial process; or tertiary sources in the form of waste from the consumption of manufactured products (Graham, 2007).

Agricultural Feedstocks

Agricultural residues encompass the “organic material left on fields” after harvesting activity has ceased (Jeanty, 2004). For example, corn stover residue includes the remaining stalks, leaves and husks left after harvest as well as unused organic material from the harvested fraction including cobbs (Jeanty, 2004). Crop residues post-harvest exist for virtually all crop types, yet the quantity and quality of the resource as a feedstock varies as a function of yield, ratios of straw to grain, and ratio of carbon to nitrogen levels within the specific crop type. Crops with relatively low carbon-to-nitrogen ratios, such as soybeans with a 20:1 ratio, decompose relatively quick after harvest as compared to crops with higher carbon ratios, such as corn with a 30:1 - 70:1 ratio (Jeanty, 2004). For this reason, not all crop types are considered in this study, even if it is grown within the study region. For the purposes of collecting residue, the crop
types considered in this study include: corn for grain, corn for silage, hay (alfalfa and other), wheat, barley, oats, and rye.

The removable amount of cellulosic material from fields varies across landscapes as a function of soil characteristics, crop type, climate and hydrologic properties. There is a substantial volume of research on this topic (Graham, 1994; 2007; Nelson, 2002; 2004; 2006; Andrews, 2006) and dedicated or short rotation energy crops (Botha, et.al., 2006; Dickmann 2006; Gallagher, et.al., 2006; Arevalo, et.al., 2007). Local soil characteristics are an important determinant of removable crop residue and are therefore important to incorporate into any local resource assessment.

**Dedicated Energy Crops**

Crops grown specifically for the purposes of energy production generally labeled as dedicated energy crops. Currently, two broad categories of dedicated energy crops are under development:

- Short rotation woody crops harvested every 3-10 years including fast growing hardwood species like willow and hybrid poplar (Kuzovkina et.al, 2004; Botha, et.al., 2006; Dickmann 2006; Gallagher, et.al., 2006; Arevalo, et.al., 2007), and
• Herbaceous energy crops harvested annually including the perennial 
grasses switchgrass, reed canary grass, miscanthus (Fallon, 2002; Sims 

These crops can often be grown on land less suitable for row or annual crops and, 
once established, these perennial and short rotation crops are lower in intensity regarding 
energy and fertilizer inputs (Adler, 2007). Research has also indicated that cellulosic 
feedstocks produce greater yields of energy per ton of feedstock, in the order of up to 
twice the yield for even the most efficient grain crops (Sims et.al, 2006). To date, there 
is a substantial volume of research on yield and recoverability of cellulosic material from 
perennial and short rotation woody crops for energy production (Adler, et.al., 2006; 
Botha, et.al., 2006; Dickmann 2006; Gallagher, et.al., 2006; Arevalo, et.al., 2007; Adler, 
et.al., 2007).

Forestland Feedstocks

Forest materials round out the primary, land based sources covered in this study, 
and include all woody material removed from forestlands for the purposes of ethanol 
production. Forestland itself is land that is at least 10 percent stocked with trees, is at 
least 1 acre in area, is not developed for non-forest use and includes all timberland and 
non-commercial forestland (Fallon, 2002). Forest residue is material that is “not 
harvested or removed from logging sites” as well as material from thinning activities and
the “removal of dead and dying trees” (Fallon, 2002). There is substantial research on the recoverable amount of cellulosic material from forestry feedstocks, though the magnitude and nature of material removed from forests can vary widely depending upon the managements practices utilized (Baath, et.al., 2002; Gullberg, et.al., 2006; von Belle, 2006; Polagye et.al., 2007).

Growing stock trees are one category of forest resource and includes all live trees (including seedlings and saplings) of commercial species used for sawtimber or poletimber. Alternatively, “low-use” or “low-grade” wood material as defined by the Pennsylvania Hardwoods Task Force (2007) encompasses non-commercial forest material “that is often not harvested due to various market factors” and is generally composed of small diameter, low grade, low value species that are not merchantable. This project combines the residue left after the logging of growing stock trees with “low-use” wood resources to represent available forest material.

**Industrial Feedstocks**

Industry residues relevant to this study include both primary mill residue and secondary wood manufacturers’ residue or waste. Mill residue from stationary sawmills is the byproduct of processing trees into lumber, plywood or paper (Fallon, 2002). Secondary manufacturers include entities that use pre-cut lumber to create wood products or components but do not harvest timber or produce lumber directly (Fallon, 2002).
Industry waste is grouped into three categories for the purposes of this report: bark, course and fine residues.

**Solid Waste Feedstocks**

For the purpose of this study, this category of resource encompasses municipal solid waste, or any residential or commercial solid waste, including non-recycled durable and non-durable goods, containers and packaging, yard trimmings, mixed office paper waste, newspaper, corrugated cardboard and other miscellaneous organic material derived from wood and plant resources that are ultimately disposed of (EIA, 2007; DEP, 2006; Fallon, 2002). Depending upon state level accounting, waste from construction and demolition suitable for ethanol production may be included in municipal solid waste totals or accounted for as a distinct waste category. For this study, construction and demolition waste was accounted for only within the municipal solid waste data.

**Cellulosic Ethanol Technology**

The five simple sugars found in cellulose that comprise the substrates for fermentation into ethanol are bound up in a dense network of undigestable lignin and hemi-cellulosic material. In order to produce ethanol from lignocellulose materials, pre-
processing of the feedstock material must be introduced into conventional ethanol production technologies (Demirbas, 2005).

The sources of sugar and the mechanism to obtain that sugar are what differentiate cellulosic ethanol from conventional varieties. Where the simple sugars and starches fermented in conventional ethanol production are relatively easy to access by yeasts, the carbohydrates bound up in the components of lignocellulose form a “recalcitrant matrix analogous to rebar in concrete” (Hess, et.al., 2007).

Chemical hydrolysis, enzymatic hydrolysis and gasification are three current methods by which lignocellulosic material is pretreated, yet all of these technologies are still in early stages of development. For the biochemical process of hydrolysis, incoming feedstock material is treated either with acid or enzymatic solutions to “liberate” the sugars bound up in lignocellulose for fermentation (Qu et.al, 2006; Badger, et.al, 2006;

![Bioethanol Production Process Diagram](http://www1.eere.energy.gov/biomass/abcs_biofuels.html#prod)

**Figure 2-1:** Ethanol production steps for sugar and starch technologies compared to cellulosic ethanol production.

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Cameron, et.al, 2007). Hess (2007) indicates that the research into enzymatic hydrolysis has advanced significantly over the last few years to the point that it is more economical than acid hydrolysis. Ideally, hybrid biorefineries will combine thermo and biochemical processes to make full use of the biomass feedstock material, for example utilizing the byproducts of biochemical hydrolysis to fuel thermochemical energy production for on-site heat and power (Lange, 2007; Hess, 2007).

**Benefits of Cellulosic Ethanol**

Cellulosic ethanol has been calculated to be as much as 85 percent less greenhouse gas intensive as oil (DOE, 2007). This differential is due, in large part, to the lower energy intensity of its feedstock production and collection, both those feedstocks directly produced for energy production and those that currently exist as waste products. Studies have shown that cellulosic feedstocks can produce higher yields of energy per ton of input. As an example, Simms, et.al. (2006) found that cellulosic feedstocks can produce as much as 10 tons of biomass available for fuel production per acre versus 4 to 5 tons from the most efficient grain crop yields. The yield per acre potential for cellulosic feedstocks is one of the primary reasons for its lower fuel and GHG intensity.

Cellulosic biomass exists in much greater quantities than starch based biomass, and can therefore be derived from many resources in many regions of the world. In
addition to the high potential biomass yields and low GHG intensity associated with cellulosic feedstocks, the appeal of this “second generation” biofuel resource is greatly increased by the diversity of potential feedstocks (Lange, 2007). The diverse nature of cellulosic material increases its potential to bear economic and environmental benefits across broader regions and populations than conventional starch based ethanol. Though the technical processing of cellulosic ethanol still remains largely in the pre-commercialization phase, pilot scale facilities are being designed to accommodate different types of material (Pu, 2007).

Finally, cellulosic residues from agriculture as well as from dedicated energy crops reduce the pressure that starch based ethanol brings to bear on food supplies while also reducing environmental impacts associated with the direct cultivation of relatively resource intensive sugar and grain crops grown exclusively for fuel (Adler, et.al., 2007).

**Disadvantages of Cellulosic Ethanol**

Despite significant and ongoing advancement in cellulosic ethanol research, there is still substantial uncertainty regarding the deployment of this technology and its viability as an alternative fuel source. A better understanding of the resource base that will provide the necessary feedstocks by fuel type, in terms of amount, location, appropriate scale of development and its subsequent environmental and economic impacts is currently needed. Graham (2007) points to five areas were local scale resource
assessments will be crucial for an accurate assessment of cellulosic ethanol development potential, including: transportation infrastructure, climate, topography, soils and land use.

Graham (2007) also points out that feedstock diversity is not only a potential benefit of this form of energy, but also imposes significant challenges for this industry in assessing resource availability over the long term. Questions exist regarding the existing resource base for not one input in the supply chain but several. Similarly, a diverse set of feedstocks will require diverse equipment for its collection and processing.

Where direct competition for the plant components that are foundational to global food supply is reduced by shifting to non-digestible cellulosic feedstocks, there is still a risk that dedicated energy crops will impose upon food resources by competing for arable land. Finally, opportunities to modify grain crops to optimize for a more energy friendly ratio of grain to residue may further impact on grain supply for food to an unknown degree.
Chapter 3

Cellulosic Biomass Resource Assessments

Quantifying cellulosic biomass volume, availability and accessibility is critical for moving this industry forward and providing the basis for biorefinery site location. Assessments of varying scales and methods have been performed across the globe and have shed light on biomass potentials in Europe, Asia, South America and Africa (Fauu et al., 1998; Hillring, 2002; Hansson, et al., 2006; Qu, et al., 2006; Wicke, 2006; Botha, et al., 2006; Batidzirai, et al., 2006). The biofuel industry, educational and research institutions and national laboratories have developed several resource potentials domestically as well, and range in scale from national to regional to state and county level. I present an overview of biomass resource assessments relevant to cellulosic ethanol development beginning with national scale investigations. State and regional assessments follow, with reference to important tools available at the sub-state level down to the individual farm level. This summary demonstrates where gaps in information exist for parties interested in developing cellulosic resources at a local, community or county level.
National Assessments

In the United States, several studies have generated relatively course scale, generalized assessments of the cellulosic resources at the national and state level. In 2005, the Department of Energy (DOE) released the Billion Ton Report assessing the nation’s ability to sustainably produce one billion tons of biomass feedstocks, including cellulosic sources (Perlack, et.al., 2005). A supply of one billion tons of biomass feedstock was the quantity of feedstock deemed necessary by the DOE to displace 30 percent of the nation’s current petroleum demand. This feasibility study considered starch based feedstocks as well as the major biomass feedstock categories described in this study including agricultural, forestry, urban and municipal waste streams as well as industrial waste products. The results of this, and other DOE studies including a geographically based biomass assessments for the US (Milbrandt, 2005) determined that the nation would be able meet the demand of one billion tons per year. These broad scale assessments are important to gauge the aggregate resource pool that exists nationally, and developed comprehensive models to do so that informed this project. Though thorough theoretically and procedurally, the application of national averages to local resource potential assessment leads to obvious resolution limitations due to local site variability.

These studies also acknowledge important prerequisites for sustainability such as terrain related forest accessibility and erosion protection from agricultural residue. However, these factors were again based upon national averages of forestland accessibility and for removable quantities of field residue rather than local soil conditions. This is understandable given the scope of the assessment, yet makes obvious
the need to determine local conditions and the resulting available biomass for development to proceed.

**State and Regional Assessments**

State-based resource assessments have been created as well, both in advance of the billion ton report and following. Fallon, *et.al.* (2002) presents a procedure for performing a literature based assessment of wood based cellulosic feedstocks based upon data and resources for the Commonwealth of Massachusetts. This article suggests some critical data sources for several categories of feedstock such as construction and demolition waste and the recoverable amount of municipal and urban waste that might be available through published data compiled at the state or city level. Fallon highlights several uncertainties and procedural challenges that arise while conducting a resource assessment, including: the risk of double counting resources captured in more than one biomass category as well as missing, incomplete or inconsistent data or biomass definitions. Fallon also questions the determination of appropriate assumptions regarding the rates of biomass growth versus harvestable biomass, the appropriateness of biomass from municipal solid waste and construction and development waste as well as demand for various feedstocks for non-energy applications including. mulch, wood fuel, soil nutrient amendments, animal bedding, pulp and fiber (Fallon, 2002).
More recent state level assessments have followed procedures similar to Perlack’s Billion Ton Report and used data sources available nationally (Jeanty, et.al. 2004, Frear, et.al., 2005). The results of these studies have therefore produced relatively similar results to the DOE assessments, though some of the underlying assumptions have varied slightly. Pennsylvania currently has two resources assessments that estimate feedstock availability for energy production. Neither assessment is exclusive to cellulosic resources or ethanol as a fuel, but they have provided important base lines for the theoretical resource potential at the state level.

Morrison et.al. (2007) recently released an assessment of several biomass sources available in the Commonwealth of Pennsylvania on a county by county level. This report captures a range of feedstocks appropriate for biofuel, electricity and heat generation. This report provides a course scale estimate of potential biofuel feedstocks in Pennsylvania that are available as crop residue, forest sources and primary wood industry residue. This is a good first step for the state in determining the potential from these categories of feedstock. Though this report focuses on describing the theoretically available resource base at the county level, it still does not address some of the key issues raised by Graham (2007) including transportation infrastructure, climate or soils.

Biofuel calculators are less common in the literature than resource assessments, yet there are examples designed to calculate biofuel production potential at the county level such as the New Jersey BioEnergy Calculator and Bioenergy Resource Database (NJAES, 2007) and the online i-Farm biofuel calculator applicable at the individual farm level (www.i-farm.org). The New Jersey calculator produces a county by county estimate of biomass energy output from several energy conversion technologies,
including cellulosic ethanol. This tool uses similar information inputs as the various state level resource assessments, including Pennsylvania, and therefore does not necessarily consider local level characteristics. The online i-Farm tool is an example of a calculator that does consider local characteristics in detail, yet intimate knowledge of agricultural practices on a field by field basis are required to use this tool. i-Farm is a very precise tool for estimating agricultural cellulosic resource potentials, yet the depth of knowledge necessary to complete the tool at a community scale may be prohibitive. Also, this tool does not include resources beyond those in the agricultural sector. Both the New Jersey calculator and i-Farm tools are informative and helped guide the development of the calculator created in this study, but they still do not provide an opportunity to estimate cellulosic production potential based upon a full suite of feedstocks at local, county or community scale with consideration for locally specific spatial characteristics. In summary, existing attempts to assess local scale cellulosic resources have either not adequately considered local site characteristics, not considered sustainable collection or, on the other extreme, have been too narrow to be effective tools at the community level.
Chapter 4

Sustainability

The sustainable use of resources is a fundamental driver behind the pursuit of cellulosic biomass and sustainability is one of the primary objectives of this project. As a broad concept, sustainable resource use requires that current activity does not compromise the ability of future generations to meet their own needs. In practice, however, the concept of sustainability has proved challenging to apply. As a concept, sustainability has evolved to encompass environmental, economic and social concerns in a highly integrated fashion since emerging into the international scene in the late 1980s via the Brundtland report (Peet, 1992; Ulcak, et.al. 2003). Ulcak (2003) describes the three tenets of sustainability, summarized in the following:

Social Sustainability – “reflects the relationship between development and valid social norms. . .Activity is socially sustainable if it complies with these norms. . .”

Economic Sustainability – . . .”should be economically effective within the framework of ecological and social limits.:}

Environmental Sustainability – “The development process must respect the carrying capacity of life-supporting systems and by doing so contribute to their preservation including biodiversity protection”

These three tenets highlight the multifaceted aspect of sustainability, and highlight the varying yet related aspects of environment, economy and society as they relate to the larger concept.

Though cellulosic ethanol production is largely pursued for sustainability purposes relative to other forms of liquid fuel, it does not come without its own set of
concerns and potential pitfalls. Issues of resource and nutrient depletion still exist, and production models do not inherently guarantee sustainable cultivation, harvesting practices, a distributed allocation of the benefits of development, or an opportunity for local communities to be involved in the decision making and technology deployment. Two key aspects of sustainability are therefore embedded into this study: distributed resource development with opportunities for local involvement and benefit allocation; and resource harvesting and production practices that do not undercut ecosystem conditions and function.

With local involvement in development with the potential for local ownership, there is an increased opportunity for the benefits of development of local resources to be retained within local economies. Additionally, if fuel derived from local material is made available locally, there is an opportunity to retain energy dollars spent on transportation within that same economy rather that exporting that wealth out of the community, state or even country, as is now occurring in large measure with oil. In reference to community based biodiesel production, Van Dyne et.al. (1996) suggests that “the greatest potential for the farm sector and rural communities to share in value-added macroeconomic benefits will occur with community-based production and local ownership.” Van Dyne goes on to say that “without these conditions, the rural sector may have another high volume, low value-added commodity that will have minimal financial benefit to them and to rural communities.”

Doubts exist that local, distributed energy production represents a viable approach to efficient resource utilization, however. Gwehenberger, et.al. (2007) investigated the impacts of production scale on both the environmental and economic performance of
ethanol production facilities. They found that smaller scale, decentralized facilities could significantly reduce ecological impacts stemming from resource collection and processing while not substantially reducing the facilities economic viability (Gwehenberger, 2007). They also determined that the fundamental conflict between economies and ecologies of scale for biofuel production hinge upon the transportation requirements of the system, for both feedstock inputs and for process outputs in the form of fuel and byproducts. Energy requirements by the facility were also critical for determining the economic and ecosystem viability. Smaller scale facilities possess a greater likelihood of meeting their own energy needs with system byproducts, with the capacity to return energy to the grid versus large scale facilities that must cover their energy requirements with energy from the grid.

Environmental sustainability is also heavily embedded in this project and practices that undermine ecosystem condition can have long term, cascading impacts that extend into economic and social spheres as ecosystem services are compromised. Local communities often pay the price for development that is disproportionately damaging to local ecosystems while not sharing benefits adequate to cover the underlying costs of that damage. J. Pretty (1998) goes further and links the “degradation of natural capital by modern agriculture to losses of biological diversity, cultural diversity and a degradation of landscape and rural space, thus reducing social capital.” This relatedness between the environment, economy and society is at the heart of contemporary concepts of sustainability.

Lack of information regarding the accessible and long term resource supply for this, or any local resource, is a considerable barrier for community involvement. This
project enables increased local involvement with the creation of a flexible tool that calculates resource potentials and can indicate, spatially, where those resources exist. Additionally, this tool employs sustainability criteria that function to limit degradation of ecosystem conditions by minimizing soil erosion and nutrient losses which can have subsequent impacts upon water quality, hydrology and general land productivity. Practices aimed at limiting negative impacts on ecosystem conditions and built into the biofuel calculator therefore include:

1. Identification of erosion prone soils in both forests and non-arable soils for agriculture and exclusion of biomass harvest activity on those soils,
2. Establishment of riparian buffer zones around all streams and water courses in forest and agricultural land within which no harvesting activity can occur,
3. Establishment of maximum residue removal rates for both forest and agricultural resources to protect against erosion and nutrient loss,
4. Utilization of existing road infrastructure only for transport of cellulosic material gathered from forests, and
5. Recognition and accommodation for potential competitive uses for cellulosic material within the study area whose replacements may simply be imported if local substitutes are not available.

The degree to which these criteria are applied directly determines the level of biomass resource deemed available for biofuel production. The scale of collection of cellulosic resources is critical for each of these criteria in terms of both depth (what fraction of a resource is collected in a given area) as well as breadth (what fraction of an
area is subject to resource collection). The section below describes these criteria in greater detail and outlines how they are applied for the purposes of this study.

**Sustainability Criteria**

Environmental issues associated with the removal and use of cellulosic material at the local scale include ecosystem impacts of erosion on water quality, altered or impaired nutrient cycles and reductions in biodiversity (Graham, 2007). The tools created in this project (the spatial analysis procedure and biomass calculator) illustrate the generation potential of a distributed, sustainable cellulosic biomass. The criteria described in the previous section were created to address, to the degree possible within the scope of this project, the environmental issues raised by Graham. The selected criteria outlined above directly address erosion, water quality and nutrient issues by limiting exposure of vulnerable soils, utilizing existing roadways, establishing riparian buffers and limiting material removals. Secondary benefits may also result from application of the selected sustainability criteria with regard to increased wildlife habitat, biodiversity and improved ecosystem function.

However, the criteria selected for this project do not reflect or encompass all of the potential environmental considerations relevant across all localities for this resource to be as environmentally benign as possible. Rather the selected criteria represent a set of practices that address some of the core, fundamental concerns associated with cellulosic biomass use and were also manageable at the level of this study. Tillage and forest
treatment practices were not explicitly selected; rather, the calculator addresses these factors only as they are reflected in current and historical biomass yields and removals, both of which are inputs into the calculator. Additional issues related to petrochemical use and organic agricultural practices were not directly addressed, though they arguably impact biomass yield.


Soil erosion and nutrient loss are important considerations when removing organic material from both forest and agricultural ecosystems. Harvesting equipment and activity can severely damage soil layers and the mass removal of organic material not only exposes topsoil layers to the elements, but can cause deficits in certain soil nutrients, organic material, and wildlife habitat. Soil types that are particularly vulnerable to harvesting activity must be identified, and those areas that cannot sustain harvesting activity without severe risk for damage should not be subject to biomass removal if the resource is to be managed sustainably.

Andrews (2006) addresses the most critical aspects of soil degradation that may result from harvesting agricultural residue, including erosion, nutrient loss, impact on soil organisms, water quantity and soil surface temperature. She suggests several guidelines for enhancing sustainability, including removal rates that adhere to established limits by soil and crop type as established by Nelson (2002) as well as conservation management practices and alternative crop types based upon local conditions (Andrews, 2006). Graham (2007) reports that even under no-till practices, up to 40 percent of cover needs
to remain on the field surface to limit erosion. Recoverable agricultural residue that will not further diminish soil organic matter for this project was established according to recommendations described in Nelson (2002) and Andrews (2006). Sustainable levels of recoverable forest material were described by Polagye et al. (2007), the Sustainable Bioenergy Framework (2007) and IPMET (2006), and influenced the selection of erosion and removal rate criteria for the forest resource category. For each land based resource, resource collection rates were based upon soil erosion vulnerability from harvesting activity and the allocation of crop types were based upon local soil characteristics and conditions.

Moreover, local harvesting of biomass for local fuel production enables greater opportunities for nutrient reapplication. If not used to produce energy for the facility, byproducts from fuel production including lignins and ash can be reapplied to the same systems that yielded the feedstock material therefore retaining a greater fraction of the initial nutrient load (IEA, 2002; Gwehenberger, 2007).

2. Water Quality and Local Hydrology

Removal of biomass material not only raises issues regarding soil erosion but also introduces risks for waterways due to increased levels of runoff. Harvesting activity, whether for the purposes of acquiring forest material or agricultural products, has a profound effect on the quality and health of natural waterways and water resources. Increased levels of runoff, non-point source pollution and increased sediment loads all
result from disturbance of the land surface associated with logging and agricultural activity. However, harvesting and agricultural practices can be managed to significantly reduce these impacts. One strategy involves establishing and maintaining riparian buffers around natural waterways, particularly for streams and wetlands. These buffers prevent direct degradation of stream banks as well as provide greater opportunities for runoff to infiltrate into ground water, naturally filtering non-point source pollution including herbicides, pesticides and other chemical residues from harvest activity.

3. Proximity of Resource to Road Infrastructure

The distance that feedstocks must travel to reach the site of fuel processing and production is an important consideration for all forms of biomass derived energy. The low mass and energy density of relatively bulky cellulosic feedstocks may dictate that the most environmentally and economically sustainable system for production is a distributed network of production facilities sited near local resources. Critical issues surround developing an infrastructure for transporting feedstocks to the processing facility and the ultimate proximity of the processing facility to market (Suurs, 2002; Towler, et al., 2004; Hamelinck, et al., 2004; Badger, et al., 2006; Hansson, et al., 2006; Wicke, 2006). Experience with the transportation of cellulosic and woody material for the Pennsylvania Fuels for Schools program has indicated that a 50 to 70 mile radius of material transport has been economically viable (Ray, personal communication). Furthermore, evidence suggests that long distance transportation of biomass feedstock may in fact be significant cost barriers to producing cost-competitive fuel (Van Dyne, 1996; Gwehenberger, 2007).
Also a factor of transportation infrastructure is the proximity of forest material to existing roadways, and the need for harvesting equipment to deliver forest material to landing sites for collection and transport. Opportunities to collect forest material within closer proximity to existing roadways will arguably decrease the impact of harvesting on forest soils and ecosystems. Yet, ultimately, the value of forest biomass in terms of dollars paid per delivered ton will dictate the harvesting system and the economically viable distance harvesters will travel to collect material, particularly in regard to low use or low value forest products. Li, et.al. (2006) summarized research indicating that thinning underutilized material can cost as much as $70 per ton while markets for thinned material for energy have historically paid only $25 to $35 per ton for energy and woodchips, respectively. The price paid by the cellulosic ethanol industry for forest biomass material may therefore dictate not only fraction of currently harvested growing stock dedicated to energy production, but also the distance which harvesting operations will go to collect residue and lower use forest material.

4. Competing Uses for Resources

There may be potential limitations on the availability of biomass for fuel production due to alternative demands on those resources, as well. Increased collection and removal of cellulosic resources for energy production may come at a cost for members of the community who rely on those same resources for other purposes. Though several categories of cellulosic biomass are generally considered waste, many potential feedstocks do in fact provide economic benefits ranging from erosion protection
to nutrient source inputs to low or no cost fuel sources for communities and households. Altering the pattern of use of these materials will therefore generate both environmental and economic repercussions, some favorable and others less so. For these reasons, this project enables competitive uses of all categories of biomass material to be considered in the final production potential.

In summary, to achieve the goal of sustainable cellulosic ethanol development that is manageable at the local level, a greater understanding of local resources must exist. The aim of this study is to create a tool that enables the sustainable development of cellulosic ethanol that is: 1) widely accessible, 2) created to determine a resource potential that is sensitive to local environmental conditions and limitations, and 3) that can investigate sustainable development potentials at scales down to the county or community level depending upon information availability.
Chapter 5
Methods and Procedure

The steps of this project include: 1) development of a procedure to determine the current cellulosic biomass feedstock sustainably available (in tons) for the production of ethanol based upon spatial analysis of land cover, soil type and distribution, topography, and existing road infrastructure; 2) creation and use of a model to calculate the ethanol production potential in gallons from an aggregated feedstock total in tons for comparison against gasoline consumption; and 3) illustration of the spatial analysis procedures and the biofuel calculator in a county level case study. This chapter presents each of these steps, in turn, including:

1) A general description of the resources considered for this project;
2) An outline of the spatial analysis process used to determine harvestable land area after application of sustainability criteria;
3) A description of the inputs and process for generating and converting a biomass total for each resource category into a biofuel production potential using the biofuel calculator; and
4) A description of the study site selected and data sources used to illustrate the application of the above spatial analysis and calculator procedures.
1. Cellulosic Biomass Resources

Varela (1999) and Fallon (2002) identified four comprehensive categories of biomass that I utilize in this study:

1. Agricultural residue and dedicated energy crops,
2. Forest material,
3. Industrial residue, and
4. Municipal solid waste.

These categories capture a large fraction of available biomass, and are commonly reflected in the literature. The agricultural residue, dedicated energy crop and forestry residue categories are referred to throughout this study as land-based resources. These resources are subject to sustainability criteria that do not directly affect the non-land based resources categories including soil erodability, water quality impacts from harvesting, and proximity to roadways. The land based aspects of the forest and agricultural resources involved direct removal of biomass from the land and therefore enabled spatial analysis of soils and water systems to be analyzed in relation to resource removal. Non-land based resources reflect biomass that has already been removed from the land and therefore soil, riparian and roadway spatial analyses are not directly applicable. It is not to be said that these issues shouldn’t be considered for these resources, but for the purposes of this study, the non-land based sources were treated as existing byproducts of other industrial processes or as consumer waste. However, non-land based sustainability criteria that were not land based in nature were applied to each resource type and include the resource removal rate, recoverability of the resource, and competitive uses for that resource.
Acres of forest and agricultural land identified as vulnerable to soil erosion (as identified by the Natural Resources Conservation Service) or within designated riparian buffer zones were removed from the total harvestable acres. The basis for removing land area based upon soil characteristics for both agricultural and forests and the basis for riparian buffer areas are detailed in subsequent section of this chapter. The magnitude of removals with regard to riparian zones defines each sustainability class applied in this study. Additionally, the high sustainability class involved residue removal rates of 40 percent for the agricultural sector versus 60 percent for the low sustainability class.

2. Harvestable Land Area: Spatial Analysis of Land Based Resources

This study was designed to utilize the analytical power of Geographic Information System (GIS) software and the depth of related data sets for the spatial analysis component in combination with the accessibility of Microsoft Excel software to perform the calculations generating local ethanol production potentials. I used ArcGIS Spatial Analyst software to identify and isolate the harvestable area for land-based feedstocks in accordance with selected sustainability criteria. The steps involved in this process include: 1) identifying existing land use patterns and isolating forest and agricultural land; 2) identifying the spatial distribution of soil types in each of these land cover types; and 3) removing soil types that violate sustainability criteria. The resulting area reflects the harvestable land area for each of the land-based resource categories.

A Land Use Land Cover (LULC) dataset identified and quantified existing land use patterns for the study site of interest, and was used to isolate areas designated as
forest or agricultural land to get total area and coverage for each respective category. In keeping with the sustainability objective of this study, all woody wetland and emergent wetland areas identified in the LULC map were not included in the harvestable area total despite the fact that they produce potential cellulosic biomass resources.

Forestland Area Removals

The U.S. Department of Agriculture’s National Resource Conservation Service (NRCS) National Forestry Manual (2002) describes soil characters and features while the NRCS Soil Survey Map locates soil types and associations spatially. National Soil Information System Interpretations ratings of soil features reported in the National Forestry Manual were used to identify soil components deemed unsuitable for various planting and harvesting activities. I isolated the following categories of soil ratings as particularly relevant to cellulosic biomass removal from forests, and provide brief descriptions of each characteristic below (NRCS, 2002):

- Potential Erosion Hazard (Off-Road/Off-Trail): Indicates the hazard or risk of soil loss from off-trail areas after disturbance activities that expose soil surface and assess sheet and rill erosion from exposed soil surfaces from silvicultural practices and result in 50-75 percent bare ground with any type of equipment.
  - Soils with erosion risks rated as very severe (significant erosion is expected, control measure costly and impractical) to severe
(erosion is very likely, control measures advised) were removed from total harvestable acres.

- **Harvest Equipment Operability**: Assesses suitability for operating harvest equipment based upon the need for off-road transport or harvest of wood by ground-based wheeled or tracked equipment for activities that disturb 35-75 percent of surface area up to a depth of 45 cm.
  - Soils rated as poorly suited (where one or more restrictions make use of equipment impractical or unsafe) were removed from total harvestable acres.

- **Suitability of Soil for Wetland Habitat** (Based exclusively on Soil Survey Designations, USDA 1981): Soils suitable for wetland habitat including marshes, swamps and open water areas (associated with submerged or floating wild herbaceous plants). Soils rated as good potential wetland habitat were removed from total harvestable acres (in addition to wetland areas identified with the LULC map analysis).

Soil component extent data came from the USDA’s Soil Survey for Centre, County Pennsylvania (1981) and Tabular Data Version (2008). Spatial analysis with ArcGIS identified and enabled extraction of the soils that surpassed the ratings described above. As a result, soils vulnerable to severe erosion under harvest conditions or soils with features which would make harvesting activity dangerous or extremely improbable due to slope or rockiness of soil, as well as soils highly suitable for wetland habitat were extracted from the total forestland identified with the LULC map. The remaining forestland was labeled as “harvestable” for the purposes of this study.
Agricultural Land Area Removals

The NRCS utilizes Land Capability Classifications (LCC) to identify harvestable land in the agricultural land category and I used this classification scheme to identify soil components suitable for crop production in a fashion similar to the process used in identifying harvestable forest acres. The LCC groups soils into eight broad classes that represent “progressively greater limitations and narrower choices for practical use” (NRCS, 1981). Classes I-IV are considered arable land and for the purposes of this study, the total sustainable agricultural area includes land identified by the LULC map as used for row or hay crops and is simultaneously recognized as arable land by LLC definitions (i.e. within classes I-IV). Arable soil classes are described below:

- Class I soils have few limitations that restrict use, allocated to conventional crop production in this study,
- Class II soils have moderate limitations that restrict use: allocated to conventional crop production in this study,
- Class III soils have severe limitations that restrict use, allocated to conventional crop production in this study, and
- Class IV soils have very severe limitations that restrict use. Soil subclasses e and s were allocated to switchgrass, subclass w were allocated to willow

Agricultural areas within soil classes I-III were allocated to conventional crops, and maintained relative production ratios for conventional crops consistent with 10-year historical averages calculated from the USDA’s National Statistical Service database for
Centre County. Agricultural land in class IV was divided by subclass $e$, $s$, and $w$ according to the NRCS classifications based upon characteristics that limit the land’s practical use for agriculture. For instance, subclass $e$ represents soil limited by risk of erosion, $s$ represents soil limited by shallowness, prone to drought or has a high stone content and $w$ represents soils limited by elevated soil moisture (NRCS, 1981). Class IV soils, considered the most marginal of arable soils, were isolated and allocated to dedicated energy crops that are purported to have higher functionality in marginal agricultural land. Soils limited by erodability and stone content were allocated to switchgrass cultivation and Class IV soils limited by high soil moisture were allocated to willow cultivation for the purposes of this study.

**Riparian Buffers**

In accordance with the sustainability objective of this project, riparian buffers were created for all streams in the county flowing through both agricultural and forestland categories. All land falling within riparian buffers was considered non-harvestable for the purposes of this study. To create the buffer zones at both high and low sustainability levels, I used National Atlas data to identify Pennsylvania streams in attainment as distinct from streams not in attainment of Environmental Protection Agency designated-use standards as defined in the Clean Water Act. The “low sustainability class” created in this study excluded land within riparian buffer zones set at 25 meters from all streams (both in attainment and non-attainment) while the “high
“sustainability” class removed all acres of land within 50 meters of streams that are in attainment of designated uses and land within 100 meters of riparian areas that are not in attainment of designated uses. These buffer distances are based upon existing buffer strip width mandates established by state and local laws as identified in a riparian zone management report by US Army Corps of Engineers (1991). The Army Corp reports stream water resource buffer widths ranging from a minimum of 1.5 m in Idaho up to 92 meters in Wisconsin with an average of reported buffer strips of roughly 26 meters. These distances vary greatly and reflect standards that are fixed as well as standards that vary according to local terrain. The buffer applied in the low sustainability class is based roughly on the average level reported by the Army Corp of Engineers of 26 meters. The buffer distance in the high sustainability class was more arbitrarily defined as 50 m for attaining and 100 m for non-attaining streams to impose more stringent protection than the low sustainability class, yet still within reasonable proximity to the highest level identified in the Army Corps of Engineers report.

Buffer zones utilized in this study were fixed distances rather than variable based upon terrain or land use, which is potentially less preferable in terms of riparian zone management. Yet, other criteria were used to account for some degree of local terrain issues which resulted in removals of land area with severe terrain limitations (e.g. extreme slope) and overlap between riparian buffers and terrain limitations were quantified. Also, where buffer zones were responsive to stream class in the high sustainability class, they were not differentially tailored to agricultural or forestry land uses. Agricultural buffer zones are often higher than those proscribed for forest areas, however, Belt et.al. (1992) reports that sediment can flow overland through a buffer as
far as 91 meters in a forest system. As a comparison, minimum NRCS filter strip recommendations for Pennsylvania are much lower than the levels selected for this study, and start at a level of 20 feet for sediment and organic particulate regulation, with an additional 30 feet added if dissolved contaminants are introduced (NRCS, 2002). Habitat creation and restoration for riparian plants and wildlife increases buffer length further (beyond the 50 cumulative feet for protection against sediment runoff and dissolved contaminants). Biomass potential was calculated only after soils extents unsuitable for harvest and riparian buffers were removed from both the forestry and agricultural land coverages.

**Distance to Roadways**

This project analyzed available forest biomass based upon increasing resource proximity to roadways. Due to the dynamic relationship between price and harvest distance, this project estimated available forest biomass in Centre County for all harvestable forestland as well as for harvestable forestland within 50 m, 100 m and 500 m of existing roadways. I generated incrementally increasing buffers around unioned National Atlas and Pennsylvania Department of Transportation road data and clipped harvestable forest acres with the resulting area to determine forestland acreage within each distance from the roadway.

In sum, the spatial analysis of land based resources resulted in a harvestable acreage total for forests and agriculture. This analysis also revealed the dominant tree
species and determined the total acres of cropland dedicated to energy crops.

Sustainability variables quantified with spatial analysis included soil limited acres, acres within riparian protection zones and forestland proximity to roadways. Additionally, agricultural acres within LCC class IV were split into subclasses based upon soil characteristics and allocated to one of two dedicated energy crop types (See Table 1).
Table 1: Land-based resources and the applied sustainability criteria impacting total harvestable land area and associated assumptions.

<table>
<thead>
<tr>
<th>Land Type</th>
<th>Criteria</th>
<th>Removals</th>
<th>Assumptions/Notes</th>
<th>Issues Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forestland</td>
<td>LULC Category</td>
<td>Isolated all conifer, mixed and deciduous forestland, excluded all other categories including woody and emergent wetland and urban</td>
<td>Based upon State Level LULC Map developed at Penn State. Assumed no major LU shift.</td>
<td>Existing local land use patterns and site characteristics</td>
</tr>
<tr>
<td>Soil Type</td>
<td></td>
<td>Removed all soils from LULC forestland limited by severe erosion potential, severe equipment limitations, or strong suitability for wetland habitat</td>
<td>Based upon soil characteristics identified and assigned by the NRCS forestry manual and county soil survey</td>
<td>Soil erosion potential and erosion impacts upon water quality based upon local site characteristics.</td>
</tr>
<tr>
<td>Riparian Buffers</td>
<td>LS buffers removed land from harvestable forest acres within 25 meters of streams. HS buffers removed land within 50 m of attaining streams and 100 m of non-attaining streams.</td>
<td>Based upon state and local level riparian buffer regulations identified by the Army Corps of Engineers</td>
<td>Water quality through erosion reduction and nutrient capture and infiltration</td>
<td></td>
</tr>
<tr>
<td>Distance to Road</td>
<td></td>
<td>Harvestable forest acres, after application of the above criteria were identified for their proximity to existing roadways: increasing from 50 m to 100m to 500m to all harvestable forest areas.</td>
<td>Arbitrary assignment of incremental distance from roadways</td>
<td>Soil erosion potential based upon harvest equipment impacts and energy intensiveness of resource harvest</td>
</tr>
<tr>
<td>Agricultural Land</td>
<td>LULC Category</td>
<td>Isolated agricultural land designated as row crops and hay/ pasture land, excluded all other categories including emergent wetland</td>
<td>Based upon State Level LULC Map developed at Penn State. Assumed no major LU shift.</td>
<td>Existing local land use patterns and site characteristics</td>
</tr>
<tr>
<td>Soil Type</td>
<td></td>
<td>Removed all soils from LULC agricultural land classified as non-arable. Assigned remaining arable agricultural land in Classes I-III to conventional crop production and Class IV to dedicated energy crops.</td>
<td>NRCS defined Land Capability Classifications identified soil components as arable and by restriction subclass.</td>
<td>Soil erosion potential and erosion impacts upon water quality based upon local site characteristics.</td>
</tr>
<tr>
<td>Riparian Buffers</td>
<td>LS buffers removed land from harvestable forest acres within 25 meters of streams. HS buffers removed land within 50 m of attaining streams and 100 m of non-attaining streams.</td>
<td>Based upon state and local level riparian buffer regulations identified by the Army Corps of Engineers</td>
<td>Water quality through erosion reduction and nutrient capture and infiltration</td>
<td></td>
</tr>
</tbody>
</table>
3. Biomass Calculator

A simple theoretical model was used to build the production potential calculator in Microsoft Excel with a series of linked worksheets for each resource category. For the forestry and agriculture categories (including dedicated energy crops), results of the spatial analysis were entered in the form of total harvestable map units. The biofuel calculator designed for this project converts the results of the spatial analysis (aerial units for the initial raster based LULC map in 30 x 30 m squares) into total harvestable acres by sustainability class (low and high) and by dominant tree type (coniferous and deciduous, referred to also as softwood and hardwood, respectively). The calculator provides an opportunity to reduce the total acreage further by removing acres of forestland that are of particular environmental interest or reserved from harvesting activity by statute (non-timberland), such as designated wilderness areas.

The calculator converts the total area (initially in square meters) into total harvestable acres of hardwood and softwood areas for forestry and by crop type and soil capability class for agriculture. I used the calculator to apply area-weighted yields based upon relative acres of softwood or hardwood-dominated forest cover and by crop composition based on a 10-year historical average calculated from county level statistics available through the National Agricultural Statistical Service (NASS) online database. This creates an annual total biomass availability total from each primary resource category.
The calculator enables the user to apply appropriate yield statistics for the purposes of their own biofuel assessment project. For the Center County case study, the yield category of “Annual Growing Stock Removals Residue ‘+’ Sustainable Low Use Wood Removals” was selected for forest biomass yields due to its capture of residue from existing logging activity and utilization of forest materials not already harvested for commercial purposes. All biofuel production potentials reported are estimated with this forest yield category, although the calculator enables the user to select forest yields based upon other levels of forest material utilization.

The rate of removal of material from forests reduces the total biomass available to accommodate retention of nutrients within forest ecosystems as well as to maintain adequate habitat for wildlife. Snag and cavity trees, as well as woody debris are important for improving, or at least maintaining forest wildlife habitat. Because both nutrient retention and wildlife habitat are influenced heavily by harvest strategy and timing, retention of woody material is critical. The biomass calculator enables the user to assign the percentage of material removed under both the high and low sustainability classification, and can be postulated by the user, independent of the yield category selected.

In the biofuel calculator, total biomass is subsequently reduced by potential competing uses for forest-derived material. By default, the “Annual Growing Stock Removals Residue ‘+’ Sustainable Low Use Wood Removals” category excludes forest biomass that is removed from growing stock for roundwood, sawlogs and poletimber and is solely composed of the residue from their harvest in combination with non-growing stock, or low-value forest material. Uses of the material included in this yield category
that may compete with resources available for biofuel production include: pulp and paper, pallets, mulch, and fuel. This list is not exhaustive but reflects some of the highest volume competing uses that may be present in the study region. Finally, a forest biomass total by forest category and sustainability class is produced after estimates of the fraction of material lost in transport and storage are applied. Transport and storage loss estimates were based upon Jeanty (2004).

For the agricultural sector, crop coverage ratios for arable land within LCC class I-III were based upon 10-year historical averages from the National Agricultural Statistical Service for total harvested crop acres for each conventional crop included in the study. The total yield for each conventional crops for the purposes of residue generation for biofuels were area-weighted based upon the 10-year average of harvested acres by crop type for all crops for the study region. Crop specific straw-to-grain ratios were also applied to conventional crops cellulosic biomass yields. For the purposes of flexibility, the calculator enables the user to apply the appropriate yield for the purposes of their own biofuel assessment project, as well as the rate of removal of agricultural material (independent of yield). The percentage of material removed for Centre County was 60 percent under the low-sustainability classification and 40 percent for the high-sustainability classification for conventional crop residues.

In the biofuel calculator, total biomass was then reduced by potential competing uses for agriculturally derived material by crop type. Competing uses for agricultural residues include animal feed, bedding, and soil amendments, and can vary between feedstocks. This list is not exhaustive but reflects some of the highest volume competing
uses that may be present in the study region. Finally, estimates of the fraction of material lost in transport and storage are applied, and an agricultural biomass total is produced.

Non-land based resource categories that did not require spatial analysis to determine harvestable area included wood industry waste and solid waste. Industry residue totals from primary and secondary manufacturers were calculated from the Timber Products Output database available through the USDA Forest Service and from studies on available wood industry wastes and residue utilization in Pennsylvania (Murphy, et al., 2006; Miller, et al., 2003). I entered wood industry residue in the form of tons of bark, woodchips and sawdust by species group into the calculator, as well as recoverability and competing use rates. A species-weighted ethanol yield was used to determine the biofuel production level for biomass from this category.

Data derived from state and county level solid waste reports were then entered into the calculator. Composition analysis data was available regionally and for Centre County from Pennsylvania’s Department of Environmental Protection Bureau of Waste Management Division (DEP, 2007). Ethanol conversion factors were entered on this worksheet as well as the recoverability rate for each category of waste. Assumptions for the study region were also entered here regarding fraction of material diverted for recycling or competing uses. For a full description of the biofuel calculator model equations and assumption, please see Appendix A.

In addition to the sustainability criteria applied during spatial analysis, the biofuel calculator enables several other variables to be entered based upon local conditions. These variables include competing uses for biomass feedstocks. For example, fuel wood use and mulch, paper and pulp production may reduce the locally available amount of
feedstock from the forest category. Similarly, local agricultural demands on residue such as animal feed and bedding or soil amendments may reduce the available amount of hay or corn stover. Finally, fractions of biomass lost during transport and storage were included as variables for manipulation within the production calculator.

The available biomass totals for each category are linked to a Cellulosic Ethanol Calculator Page which converts the biomass totals from each resource category into an ethanol production potential in gallons of gasoline equivalent per year as well as million BTU per year for each sustainability class. Ethanol conversion factors by category were weighted by species group for forestry and industrial waste, crop type for agriculture and dedicated energy crops, and waste type for municipal solid waste. This worksheet is then linked to the consumption comparison worksheet where cellulosic ethanol production potentials are contrasted with gasoline consumption rates in gallons per year.

4. Case Study Site Selection

The bulk of corn-based ethanol is produced in the Midwestern U.S., linked spatially with major corn producing areas. Areas that are not major corn producers are already importing corn from this region to supply ethanol facilities in their own non-corn producing regions. However, as cellulosic ethanol technology advances and the diversity of potential feedstocks broaden, other regions of the country will have the opportunity to utilize biomass resources for energy production that exist more locally. One region of great promise for harnessing cellulosic biomass is the Appalachian region of the U.S. Appalachia is engaged in significant agricultural activity, yet also possesses vast forest
resources as well as related industrial activities involving wood processing. Where the Appalachian region as a whole may have significant resources available for production of cellulosic ethanol, its potential is largely untested.

Centre County, Pennsylvania

Centre County is located in the geographic center of the state of Pennsylvania and encompasses both the Allegheny Plateau and Ridge and Valley provinces. With a total of approximately 713,000 acres, the county is composed of both forested and agricultural land which makes it an ideal location to test a method aimed at assessing cellulosic resources from each of these land cover types (Soil Conservation Service, 1981; 2004; NRCS, 2007). Centre County Pennsylvania has approximately equal acres of timber land that is privately and publicly owned, or approximately 250,000 acres each (FIA, 2007).

Defining the county as the resource catchment area for the assessment of cellulosic material is appropriate for the development scale of interest in this report, fitting well within the ~50 mile radius for feedstock transport mentioned earlier. However, the procedures and tools developed in this study can be applied at scale both above and below the county level depending upon the boundaries established for spatial analysis and available statistical data.

It is important to note that this model relies upon fixed rather than dynamic data, and does not include any projections pertaining to growth rates in fuel demand, improvements in fuel conversion technology or changes in land use cover. Rather, the
data entry fields in this calculator are flexible and can be modified in response to the new spatial analysis, technological specifications for conversion, competing uses for material, etc.
Chapter 6

Results and Discussion

Regions not currently engaged in starch based ethanol production may have opportunities to develop ethanol from cellulosic biomass; however, there is little information available for local communities to gauge the level of resources available for fuel production in their areas. Similarly, there is no substantial information available regarding sustainable cellulosic fuel production based upon local site characteristics.

I present a methodology for estimating the cellulosic biomass potential for a given region and illustrate its utility by determining the biomass potential for Centre County, Pennsylvania. This method is based upon local site characteristics and takes into account ecosystem sustainability. For this methodology I developed sustainability criteria, conducted a spatial analysis of existing land use patterns, and created a calculator to convert acreage totals into tons of cellulosic biomass and gallons of biofuel. This calculator enables the user to select the site and scale of analysis, the biomass resources to include, and the sustainability criteria to consider.

I begin by presenting the spatial analysis results for the land-based resources: forests at each proximity level to roads, agricultural land, and dedicated energy crops. I then present biomass totals for the non-land based resources: mill and wood manufacturing residues and biomass material found in municipal solid waste. Eight unique totals are presented for each of four levels of forest harvesting activity based upon
decreasing proximity to roads at two sustainability levels which vary by the degree of forest and crop residue harvesting activity, fraction of material removal and riparian buffer areas. Following each individual resource category total, an aggregate county level biomass total and subsequent fuel potential is presented. This fuel production potential is then compared against an estimate of the study site’s fuel consumption to determine the degree to which the local cellulosic fuel production potential can offset fossil fuel demand within the study site.

The results show that Centre County can meet nearly 10 percent of estimated fuel consumption under the high sustainability level for forest material located within 50 meters of roads. This fraction increased up to approximately 25 percent of consumption when all harvestable forestland is subject to biomass removal under the low sustainability scenario.

Furthermore, production estimates for Centre County indicate that local resources may be capable of producing all of the ethanol necessary if a universal E10 gasoline requirement were instituted. Similarly, county level resources could meet over 40 percent of the ethanol needed for a county wide E85 gasoline requirement if all harvestable forests in the county were accessed independent of proximity to roads. In sum, though this paper shows that local biofuel potential cannot fully meet total liquid fuel demand for the study site, a considerable resource potential is present. In addition, economic development opportunities could be created through the sustainable collection of local cellulosic resources and the production of a value-added product such as ethanol.
Harvestable Forestland

All Forests

Based upon analysis of the LULC map of Centre County, there is a total of 556,259 acres of forestland, including conifer-dominant, mixed forest and deciduous-dominant forests (see Table 2.).

<table>
<thead>
<tr>
<th>Distance from Road:</th>
<th>50 m</th>
<th>100 m</th>
<th>500 m</th>
<th>All Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forested Area (acres)</td>
<td>40,699</td>
<td>78,322</td>
<td>280,630</td>
<td>556,259</td>
</tr>
<tr>
<td>Soil Limited Area (acres):</td>
<td>10,734</td>
<td>22,359</td>
<td>98,381</td>
<td>203,982</td>
</tr>
<tr>
<td>Riparian Buffer Protected Area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Sustainability (acres)</td>
<td>3,121</td>
<td>5,756</td>
<td>13,800</td>
<td>25,719</td>
</tr>
<tr>
<td>High Sustainability (acres)</td>
<td>6,702</td>
<td>12,239</td>
<td>29,971</td>
<td>56,016</td>
</tr>
<tr>
<td>TOTAL Harvestable Forest Area (acres):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Sustainability (acres)</td>
<td>28,108</td>
<td>52,548</td>
<td>169,976</td>
<td>328,181</td>
</tr>
<tr>
<td>Coniferous Area (acres):</td>
<td>3,006</td>
<td>5,172</td>
<td>12,854</td>
<td>20,211</td>
</tr>
<tr>
<td>Deciduous Area (acres):</td>
<td>25,102</td>
<td>47,376</td>
<td>157,123</td>
<td>307,970</td>
</tr>
<tr>
<td>High Sustainability (acres)</td>
<td>26,210</td>
<td>48,989</td>
<td>165,529</td>
<td>321,081</td>
</tr>
<tr>
<td>Coniferous Area (acres):</td>
<td>2,758</td>
<td>4,656</td>
<td>11,968</td>
<td>19,731</td>
</tr>
<tr>
<td>Deciduous Area (acres):</td>
<td>23,452</td>
<td>44,293</td>
<td>153,560</td>
<td>301,351</td>
</tr>
</tbody>
</table>

Application of sustainability criteria encompassing soil limited areas reduced harvestable forestland by 203,982 acres, or 36.7 percent of the total forest area (see Figure 6-1 a and b).
Figure 6-1a: Map of Harvestable Forest Area in Centre County, Pennsylvania. Map insert shows forested area falling within 50 m and 100 meters of existing roadways.

Figure 6-1b: Harvestable Forest area in Centre County by sustainability class and proximity to roadway.
Low sustainability riparian protection, which excludes all acres within 25 meters of streams, reduced harvestable forest area by an additional 31,195 acres leaving a total of 328,181 acres of harvestable forests. Application of the high level riparian protection scenario, which excluded all acres within 50 meters of attaining streams and 100 meters of non-attaining streams further reduced the harvestable area by 7,100 acres leaving a total of 321,081 harvestable acres (see Figure 6-2). Areas of overlap between soil-limited forest acres and riparian buffer zones were identified and quantified for each respective forest area so that double counting, or double removal of those acres did not occur.

Figure 6-2: Total harvestable area for all forestland in Centre County by sustainability class.
Forestland Within 500 meters of Roads

A total of 280,630 acres of forestland is located within 500 meters of roadways in Center County, PA. Application of soil based sustainability criteria removed a total of 98,381 acres or 35.1 percent of the total forestland. Application of the low level riparian protection for forest area within 500 meters of roads further reduced the total harvestable area by 16,720 acres. This created a total of 169,976 acres of harvestable forests in the county within 500 meters of roads (see Figure 6-3a and b). Application of the high level riparian protection scenario reduced harvestable acreage by an additional 4,448 acres beyond the low riparian protection scenario, totaling 165,529 acres of harvestable forests at this distance from roadways. All areas of overlap between soil-limited acres and those acres that fell within riparian buffers were quantified to prevent double counting.
Figure 6-3a: Harvestable forestland in Centre County, Pennsylvania within 500 meters of roadways. Gray areas are beyond 500 m from roadways.

Figure 6-3b: Harvestable forestland within 500 meters of roads by sustainability class.
**Forestland Within 100 meters of Roads**

For land within 100 meters of roadways, a total of 78,322 acres of forestland is present (see Figure 6-4a and b). After applying sustainability criteria, the total amount of harvestable resources for biofuel was reduced by 22,359 acres or 28.5 percent of the total forestland.

Incorporating low-level riparian protection for forest areas within 100 meters of roads reduced the total harvestable area by 7,014 acres, leaving a total of 52,548 acres of harvestable forests (see Figure 6-4b). Adjusting this calculation for a high level of riparian protection reduced harvestable acreage by an additional 3,599 acres beyond the low riparian protection scenario leaving a total of 48,949 harvestable acres. All areas of overlap between soil limited acres and those acres that fell within riparian buffers were quantified to prevent double counting.
Figure 6-4a: Harvestable forestland in Centre County, Pennsylvania within 100 meters of roads.

Figure 6-4b: Harvestable forestland in Centre County, Pennsylvania within 100 meters of roads by sustainability class.
Forestland Within 50 meters of Roads

Finally, for land within 50 meters of roadways, a total of 40,699 acres of forestland is present. Adding sustainability criteria to the analysis removed a total of 10,734 acres or 26.4 percent of the total forestland. Application of the low-level riparian protection for forest area within 50 meters of roads reduced the total harvestable area by 3,755 acres. This created a total of 28,108 acres of harvestable forest within 50 meters of roadways (see Figure 6-5a). The high-level riparian protection scenario reduced harvestable acreage by an additional 1,898 acres beyond the low-riparian protection scenario, leaving a total of 26,210 harvestable forest acres (see Figure 6-5b). All areas of overlap between soil limited acres and those acres that fell within riparian buffers were quantified to prevent double counting.
Figure 6-5a: Harvestable forestland in Centre County, Pennsylvania within 50 meters of roads.

Figure 6-5b: Harvestable forestland in Centre County, Pennsylvania within 50 meters of roads by sustainability class.
The relative amounts of forestland available for harvest between all forest categories are presented in Figure 6-6.

Figure 6-6: Harvestable forestland within each forest category by sustainability class.
Forest Biomass

The biomass potential from forestland was calculated by multiplying the total available acreage by forest category (i.e. all forests, forests within 500 m of roads, etc.) by biomass yield per acre. I applied area-weighted yields to hardwood-dominated and softwood-dominated forest types based upon fractional forest coverage for each forest category. Estimated yields of forest material in dry tons per acre ranged from 0.79 and 0.1 for net annual growth for hardwoods and softwoods respectively, down to 0.2 and 0.001 for residues from current growing stock removals. For the purposes of this study, forest biomass yield per acre was based upon the remaining residue present after currently levels of harvesting activity combined with a sustainable removal rate of low use wood as determined by the PA Hardwoods Development Council (2007). Though only one yield category was used in the case study, available biomass was calculated for other yield categories for the purposes of comparison. Table 3 and Figure 6-7 provide an example of the range of estimated biomass for forests within 500 m of roads as a function of applied yield category.
Table 3: Total harvestable forest biomass by yield category for forestland within 500 meters of roadway.

| Yield Category | Biomass (dry tons/acre/year):  
<table>
<thead>
<tr>
<th>500 m – Low Sustainability</th>
<th>500 m – High Sustainability</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Live Trees</td>
<td>2,099,302</td>
</tr>
<tr>
<td>Growing Stock</td>
<td>2,023,176</td>
</tr>
<tr>
<td>All Live Trees – Growing Stock</td>
<td>76,126</td>
</tr>
<tr>
<td>Net Annual Growth</td>
<td>70,102</td>
</tr>
<tr>
<td>Annual Growing Stock</td>
<td></td>
</tr>
<tr>
<td>Removals Residue + Sustainable Low Use Wood Removals*</td>
<td>56,601</td>
</tr>
<tr>
<td>Annual Growing Stock Removals</td>
<td>44,850</td>
</tr>
<tr>
<td>Sustainable Low Use Wood Removals</td>
<td>39,213</td>
</tr>
<tr>
<td>Annual Growing Stock Removals Residue</td>
<td>17,388</td>
</tr>
</tbody>
</table>

*Biomass yield used in case study.

Figure 6-7: Total biomass for harvestable forestland within 500 meters of roads by yield category.
Centre County’s available biomass for each forest category, by sustainability class, is listed in Table 4 and Figure 6-8.

Table 4: Total forest biomass in Centre County, Pennsylvania for each forest category by sustainability class.

<table>
<thead>
<tr>
<th>Forest Category:</th>
<th>&lt;50 m</th>
<th>&lt;100 m</th>
<th>&lt;500 m</th>
<th>All Forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Sustainability</td>
<td>10,851</td>
<td>20,413</td>
<td>67,633</td>
<td>133,281</td>
</tr>
<tr>
<td>High Sustainability</td>
<td>8,994</td>
<td>16,903</td>
<td>58,545</td>
<td>114,750</td>
</tr>
</tbody>
</table>

Figure 6-8: Total available biomass for Centre County, Pennsylvania for each forest category by sustainability class.
Harvestable Agricultural Land

Based upon the LULC map of Centre County, there are 180,908 acres of hay, pasture and row crops. Land not in LCC categories I-IV, deemed as arable land, were excluded from the total harvestable agricultural acres. Analysis revealed a total of 144,168 total acres of arable land suitable for agricultural activity in the county. Class I-III soils, designated to conventional crops capable of producing residue for fuel production, totaled 114,885 acres and class IV soils designated to energy crops totaled 29,284 for Centre County (see Table 5 and Figure 6-9).

Table 5: Total agricultural area in Centre County, Pennsylvania by soil class.

<table>
<thead>
<tr>
<th>Agricultural Land in Centre County</th>
<th>Acres</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Agricultural Area (LULC)</td>
<td>180,908</td>
</tr>
<tr>
<td>Total Arable Acres (CI-IV)</td>
<td>144,168</td>
</tr>
<tr>
<td>Soil Class I-III</td>
<td>114,885</td>
</tr>
<tr>
<td>Soil Class IV</td>
<td>29,284</td>
</tr>
</tbody>
</table>

Figure 6-9: Total harvestable agricultural land in Centre County, PA by soil class.
Application of the low-sustainability riparian buffer to harvestable agricultural areas reduced arable acres by 7,295 for all soil classes. The high-sustainability riparian buffer reduced harvestable acres by an additional 5,148 acres beyond the low-riparian protection scenario, removing a total of 12,444 acres from arable agricultural land in Centre County (see Table 6).

Table 6: Total arable agricultural land in Centre County, Pennsylvania by soils class with associated riparian buffer removals by sustainability class.

<table>
<thead>
<tr>
<th>Arable Agricultural Land</th>
<th>Acres</th>
<th>Riparian Buffer Removable</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Area CI-III: Conventional Crops</strong></td>
<td>114,885</td>
<td>--</td>
</tr>
<tr>
<td>Low Sustainability</td>
<td>108,536</td>
<td>6,348</td>
</tr>
<tr>
<td>High Sustainability</td>
<td>104,760</td>
<td>10,124</td>
</tr>
<tr>
<td><strong>Total Area CIV(e,s) for Switchgrass</strong></td>
<td>20,450</td>
<td>--</td>
</tr>
<tr>
<td>Low Sustainability</td>
<td>20,032</td>
<td>418</td>
</tr>
<tr>
<td>High Sustainability</td>
<td>18,875</td>
<td>1,576</td>
</tr>
<tr>
<td><strong>Total Area CIV(w) for Willow</strong></td>
<td>8,833</td>
<td>--</td>
</tr>
<tr>
<td>Low Sustainability</td>
<td>8,305</td>
<td>528</td>
</tr>
<tr>
<td>High Sustainability</td>
<td>8,090</td>
<td>744</td>
</tr>
</tbody>
</table>

*Conventional Crop Area*

Low-sustainability riparian buffers removed a total of 6,348 acres from class I-III soils, with 108,536 acres remaining for cultivation for conventional crops. High-sustainability riparian buffers removed a total of 10,124 acres, with 104,760 acres remaining for cultivation for conventional crops (see Figure 6-10a and b).
Figure 6-10a: Harvestable arable land in Centre County by soil class and riparian buffer sustainability class.

Figure 6-10b: Total harvestable arable land for Class I-III soils in Centre County by sustainability class.
Dedicated Energy Crop Area

For dedicated energy crops, class IV $e$ and $s$ soils designated for switchgrass cultivation totaled 20,450 acres. Low-sustainability riparian buffers removed 418 acres from this total and high-sustainability buffers removed 1,576 acres from this total (see Figure 6-11).

![Total Harvestable Acres for Switchgrass Cultivation: Class IV e/s Soils](image)

Figure 6-11: Harvestable acres in Centre County for Class IV $e/s$ soils by sustainability class.

Class IV $w$ soils allocated to willow cultivation totaled 8,833 acres. Low-sustainability riparian buffers removed 528 acres from this total and high-sustainability buffers removed 744 acres from this total (see Figure 6-12).
Total area within LULC categories encompassing agricultural activity for all arable soil categories I-IV is shown in Figure 6-13a and b.
Figure 6-13a: Total harvestable, arable land in Centre County for all soil and sustainability classes.

Figure 6-13b: Harvestable acres of Class IV agricultural land in Centre County by sustainability class.
Agricultural Residues from Conventional Crops

For Centre County, yields were calculated from 10-year historical averages of annual crop planting and harvesting activity produced by the National Agricultural Statistical Service for Centre County. The total yield for conventional crops for the purposes of residue generation were area-weighted based upon a 10-year average of harvested acres by crop type for all crops in Centre County (see Figure 6-14) and as a relative fraction of crops producing cellulosic feedstocks (see Figure 6-15).

Figure 6-14: Relative percentage of acres of conventional crops generating residue relative to total harvested acres for all Centre County crops.
Centre County’s available biomass from agricultural residues is shown in Figure 6-16 and Table 7.

Figure 6-15: Relative percentage harvested acres of conventional crops generating biomass residue within Centre County.

Figure 6-16: Available biomass from convention crop residue in tons per acres per year from each crop type.
Biomass from Dedicated Energy Crops

Agricultural land classified as C IV was allocated to switchgrass and willow for the purposes of this study, although other varieties of energy crops may be more suitable in some circumstances. For agricultural land classified as C IV, areas prone to erosion or drought, subclasses e and s, were allocated to switchgrass cultivation while areas prone to wetness and soil saturation were allocated to willow cultivation. The ratio of C IV land dedicated to each crop type is shown in Figure 6-17.

Table 7: Total Available Biomass for Centre County by Crop Type and Sustainability Class

<table>
<thead>
<tr>
<th>Sustainability Class</th>
<th>Corn: Grain</th>
<th>Corn: Silage</th>
<th>Hay</th>
<th>Wheat</th>
<th>Barley</th>
<th>Oats</th>
<th>Total Residue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>16,819.7</td>
<td>11,042.3</td>
<td>22,050.8</td>
<td>1,194.9</td>
<td>230.8</td>
<td>1,337.1</td>
<td>52,675.6</td>
</tr>
<tr>
<td>High</td>
<td>10,823.0</td>
<td>7,105.5</td>
<td>14,189.1</td>
<td>768.9</td>
<td>148.5</td>
<td>860.4</td>
<td>33,895.4</td>
</tr>
</tbody>
</table>

Figure 6-17: Fraction of harvestable CIV land in Centre County allocated to switchgrass and willow.
The percentage of material removed from each dedicated energy crop for Centre County was 75 percent for the low-sustainability classification and 60 percent for the high-sustainability classification.

In the same fashion as conventional crop residues, total biomass from dedicated energy crops was reduced by the fraction of material lost in transport and storage. A dedicated energy crop biomass total was then produced for both residue and dedicated energy crops for both sustainability classes, as shown in Figure 6-18 and Table 8.

![Available Biomass from Dedicated Energy Crops by Sustainability Class](image)

**Figure 6-18**: Total available biomass from dedicated energy crops by sustainability class

<table>
<thead>
<tr>
<th>Sustainability Class</th>
<th>Switchgrass</th>
<th>Willow</th>
<th>Total Residue</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low</strong></td>
<td>56,1 78.8</td>
<td>8,478.7</td>
<td>64,657.5</td>
</tr>
<tr>
<td><strong>High</strong></td>
<td>42,3 46.7</td>
<td>6,607.1</td>
<td>48,953.8</td>
</tr>
</tbody>
</table>

**Table 8**: Total Available Biomass (tons/acre/year) from Dedicated Energy Crops for CIV Agricultural Land.
**Industrial Residue**

The total residue for industrial waste was determined by applying rates of availability reported in an assessment of wood residue utilization by Murphy *et al.* (2007) to total residue generated for Centre County as estimated by Miller *et al.* (2003). Murphy (2007) determined that as of 2003, only 1 percent of all residues from roundwood purchasers in Pennsylvania were unutilized. Biomass totals and availability are shown in Figure 6-19 and Figure 6-20.

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**Figure 6-19:** Total Biomass Residue Generated from Mills and Secondary Manufacturers
As these figures show, there are substantial levels of biomass residue generated in this category, however very little is currently available for biofuel production. Similar to the degree to which forest material will be harvested for biofuel production, economic factors such as the price paid for biofuel feedstock may dramatically alter the patterns of use for this resource type.

**Municipal Solid Waste**

The Pennsylvania Bureau of Land Recycling and Waste Management reported the total tons of waste for Centre County in 2006 as 91,024 metric tons (see Table 9). Also shown are the relative fractions of waste material suitable for cellulosic ethanol production. The Bureau of Land Recycling and Waste Management also made available
the local composition analysis of disposed solid waste produced in 2003 for the north central region of Pennsylvania, with field sampling performed at the Centre County Transfer Station.

Table 9: Total disposed waste and waste composition for biogenic/cellulosic materials for Centre County, 2006.

<table>
<thead>
<tr>
<th>MATERIAL:</th>
<th>Proportion of Disposed Waste</th>
<th>Biomass (tons)</th>
<th>Recyclable Fraction / Competing Uses</th>
<th>% Recoverable</th>
<th>Available Biomass (tons)</th>
<th>Fraction of Cellulosic Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paper</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newspaper</td>
<td>3.0%</td>
<td>2,730.7</td>
<td>50%</td>
<td>75%</td>
<td>1,024.0</td>
<td>4.3%</td>
</tr>
<tr>
<td>Magazine/ Glossy Corrugated Cardboard</td>
<td>2.3%</td>
<td>2,093.6</td>
<td>5%</td>
<td>75%</td>
<td>1,491.7</td>
<td>6.3%</td>
</tr>
<tr>
<td>Mixed Paper</td>
<td>7.1%</td>
<td>6,462.7</td>
<td>50%</td>
<td>75%</td>
<td>2,423.5</td>
<td>10.2%</td>
</tr>
<tr>
<td>Non-Recyclable Paper</td>
<td>5.2%</td>
<td>4,733.2</td>
<td>5%</td>
<td>75%</td>
<td>3,372.4</td>
<td>14.2%</td>
</tr>
<tr>
<td>Office</td>
<td>10.1%</td>
<td>9,193.4</td>
<td>0%</td>
<td>75%</td>
<td>6,895.1</td>
<td>29.0%</td>
</tr>
<tr>
<td><strong>Organics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yard Waste-Grass</td>
<td>1.3%</td>
<td>1,183.3</td>
<td>25%</td>
<td>75%</td>
<td>665.6</td>
<td>2.8%</td>
</tr>
<tr>
<td>Yard Waste-Other</td>
<td>1.9%</td>
<td>1,729.5</td>
<td>25%</td>
<td>75%</td>
<td>972.8</td>
<td>4.1%</td>
</tr>
<tr>
<td>Wood-Unpainted</td>
<td>6.4%</td>
<td>5,825.5</td>
<td>0%</td>
<td>75%</td>
<td>4,369.2</td>
<td>18.4%</td>
</tr>
<tr>
<td>Wood-Painted</td>
<td>1.5%</td>
<td>1,365.4</td>
<td>0%</td>
<td>75%</td>
<td>1,024.0</td>
<td>4.3%</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td>39,413.4</td>
<td>23,774.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Under Pennsylvania Act 101, which mandates recycling in the commonwealth’s larger municipalities, recyclable paper-based materials were reduced by 50 percent to accommodate increases in recycling activity for those materials. Recyclable materials not included in Act 101 were reduced by 5 percent only. Organic yard waste entering landfills was reduced by 25 percent to accommodate potential competing uses such as compost and mulch. Recoverability was assumed to be 75 percent of the total cellulosic resource. Totals are shown in Figure 6-21.
Ethanol conversion factors were based upon estimates provided by the Energy Information Administration’s 2007 “Methodology for allocating municipal solid waste to biogenic and non-biogenic energy,” the EERE Theoretical Ethanol Yield Calculator and the New Jersey BioEnergy Calculator.

**Biomass Total for Centre County, Pennsylvania**

The total biomass, reported in tons/year, from each feedstock category was then summed for Centre County, for each sustainability class and for each forest category at increasing distances from roadways. Totals are reported for forest resources within 500 meters of roads for both the low- and high-sustainability classes (see Table 10).
The relative contribution of each resource category is shown in Figure 6-22 for the low-sustainability class and Figure 6- for the high-sustainability class.

### Table 10: Biomass Totals (tons/year) for Centre County for Forests within 500 m of Roads by Sustainability Class.

<table>
<thead>
<tr>
<th>Biomass Category</th>
<th>Low Sustainability</th>
<th>High Sustainability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest Resources</td>
<td>69,724.3</td>
<td>60,355.4</td>
</tr>
<tr>
<td>Crop Residue</td>
<td>52,675.6</td>
<td>33,895.4</td>
</tr>
<tr>
<td>Dedicated Energy Crops</td>
<td>64,657.5</td>
<td>48,953.8</td>
</tr>
<tr>
<td>Mill Residue</td>
<td>725.2</td>
<td>725.2</td>
</tr>
<tr>
<td>Secondary Manufacturer Residue</td>
<td>137.2</td>
<td>137.2</td>
</tr>
<tr>
<td>Municipal Solid Waste</td>
<td>23,774.3</td>
<td>23,774.3</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td><strong>211,694.2</strong></td>
<td><strong>167,841.4</strong></td>
</tr>
</tbody>
</table>

Figure 6-22: Relative contribution of each cellulosic biomass category to Centre County’s biomass total under the low sustainability class.
Interestingly, the relative contribution of forest resources increased from the low-sustainability class to the high-sustainability class, from 32.9 percent to 36 percent, while the contribution of agricultural residues decreased from low to high, from 24.9 percent to 20.2 percent. This is likely due to the fact greater amounts of agricultural land are removed from total harvestable agricultural acres with high levels of riparian protection relative to acres removed forestland for this purpose. Terrain limitations associated with riparian areas within forests may also have resulted in many of these acres being removed from harvestable forest acres prior to application of riparian buffers. Further review of spatial analysis results, particularly in regard to slope and soil types surround riparian forest areas may explain this further. The relative contribution of dedicated energy crops was similar between sustainability classes, 30.5 percent and 29.2 percent for low and high sustainability, respectively.
Ethanol Production Potential

Ethanol conversion factors were applied to each respective type of biomass feedstock (area weighted by species and crop type and volume weighted for other resource subcategories) to create an ethanol production potential for each biomass category for the County (shown in Table 11).

Table 11: Total production potential by resource category for Centre County, PA.

<table>
<thead>
<tr>
<th>Biomass Category</th>
<th>Low Sustainability</th>
<th>High Sustainability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest Resources</td>
<td>7,079,326.2</td>
<td>6,128,073.9</td>
</tr>
<tr>
<td>Crop Residue</td>
<td>4,295,294.0</td>
<td>2,763,909.4</td>
</tr>
<tr>
<td>Dedicated Energy Crops</td>
<td>6,312,230.7</td>
<td>4,779,148.1</td>
</tr>
<tr>
<td>Mill Residue</td>
<td>54,390.0</td>
<td>54,390.0</td>
</tr>
<tr>
<td>Secondary Manufacturer Residue</td>
<td>10,462.3</td>
<td>10,462.3</td>
</tr>
<tr>
<td>Municipal Solid Waste</td>
<td>1,589,158.4</td>
<td>1,589,158.4</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td><strong>19,340,861.6</strong></td>
<td><strong>15,325,142.2</strong></td>
</tr>
</tbody>
</table>

The relative contribution of each category of biomass to ethanol potential differed slightly from its contribution to the biomass total due to varying ethanol conversion rates between sources. The relative contributions of each resource to the ethanol production total for the County are shown in Figure 6-24 for the low-sustainability class and in Figure 6-2 for the high-sustainability class.
Figure 6-24: Relative contribution of each biomass category to Centre County’s ethanol production potential under the low sustainability class

Figure 6-25: Relative contribution of each biomass category to Centre County’s ethanol production potential under the high sustainability class
Similar relationships to the biomass totals exist for ethanol production potentials with regard to the forestry and agricultural production potentials. Forestry resources contribute a greater fraction to the total under the high-sustainability class than the low-sustainability class while crop residues contribute a greater fraction in the low-sustainability class. Dedicated energy crops contribute a similar amount in both sustainability classes, and the non-land based resources do not change between the high and low sustainability classes.

**Comparison of Ethanol Production Potential to Centre County Gasoline Consumption**

Centre County’s gasoline consumption was estimated to be 8,750,000 million BTU by Pennsylvania State University’s Center for Integrated Regional Analysis (Knuth, *et al.*, 2005). This total was converted to US gallons in the biofuel calculator with a conversion rate of one US gallon = 115,000 BTU, resulting in 76,086,957 gallons of gasoline consumed annually in Centre County. The authors of the Centre County estimate of fuel demand stress that this estimate may not reflect actual consumption due to the lack of data availability at the county level, and the resulting uncertainty involved in applying state and national statistics at the local level. Alternatives methods to estimate local gasoline consumption were explored, though ultimately determined to beyond the scope of this report. For this reason, CIRA’s estimate was considered the best available assessment of Centre County fuel consumption.
Additionally, the authors of the CIRA study noted that their consumption estimate for Center County was significantly higher than the state average as indicated by rates of spending on gasoline at the County level, which may be important to consider when comparing biofuel production potentials against consumption estimates for the Centre County Case Study.

To enable direct comparison of production to consumption, Centre County’s ethanol potential, in gallons, was converted into gallons of gasoline equivalent based upon the high heating value of a gallon of ethanol relative to a gallon of gasoline, or 84,000 Btu/gallon to 115,000 Btu/gallon respectively. The combined total for all resource categories by sustainability class and level of forest resource use are shown in Table 12 and Figure 6-26.

Table 12. Ethanol Production Potential (gallons of gasoline equivalent) for Centre County Relative to Local Gasoline Consumption.

<p>| Center County Gasoline Consumption (gallons) | 76,086,956.5 |</p>
<table>
<thead>
<tr>
<th>Production Potential (g gas equivalent/ yr)</th>
<th>Ethanol Production Potential (g gas equivalent/ yr)</th>
<th>% of Consumption</th>
<th>Volume of Ethanol to Meet E10 Blend (g)</th>
<th>Volume of Ethanol to Meet E85 Blend (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Within 50 m of Roads</strong></td>
<td></td>
<td></td>
<td>Availability</td>
<td>Availability</td>
</tr>
<tr>
<td>Low Sustainability</td>
<td>9,787,574.6</td>
<td>12.86%</td>
<td>176.1%</td>
<td>20.7%</td>
</tr>
<tr>
<td>High Sustainability</td>
<td>7,406,909.1</td>
<td>9.73%</td>
<td>133.3%</td>
<td>15.7%</td>
</tr>
<tr>
<td><strong>Within 100 m of Roads</strong></td>
<td></td>
<td></td>
<td>Availability</td>
<td>Availability</td>
</tr>
<tr>
<td>Low Sustainability</td>
<td>10,519,544.9</td>
<td>13.83%</td>
<td>189.3%</td>
<td>22.3%</td>
</tr>
<tr>
<td>High Sustainability</td>
<td>8,012,284.5</td>
<td>10.53%</td>
<td>144.2%</td>
<td>17.0%</td>
</tr>
<tr>
<td><strong>Within 500 m of Roads</strong></td>
<td></td>
<td></td>
<td>Availability</td>
<td>Availability</td>
</tr>
<tr>
<td>Low Sustainability</td>
<td>14,127,238.0</td>
<td>18.57%</td>
<td>254.2%</td>
<td>29.9%</td>
</tr>
<tr>
<td>High Sustainability</td>
<td>11,194,016.9</td>
<td>14.71%</td>
<td>201.4%</td>
<td>23.7%</td>
</tr>
<tr>
<td><strong>All Harvestable Forests</strong></td>
<td></td>
<td></td>
<td>Availability</td>
<td>Availability</td>
</tr>
<tr>
<td>Low Sustainability</td>
<td>19,139,188.1</td>
<td>25.15%</td>
<td>344.4%</td>
<td>40.5%</td>
</tr>
<tr>
<td>High Sustainability</td>
<td>15,484,990.8</td>
<td>20.35%</td>
<td>278.6%</td>
<td>32.8%</td>
</tr>
</tbody>
</table>
The percentage of consumption that each production potential covers is shown in the above table and in Figure 6-27, as well as the volume of ethanol needed to blend all county gasoline consumption at E10 and E85 levels, shown in Figure 6- and

**Figure** Error! Reference source not found..

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**Figure 6-26**: Total ethanol production for Centre County by forest use level and sustainability class.
Figure 6-27: Ethanol potential as a percent of Centre County fuel demand.

Figure 6-28: Percent of ethanol available to meet E10 fuel blends for Centre County.
In Centre County, ethanol production potential increased from a level capable of meeting just under 10 percent of consumption under the high-sustainability scenario where forest resources within 50 meter of roads were harvested up to a maximum of just over 25 percent of consumption under the low-sustainability scenario for all harvestable forestland. A production facility of this size would fit within the existing range of ethanol plants currently producing starch-based ethanol ranging from 3 mgy up to over 500 mgy (RFA, 2008), with the average dry mill ethanol plant in use produces approximately 50 mgy (Soloman, 2007).

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**Discussion**

In Centre County, ethanol production potential increased from a level capable of meeting just under 10 percent of consumption under the high-sustainability scenario where forest resources within 50 meter of roads were harvested up to a maximum of just over 25 percent of consumption under the low-sustainability scenario for all harvestable forestland. A production facility of this size would fit within the existing range of ethanol plants currently producing starch-based ethanol ranging from 3 mgy up to over 500 mgy (RFA, 2008), with the average dry mill ethanol plant in use produces approximately 50 mgy (Soloman, 2007).
Production estimates for Centre County also indicate that local resources may be capable of producing all of the ethanol necessary at the county level if a universal E10 blended gasoline requirement were instituted. Similarly, if an E85 gasoline requirement were instituted. County level resources could meet just over 40 percent of the ethanol needed when all harvestable forests are tapped.

While it is becoming more evident that cellulosic ethanol may be a more suitable alternative to oil than starch-based ethanol, there are still questions that need to be addressed in order to fully gauge its viability as a major fuel resource into the future. Decisions are being made now that will set the stage for development of this resource for an indefinite period of time. The results of this study provide a greater understanding of the potential for local resources to be collected sustainably and used locally to meet liquid fuel demands.

There are several caveats to the approach of this study that must be mentioned. First, the calculator is built upon several assumptions for each resource category and therefore greatly increase the uncertainly associated with final production estimates. Along a similar vein, this study reflects static production and consumption levels that do not reflect technological changes on the part of crop or production yields as well as changes in consumption patterns for the study area. Use of the biofuel calculator as a tool, however, is highly flexible in the input and can be easily modified to keep pace with new technological specifications for the ethanol industry as well as potential increases or decreases in biomass yields, consumption rates and land use patterns at the study site level.
Though this project illustrates a production potential based upon existing land use patterns, several concerns surrounding the use of biomass for fuel production remain, whether from cellulosic sources or non-cellulosic sources. Pressure on food production from cellulosic biomass may become a serious issue if it begins to compete heavily with food crops for primary agricultural land, similar to pressure on crops from urban growth. Food security is of considerable importance in this regard, particularly for poorer nations who import a high fraction of their food. Also, increasing fuel consumption is driving global scale importation of biomass feedstocks and fuel, evidenced already in the US, Europe, China and Japan.

Concerns around sustainable forestry practices both locally and internationally have the potential to be exacerbated by cellulosic ethanol production. Overharvesting of forest material for non-energy related applications already exists, and introducing a further demand on forest based resources could potentially increase overharvesting activities. This is an important argument for the introduction of sustainable resource harvesting for cellulosic ethanol in the early, planning stages of development. Also, though cellulosic biomass development is touted as a means to increase diversity in a relatively species-impoverished industry such as agriculture, there remains the potential for a narrow range of crops to ultimately dominate this market, particularly if genetic modification catapults one or two species to the fore. Access to biomass and a downward pressure on crop diversity within the cellulosic sphere are also of potential concern (Knauf, et.al. 2007).

Finally, questions remain as to whether this region can or will take advantage of any potential opportunity and to what degree of sustainability, as well as the nature of
real or perceived affects of biofuel production on the livelihoods of residents of the region. Considerations for how a sustainable biofuel trajectory might be further encouraged at this early stage are an important next step. Encouraging even broader technologies for ethanol production may be promising, as well. For example, there is substantial interest in algae based ethanol production which has dramatically different inputs into its production than the land based resources considered here. Expansion of such ethanol production technologies may ultimately reduce pressure on agriculture and forest ecosystems and may improve the industry’s sustainability potential further.
Bibliography


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NJAES (2007). The New Jersey BioEnergy Calculator and Bioenergy Resource Developed by the New Jersey Agricultural Experiment Station - Rutgers the State University of New Jersey.


Appendix A

Biomass Calculator Model Assumption

The total residue available from cellulosic ethanol feedstocks within the primary resource categories (forestry and agriculture/ dedicated energy crops) is based upon the following equation:

\[ A_b \times Y_b \times R_{brem} = \text{Available Cellulosic Biomass (tons)} \]

where \( A \) is the number of acres producing biomass type \( b \), \( Y \) is the yield of biomass type \( b \), and \( R_{brem} \) is the removable fraction of residue generated by biomass type \( b \) (tons/acre). Additional terms were ultimately introduced into the calculator to accommodate the complexity of the system, including the rate of recovery for each crop type (\( R_{Recovery} \)), and the level of competing uses for agricultural products (\( R_{comp} \)).

The differences between sustainability classes result from variable input quantities for both the productive acreage (\( A \)) removable biomass (\( R_{brem} \)). Productive acreage made available for biomass production or harvesting was reduced from current land use patterns for agricultural and forest resources to create the low and high sustainability classes based upon the degree of compliance with Clean Water Act designated use regulations.

Varying intensities of biomass removal (\( R_{brem} \)) will be considered in each sustainability case as well, defined sustainability parameters found in the body of this report, and are based upon the literature and/ or best management practices for each
resource group. For example, the necessary quantity of residue that must remain on the field following harvest to protect against erosion will not only vary by soil type and climate but also to the degree to which the system will sustain nutrients for the next growing cycle. High sustainability cases may retain higher levels of residue as a means to reduce nutrient loss from the system, thereby reducing subsequent application of fossil based nutrients.

**Agricultural Residue**

For the agricultural category, quantification of the total residue produced is based upon Nelson, *et al.*, (2002), where the residue produced by each specific crop type ($R_{prod}$) is defined as:

\[
Y \times CF \times SGR = R_{prod} \text{ (tons/acre)}
\]

and is a function of $Y$ or yield (bushels or tons /acre/ year), CF or measurement conversion factor (bushels to tons) and SGR is the crop specific straw to grain ratio.

**Dedicated Energy Crops**

Ultimately, the fuel production potential or yield of non-grain based cellulosic biomass is a direct function of biomass productivity or crop yield (Adler, 2007). Crops
that have a greater yield in terms of pounds or tons per acre can produce fuel more efficiently than those crops that have relatively lower yields. For this reason, different crops will perform better and worse in terms of yield based on local soil, climate and management conditions. Consideration of the local climate conditions in conjunction with land categories appropriate for different crop types determined the assignment of crop types by Land Capability Classifications enhance the accuracy of local resource assessments.

Though similar in the base procedure to calculate cellulosic biomass potential, the dedicated energy crop category will be quantified with slightly modified equation which is simply a function of yield (lbs/acre and weight (lbs):

Eq. 4

\[ Y \times W \text{ (lbs)} = R_{\text{prod}} \text{ (lbs/acre)} \]  

Data on dedicated energy crop yields will be based on the EERE's Theoretical Ethanol Yield tool, biomass properties tool, Adler (2006; 2007), NJAES biofuel calculator, and i-farm's online prediction tool, namely for switchgrass for regions suitable for perennial grasses. Volk et.al. (2006) and Kuzovkina, et.al. (2004) provide the basis for assumptions for willow in agricultural areas limited by water based upon NRCS designations.

Total acres for each sustainability class were calculated, and assigned a designated crop for production based upon NRCS crop suitability and historical averages of crop percentage at the county level from NASS analyzed data.
Forest Resources

Data assessed by the USDA’s Forest Service in terms of average annual growth by forest stand type is the most widely used source of information on biomass within Pennsylvania forests. In concert with information processed by the PA Hardwoods Development Council on low use wood (Craig, 2007), FIA data will be utilized to determine the productivity, or biomass yields for local forests. Sustainability parameters based upon topography, soil conditions, transportation infrastructure will be imposed upon this data, as in the other resource categories as well as management practices for plant and wildlife habitat protection (Keefer, et.al., 2000).

Forest Products Industry

The amount of this residue that is actually available for fuel production after competing uses are accounted for seems to be much smaller than has been suggested in other resource assessments. A study by Murphy et.al. (2007) examined how wood residue was been utilized by roundwood purchasers in Pennsylvania between 1998 and 2003. The results of Murphy’s survey suggests that much of the reside produced from sawmills is utilized for many varying purposes ranging from animal bedding to wood composite production to on-site for energy and steam production. The results of this assessment indicated that approximately 99 percent of mill residues in Pennsylvania were utilized in 2003 (Murphy, 2006). However, the authors suggest that a new market for this residue would enable full utilization of those residues not currently utilized and that, as is
the case with each of the other resources categories, the price paid per ton will ultimately dictate the destination of this potential resource.

The theoretical model employed in quantifying the primary resource categories is simplified for calculating the resource potential for both the secondary and tertiary resource categories, captured in the following equation:

Eq. 5

\[ R_{\text{rem}} \times RR_p = \text{Available Biomass Material (lbs)} \]

where \( R_{\text{rem}} \) is the removable fraction of residue generated by process and \( RR_p \) is the rate of recovery for the removable residue or material produced. The amount of removable residue \( R_{\text{rem}} \) is the difference between the quantities of residue produced \( (R_{\text{prod}}) \) and the residue dedicated to competing uses

Eq. 6

\[(R_{\text{comp}}): \ R_{\text{rem}} = R_{\text{prod}} - R_{\text{comp}}\]

Data on \( R_{\text{prod}} \) and \( R_{\text{comp}} \) will come from Murphy (2006) and Craig (2007).

**Municipal Solid Waste**

Regional composition analyses are available which present the fraction of fiber and organic material present in incoming loads of material to local landfills as well as the fraction of recyclable material.
The largest issue with this resource is material recovery from landfills, and the infrastructure necessary to either separate prior to arrival or removal following arrival.

Rates of recycling at the local level and the composition of the material coming into land fill facilities were determined in a region specific municipal solid waste composition analysis from the Department of Environment Protection (DEP, 2006) and will be critical in establishing the available cellulosic material present in Centre County facilities. Data on $R_{prod}$ and $R_{comp}$ for the MSW category will come from state and county level data (DEP, 2006;2007).

**Fuel Production Potential and Local Fuel Consumption**

The quantitative assessment of cellulosic feedstock, available in tons per year, from each of the above categories will be converted into gallons of produced liquid fuel. This will be based upon best available technological specifications and will be compared against a county level fuel demand calculated by Knuth *et.al.* (2006).

The direct comparison of these figures will provide a first cut assessment of the viability of Appalachian cellulosic biomass to function as an environmentally sustainable distributed fuel source. Maps overlaying existing land-use, ownership and transportation network with available cellulosic biomass feedstocks were created as a visualization of the results of this study during the spatial analyses section.

Ideally, the template used in the quantification of biomass potential in this study will be made available as a web tool for local resource managers and decision makers.
Appendix B

Biofuel Calculator Pages

Figure 2-1 shows the Production Comparison page of the Biofuel Calculator.

![Production Comparison Page]

Fields in yellow indicate data entry cells. Fields in orange reflect critical results.

Figure 2-2 shows the Production Potential page of the Biofuel Calculator. There are no data entry fields on this page, all data is loaded from other worksheets in the calculator.
Figure 2-3 shows the Forest Spatial Analysis Data Entry page of the Biofuel Calculator. Results of the spatial analysis are entered into the fields in yellow, for LULC 30 x 30 m map units.
Figure 2-3: Forest GIS Spatial Analysis Data Entry Page

Figure 2-4 shows the Agriculture Spatial Analysis Data Entry page of the Biofuel Calculator. Results of the spatial analysis are entered into the fields in yellow, for LULC 30 x 30 m map units.
Figure 2-5 shows the Forest Variables page of the Biofuel Calculator. Fields in yellow represent data inputs or assumption entry fields for the user. Gray fields represent formula based calculations.

![Figure 2-4: Agricultural GIS Spatial Analysis Data Entry Page](image-url)
Figure 2-6 shows the Agricultural Variables page of the Biofuel Calculator.

Fields in yellow represent data inputs or assumption entry fields for the user. Gray fields represent formula based calculations.
Figure 2-6: Agricultural Variables Page

Figure 2-7 shows the Yield Assumptions page for the Biofuel Calculator. Fields in yellow represent data inputs or assumption entry fields for the user. Gray fields represent formula based calculations.
Figure 2-8 shows the Industrial Residues page for the Biofuel Calculator. Fields in yellow represent data inputs or assumption entry fields for the user. Gray fields represent formula based calculations.
Fields in yellow represent data inputs or assumption entry fields for the user. Gray fields represent formula based calculations.
### Municipal Solid Waste Composition

<table>
<thead>
<tr>
<th>Resource Variable</th>
<th>By Weight</th>
<th>By Volume</th>
<th>FRC (%)</th>
<th>MW (%)</th>
<th>ML (%)</th>
<th>Organic (%)</th>
<th>Fraction of Total</th>
<th>Residual (%)</th>
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</thead>
<tbody>
<tr>
<td>Paper</td>
<td>31.6%</td>
<td>24.6%</td>
<td>9.0%</td>
<td>32.4%</td>
<td>11.9%</td>
<td>3.7%</td>
<td>48%</td>
<td>52%</td>
</tr>
<tr>
<td>Newspapers/Office</td>
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<td>25.0%</td>
<td>9.6%</td>
<td>34.0%</td>
<td>13.2%</td>
<td>3.6%</td>
<td>48%</td>
<td>52%</td>
</tr>
<tr>
<td>Magazines/Books</td>
<td>26.0%</td>
<td>25.0%</td>
<td>9.7%</td>
<td>31.8%</td>
<td>12.6%</td>
<td>3.7%</td>
<td>48%</td>
<td>52%</td>
</tr>
<tr>
<td>Bottle/Cans</td>
<td>7.6%</td>
<td>7.6%</td>
<td>4.5%</td>
<td>16.6%</td>
<td>13.7%</td>
<td>2.6%</td>
<td>48%</td>
<td>52%</td>
</tr>
<tr>
<td>Meat/Produce</td>
<td>6.7%</td>
<td>5.9%</td>
<td>4.2%</td>
<td>16.6%</td>
<td>15.1%</td>
<td>2.5%</td>
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<td>52%</td>
</tr>
<tr>
<td>NonRecyclable Pack</td>
<td>6.0%</td>
<td>5.9%</td>
<td>4.3%</td>
<td>16.6%</td>
<td>15.1%</td>
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<td>52%</td>
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<tr>
<td>Plastic</td>
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<td>15.1%</td>
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<td>52%</td>
</tr>
<tr>
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<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
<td>100.0%</td>
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<td></td>
</tr>
</tbody>
</table>

**TOTAL (combustible fuel):** 25,774.5 (45.8%)

**TOTAL (incombustible fuel):** 39,416.1 (54.2%)


Figure 2-9: Municipal Solid Waste Page