Forestry Biofuel Statewide Collaboration Center (FBSCC) Task B4 Final Report

Michigan Technological University Sustainable Futures Institute (SFI)

DE-EE-0000280

April 10, 2010 - April 30, 2011

Project Investigator: Dana M. Johnson, Ph.D., Professor, Operations and Supply Chain Management, School of Business and Economics; Adjunct Professor, Mechanical Engineering-Engineering Mechanics, Michigan Tech

Senior Personnel: Mark A. Johnson, Ph.D., Associate Professor, Mechanical Engineering Technology, School of Technology; Adjunct Associate Professor, Mechanical Engineering-Engineering Mechanics, Michigan Tech

Graduate Research Assistant: Fengli Zhang, Ph.D. Student, Mechanical Engineering-Engineering Mechanics, Michigan Tech

Aug 17, 2011

Acknowledgment: This material is based upon work supported by the Department of Energy under Award Number DE-EE-0000280.

Disclaimer: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Units of measurement: Biomass feedstock is measured in green, short tons. A rough estimate of the ratio between green tons and dry tons is 2:1. The system performance indicators are measured based on the units of biomass feedstock. For example, the delivered feedstock cost is measured in U. S. dollar per green, short ton of biomass being transported to a biofuel facility. Energy consumption is measured in Btu by delivering per green, short ton of biomass. Greenhouse gas emissions are measured in lbs. of CO2e per green, short ton of biomass being delivered.

TABLE OF CONTENTS

Appendices

List of Figures

List of Tables

FINAL REPORT FOR FORESTRY BIOFUEL STATEWIDE COLLABORATION CENTER (FBSCC) - SUBTASK B4: EXTENDED SUPPLY CHAIN MODEL AND ASSESS ECONOMIC BUSINESS VIABILITY PROJECT

EXECUTIVE SUMMARY

The supply chain models were developed in conjunction with the Forestry Biofuel Statewide Collaboration Center exploring the option of a biorefinery in the upper portion of the Lower Peninsula of Michigan. The models integrated information from several of the project tasks and allowed for an evaluation of cost, emissions, and energy consumption impacts of forest resources as feedstocks for potential biofuels facilities in Michigan. The initial project intent was to apply the models in relation to biorefineries only. In reality, the feedstock supply chain would be the same for biomass supplied to a biorefinery, biomass fired or co-fired power plant, or torrefaction/pelletization operations.

Project Scope

A literature summary was conducted to identify gaps and investigate why the optimization models are unique from what has been completed in the past. A Geographic Information Systems (GIS)-based approach was used to select potential biofuel facility locations in Michigan. Two models were developed for the biofuel supply chain: the optimization model and the simulation model. The two models focused on different areas and addressed different issues in the supply chain.

Literature Review

The complexity of a biomass supply chain has been a significant challenge that hinders increased biomass utilization for energy production due to the distributed nature of biomass feedstock. A literature review allowed for the development of a comparative analysis to a unique biomass supply chain designed for the FBSCC project in Michigan.
Based on the current literature, there are a number of research gaps filled by the biomass feedstock supply chain research for the FBSCC project. The literature from existing cellulosic ethanol supply chains served as a basis for the development of supply chain management decision support tools.

Candidate Location Selection

To implement cost-effective biofuel production, the selection of the best location for a processing facility becomes a critical concern. This is because biomass feedstock is geographically dispersed, and the location of a biofuel facility significantly influences transportation costs. Through the use of Geographic Information Systems (GIS), nine candidate locations were selected based on a set of evaluation criteria. The criteria are:

- county boundaries,
- a railroad transportation network,
- a state/federal road transportation network,
- water body (rivers, lakes, etc.) distribution,
- city and village distributions,
- a population census,
- biomass production, and
- no co-location with co-fired power plants

Optimization Modeling

The optimization model and supporting information is provided after the biofuel facility candidate location selection. The optimization model was developed using single location and three multi-location configurations. For the single location models, cost, emissions, and energy were minimized to optimize the individual attributes. In the case of the multi-location configurations, only cost was evaluated. Since the project scope was limited, there were no estimates regarding the future transportation costs, emissions data, and energy inputs. The optimization model is a static, Excel-based application which allows for sensitivity analysis by changing inputs to evaluate different scenarios. The optimization model can also be applied to multiple years and can changes in data inputs.

Simulation Modeling

The simulation model, with an easy-to-use graphical user interface, has been designed and implemented using the Arena Simulation Software, available from Rockwell Automation[1]. The simulation model confirms the one year look conducted by the optimization model. Compared with the optimization model, the simulation model represents a more dynamic look at a 20-year operation by considering the impacts associated with building inventory at the biorefinery to address the limited availability of biomass feedstock during the spring breakup period. Since the simulation model cannot capture all the features of a supply chain system, a series of assumptions were made to simplify the supply chain and the constraints and limitations introduced by the assumptions are discussed.

Infrastructure Analysis

An initial assessment of the infrastructure needs for the top couple of locations is addressed in the final section. An infrastructure analysis was conducted to investigate the feasibility of growing the transportation infrastructure in order to realize the necessary network system needed to transport sufficiently large volumes of biomass in the Lower Peninsula of Michigan. The analysis is conducted on the road transportation network and equipment by examining existing roads and truck fleets as well as comparing with the needs for road and truck infrastructure forecasted for the supply chain model. The capital investment on road and truck infrastructure is also discussed.

[1] Arena Simulation Software. http://www.arenasimulation.com/

FINAL REPORT FOR FORESTRY BIOFUEL STATEWIDE COLLABORATION CENTER (FBSCC) - SUBTASK B4: EXTENDED SUPPLY CHAIN MODEL AND ASSESS ECONOMIC BUSINESS VIABILITY PROJECT

1. ABSTRACT

Work on subtask B4 commenced in Fall 2009 with only minor progress until it was restarted in mid May 2010 and the work was completed by April 30, 2011. Given the limited time for this project, prototype optimization and simulation models were developed with emphasis on biorefinery location(s) in the upper portion of the Lower Peninsula of Michigan. Through the use of Geographic Information Systems (GIS), nine candidate locations were selected based on a set of evaluation criteria. The optimization model was developed using single location and three multi-location configurations while the simulation model only used single locations. For the single location models, cost, emissions, and energy were minimized to optimize the individual attributes. In the case of the multi-location configurations, only cost was evaluated. Preliminary capital investment infrastructure requirements were briefly discussed. These models and the infrastructure analysis can be extended to a larger study area at a point in time when additional funding becomes available.

2. PROJECT OVERVIEW

Overview

The supply chain model was developed in conjunction with the Forestry Biofuel Statewide Collaboration Center to encompass all forest regions in Michigan. However, because of the limited time and funding for this subtask, the work completed was limited to the upper portion of the Lower Peninsula of Michigan. The model integrated information from several of the project tasks and allowed for an evaluation of cost, emissions, and energy consumption impacts of forest resources as feedstocks for potential biofuels facilities in Michigan. The initial project intent was to apply the models in relation to biorefineries only. In reality, the feedstock supply chain would be the same for biomass supplied to a biorefinery, biomass fired or co-fired power plant, or torrefaction/pelletization operation. Because of limited travel distance (100 mile radius) from the woody biomass feedstock source to the biorefinery locations, the only transportation method considered in the models was truck transportation for inbound woody biomass feedstock. Optimization and simulation models were developed. The optimization model is a static model that focuses on a single time period; whereas the simulation model focuses on the operation of a biorefinery over a 20 year period. Further, the latter model takes into consideration an assumed starting inventory along with increased inventory prior to spring break up to deal with limited supply during that time period.

If the volumes of woody biomass required exceed the current removals of the supply chain, the supply system can be modified to meet the increased requirement for roads, trucks, and other equipment. Thus, additional significant capital investment is required by biorefinery investors, harvesting/processing operators, loggers, developers of the infrastructure (i.e., roads, water treatment, utility connections, etc.), and transportation companies. Preliminary recommendations in relationship to the top three locations identify some of the infrastructure requirements necessary to begin operations from a macro level perspective. A critical ingredient is to sufficiently identify the optimal costs associated with capital investment along with the required maintenance and operational costs for longer-term viability and sustainability. The capital investment costs will be split between infrastructure (i.e., roads, railways, utilities, etc.) and equipment (i.e., harvesting, processing, and transportation). These two components are addressed by other subtasks. Specifically, *Task B1: Evaluation Michigan Biomass Transportation Systems*, which evaluates different modes of transportation. The focus for the supply chain model was to use truck transportation only. Different configurations are noted in Task B1. Task B2.5 *Select feasible processing technologies* and B2.6 *Analyze supply chain cost of processing technologies* both include capital investment costs information as well as other data that will be available in the future and can be entered into the model. Due to uncertainty in the information and the lack of a cohesive set of numbers, it was not possible to complete the economic evaluation using traditional financial tools to identify the net present value (NPV) and payback periods. Since total cost information for a longer period of time would be required and there is much uncertainty surrounding the configuration of any specific location (i.e., size, location, etc.) we were unable to complete an economic/business viability analysis of different alternatives other than to identify the least costly location for transportation of woody biomass. This discussion was enhanced by not only computing the transportation cost differential but taking into consideration the emissions generated on pounds basis and energy consumption computed in Btus.

It is unlikely that there will be a statistically significant difference in the price of biomass feedstock (harvesting/processing and stumpage price) from one location to another or between ownership types. The major differentiator in location is the transportation cost. In other words, the locations that are closest to dense forestation are the preferred locations. This is an assumption that has been made at this point in time. As the demand for woody biomass grows, it is likely that there will be price differentials between the different ownership classes, specifically public versus private land ownership. As the size of the facility grows, the feedstock supply radius from the facility will increase. Although the current radius is 100 miles, for each of the optimized locations it is less. It can be observed that on a per ton basis for transportation cost, the larger the facility size, the further the distance, and the longer the haul, with transportation cost per ton that is higher.

The report covers the literature summary gap identification and why these models are unique and different from what has been completed in the past. The optimization model and supporting information is provided after the literature summary. The optimization model represents a one year snapshot but can be applied to multiple years assuming there are no changes in data inputs. Since the project scope was limited, there were no estimates regarding the future transportation costs, emissions data, and energy inputs. The model is a static, Excel-based application which allows for sensitivity analysis by changing inputs to evaluate different scenarios. It provides information on each of the nine locations and presents three possible multi-location configurations. The simulation model represents a more dynamic look at a twenty year operation by considering the impacts associated with building inventory at the biorefinery to address the limited availability of biomass feedstock during the spring breakup period. Finally an initial assessment of the infrastructure needs for the top couple of locations is addressed in the final section.

3. GAPS IDENTIFIED IN THE LITERATURE

The original information provided in the first status report has been modified and is now under review for the Decision Sciences Institute Conference. The information is outlined below and also included in the publications section of the report. The title of the paper is *Comparative Review of Biofuels Supply Chains*.

Abstract
The complexity of a biomass supply chain has been a significant challenge that hinders increased biomass utilization for energy production due to the distributed nature of biomass feedstock. A literature review allowed for the development of a comparative analysis to a unique biomass supply chain designed for the Forestry Biofuel Statewide Collaboration Center (FBSCC) project in Michigan. Research gaps were used to develop models for the FBSCC.

Keywords: cellulosic ethanol, biomass supply chain, comparative analysis, literature review

Introduction
Numerous studies have been conducted to develop models for cellulosic ethanol supply chains, which included a wide variety of different types and forms of biomass feedstock. The Forestry Biofuel Statewide Collaboration Center (FBSCC) project has focused supply chain research and modeling on the use of woody biomass feedstock, including both hard and soft wood species. The main purpose of the FBSCC supply chain is to develop a supply chain model specific to the FBSCC facilities. The model developed by the FBSCC project incorporates other biomass supply chains and mathematical models as its foundation but is tailored to meet local criteria and demands for operating in Michigan. The potential biorefinery in the FBSCC project performs secondary processing at their facility, which differs from other supply chains. This unique supply chain model focused on key activities and characteristics of supply chains. The main goal of the FBSCC supply chain system is to develop a supply chain specific for the FBSCC facilities.

A literature review was performed to compare current models and their attributes. Specific models used for comparison are described in greater detail to allow for clearer understanding. The literature review allowed the unique aspects of the FBSCC model to be identified clearly and addressed. The synopsis in this paper is a summary of a much larger overall detailed report. We focused on the most salient points in the remainder of the discussion.

Comparison Description of the Selected Literature

Based on the current literature, there are a number of research gaps filled by the biomass feedstock supply chain research for the FBSCC project. The literature from existing cellulosic ethanol supply chains served as a basis for the development of supply chain management decision support tools. A unique supply chain model was tailored for the FBSCC. Information from previously developed biomass supply chains and mathematical models formed the foundation for the development of a unique biomass feedstock supply chain model.

National Biofuels Plan

The National Biofuels Plan developed by the Biomass R&D Board (2008) includes sustainability as an action area for successful development of the supply chain. This is similar to the FBSCC facilities because sustainability issues are one of the key drivers behind why the facility will be built. The Biomass R&D Board (2008) includes environment, health, and safety into an action area of its biofuels plan. The addition of these elements ensures that the supply chain can operate in a manner that is safe and compliant with energy policies, procedures, laws, and regulations. The FBSCC facilities relates to this part of the plan from an environmental and sustainability policy prospective.

The Biomass R&D Board (2008) also focuses on feedstock logistics because of its effect on the finished cost of cellulosic ethanol. These same feedstock logistics costs will be considered when developing the supply chain for the FBSCC facilities. The areas of focus for feedstock logistics in the biofuels plan that relate to the FBSCC project are harvesting process, storage facilities, and transportation of the feedstock.

The supply chain model for the FBSCC facilities differs from the National Biofuels Plan in that it uses woody biomass (including logs, forest residues or chips) for its feedstock. National Biofuel Plan considered agricultural residues and energy crops as the feedstock. Also, the FBSCC facilities supply chain will be tailored to meet the local criteria and demands of operating in Michigan, as opposed to a nationwide scale supply chain like the National Biofuels Plan. The Biomass R&D Board (2008) also focuses on conversion science and technology, distribution technology for the ethanol, and blending of the ethanol, which are all out of the scope of the project for the FBSCC supply chain team. Since there are a number of government agencies and researchers conducting research concurrently, we uncovered several other relevant models.

Idaho National Laboratory

Idaho National Laboratory (INL) also developed a biomass supply chain for ethanol. Hess et al. (2007) proposed a uniform-format feedstock supply chain that can be implemented at a nationwide level. This is different from the scope of the supply chain team for the FBSCC facilities. Also, unlike the supply chain model that uses woody biomass (including logs, forest residues or chips), the Idaho National Laboratory mainly uses wheat straw and agricultural residues as primary feedstocks. One of the variables identified by Hess et al. (2007) is the different demands of varying products that compete for biomass to use in energy production. This is similar to the FBSCC facilities. Some of the forest products will also be used by mills in the pulp and paper industry. Another recent source of demand for wood resources is the increasing number of combined heat and power (CHP) operations using co-firing of coal and woody biomass or complete operation with woody biomass. There will be a limited amount available for conversion to ethanol. Preprocessing of the biomass is moved prior to the transportation and handling in the INL report. This allows the transportation and handling procedures to be uniform no matter what type of feedstock is used. This differs from the FBSCC facilities supply chain since all of the preprocessing and chipping will occur at the biorefinery. Because of this unique feature, it will be not included in the supply chain model for FBSCC. Hess et al. (2007) also highlight that transportation and handling costs account for nearly 30% of the annual cost for feedstock. The supply chain team will work to minimize transportation costs through the use of simulation and optimization to the nine potential FBSCC facilities to ensure the system is cost effective.

The INL (2009) study included some critical success factors for a supply chain feedstock model using wheat and barley straw. One of the critical success factors includes the ability to contract straw from a specified distance. Even though the feedstock type is different from that of the FBSCC facilities, the issue outlined is very relevant. Woody biomass need to be harvested from specific harvest areas within a 100-mile radius of the facility. INL (2009) highlighted areas of concern for the feedstock supply chain system. The areas that relate to the FBSCC facilities include: (1) the cost of feedstock will vary with demand; (2) the logistics of moving the feedstock are complicated; (3) storage of feedstock may be subject to fire codes; (4) unloading the feedstock after transportation will vary with each case; and (5) the amount of field energy used while handling and transporting the feedstock.

Sandia National Laboratory

Sandia National Laboratories (SNL) performed a study assessing the feasibility of achieving national goals to produce 90 billion gallons of biofuels by 2030 (SNL, 2009; West et al., 2008). The study considered corn-based ethanol to support the national goal. The ethanol in this study is cellulosic ethanol from energy crops and agricultural and forest residues. This is different from the FBSCC facilities since the supply chain will only incorporate woody biomass supplied from the forest. Corn-based or agricultural residues-based ethanol will not be in the scope of the supply system. SNL developed a model with inputs such as conversion yield, capital investment/annual capacity per cellulosic plant, energy prices, and feedstock yield improvements. However, the supply chain model developed for FBSCC includes supply chain inputs such as feedstock inventory and availability, harvesting/processing, storage at biorefinery, transportation, and environmental policy considerations.

Oak Ridge National Laboratory

The Oak Ridge National Laboratory (ORNL) investigated the feasibility of expanding the ethanol industry. Reynolds, R.E. (2002) studied two different cases for this expansion scenario. Costs associated with building additional infrastructure were estimated. Similarly, the FBSCC supply chain will consider building infrastructure to meet the demand and the associated cost. The ORNL also calculated transportation costs, which is also an important consideration to the supply chain team for the FBSCC facilities. However, these ORNL costs will differ from those observed by the supply system for FBSCC. The FBSCC facilities only include woody biomass primarily in Michigan within a 100 mile radius of an ethanol plant studied other regions and included more sources of feedstock including agricultural residues and grasses. The supply chain team will fill the research gap of producing a woody biomass supply system for ethanol plants in Michigan.

Mathematical Models

Preprocessing at the facility will vary and be dependent on the technological process used to produce cellulosic ethanol. There are different preprocessing steps that can occur. One of those steps is chipping. The chipping of debarked logs may be necessary to reduce the size of the woody biomass to meet the input specifications for feedstock size to more efficiently produce cellulosic ethanol. Gronalt and Rauch (2007) investigated the issue of centralized and decentralized chipping when designing a forest fuel network. The work described by Gronalt and Rauch (2007) solved the supply system problem for several plants at once using numerous storage facilities and terminals to meet the varying demands of each plant. This accumulation of materials from multiple locations is similar to the work that will be done with the FBSCC facilities. The FBSCC model will identify 3-4 best locations for biorefinery facilities by concurrently using simulation and optimization models to minimize cost, emissions, and energy consumption in the transportation process to the mill gate. In another study, mixed integer programming models were used to optimize cost. Gunnarsson et al. (2004) proposed a solution to the supply chain problem involving a forest fuel network structure through a large mixed integer linear programming (MLP) model. The main product used is forest fuels, which are forest residues from harvest areas or byproducts from sawmills. The destination for the forest fuel is a combined heat and power (CHP) plant instead of a biorefinery. This is different from the FBSCC facilities because the primary demand for feedstock is for use in the biorefinery process, with a secondary use for providing power through co-generation of residues from the preprocessing and waste in the production of cellulosic ethanol. The study also raised the issue of forests that are owned by the CHP plant as opposed to contracted forests. Feedstock coming from forests owned by the plant would not have to be purchased; while contracted forests would have to be purchased. All the woody biomass feedstock from the FBSCC facilities will have to be purchased, differentiating it from the Gunnarsson model.

Another study by De Mol et al. (1997) created both simulation and optimization models for the logistics of biomass fuel collection. The network structure associated with the models includes nodes that correspond to source locations, collection sites, transshipment sites, pre-treatment sites, and the energy plant itself. Arcs connect the nodes that represent road, water, or rail transportation. This network structure is similar to the FBSCC facilities structure; but water and rail transportation modes are not included in the FBSCC study. The simulation model created by De Mol et al. (1997) is similar to the simulation model being developed for the FBSCC facilities. Both simulation models include a similar network structure. The model for the FBSCC facilities investigates a variety of different facility locations for an ethanol biorefinery, which is the same as the De Mol et al.'s (1997) simulation model. The optimization model created by De Mol et al. (1997) combines different types of biomass, different nodes, and pre-treatments scenarios to develop the optimal network structure. The fact that the optimization model includes different pre-treatment situations differentiates it from the FBSCC optimization model. The overall goals of supplying an ethanol plant with biomass are the same for both.

In another study, McNeil Technologies, Inc. (2005) investigated the feasibility of building a biomass plant in Jefferson County, Colorado. Several scenarios were considered including centralized and decentralized facilities, various conversion techniques, and different harvesting processes. Similarly, the goal of the FBSCC model is to investigate the feasibility of building one or more biorefineries across Michigan by conducting sensitivity analysis of different plant sizes. Urban wood waste and forest biomass travels through the supply chain from procurement to storage and finally to the energy plant (2005). Woody biomass is used to fuel heating and power plants throughout Jefferson and nearby counties (2005). While this study considers the feasibility of a biomass facility, an optimum facility or process is not chosen. This decision remains in the hands of Jefferson county officials. Different from this study, the FBSCC model will give one or more best locations for biorefinery in Michigan as one of the model outputs.

Sokhansanj, et al. (2006) examined an integrated biomass supply analysis and logistics model (IBSAL). This model examines the supply chain of corn stover through harvesting, storage, and transportation to the biorefinery. The IBSAL model examines costs and optimum conditions for harvesting and transportation logistics of biomass material. Weather conditions and routine equipment maintenance are entered in the model to calculate moisture content of the stover and equipment performance. This is similar with the FBSCC model since the FBSCC supply chain also considers cost, energy use and GHG emissions involved in equipment maintenance. The IBSAL model only considers flatbed trucks which are similar with the FBSCC supply chain by considering truck transportation only. This similarity offers valuable information for the design of the FBSCC supply chain.

The FBSCC supply chain is greatly affected by policy related constraints. This gap was reviewed and constraints addressed in the simulation model. The literature reviewed provides guidance expanding the body of knowledge and application to develop an efficient and cost effective biomass feedstock supply chain model.

Comparison Summary of Key Features of Biomass Supply Chain

Based on the compassion description in previous paragraphs, a comparison summary of the key features involved in biomass feedstock supply chain was illustrated in Table 1. The key features include feedstock type, harvesting procedures, transportation methods, storage facilities, preprocessing facilities, biorefinery distribution, and model outputs.

	Idaho National Laboratory Hess, et al. (2007); Hess, et al. (2009); Idaho National Laboratory (2006)	**Sandia National Laboratory** Sandia National Laboratories (2009); West, et al. (2009)	**National Biofuels Plan** Biomass Research and Development Board (2008)	**Oak Ridge National Laboratory** Reynolds (2002)
Feedstock Type	Wheat Straw	Corn-based/agricultural and forest residues	Corn, crop residues, woody residues	Corn stover, forest residues/thinnings, agricultural residue, urban waste
Harvesting Procedures	Industrial harvesting (Crop harvesting, residue collection)	Not Identified	Industrial harvesting (Feller-buncher, skidder, crop harvesting, residue collection)	Not Identified
Transportation Methods	Truck/Rail/Water	Truck/Rail	Truck/Rail/Water	Truck/Rail/Water
Locations and Facilities	Harvesting and collection sites, storage facilities, preprocessing locations, ethanol plant	Source locations, storage sites, conversion plants, blending locations, distribution facilities	Harvesting and collection sites, storage facilities, preprocessing locations, ethanol plant	Source locations, terminals, ethanol plant
Preprocessing Facilities	Reports suggest moving preprocessing of the biomass to early on in the supply chain	Not Identified	Various locations along the supply chain specific in each case	Not Identified
Biorefinery or Energy Operations	Numerous ethanol plants	Numerous ethanol plants	Numerous ethanol plants	Single plant destinations
Output	Cellulosic Ethanol	Cellulosic Ethanol	Cellulosic Ethanol	Cellulosic Ethanol

Table 1 Comparison Summary of Key Features of the Selected Literature

	Simulation and Optimization De Mol et al. (1997)	Forest fuel network design Gronalt and Rauch (2007)	Supply chain Optimization in the Forest Industry Gunnarsson (2007)	Jefferson County Biomass Facility Feasibility Study McNeil Technologies, Inc. (2005)	Integrated biomass supply analysis and logistics model (IBSAL) Sokhansanj et al. (2006)	FBSCC Model
Feedstock Type	Thinnings, prunings, waste wood, sewage sludge, waste paper	Forest Fuel	Forest fuel, pulp products	Urban wood waste, forest biomass	Corn stover	Woody biomass
Harvesting Procedures	Not Identified	Industrial harvesting (Feller-buncher, skidder)	Not Identified	Industrial Harvesting (chainsaw, feller-buncher, harvester, skid steer, masticator)	Shredding, Baling, Stacking	Industrial harvesting (Feller-buncher, skidder)
Transportation Methods	Truck/Rail/Water	Truck	Truck/Rail/Vessels/Barges	Truck	Truck (flatbed trailers)	Truck
Locations and Facilities	Source locations, collection sites, transshipment sites, pre-treatment sites, the energy plant	Harvesting site, regional terminals, industrial terminals, energy plant	Storage terminals, saw mill, pulp mill, paper mill, heating plant	Harvesting site, landing, energy plant	Harvesting site, satellite storage, biorefinery	Harvesting site, storage at biorefinery
Preprocessing Facilities	Optimization and simulation found preprocessing can best be done at the plant	A central terminal where all the chipping can occur and mobile chipping options were analyzed	Chipping occurs at the forest or at the mill prior to transport to the heating plant	Chipping occurs at the landing	Grinding occurs at the biorefinery	Chipping occurs at biorefinery
Biorefinery or Energy Operations	One central location	Numerous energy plants	Numerous CHP facilities	Central facility, semi-mobile plant, existing facility, heating and cooling system	Biorefinery	Numerous ethanol plants
Output	Some type of fuel from Biomass	Fuel for heating and bioenergy plants	Saw wood, paper, forest fuels	Fuel for heating and power plants	Biorefinery	Cellulosic ethanol

Table 1 Comparison Summary of Key Features of the Selected Literature (continued)

Conclusion
A series of studies regarding existing biomass supply chains were reviewed and compared with the supply chain developed for the FBSCC facilities in Michigan. The FBSCC supply chain has similarities with existing biomass supply chain models, including the output of the supply chain (cellulosic ethanol), the method of transportation (truck), and land ownership (i.e., federal, state, private) issues. The FBSCC supply chain differs from existing feedstock supply chains in biomass feedstock types and activities (i.e. storage along the supply chain and chipping) along the supply chain. The FBSCC facilities supply chain uses only woody biomass as the type of feedstock. The combination of these differences from existing supply chains creates a unique opportunity to develop a new supply chain using woody biomass as the primary feedstock to support the FBSCC facilities.

The detailed literature review is contained in Appendix B4-A.

4. IDENTIFICATION OF CANDIDATE LOCATION

Nine potential locations to construct and operate an ethanol facility were identified in the upper portion of the Lower Peninsula of Michigan. This analysis was based on criteria used in a renewable assessment report (Jenkins, 2008) and additional items. The criterion includes:

1) Location within one mile of a major state road (Jenkins, 2008);
2) Location within one mile of railway (Jenkins, 2008);
3) Location within a community size of at least 1,000 (Jenkins, 2008);
4) Location within ¼ mile of a water body (rivers, lakes, etc.);
5) The minimum residues within a 100 mile radius of any select community have to be at least 0.7 million dry tons / 1.4 million green tons (a rough estimate of the ratio between *green tons* and *dry tons* is 2:1[2]) to support a facility producing 50 million gallons of fuel each year; and
6) Location does not have a co-fired power plant around (there are co-fired power plants in Grayling, Mancelona and Cadillac).

The list of the nine potential sites for biorefinery in the lower peninsula of Michigan, as well as the distance (miles) to a closest co-fired power plant, is shown in Table 2. The map in Figure 1 shows the distribution of the nine potential sites.

[2] Minnesota Woody Biomass Facility Survey. Minnesota Department of Natural Resources Division of Forestry Forest Products Utilization & Marketing Program. http://files.dnr.state.mn.us/forestry/um/biomass/minnesotawoodybiomassutilization_report.pdf; 2008

City / Village	Distance to a Nearest Biomass Power Plant (miles)
Manton City	11.19
Roscommon Village	12.81
Kingsley Village	23.86
Kalkaska Village	23.94
Gaylord City	25.49
Clare City	33.97
West Branch City	35.29
Traverse City	36.03
Boyne City	41.24

Table 2 Potential Site for Biorefinery in Lower Peninsula of Michigan

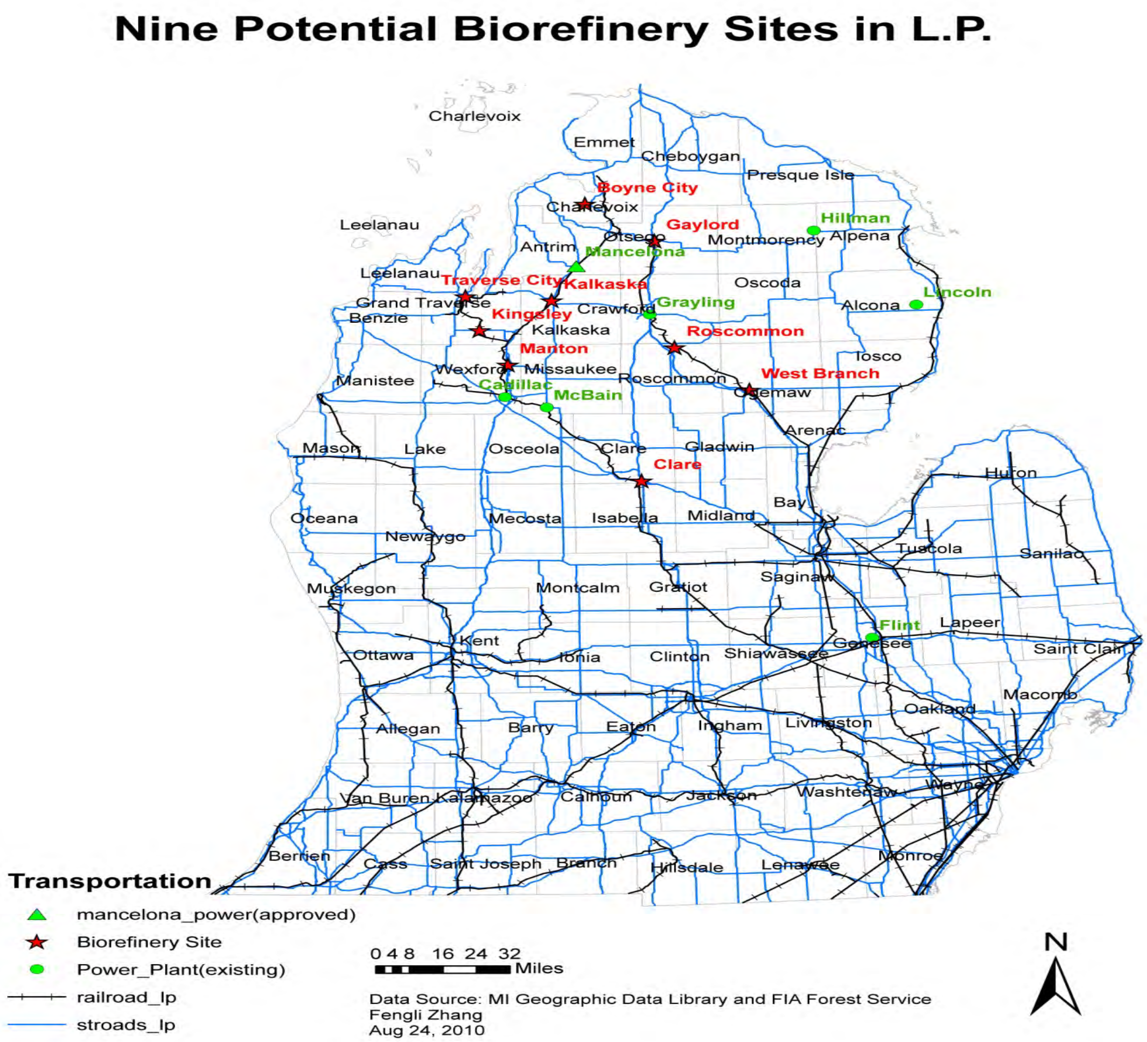


Figure 1 Map of Nine Candidate Locations for Biorefinery Plant in Lower Peninsula of Michigan

Each of the candidate locations and the 100 mile radius are shown in Appendix B4-C *Counties within 100 mile radius of each location.*

Existing/Approved Wood-Fueled Biomass Power Plants in Michigan

There are several electric power generation facilities using wood fuel as feedstock in Michigan. These utilities have a combined capacity of 173,000 kW, or approximately half of Michigan's wood-based energy production capability. Table 3 shows each facility's information, including the name of the power plants, locations, capacities, and approximate wood fuel consumption in tons per year. In order to avoid competition, e.g., pulpwood, workforce, and other resources, with the power facilities listed in the table, potential ethanol conversion plants will not be located in adjacent areas. The exact type and mix of woody biomass used for firing these operations is unknown and varies by each location.

Power Plants	Location	Capacity (kW)	Wood Fuel Consumption (tons/yr)
Grayling Generating Station	Grayling	38,000	250,000-300,000
Viking Energy--McBain[a]	McBain	18,000	150,000
Cadillac Renewable Energy[a]	Cadillac	39,600	375,000
Hillman Power Co.[a]	Hillman	20,000	230,000
Viking Energy--Lincoln[a]	Lincoln	18,000	150,000
Genesee Power Station[a]	Flint	39,500	300,000
Mancelona Biomass Plant[b]	Mancelona	36,000	Approximately 300,000

Table 3 Existing/Approved Wood-Fueled Biomass Power Plants in Michigan

[a]Source: REPIS, http://www.nrel.gov/analysis/repis/

[b]Source: McWhirter S., "Mancelona biomass plant awaits utility deal."

Overlap in Study Area

There is an overlap in the study area with the Frontier Renewable Resources biorefinery to be constructed in Kinross, MI. Figure 2 is a map of the overlapping counties under consideration for both projects. The radial lines in Figure 2 identify the zone distances (60-150 miles) from the Kinross plant.

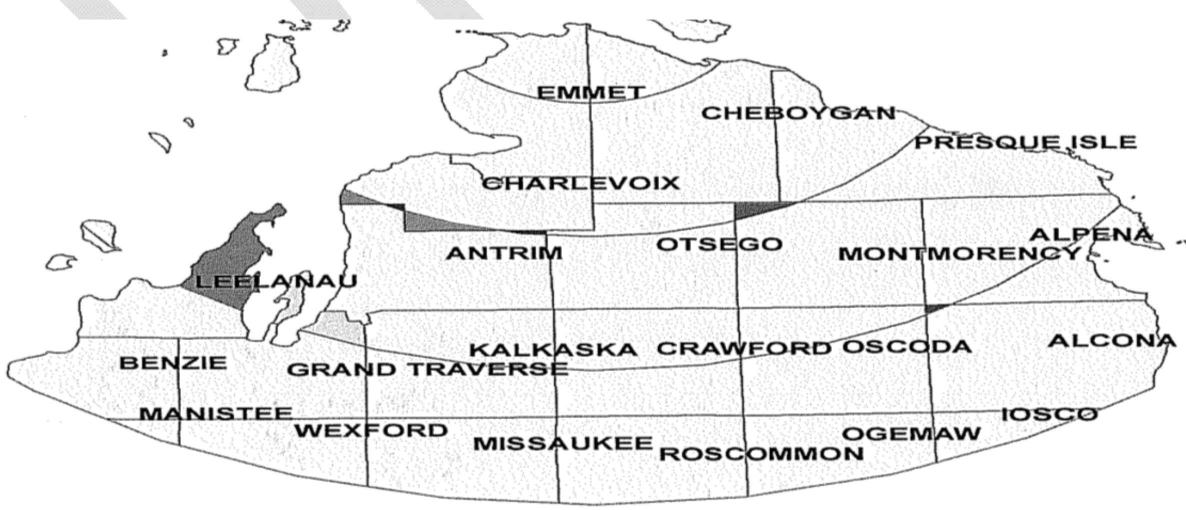


Figure 2 Overlapping Counties with Frontier Renewable Resource for Competing

Also, there are special considerations that need to be noted for some of the overlapping counties. This information is detailed in Figure 3. The special considerations do not apply to FBSCC because FBSCC considers a county as a harvesting area while one county is split into several harvesting areas for the Frontier Renewable Resources biorefinery.

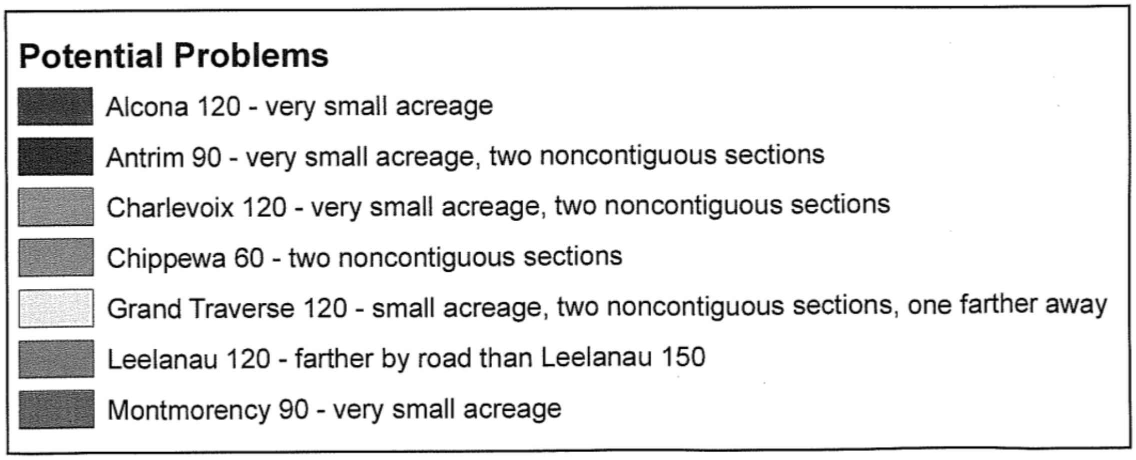


Figure 3 Overlapping Counties with Special Considerations

Modification of Original Approach

The original intent was to use a two-step methodology to identify the cost optimal locations, however, this approach proved to not be the best method for identifying candidate locations. Two papers outlining this approach titled, Zhang, F., Johnson, D.M., and Sutherland, J.W. (May 2010) "GIS-based approach of identification of the optimal pulpwood-to-biofuel facility location in Michigan's Upper Peninsula," 2010 Production and Operations Management Society (POMS) Conference, Vancouver, British Columbia, CA and Zhang, F., Johnson, D.M., and Sutherland, J.W. (June 2011) "A GIS-Based Method for Identifying the Optimal Location for a Facility to Convert Forest Biomass to Biofuel," *Biomass and Bioenergy*, discussed this approach.

5. SUMMARY OF DATA INPUTS

Information was obtained from other subtasks that have specific assumptions and limitations which go beyond those that apply specifically to each of the models.

Analysis of Spring Breakup Data

Data Collection

In Michigan, there are weight restrictions to prevent damage to roads during the freeze-thaw cycle from winter to spring. All the weight restriction dates (including start dates and end dates) from 2006 to 2010 for all harvesting areas are identified according to the maps provided by Michigan Department of Transportation (MDOT) (Appendix B4-D). The start and end dates are clearly colored in the map. We identified the start as the day one county is colored and the end as the day the color disappears. The duration calculation required adding one day to the difference between the start and end dates to determine the total number of days.

Statistical Analysis

Statistical analysis was conducted for the weight restriction dates in order to describe the data using a mathematical model (either theoretical or empirical). Statistical analysis can also help to find the correlation between weight dates for different harvesting areas. Two methods are used for analysis. First, a normal probability plot is generated to graphically assess whether the sampling data could come from a normal distribution. Second, the Lilliefors tests were performed as a supplement for the normal probability plots to further check whether the samples come from normal distributions. The Lilliefors test was utilized because it is appropriate for small sample size. An example analysis of Ogemaw County (a harvesting area) was performed. The original data for Ogemaw County is shown in Table 4. The transformed data (representing Number of Days from Jan. 1) is shown in Table 5. The normalized numerical data in Table 6 is calculated based on the transformed data in Table 5.

Spring Break	2002	2003	2004	2005	2006	2007	2008	2009	2010
Start	18-Feb	17-Mar	1-Mar	9-Mar	8-Mar	9-Mar	17-Mar	6-Mar	8-Mar
End	17-Apr	24-Apr	19-Apr	18-Apr	7-Apr	13-Apr	23-Apr	22-Apr	1-Apr
# of Days	59	39	50	41	31	36	38	48	25

Table 4 Original Data

Spring Break	2002	2003	2004	2005	2006	2007	2008	2009	2010	Average	Standard Deviation
Start	49	76	61	68	67	68	77	65	67	66	8.25
End	107	114	110	108	97	103	114	112	91	106	7.90
# Of Days	59	39	50	41	31	36	38	48	25	41	10.29

Table 5 Numerical Dates (Representing Number of Days from Jan. 1)

Spring Break	2002	2003	2004	2005	2006	2007	2008	2009	2010
Start	-2.12	1.16	-0.66	0.19	0.07	0.19	1.28	-0.18	0.07
End	0.10	0.98	0.48	0.22	-1.17	-0.41	0.98	0.73	-1.93
# of Days	1.77	-0.17	0.90	0.02	-0.95	-0.46	-0.27	0.70	-1.53

Table 6 Normalized Numerical Dates

Normal Probability Plot

The purpose of the normal probability plot is to graphically assess whether the sampling data could come from a normal distribution. If the data are normal the plot will be linear. Other distribution types will introduce curvature in the plot. Normal probability plots were created for the spring break duration (Figure 4), start (Figure 5), and end (Figure 6) for Ogemaw County separately. There is strong evidence that the three plots are linear, except some outliers in the start and end plots. The identified outliers may be the result of irregular warm climate or data error.

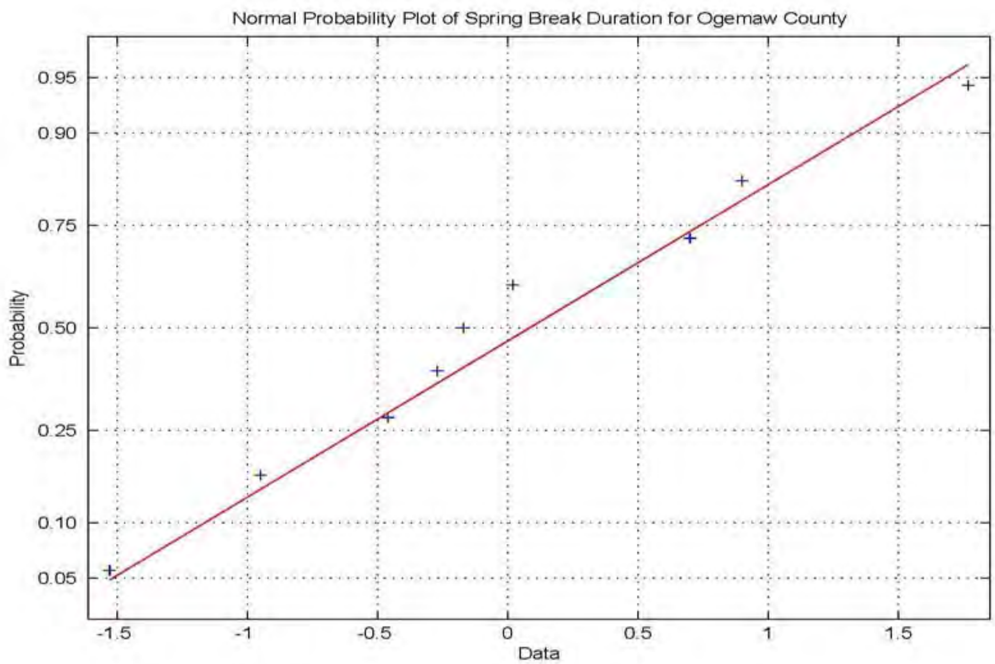


Figure 4 Normal Probability Plot of Spring Break Duration for Ogemaw County

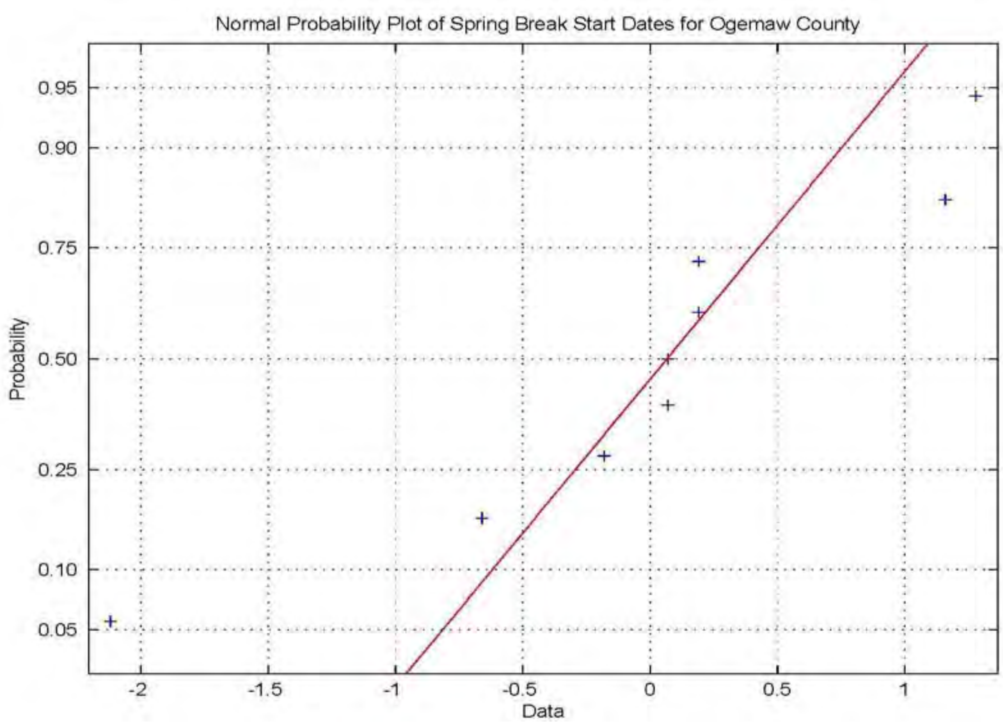


Figure 5 Normal Probability Plot of Spring Break Start for Ogemaw County

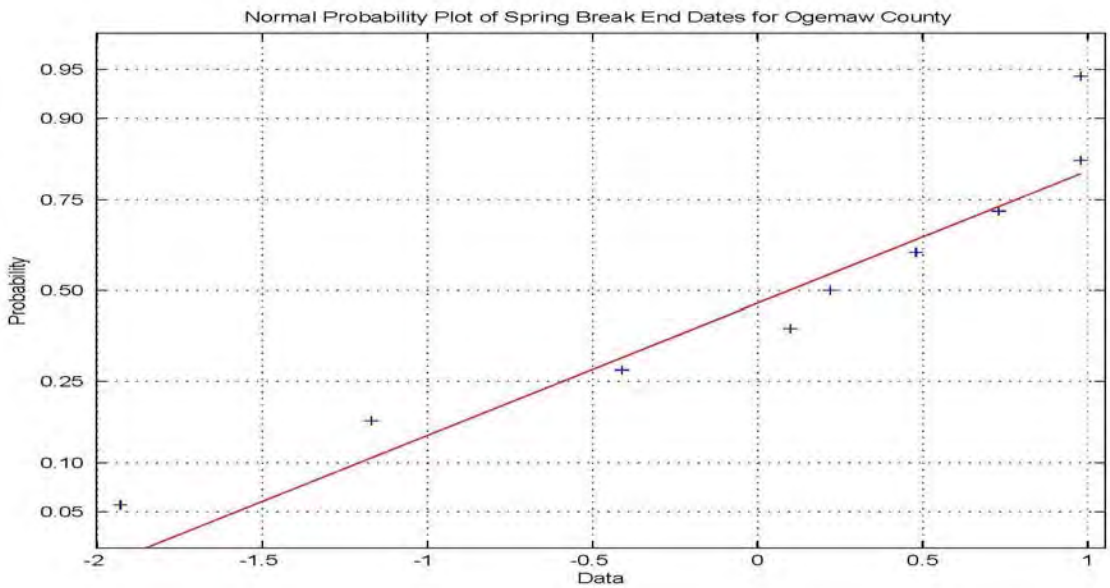


Figure 6 Normal Probability Plot of Spring Break End for Ogemaw County

Lilliefors Test

The Lilliefors tests were performed as a supplement to the normal probability plots to validate whether the samples come from normal distributions. The Lilliefors test was utilized because it is appropriate for small sample size. The tests failed to reject the null hypothesis that the values come from a normal distribution. Figures 7-9 graphically illustrate the comparison between empirical and theoretical distributions (standard normal distribution was used in this study).

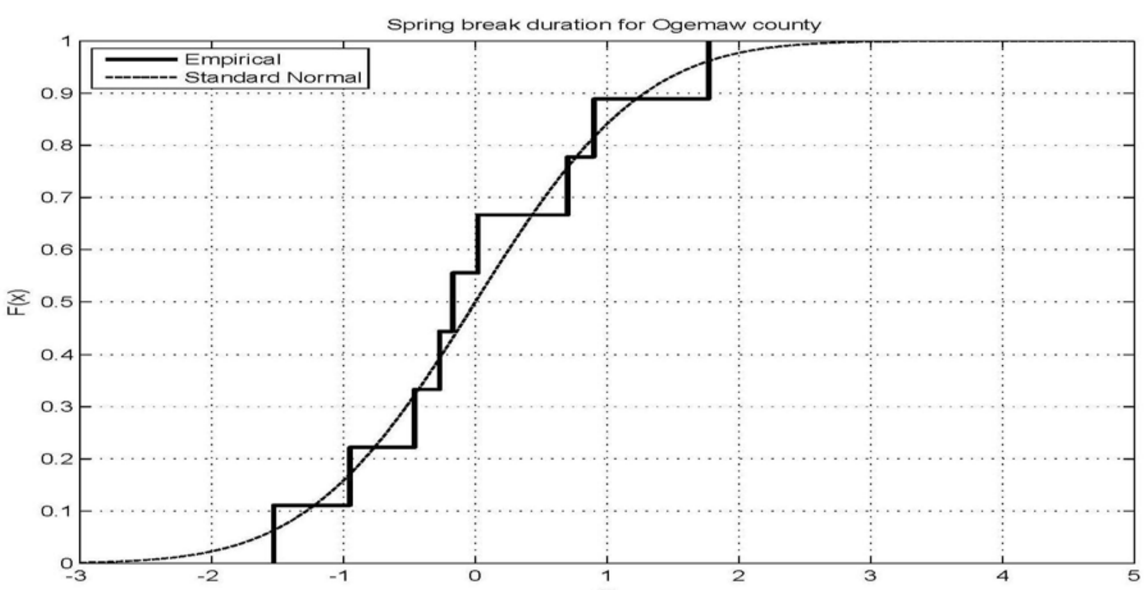


Figure 7 Comparison of Spring Break Duration Empirical CDF with Standard Normal CDF

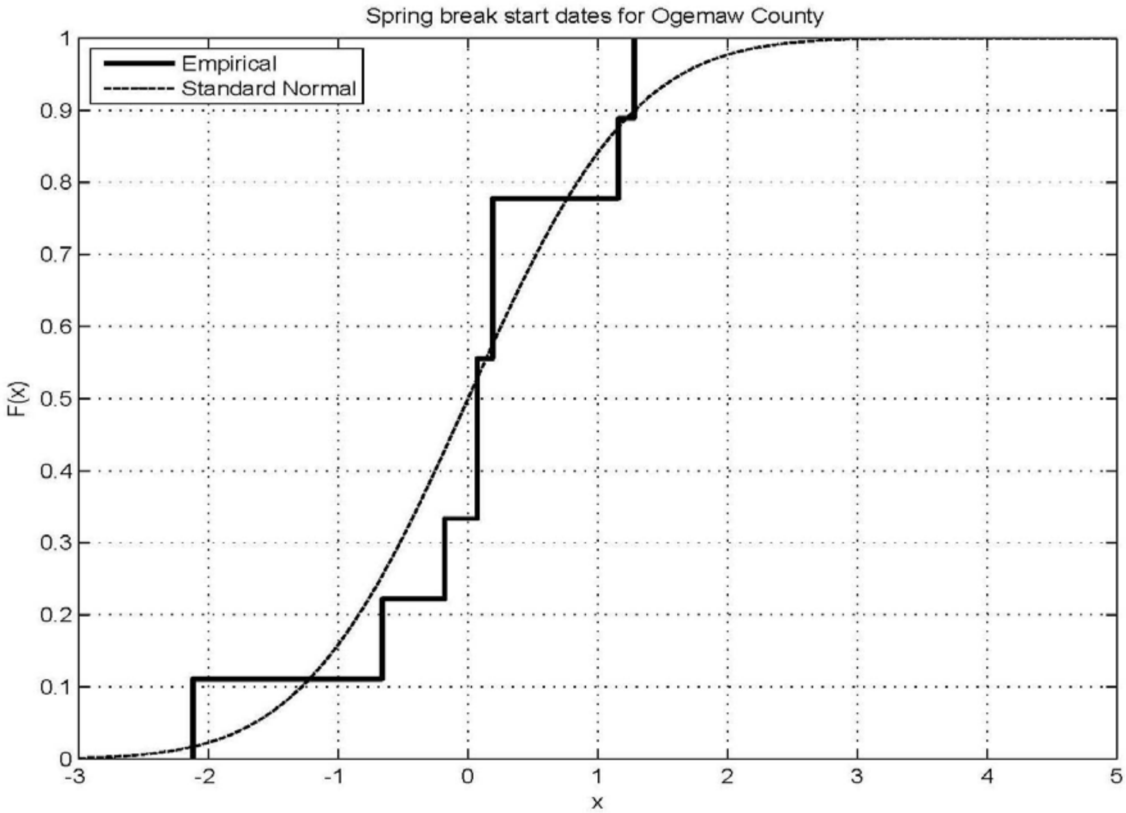


Figure 8 Comparison of Spring Break Start Empirical CDF with Standard Normal CDF

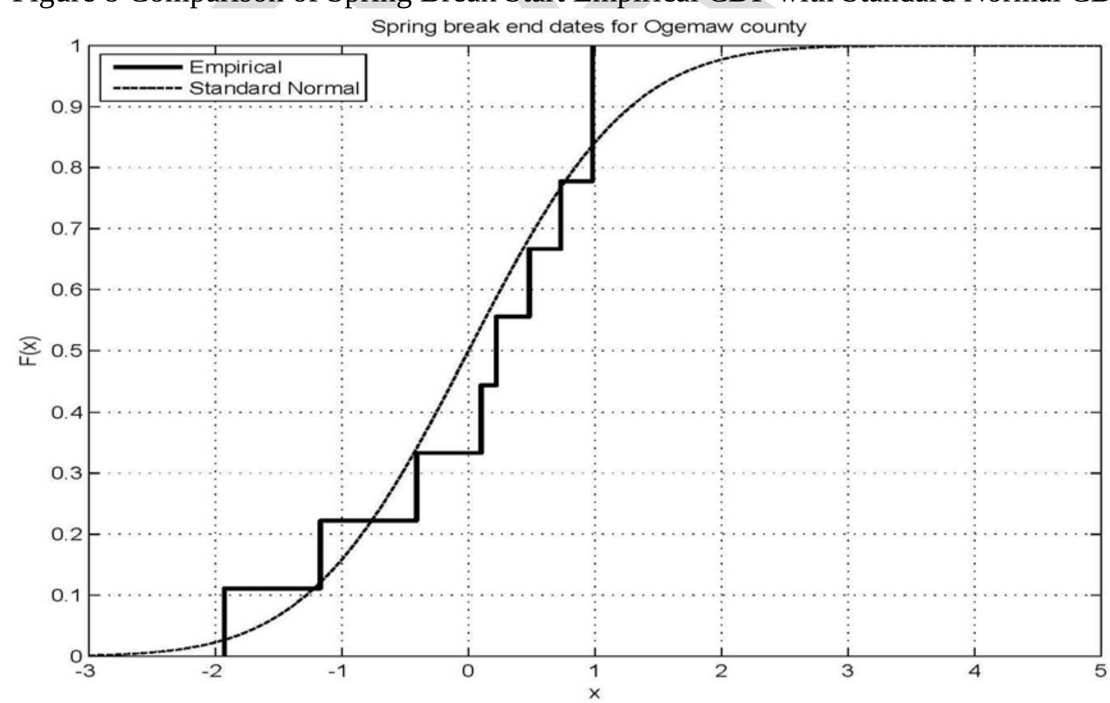


Figure 9 Comparison of Spring Break End Empirical CDF with Standard Normal CDF

Goodness-of-Fit Test Using Arena Input Analyzer

The goodness-of-fit test was applied using Arena Input Analyzer. The results are shown in Table 7 and confirm the prior analysis.

Spring Break Start Distribution Summary	
Distribution:	Normal
Expression:	NORM(66.4, 7.78)
Square Error:	0.11992
Spring Break End Distribution Summary	
Distribution:	Normal
Expression:	NORM(106, 7.45)
Square Error:	0.097101
Spring Break Duration Distribution Summary	
Distribution:	Normal
Expression:	NORM(40.8, 9.7)
Square Error:	0.082609

Table 7 Goodness-of-Fit Test Results

Conclusion

For Ogemaw County normal distributions can describe the spring break data, including start, end, and number of days. However, for most of the supplier counties, limited data is available for accurate statistical analysis. The analysis was not included in the report for all counties. Ogemaw County was used to provide an example.

Michigan state law indicates that the months of March, April and May are automatically reduced loading months, but the statute also allows the Michigan Department of Transportation (MDOT) and the county road commission to implement those restrictions earlier or suspend reduced loading, depending upon weather conditions (MSP, 2004). Since the area under study is the upper portion of the Lower Peninsula of Michigan where spring breakup ends earlier, an assumption of using March and April as the spring breakup months was made.

Forest Biomass Data

The forest biomass data is characterized by ownership type: federal forests (national), state forests, and private landowner including corporate. The forest biomass data was provided by Dr. Robert Froese from the Forest Service Inventory EVALIDator web application version 4.01 (Miles, 2011) (Task A1: *Develop a Geospatial Forest Based Biomass Inventory Task* A2: *Develop a Forest Biomass Information System (FBIS)*).

Ownership

There were three broad land ownership categories for the forest biomass data. These included federal (national) forests, state forests, and private forests. The private forests are in aggregate and do not delineate between corporate ownership or large or small ownership.

Species

The species are aggregated by soft and hard wood but are not separated in any greater detail. The user of the models should exercise caution as the mix of species and the proportion of each type are not included. Also, the data input for the model allows for determining the percentages of roundwood versus forest residues.

Availability

Net growth after removals was calculated. In other words, the net growth accumulating in the forest on an annual basis, after accounting for losses to mortality, timber harvesting, reversion (land becoming forest) and conversion (land becoming nonforest). This is a straightforward query using the EVALIDATOR interface. The fraction of net growth, that is net growth after removals, is equal to 1minus the fraction of net growth of current removals was used. The forest biomass data is located in Appendices B4-F through B4-H by ownership type, soft and hardwood, and availability factors. These represent data input cells in the models and can be modified if the data and/or assumptions regarding availability change. Figure 10 (Leatherberry and Spencer, 1996) shows the four regions in Michigan. There are the two regions where counties are located within a 100-mile radius of the nine selected locations: Northern Lower Peninsula (N) and Southern Lower Peninsula (L). Because of the competing uses in the Upper Peninsula (U.P.) of Michigan, we did not use feedstock from the U.P. so Eastern and Western U.P. are not relevant at this point.

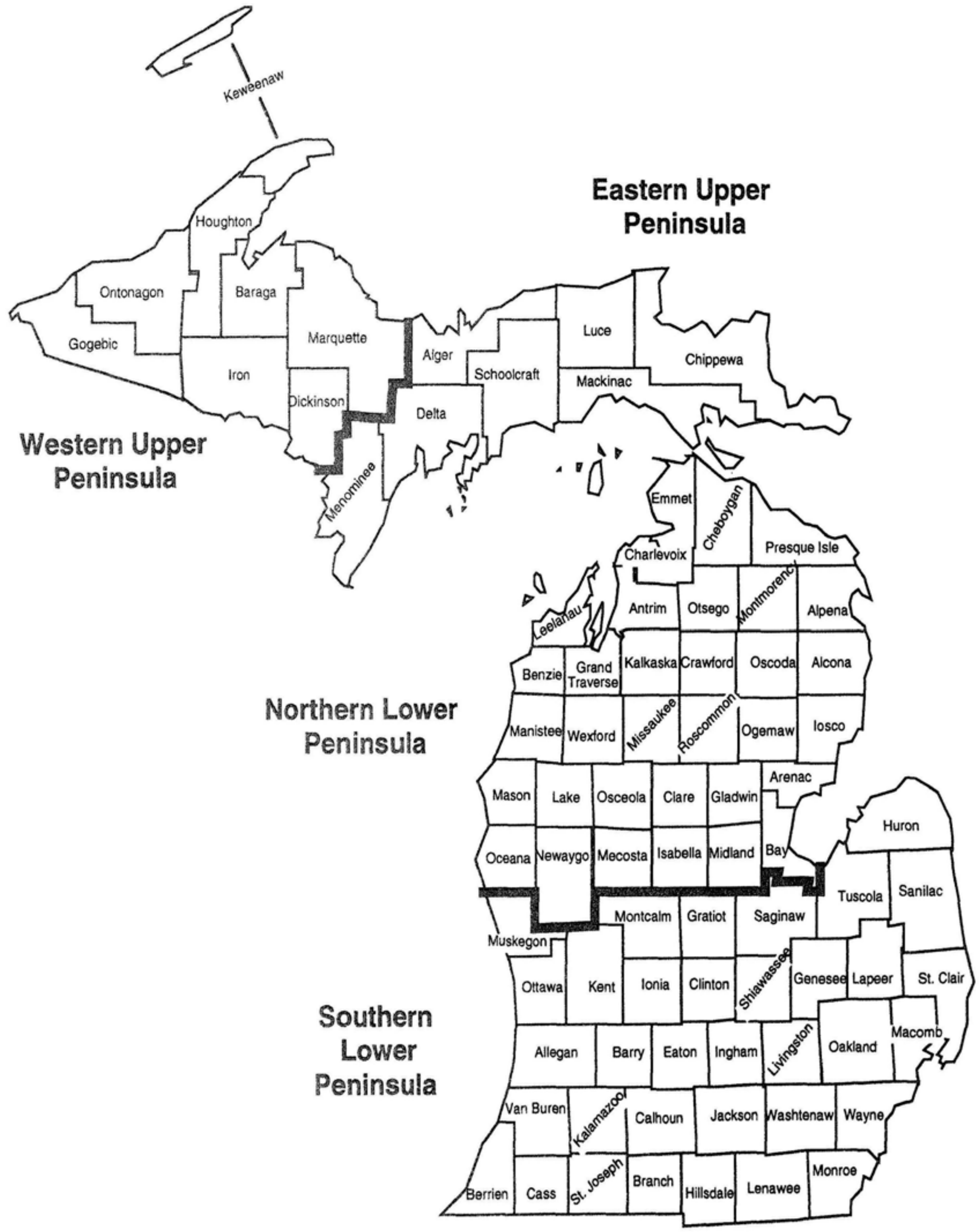


Figure 10 Michigan Map Showing Regions

Adjustment Factors

The ability to adjust the quantities for known, planned uses of forest biomass has been included. This includes an adjustment of hardwood information for overlapping counties for the planned biorefinery plant in the eastern portion of the Upper Peninsula of Michigan. Additionally, an adjustment can be made to the resource availability for the planned combined heat and power (CHP) of a fully biomass fired operation in

Mancelona, MI, in the eastern portion of the upper, Lower Peninsula of Michigan. In Michigan there are currently six wood-based electricity generating plants (as indicated earlier in the report). These operations use mostly logging residues, chips, sawmill or other mill residues, and municipal or industrial wood waste, listed in highest to lowest consumption pattern.

Distance Data

The distances from the centroid of the counties within a 100-mile radius to each of the candidate locations calculated using the latitude and longitude for rectilinear distance are shown in Appendix B4-I. The level of detail is aggregate and is not specifically linked to road networks.

Cost Data

The cost data includes the transportation cost only. The table was computed by using the rectilinear distance for latitude and longitude (Appendix B4-I) of the centroid for each of the counties within a 100-mile radius of the specific location and the selected biorefinery location. The cost model included a fixed and variable portion and is calculated as follows: Variable cost = 0.074 \$/ton-mile and Fixed cost = 3.72 \$/ton. The final models allow for inputs for harvesting/processing and stumpage costs. The transportation cost for each candidate location by county within a 100 mile radius is shown in Appendix B-4J.

Emissions and Energy Data

Greenhouse gas (GHG) emissions and fossil energy demand due to forest feedstock production (harvesting/processing) and transportation have been calculated using the assumptions and literature values (Tables 8 and 9). In both supply chain stages, diesel fuel use was the primary driver of environmental burdens. Forest feedstock production was assumed to take place with a full processor and forwarder equipment configuration. Truck transportation of forest biomass was assumed using Michigan log trucks which are typically “truck + trailer” units capable of hauling much larger loads (45 - 50 ton average assumed) than is typical in neighboring states. Emissions factors and energy demand factors have been normalized to one ton of biomass production, assumed to be a ‘green’ ton containing roughly 50% moisture.

Item	***Data***	***Source***
Harvesting and Forwarding		
Gallons diesel / hr	30 L / hr, full processor and forwarder	White 2005
Productivity / hr	4 cords/hr , 2.35 tons/cord	Logger interviews (Handler 2010)
Diesel emissions factors	13.63 kg CO_2e / gal 30.05 lb CO2e / gal	GREET 1 upstream production (Wang 2009); US LCI combustion (U.S. Life-Cycle Inventory Database 2009)
Diesel energy impact factor	40.5 MJ / L 38,387 Btu / L	Klvac 2003
Emissions factors for machine production, maintenance	0.1 kg CO_2e / ton timber 0.2 lb CO_2e / ton timber	Assumed burden for lifetime of production, normalized to 1 ton
Energy impact factor for machine production, maintenance	15.7 MJ / ton 14,881 Btu / ton	Athanassiadis 2002 , lubricant use from logger interviews (Handler 2010)
Total GHG emissions (Harv. & Forw.)	*11.6 kg CO_2e / ton* *25.6 lb CO_2e / ton*	
Total Fossil Energy Demand (Harv. & Forw.)	*145 MJ / ton* *137,433 Btu / ton*	

Table 8 Data and assumptions for roundwood harvesting/forwarding (Zhang, Handler et al., 2011)

\

Item	Data	Source
Truck transportation		
Diesel emissions factor	13.63 kg CO_2e / gal 30.05 lb CO2e / gal	GREET upstream production (Wang 2009); US LCI combustion (U.S. Life-Cycle Inventory Database 2009)
Log truck fuel use per ton-mile	4 miles / gallon 45 ton loaded average 50% loaded miles 0.0111 gal / ton-mile	Logger interviews (Handler 2010)
Emissions for log truck production, maintenance	290,000 kg CO_2e 639,341 lb CO_2e Must normalize to lifetime ton-miles of truck operation	GREET 2 vehicle analysis (Athanassiadis 2000), scaled to log truck weight
Lifetime ton-miles of log truck	8 yr productive life 70,000 miles / yr 45-50 ton loads, 50% loaded miles	Assumed
Diesel Energy Impact factor	40.5 MJ / L 38,387 Btu / L	Klvac 2003
Total Log Truck GHGs / ton-mile	*0.174 kg CO_2e / ton-mile* *0.384 lb CO_2e / ton-mile*	
Total Fossil Energy Demand, Log Truck	*1.68 MJ / ton-mile* *1592 Btu / ton-mile*	

Table 9 Data and assumptions for truck transportation (Zhang, Handler et al., 2011)

The energy and emissions values used in the optimization model are located in Appendices B4-K and B4-L respectively.

Data Requirements Summary Tables

The summary tables showing the data requirements for the optimization and simulation models are shown in Appendix B4-M.

Plant Size and Conversion Ratio

For this study, three different plant sizes were evaluated: 50 million gallons per year (50 MGY), as well as 30 MGY and 40 MGY. Numerous studies indicate varying levels of conversion of forest biomass to fuels. This variance is based on the moisture content of wood and ranges from a low of 40 gallons per ton to a high of 75 gallons per ton. The low end of the spectrum is assumed to use biomass that has higher moisture content (approximately 40-50%) and is typically referred to as “green tons”, whereas the higher end of the spectrum would be characteristic of wood that has a much lower moisture content in the range of 15-25% (Maker, 2004; Aerts and Ragland, 2000; Ragland, et. Al, 1991). In this study, green tons were assumed with an approximate conversion factor of 1 green (short) ton could produce 40 gallons of fuel (Aden et al., 2002).

6. OPTIMIZATION MODEL

Overview

The optimization model was designed to be utilized by any user who has an interest in exploring the option of a biorefinery in the upper portion of the Lower Peninsula of Michigan. The same feedstock supply chain would exist for a wood-fired or co-fired power plant so the model serves multiple users. This section provides information on the purpose/objectives of using optimization models, model assumptions, model description, model constraints/limitations, Microsoft Excel™ 2007 Solver model, discussion of results, overall limitations, summary, and identification of future work.

Purpose/Objectives

Optimization is a modeling technique designed to identify optimal decisions and is used as a management decision support system. For example, minimize total system cost, select the best location for a biofuel production facility or facilities, or minimize emissions or energy consumption, are representative of decisions made through optimization. Optimization provides an integrated tool for several interrelated planning situations. The model can be used both as a tool for tactical planning, and as a strategic tool to analyze the effects on the current planning in various situations (Gunnarsson, et. al., 2004). We used single objective optimization to identify the optimum location or locations for a biorefinery. *In other words, the question to be addressed is can the study area support more than one biorefinery and what is the optimum location?* The three decision criteria for the optimization model are characterized as cost, emissions, and energy. Evaluation of each of the nine locations based on the three criterion along with three multiple location configurations were completed. In conjunction with the optimization results, a weighted-average approach was conducted to determine ranking of the nine locations.

The optimization model of the woody biomass supply chain was developed using Microsoft Excel. Although Excel does have some limitations regarding model size, it is a widely used software package that is readily available. The intent was to allow the optimization model to be downloaded by users who can then modify the input parameters to allow for decision making and sensitivity analysis. Although it is limited to the nine selected locations and three multi-location configurations, it is an aggregate tool that requires little knowledge on using Excel or any other package.

The optimization model was designed to answers some of the following potential questions:

- What is the cost for harvesting/processing, stumpage, and transportation?
- How many plants can be supported with the existing and future woody biomass resources and given there are other competing sources for the same feedstock?
- What is the best location?

Model Assumptions

The assumptions are divided into several categories: biorefinery locations, biorefinery operations, transportation, and biomass availability and inventory.

Assumptions for identifying initial prospective biorefinery locations

- Accessibility to the state/federal road and county road (road must be paved – either concrete or asphalt) transportation networks (i.e., the facility is within one mile of a network) is required. This guarantees the input (pulpwood feedstock) and output (biofuel products) can be easily transported;
- The biorefinery is also required to be within one mile of rail access;
- Only cities, villages and township with populations greater than 1,000 will be considered for locating biorefinery, to ensure the availability of a workforce;
- Accessibility to water connections within ¼ mile of location;
- Accessibility to sewer/water connections or would required to add a septic system and well; and
- Accessibility to electricity infrastructure.

Assumptions for biorefinery operation

- The biorefinery will operate 20 years continuously;
- The biorefinery operates 24/7, 50 weeks per year with 2 weeks shutdown for maintenance;
- The biorefinery production is level (i.e., same production volumes each week); and
- The biorefinery will not have a dedicated supply source for any of the feedstock requirement; all biomass will be purchased from multiple sources and the optimum price.

Assumptions for transportation

- Transportation radius is less than 100 miles;
- The centroid of the county is used as the origin for the feedstock to the facility location; and
- Truck carrying capacity is 50 tons.

Assumptions for biomass availability and inventory

- The biorefinery(ies) will not have a dedicated supply source for any of the feedstock requirement; all biomass will have to be purchased.;
- The land area within the 100-mile radius will be subdivided into harvesting areas to incorporate county level information;
- The harvest areas have a target size that allows a suitable balance between having detailed information about the resource locations;
- During spring break, the only access to feedstock for the biorefinery will be from its own storage yard;
- Delivery of feedstock will remain constant during the periods of June 1 through November 30 while December 1 through the end of February will have increased delivered quantities for inventory build up to address road load restrictions during spring break up;
- Woody biomass feedstock includes logs and forest residues;
- One green ton is used to produce 40 gallons of biofuel. A green ton is defined as woody biomass that is less than 90 days old;
    - For a 30 million gallon facility the total green tons required is 750,000.
    - For a 40 million gallon facility the total green tons required is 1,000,000.

- For a 50 million gallon facility the total green tons required is 1,250,000.

- No feedstock will be transported over the Mackinaw Bridge (hereafter referred to as "bridge"[3]. It is assumed that all feedstock in the Upper Peninsula is not available for transport over the bridge and will be consumed by others in the Upper Peninsula; and
- Reduced by a percentage to be determined based on the biomass combined heat and power facilities and mill consumption for operations that are not currently consumers of feedstock. This includes the Frontier Renewable Resources biorefinery and the planned 36MW combined heat and power plant planned for Mancelona, MI. For both of these planned operations, it is anticipated that they will require a combined total of approximately 800,000 green tons per year for steady-state operation.

Constraints/Limitations

One of the most challenging issues that confront FBSCC biorefinery(ies) is securing woody biomass when unusually warm weather forces road weight restrictions to be imposed much earlier than expected. The wood must be in areas that can be logged rapidly and directly from Class A highways. The land ownership data will greatly facilitate this process. The large non-public owners are the most likely partners for FBSCC facilities to develop relationships with to secure wood. Some of the constraints/limitations may include the following:

- Biomass supplied cannot exceed the biomass production at each harvesting area.
- Use of same feedstock for CHP facilities, biorefinery, etc. There is a need to locate and use underutilized woody biomass, specifically forest residues where an existing supply chain is rather limited because of minimal demand for this form of feedstock.
- The amount available from private landowners is largely unknown and subject to a high level of uncertainty and variability. There are numerous factors that impact the availability which were not fully evaluated in this report.
- The total supply of biomass is equal to the demand at biorefinery(ies).
- Demand for biomass at biorefinery(ies) must be satisfied.
- The transportation distance may be more than 100 miles based on the transportation networks.
- All storage will be at the biorefinery whereas in practice, there may be multiple storage locations or roadside landing storage.
- Transport capacity for each time period varies. We assume constant.
- Policy constraints may include GHG emissions and Forbidden areas/reserve areas
- Sustainability constraints that were not factored into the model:
  [1] Sustainable harvesting (percentage of harvestable);
  [2] Traffic congestion;
  [3] Damage to roads as a result of higher volumes of traffic;
  [4] Noise;

[3] The Mackinac Bridge is a suspension bridge spanning the Straits of Mackinac to connect the non-contiguous Upper and Lower peninsulas of the U.S. State of Michigan. Opened in 1957, the bridge (familiarly known as "Big Mac" and "Mighty Mac") is the third longest in total suspension in the world and the longest suspension bridge between anchorages in the Western hemisphere. The Mackinac Bridge carries Interstate 75 across the straits and connects the city of St Ignace on the north end with the village of Mackinaw City on the south. (Wikipedia, 2010)

[5] Air quality; and
[6] Water quality.

Model Description

Objective Functions

The optimization models optimize the following items associated with activities including harvesting/processing, transportation, and storage on site for the biomass feedstock supply chain system for biofuel production. Each variable was optimized individually.

- Minimize delivered feedstock cost
- Minimize energy use; and
- Minimize GHG emissions.

Inputs

- Stumpage cost ($/ton);
- Harvesting cost ($/ton);
- Transportation cost, including cost ($/ton) and cost ($/ton-mile);
- GIS-based data describing the annual yields of feedstock of each type (forest residues and roundwood) in aggregate (hardwood and softwood) and not by species;
- Distances between harvesting sites (centroid of county) and biorefineries for transporting feedstock by trucks (rail was not included because it is not economically feasible for a 100 mile radius used in this study);
- Latitude and longitude of the centroid of each county to the latitude and longitude of the biorefinery location to determine the transportation distances;
- GHG emissions of harvesting/processing (lbs/ton green biomass) and transporting (lbs/ton-mile) of feedstock;
- Energy use of harvesting/processing (Btu/ton green biomass) and transporting (Btu/ton-mile) of feedstock;
- Amount (tons) of biomass available at a harvesting area in a time period; and
- Conversion rate (gallon/green ton) of biomass to ethanol, which is 40 gallons per 1 green, short ton of biomass. Green ton has an approximate moisture content of 50%.

Decisions/Outputs

- The minimum total delivered feedstock cost ($) for supplying woody biomass feedstock for ethanol production;
- The minimum system energy use (Btu);
- The minimum GHG emissions (lbs/ton green biomass);
- Numbers, locations and sizes (gallons per year) of new biorefinery(ies); and
- The optimal allocation of biomass resources to biorefinery.

Constraints/Limitations

- *Constraints at harvesting sites*
    - Delivered amount (tons) of biomass feedstock at each harvesting area cannot exceed its corresponding maximum yearly availability; and
    - Amount available for biorefineries after other competing uses are met. All current uses are assumed to be in the existing data. Other uses, such as a new

40MGY biorefinery in the eastern portion of the Upper Peninsula of Michigan in Kinross, and the 36 MW wood-fired power plant expected to be operational in 2013 in Mancelona, Michigan, have been factored into by using adjustment factors to reduce the potential amount available for a biorefinery.

- *Constraints at biorefineries*
  - Total gallons of ethanol produced at a biorefinery in a time period equals the amount (tons) of feedstock transported to that biorefinery multiplied by the associated energy conversion rates (gallons/ton);
  - There is no fuel production capacity unless there is a refinery opened; and
  - The designed biorefinery capacity (gallons/yr) must not exceed the maximum allowable biorefinery capacity.
- *Nonnegativity constraints*
  - The amount (tons) of feedstock harvested at a harvesting site in a time period is nonnegative;
  - The amount (tons) of feedstock transported from a harvesting site to a biorefinery in a time period is nonnegative;
  - The designed biorefinery capacity (gallon/yr) is nonnegative; and
  - Ethanol production at a biorefinery in a time period is nonnegative.

Network Representation of Biomass Supply Chain

There are three important components in the biomass supply chain for a biorefinery: harvesting, transportation, and storage at the biomass processing facility. Truck is the only form of transportation utilized in this project. The abstract representation of this supply chain is given in Figure 11.

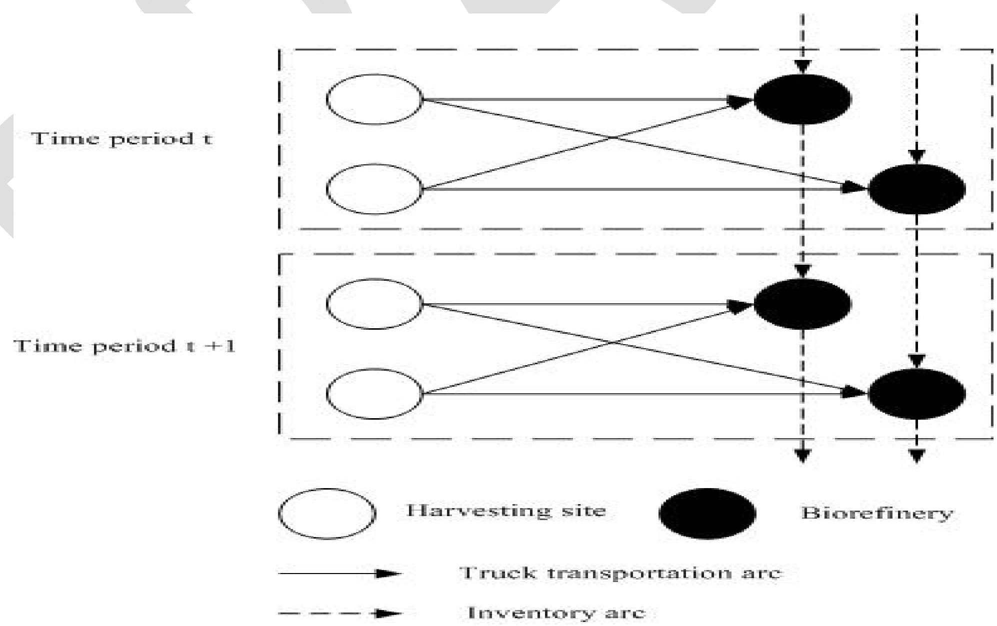


Figure 11 Segment of Network Representation of Biomass Supply Chain

Indices

- I	Set of harvesting sites, indexed by i

- K Set of potential locations for biorefineries, indexed by k

Model Parameters

- s Unit stumpage price ($/ton) of biomass
- h Unit harvesting price ($/ton) of biomass
- t_d Truck variable mileage cost ($/ton/mile)
- t_{lu} Truck fixed cost ($/ton), includes one loading and unloading routine
- d_{ik} Distance (miles) between harvesting site i and biorefinery k
- Q_i Amount of biomass available at harvesting area i
- γ Conversion rate (gallon/green ton) of biomass to ethanol
- w_h CO_2 emission (lbs/ton green biomass) for harvesting / forwarding feedstock
- f_h Energy use (Btu/ton green biomass) for harvesting / forwarding feedstock
- w_{tr} CO_2 emission (lbs/ton-mile) for truck transportation
- f_{tr} Energy use (Btu/ton-mile) for truck transportation
- CAP_k Capacity (gallons of ethanol per year) of biorefinery k

Decision Variables

- q_i Amount (tons) of biomass harvested at site i

Objective Functions

Three objective functions are: (1) minimize the annual supply chain system cost of: stumpage, harvesting, and transportation (C_s), (2) minimize the energy use across the supply chain, (EU_s), and (3) minimize CO_2 emissions (EM_s) across the supply chain. Note: The mathematical model is based on one year operation for a single biomass processing facility.

$$C_{tot} = \sum_{k=1}^{K} \sum_{i=1}^{I} (s + h + t_{lu} + t_d \cdot d_{ik}) \cdot q_{ik} \tag{1}$$

$$F_{tot} = \sum_{k=1}^{K} \sum_{i=1}^{I} (f_h + f_{tr} \cdot d_{ik}) \cdot q_{ik} \tag{2}$$

$$W_{tot} = \sum_{k=1}^{K} \sum_{i=1}^{I} (w_h + w_{tr} \cdot d_{ik}) \cdot q_{ik} \tag{3}$$

Constraints/Limitations

- The sum of the amount of biomass harvested at a harvesting site i and sent to a biorefinery k cannot exceed the harvesting site's maximum yield per year

$$\sum_{k=1}^{K} q_{ik} \le Q_i \, , \; i \in I \tag{4}$$

- Total biomass amount of biomass delivered to a biomass processing facility meets the demand for biomass feedstock at the biomass processing facility

$$\sum_{i}^{I} q_{ik} \ge \frac{CAP_k}{\gamma} \, , \; k \in K \tag{5}$$

- Amount (tons) of biomass harvested at harvesting area i is nonnegative

$$q_{ik} \ge 0 \, , \; i \in I \; k \in K \tag{6}$$

Microsoft Excel™ Model

Microsoft Excel™ using Excel Solver was the software used to develop and solve the optimization models. Solver does have size limitations regarding the number of changing cells and number of decisions. The underlying model is a linear optimization model based on transportation networks. Solver applies the simplex method to rapidly solve larger scale problems. This problem is characterized as a minimization problem so as to minimize cost, energy, or emissions. Sensitivity and “what-if” scenario analysis can be easily conducted with this model.

The Master page of the workbook shows all the inputs required and buttons to update the model after each change. The input screen is split into multiple views to provide a brief explanation of each of the different data areas. Information for cost, energy, emissions, feedstock availability factors, percentages of residue and roundwood, and adjustments for Frontier Renewable Resources as well as other adjustments (i.e., biomass fired power plant in Mancelona) are included in this initial screen. This input screen is shown in Table 10. A key is provided to indicate which cells are inputs, calculated, and results. The same key is used for all entry screens.

	Stumpage		*Harvest*			*Transport*			*Total*	
Cost	0.00	*$/ton*	0.00	*$/ton*		3.72	*$/ton*		3.72	*$/ton*
						0.074	*$/ton-mile*		0.074	*$/ton-mile*
Energy			137.4330	*1000 Btu/ton*		1.5924	*1000 Btu/ton-mile*			
Emissions			25.6	*lb GHG/ton*		0.377	*lb GHG/ton-mile*			
Federal		*Region*	*Factor*		*Residue*	*Roundwood*	*Total*			
Availability	*Soft*	*N*	0.93288219		0%	100%	100%			
		S	0.93288219		0%	100%				
	Hard	*N*	0.90959717		0%	100%	100%			
		S	0.90959717		0%	100%				
State		*Region*	*Factor*		*Residue*	*Roundwood*	*Total*			
Availability	*Soft*	N	0.54210441		0%	100%	100%			
		S	0.89363253		0%	100%				
	Hard	*N*	0.48138431		0%	100%	100%			
		S	0.88568285		0%	100%				
Private		*Region*	*Factor*		*Residue*	*Roundwood*	*Total*			
Availability	*Soft*	N	0.68544762		0%	100%	100%			
		S	0.95282162		0%	100%				
	Hard	N	0.56189444		0%	100%	100%			
		S	0.75485393		0%	100%				
								KEY:		
FRR	500,000	*tons hardwood (roundwood)*							INPUT CELLS	
Soft adjust	*Species*			**Hard adjust**	*Species*				CALCULATED CELLS	
	Residue	80%			*Residue*	100%				
	Roundwood	80%			*Roundwood*	100%			MODEL RESULTS	

Table 10 Data entry screen for cost, energy, emissions, feedstock availability factors by ownership type, and adjustment factors for other planned uses of woody biomass feedstock

The next screen shot shows the input for the biorefinery size in million gallons per year (MGY). Results will be provided in the results section for 50 MGY, 40 MGY, and 30 MGY per year facilities. As indicated earlier the conversion rate is 40 gallons per green, short ton. Table 11 also shows the summary of Model Output for the selected biorefinery size (in this case it is for 50 MGY) and details the total and average per ton in the specified units. After entering data and to update the Model Output, select the Cost, Energy, and Emissions buttons and the Model Output table will be updated with the changes. This allows for performing a sensitivity analysis.

Facility	Location	Size (MGY)	Conversion Rate (gal/ton)	Biomass Feedstock
	Manton	50	40	1,250,000
	Roscommon	50	40	1,250,000
	Kingsley	50	40	1,250,000
	Kalkaska	50	40	1,250,000
	Gaylord	50	40	1,250,000
	Clare	50	40	1,250,000
	West Branch	50	40	1,250,000
	Traverse City	50	40	1,250,000
	Boyne City	50	40	1,250,000

KEY:

- INPUT CELLS
- CALCULATED CELLS
- MODEL RESULTS

Update Model: Cost | Energy | Emissions

MODEL OUTPUT

Location	Cost		Energy (1000 Btu)		Emissions (lbs/ton)	
	Total	Average ($/ton)	Total	Average	Total	Average
Manton	$ 10,036,545	8.02924	287,703,874	230.163	59,442,263	47.55381
Roscommon	$ 10,442,290	8.35383	296,435,065	237.148	61,509,368	49.20749
Kingsley	$ 10,503,858	8.40309	297,759,956	238.208	61,823,036	49.45843
Kalkaska	$ 10,594,473	8.47558	299,709,893	239.768	62,284,682	49.82775
Gaylord	$ 9,722,602	7.77808	280,948,168	224.759	57,842,852	46.27428
Clare	$ 11,109,941	8.88795	310,802,186	248.642	64,910,778	51.92862
West Branch	$ 10,730,698	8.58456	302,641,296	242.113	62,978,691	50.38295
Traverse City	$ 11,360,514	9.08841	316,194,255	252.955	66,187,348	52.94988
Boyne City	$ 11,239,737	8.99179	313,595,256	250.876	65,572,036	52.45763

Table 11 Input for biorefinery size, conversion rate, biomass feedstock requirements calculation, and optimization results for cost, energy, and emissions

Because of size limitations, one possible configuration of three possible multiple locations were selected. The first configuration is for three plants that are spaced and not close to one another. The next two configurations are four possible locations each. However, this hits the maximum of the Solver limitations and will give an error message that it will not process results. When you select the Solve button when the error appears, it completes the calculation and gives an accurate result. The multiple location figures were only evaluated using cost optimization (minimizing cost) and to demonstrate the maximum number of locations at the maximum size. Given the current feedstock availability, no more than four plants (biorefinery) can be supported. There are limitations with Excel Solver and also limitations with feedstock availability that limits the maximum number and size of possible biorefineries. The details of the multiple location models are located in Table 12.

MULTIPLE LOCATIONS				
Configuration 1		***Size (MGY)***	***Conversion Rate (gal/tons)***	***Biomass Feedstock (tons)***
	Roscommon	50	40	1,250,000
	Clare	50	40	1,250,000
	Boyne City	50	40	1,250,000
Configuration 2				
	Roscommon	50	40	1,250,000
	Clare	50	40	1,250,000
	Boyne City	50	40	1,250,000
	Traverse City	50	40	1,250,000
Configuration 3				
	Traverse City	50	40	1,250,000
	Kalkaska	50	40	1,250,000
	Kingsley	50	40	1,250,000
	Manton	50	40	1,250,000

KEY:
INPUT CELLS
CALCULATED CELLS
MODEL RESULTS

Update Model Multi Cost

Note: For Multiple Locations, the model exceeds the Solver parameters and will request that you click Solve. It will result in an optimal solution.

Table 12 Input for three selected multiple location configurations, including inputs for biorefinery size, conversion rate, and calculations of biomass feedstock

Table 13 shows the model output for the cost optimization for the three selected multiple location configurations. The total cost by configuration as well as the average dollar cost per ton is summarized in the table.

MODEL OUTPUT					
Configuration 1		Total Cost by Location	Average ($/ton)	Total Cost by Configuration	Average ($/ton)
	Roscommon	$ 11,609,108	$ 9.28729		
	Clare	$ 11,583,556	$ 9.26684		
	Boyne City	$ 11,354,180	$ 9.08334		
Total Configuration 1				$ 34,546,844	$ 9.21249
Configuration 2					
	Roscommon	$ 11,894,912	$ 9.51593		
	Clare	$ 11,682,077	$ 9.34566		
	Boyne City	$ 12,475,818	$ 9.98065		
	Traverse City	$ 11,905,801	$ 9.52464		
Total Configuration 2				$ 47,958,609	$ 9.59172
Configuration 3					
	Traverse City	$ 15,615,295	$ 12.49224		
	Kalkaska	$ 16,806,034	$ 13.44483		
	Kingsley	$ 15,653,106	$ 12.52248		
	Manton	$ 15,834,518	$ 12.66761		
Total Configuration 3				$ 63,908,953	$12.78179

KEY:	
	INPUT CELLS
	CALCULATED CELLS
	MODEL RESULTS

Table 13 Cost optimization model output for three selected multiple locations

Discussion of Results

The results for each of the nine candidate locations are summarized in this section with supporting details relating to the specific counties that would supply feedstock for each of the locations in the Appendices. Each of the different variables, transportation cost, energy, and emissions are summarized and include individual as well as combined rankings.

Transportation Cost

The transportation cost per green ton delivered by each candidate location by size is shown in Table 14. The details related to which counties will supply each location by size are located in Appendices B4-N to B4-P.

	Transportation Cost Per Green Ton Delivered								
MGY/Green Tons	Manton	Roscommon	Kingsley	Kalkaska	Gaylord	Clare	West Branch	Traverse City	Boyne City
50MGY - 1,250,000	$8.02924	$ 8.35383	$8.40309	$8.47558	$7.77808	$8.88795	$8.58456	$9.08841	$8.99179
40MGY - 1,000,000	$7.54038	$ 8.11689	$7.84365	$7.91999	$7.19287	$8.32781	$8.05903	$8.45935	$8.34225
30MGY - 750,000	$7.02973	$ 7.74899	$7.19957	$7.11791	$6.47805	$7.78447	$7.54163	$7.66297	$7.86804

Table 14 Transportation Cost Per Green Ton Delivered by Candidate Location by Size

In reviewing the transportation costs, as the plant size grows, the cost per ton increases. This is because more feedstock is required and transporters have to travel a longer distance to bring the feedstock to the biorefinery. Cost per ton by plant size was ranked from lowest to highest cost, with the lowest cost receiving a ranking of “1” and the highest cost receiving a ranking of “9”. The rankings are shown in Table 15. The rankings were summed and an overall cost ranking was developed. The best location overall is Gaylord. The worst location (in terms of highest transportation cost per ton) is Boyne City. This in part can be attributed to the fact that feedstock is assumed to not be transported over the bridge, even though counties in the Upper Peninsula of Michigan are within the 100 mile radius of this location. This limitation likely added to the increased costs. There was a tie between West Branch and Roscommon. Because West Branch had two plant sizes ranked at 5, this location was arbitrarily chosen as the 5th ranked overall.

	Rank by Lowest to Highest - Transportation Cost Per Green Ton Delivered								
MGY/Green Tons	*Manton*	*Roscommon*	*Kingsley*	*Kalkaska*	*Gaylord*	*Clare*	*West Branch*	*Traverse City*	*Boyne City*
50MGY - 1,250,000	2	3	4	5	1	7	6	9	8
40MGY - 1,000,000	2	6	3	4	1	7	5	9	8
30MGY - 750,000	2	7	4	3	1	8	5	6	9
SUM	6	16	11	12	3	22	16	24	25
Overall Rank - Cost	2	6	3	4	1	7	5	8	9

Table 15 Ranking by Transportation Cost Per Green Ton Delivered by Candidate Location by Size and Overall Ranking

Energy

The energy per green ton delivered (1000 Btu) by each candidate location by size is shown in Table 16. The details related to which counties will supply each location by size are located in Appendices B4-Q to B4-S.

	Energy Per Green Ton Harvested/Processed and Delivered (1000 Btu)								
MGY/Green Tons	*Manton*	*Roscommon*	*Kingsley*	*Kalkaska*	*Gaylord*	*Clare*	*West Branch*	*Traverse City*	*Boyne City*
50MGY - 1,250,000	230.163	237.148	238.208	239.768	224.759	248.642	242.113	252.955	250.876
40MGY - 1,000,000	219.643	232.049	226.169	227.812	212.165	236.588	230.804	239.419	236.899
30MGY - 750,000	208.655	224.132	212.310	210.552	196.783	224.896	219.670	222.281	226.694

Table 16 Energy Per Green Ton Harvested/Processed and Delivered (1000 Btu) by Candidate Location by Size

In reviewing the energy consumption data, as the plant size grows, the energy consumed per ton increases. This is because more feedstock is required and transporters have to travel a longer distance to bring the feedstock to the biorefinery. There is no change in the energy consumption on a per ton basis associated with the energy consumption, only in total because of the higher volume. Energy per ton by plant size was ranked from lowest to highest cost, with the lowest cost receiving a ranking of "1" and the highest cost receiving a ranking of "9". The rankings are shown in Table 17. The rankings were summed and an overall cost ranking was developed. The best location overall is Gaylord. The worst location (in terms of highest transportation cost per ton) is Boyne City. This in part can be attributed to the fact that feedstock will not be transported over the bridge, even though counties in the Upper Peninsula of Michigan are within the 100 mile radius of this location. This limitation likely added to the increased energy consumption because of greater distance traveled. Traverse City is a close 8 and likely experiences the same issues as Boyne City, with an additional factor of being positioned close to water. If marine transportation is considered at some point in time to transport biomass from the Upper Peninsula to the Lower Peninsula of Michigan, this alternatives ranking would like be more favorable. There was a tie between West Branch and Roscommon. Because West Branch had two plant sizes ranked at 5, this location was arbitrarily chosen as the 5th ranked overall.

Rank Lowest to Highest - Energy Per Green Ton Harvested/Processed and Delivered (1000 Btu)									
MGY/Green Tons	***Manton***	***Roscommon***	***Kingsley***	***Kalkaska***	***Gaylord***	***Clare***	***West Branch***	***Traverse City***	***Boyne City***
50MGY - 1,250,000	2	3	4	5	1	7	6	9	8
40MGY - 1,000,000	2	6	3	4	1	7	5	9	8
30MGY - 750,000	2	7	4	3	1	8	5	6	9
SUM	6	16	11	12	3	22	16	24	25
Overall Rank-Energy	2	6	3	4	1	7	5	8	9

Table 17 Ranking Energy Per Green Ton Harvested/Processed and Delivered (1000 Btu) by Candidate Location by Size and Overall Ranking

Emissions

The emissions per green ton delivered (in pounds) by each candidate location by size is shown in Table 18. The details related to which counties will supply each location by size are located in Appendices B4-T to B4-V.

	Emissions Per Green Ton Harvested/Processed and Delivered in Pounds								
MGY/Green Tons	***Manton***	***Roscommon***	***Kingsley***	***Kalkaska***	***Gaylord***	***Clare***	***West Branch***	***Traverse City***	***Boyne City***
50MGY - 1,250,000	47.55381	49.20749	49.45843	49.82775	46.27428	51.92862	50.38295	52.94988	52.45763
40MGY - 1,000,000	45.06329	48.00036	46.60830	46.99726	43.29286	49.07492	47.70560	49.74509	49.14848
30MGY - 750,000	42.46171	46.12606	43.32699	42.91099	39.65114	46.30681	45.06965	45.68781	46.73256

Table 18 Emissions Per Green Ton Harvested/Processed and Delivered in Pounds by Candidate Location by Size

In reviewing the emissions data, as the plant size grows, the emissions generated per ton increases. This is because more feedstock is required and transporters have to travel a longer distance to bring the feedstock to the biorefinery. There is no change in the emissions on a per ton basis associated with the energy consumption, only in total because of the higher volume. Energy per ton by plant size was ranked from lowest to highest cost, with the lowest cost receiving a ranking of “1” and the highest cost receiving a ranking of “9”. The rankings are shown in Table 19. The rankings were summed and an overall cost ranking was developed. The best location overall is Gaylord. The worst location (in terms of highest transportation cost per ton) is Boyne City. This in part can be attributed to the fact that feedstock will be transported over the bridge, even though counties in the Upper Peninsula of Michigan are within the 100 mile radius of this location. This limitation likely added to the increased energy consumption because of greater distance traveled. Traverse City is a close 8 and likely experiences the same issues as Boyne City, with an additional factor of being positioned close to water. If marine transportation is considered at some point in time to transport biomass from the Upper Peninsula to the Lower Peninsula of Michigan, this alternatives ranking would like be more favorable. There was a tie between West Branch and Roscommon. Because West Branch had two plant sizes ranked at 5, this location was arbitrarily chosen as the 5th ranked overall.

	Rank Lowest to Highest - Emissions Per Green Ton Harvested/Processed and Delivered in Pounds								
MGY/Green Tons	***Manton***	***Roscommon***	***Kingsley***	***Kalkaska***	***Gaylord***	***Clare***	***West Branch***	***Traverse City***	***Boyne City***
50MGY - 1,250,000	2	3	4	5	1	7	6	9	8
40MGY - 1,000,000	2	6	3	4	1	7	5	9	8
30MGY - 750,000	2	7	4	3	1	8	5	6	9
SUM	6	16	11	12	3	22	16	24	25
Overall Rank-Emissions	2	6	3	4	1	7	5	8	9

Table 19 Ranking Emissions Per Green Ton Harvested/Processed and Delivered in Pounds by Candidate Location by Size and Overall Ranking

Comparative Table - Overall Rank

Because the overall rankings for each of the locations came up to be the same, there is no real need at this point to change the weighting factors for each of the three variables. However, this option is available. Table 20 shows the comparative analysis. The best location choice is Gaylord with the least desirable location identified as Boyne City.

		Manton	Roscommon	Kingsley	Kalkaska	Gaylord	Clare	West Branch	Traverse City	Boyne City
Overall Rank - Cost		2	6	3	4	1	7	5	8	9
Overall Rank-Energy		2	6	3	4	1	7	5	8	9
Overall Rank-Emissions		2	6	3	4	1	7	5	8	9
Total Average		2.0	6.0	3.0	4.0	1.0	7.0	5.0	8.0	9.0
Total Ranking		2	6	3	4	1	7	5	8	9
Cost Weight	60%									
Energy Weight	20%									
Emission Weight	20%									
Total Weighted		0.8	2.4	1.2	1.6	0.4	2.8	2	3.2	3.6
Total Weighted Ranking		2	6	3	4	1	7	5	8	9

Table 20 Comparative Overall Ranking

Sensitivity Analysis

The extent of the sensitivity analysis was based on looking at three different sized biorefinery plants. However, more extensive sensitivity analysis can occur by varying the model inputs, allowing for many different variants on the variables that were presented in this report.

Maps Showing Feedstock Requirements for 50 MGY Facility

As indicated in earlier discussion of results, individual plants and multi location configurations indicate there is sufficient feedstock to supply candidate biorefineries within a 100-mile radius. A visual depiction of each candidate location optimal cost supply by county is shown in Appendix B4-W. The shading depicts the counties to supply the candidate location sufficient feedstock for a 50 million gallon per year facility. In most cases it would appear that the feedstock is readily available in somewhere between 50-75 mile radiuses of the candidate facility.

Hardware Requirements

The minimum system requirements (Microsoft Office, 2009) to install Microsoft Office Professional Plus 2007 system products are:

- Computer and processor: 500 megahertz (MHz) processor or higher
- Memory: 256 megabyte (MB) RAM or higher
- Hard disk: 2 gigabyte (GB); a portion of this disk space will be freed after installation if the original download package is removed from the hard drive.
- Drive: CD-ROM or DVD drive
- Display: 1024x768 or higher resolution monitor

The details of the requirements can be found at:
http://www.microsoft.com/officebusiness/products/technical-requirements.aspx

Summary

The optimization model, selected locations, and results of study provide one tool for a decision maker to determine the optimal cost, energy consumption, and emissions for candidate locations. Because the optimization model is a static look for a single period of time, it should be utilized in conjunction with the simulation model. The simulation model confirms the one year look but also extends the analysis to consider multiple years of operations. The simulation model considers the operations of a biorefinery over a 20 year period of time and is presented in the next section.

7. SIMULATION MODEL

Overview

To facilitate the exploration of a wide variety of conditions that promise profitable biomass utilization, a biomass supply chain model has been designed for biofuel production. The model considers key supply chain activities including biomass harvesting/processing, transportation, and storage. In order to have a visual depiction of the proposed supply chain and allow for a comprehensive analysis of the key elements and components to be addressed, an activity model was developed using Integrated DEFinition (or IDEF). This activity model aids in the formulation of the simulation of the biomass supply chain. The simulation model with an easy-to-use graphical user interface has been designed and implemented using the Arena Simulation Software, available from Rockwell Automation. Since the simulation model cannot capture all the features of a supply chain system, a series of assumptions were made to simplify the supply chain and the constraints and limitations introduced by the assumptions are discussed. The model was applied to the potential biofuel facility locations identified in the previous sections and the results are discussed. Finally, future work and possible improvement opportunities regarding the model are identified.

Purpose/Objectives

As previously stated, the model is a simulation of the biomass supply chain for biofuel production in the Lower Peninsula of Michigan. The model simulates the flow of biomass from harvesting areas to the onsite storage at a biomass processing facility. The simulation operates on a set of prescribed rules for harvesting, transporting, and storing biomass. Using the simulation model can better address some uncertainties (e.g., timing of spring breakup) and includes the following capabilities:

- Optimize the location of plant(s) through minimum total cost,
- Minimize energy consumption,
- Minimize emissions,
- Additional outputs may include to:
- Provide dynamic information about daily inventory of the biorefinery;
- Provide cost information, including total cost per year;
- Provide data about energy usage;

- Provide GHG emissions information;
- Examine the reliability of the supply chain to satisfy the daily demand, especially during the spring break-up;
- Find improvement opportunities, simulate alternatives and make comparison. Find the best alternative.

Activity Model

The activity model was developed using a standardized format to aid in the formulation of the biomass feedstock supply chain simulation. Integrated DEFinition (or IDEF) provides a visual depiction of the biomass feedstock supply chain activities and related inputs, outputs, controls, mechanisms, and metrics (Hanrahan, 1995). With a visual depiction of the proposed simulation model, a comprehensive analysis of the key elements and components can be addressed through the entire supply chain. An overview of the model (the first level) is shown in Figure 12. A detailed second level model is shown in Figure 13. The detailed transportation model (third level) is illustrated in Figure 14.

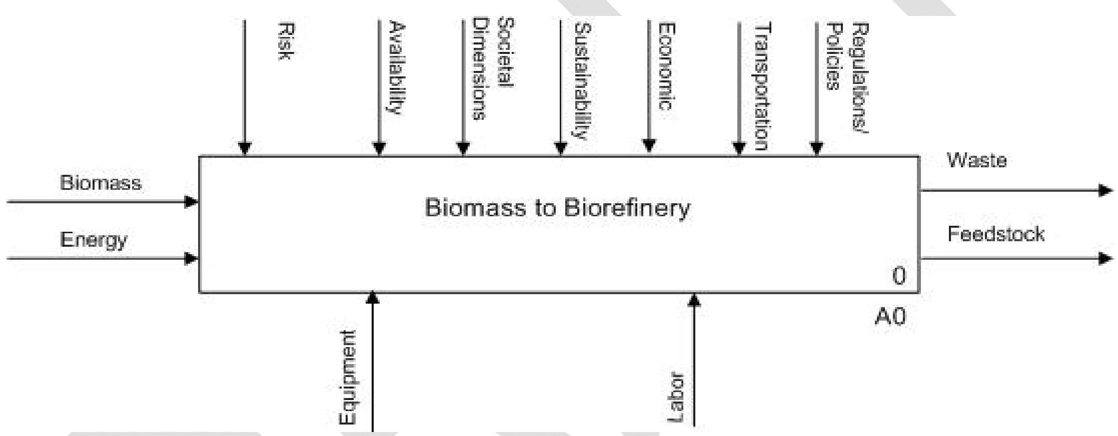


Figure 12 Overview Activity Model

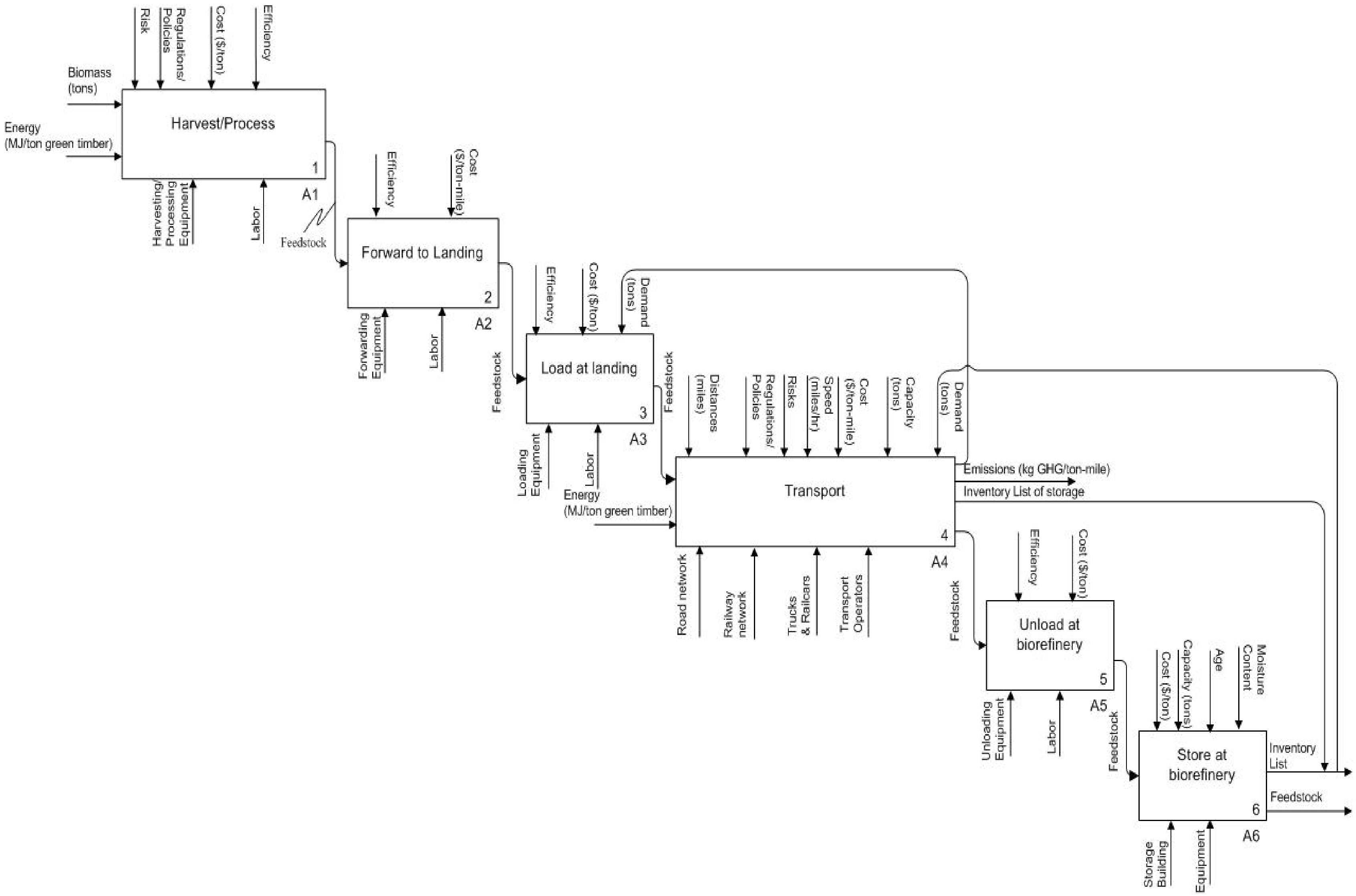


Figure 13 Complete Biomass Feedstock Supply Chain Model

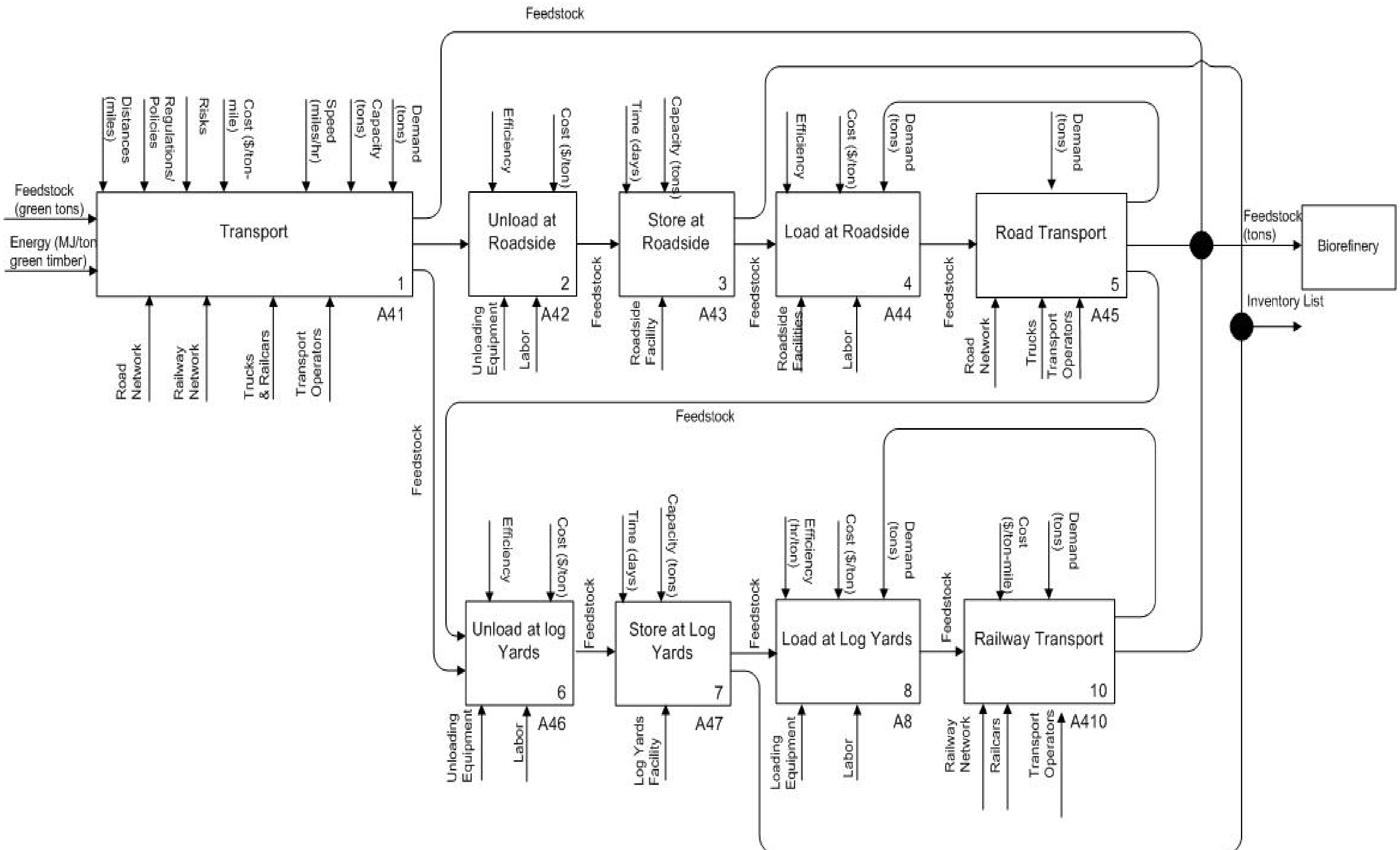


Figure 14 Transportation Model

Model Assumptions

The supply chain activities include harvesting, transportation, and storage at the biomass processing facility. A series of assumptions were made associated with each activity to simplify the supply chain (Zhang, Johnson, Johnson et al., 2011).

- *Harvesting*
  - Harvesting areas are defined on a county-basis. The centroid of each county is the starting point of transportation;
  - No feedstock will be transported over the bridge from the Upper Peninsula of Michigan. It is assumed that all feedstock in the Upper Peninsula is not available for transport over the bridge and will be consumed by others in the Upper Peninsula;
- *Biorefinery*
  - For a biorefinery that produces 50 million gallons of ethanol per year (MGY), the biomass feedstock required is 1,250,000 green tons with a conversion factor of 40 gallons of biofuel per green ton of biomass. The daily demand for biomass feedstock would be about 3,572 green tons assuming that the biorefinery operates 350 days (50 weeks) per year with 2 weeks for maintenance;
  - The biorefinery operates on a 24/7 schedule;
  - The biorefinery operates 20 years continuously;
  - The starting inventory quantity required to commence operations is 25,000 tons of woody biomass for a biorefinery that produces 50 million gallons of ethanol per year;
- *Transportation*
  - The transportation radius is assumed to be less than 100 miles;
  - Biomass feedstock is delivered by diesel truck. This is important in order to estimate energy consumption and GHG emissions associated with biomass transportation;
  - No rail transportation is considered;
  - All trucks are initially located at the harvesting areas;
  - Trucks have a carrying capacity of 50 tons;
  - Trucks are fully loaded for each trip from a harvesting area to the biorefinery;
  - Outgoing trucks carry an empty load;
  - The truck transportation provider will also provide loading and unloading. No additional/independent loaders/unloaders are necessary;
  - Trucks work on a 5-day schedule. No transportation occurs on weekends;
  - The number of hours per day that a log truck driver will operate is 5 hours of driving plus 5 hours of loading/unloading;
  - During the regular/normal working days (May 1st to October 31st), 40% (2/5 = 0.4) more biomass than the daily demand is needed to be harvested due to the 5-day schedule of truck transportation activities; based on the daily demand of 3,572 green tons biomass feedstock at the biorefinery, 100 round trips (50 trucks) (3,572 tons per day * 1.4 / 50 tons per round trip = 100 round trips per day) are needed per day during the regular/normal working days (May 1st to October 31st);
- *Spring breakup*
  - Spring breakup, where road load restrictions are in place, is assumed to be March

1 through April 30[4] (61 days in this duration) for all the harvesting areas;
- Delivery of feedstock will remain constant during the periods of May 1st through October 31st , while the building inventory phase for spring breakup occurs November 1st through the end of February;
- From November 1st through the end of February, there are about 35 days of weekends (34.32 days on average based on a 25-year (2010-2035) data sample) when there are no transportation activities. Thus the average number of weekdays is about 85 during this period;
- Starting with November 1st, 72% (61/85 = 0.72) more biomass than the regular daily demand is needed every day to build up inventory;
- Based on biomass feedstock daily demand of 3,572 green tons at the biorefinery, 122 round trips (61 trucks) (3,572 tons per day * 1.72 / 50 tons per round trip = 122 round trips per day) are needed per day from November 1st through the end of February to ensure sufficient inventory during spring breakup;
- Demand for biomass feedstock at the biorefinery during spring breakup is pulled from on site inventory only; there is no offsite storage of inventory. This assumes that there is adequate storage at the biorefinery;

- *Others*
  - The moisture content is constant throughout the supply chain (50%); therefore, biomass weight delivered from harvesting areas to the biorefinery remains the same;
  - No dry matter loss is taken into account through the supply chain, for example, weight loss during storage due to insect infestation.

Model Description

As has been noted, the model is evaluated using three key performance indicators: the delivered feedstock cost, energy consumption, and GHG emissions. Mathematical models of the three indicators are now presented.

Delivered Feedstock Cost

The delivered feedstock cost consists of a stumpage cost, harvesting/processing cost, and the transportation cost (including loading cost and unloading cost). The stumpage cost is the payment made to land owners The unit stumpage cost (s, \$/ton) and the unit harvesting/processing cost (h, \$/ton) are assumed to be constant for all the harvesting areas within the study region (i = 1, 2, …, I) in any time period (t = 1, 2, …, T). The daily biomass recovery at harvesting area i is defined as q_{it}. The stumpage cost and harvesting/processing cost (C_{sh}, \$) is calculated as:

$$C_{sh} = \sum_{t=1}^{T}\sum_{i=1}^{I}(s+h)\cdot q_{it} \tag{7}$$

The transportation cost (C_{tr}, \$) consists of two major terms: one for truck transportation and one for rail transportation. The truck transportation cost has a fixed cost (t_{lu}, \$/ton, which includes one loading and unloading routine) and a variable (distance-dependent)

[4] Michigan State Policy, http://www.michigan.gov/msp/0,1607,7-123-1586_1710-87560--,00.html, accessed on Sep. 26, 2010.

cost (t_d, \$/ton-mile). The transportation cost is calculated as:

$$C_{tr} = \sum_{t=1}^{T}\sum_{i=1}^{I}\left(t_{lu} + t_d \cdot d_i\right)\cdot q_{it} \quad (8)$$

where d_i is the transportation distance from harvesting area i to the biorefinery.

The total delivered feedstock cost (C_{tot}, \$) is the sum of stumpage cost, harvesting/processing cost, and transportation cost. The calculation is

$$C_{tot} = C_{sh} + C_{tr} \quad (9)$$

Energy Consumption

Energy consumption (Btu) is assumed to only be associated with harvesting/processing and transportation activities. The energy consumed per unit of biomass (Btu/ton) for harvesting/processing is termed f_h, and the truck transportation energy intensity is termed f_{tr} (Btu/ton-mile). The energy used in harvesting/processing (F_h, Btu) is calculated as:

$$F_h = \sum_{t=1}^{T}\sum_{i=1}^{I} f_h \cdot q_{it} \quad (10)$$

Transportation energy consumption (F_{tr}, Btu) for truck is calculated as:

$$F_{tr} = \sum_{t=1}^{T}\sum_{i=1}^{I} f_{tr} \cdot d_i \cdot q_{it} \quad (11)$$

The total energy consumption (F_{tot}, Btu) is the sum of energy use associated with harvesting/processing, and transportation, and is given by Equation (12):

$$F_{tot} = F_h + F_{tr} \quad (12)$$

GHG Emissions

In terms of the processes that deliver biomass to a processing facility, GHG emissions (lb) are assumed to only be associated with harvesting/processing and transportation activities. w_h is the GHG emissions per unit of biomass (lb/ton) for harvesting/processing and w_{tr} is the truck transportation GHG emission intensity (lb/ton-mile). GHG emissions (W_h, lb) associated with harvesting/processing are then calculated as:

$$W_h = \sum_{t=1}^{T}\sum_{i=1}^{I} w_h \cdot q_{it} \quad (13)$$

And, the GHG emissions (W_{tr}, lb) associated with transportation are

$$W_{tr} = \sum_{t=1}^{T}\sum_{i=1}^{I} w_{tr} \cdot d_i \cdot q_{it} \quad (14)$$

The total GHG emissions (W_{tot}, lb) are the sum of the emissions associated with harvesting/processing and transportation:

$$W_{tot} = W_h + W_{tr} \quad (15)$$

Simulation Model Using Arena

The development of a biomass feedstock supply chain for a facility considers a number of key activities and processes: biomass harvesting and forwarding to a roadside collection point, transportation from the roadside collection point to a biomass processing facility by truck, and storage at the biorefinery. Size reduction (chipping) activity is assumed to occur at the biofuel facility where the biomass can be processed more efficiently. The purpose of a simulation model is to evaluate the supply chain based on multiple criteria that include the delivered feedstock cost, energy consumption, and GHG emissions. The delivered feedstock cost, as stated earlier, consists of stumpage cost (payment to land owners), harvesting/processing cost, transportation cost (including loading and unloading cost). For the supply chain, energy use and GHG emissions are assumed to be associated with harvesting/processing and transportation activities. The model also tracks the inventory level at the biomass processing facility over time, and picks the most preferable harvesting sites for each facility. The other model consideration is the road restrictions associated with the spring thaw that limits use of truck transportation during that time.

The simulation model was built using Arena Simulation Software. The model consists of three sub-models: reading model inputs, supply activities (including harvesting/processing, transportation and storage at the biomass processing facility), and daily biomass processing. Sub-models communicate with each other via signals. Two types of signals are created: transportation signals (brown arrows in Figure 15) and reading data signals (green arrow in Figure 15). Transportation signals can either come from the reading model inputs sub-model or the daily biomass processing sub-model. Reading data signals are created by the supply sub-model and sent to the reading model inputs sub-model.

The two simulation model drivers are daily demand for biomass feedstock at a biorefinery and the daily biomass recovery at harvesting sites distributed across a harvesting region (the biorefinery is located at one of the nine locations). In other words, it is a combined “pull” and “make-to-order” supply chain system. Each day the biorefinery requires a specified quantity of biomass feedstock from the harvesting areas or on-site storage. Figure 15 illustrates the model logic. The detailed logic for each sub-model is described separately below.

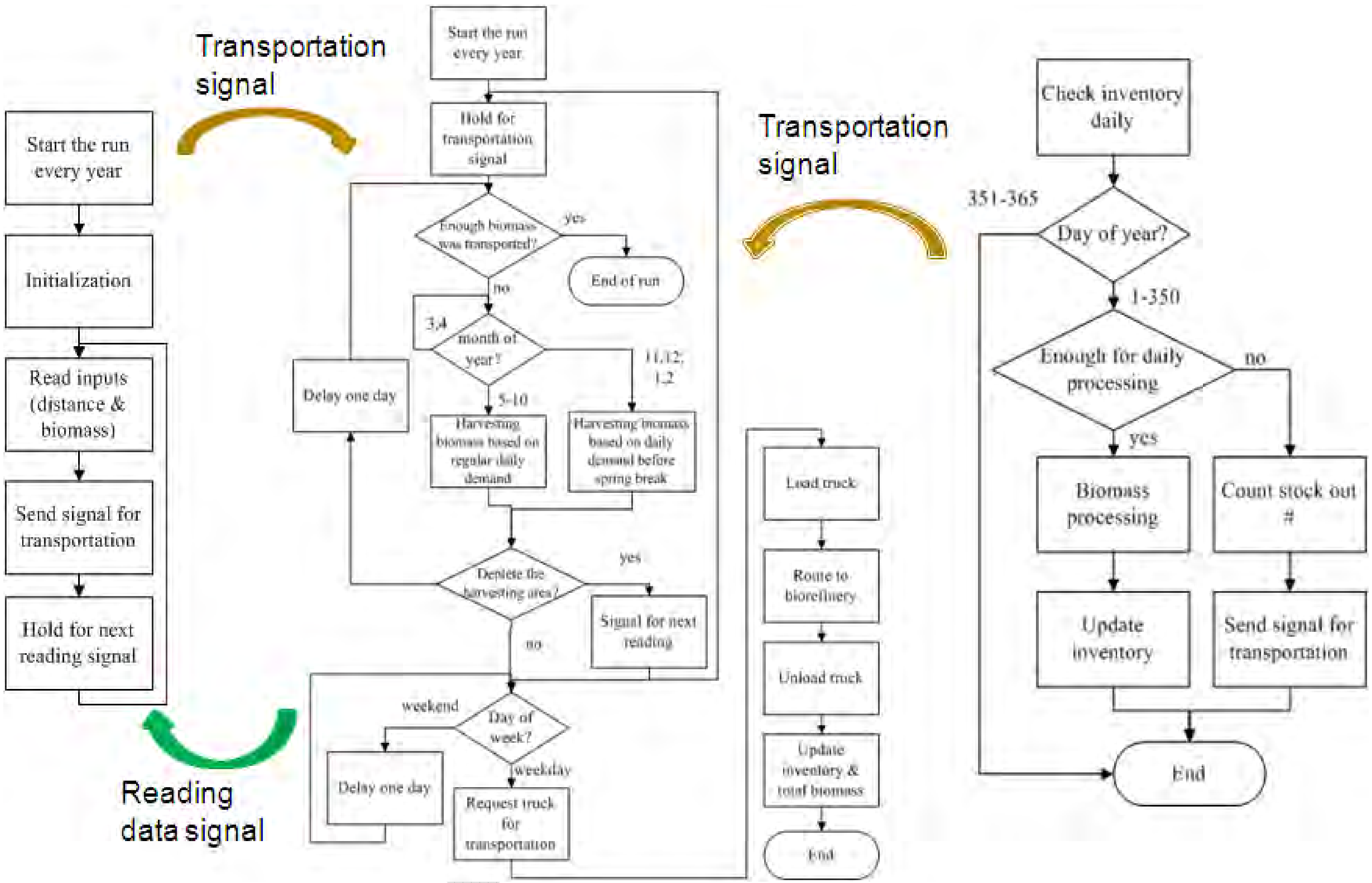


Figure 15 Logic for Biomass Supply Chain Model

Reading Model Inputs

This sub-model (Figure 16) reads two types of data for model configuration before beginning the simulation: biomass inventory levels at a harvesting area within a given region and the transportation distance from the harvesting area to the biorefinery. As has been noted before, two types of signals (transportation signals and reading data signals) are used to exchange information between the three sub-models. On the first operation day in a year, the reading model inputs sub-model starts with initializing some model parameters, for example, the number of days the biorefinery has been operating in a year, and the inventory level at the biorefinery. After initialization, the sub-model checks the month of the year to identify if it is spring breakup. If it is spring breakup, the sub-model does nothing but delays one day and goes back to check the month of the year again. This loop continues until spring breakup ends. On the other hand, if it is not spring breakup or the loop ends, the model will check the day of the week. If it is weekend the sub-model does nothing but delays one day and goes back to check the day of week again. If it is weekday, the sub-model reads inputs for one harvesting area. After the first reading, a transportation signal is created and sent to the harvesting area to inform of the delivery. Then the reading procedure is put on hold waiting for a reading data signal. The reading data signal will be created and sent by the harvesting area when the inventory at the harvesting area is depleted. After the reading data signal is picked up by the reading procedure, it will read the next input (data for the second closest harvesting area to the biorefinery). These iterations will continue until the yearly demand for biomass at the biorefinery is met.

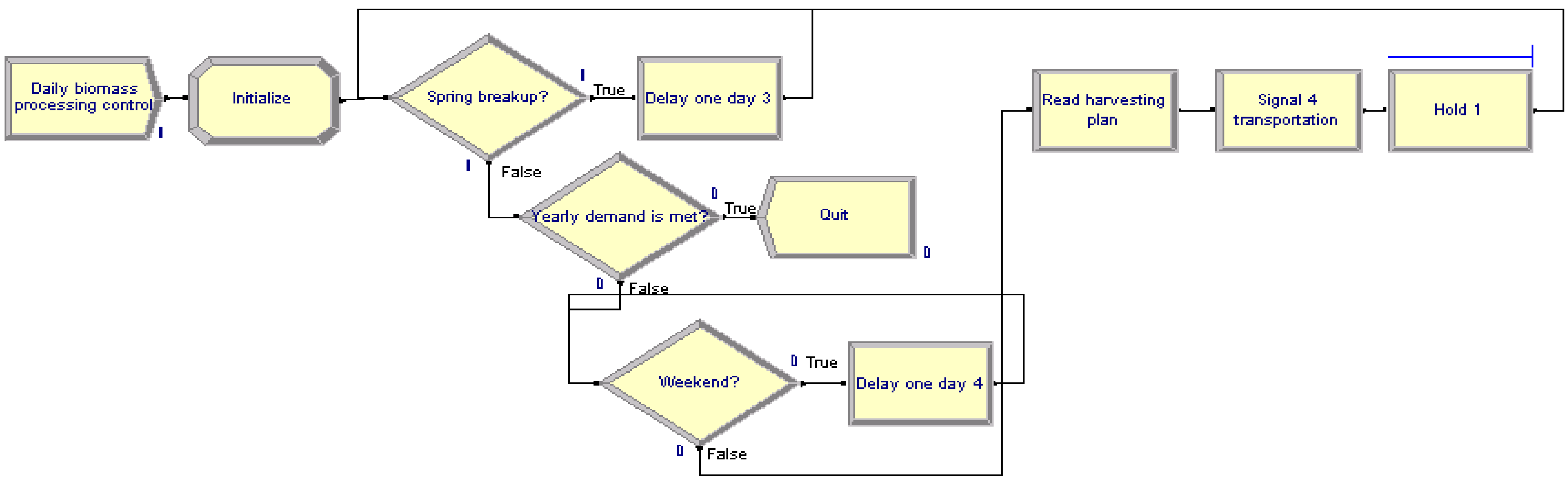


Figure 16 Sub-model Design for Reading Model Inputs

Supply Activities
Supply activities (Figure 17) include biomass harvesting/processing, transportation, and storage at the biomass processing facility. The transportation activity consists of loading transporters, transporting, and unloading transporters at the biorefinery.

Before any signal is received, the sub-model is put on hold. Once the transportation signal is received, the harvesting area starts to harvest a certain amount of biomass which varies based on the month of the year. After the harvesting is done, the sub-model will request a truck for transportation followed by a loading process. When the truck is fully loaded, it routes to the biorefinery. While, at the same time, the biomass inventory level at the harvesting area is updated. If there is still biomass available at the harvesting area, the harvesting procedure will start on the second day. If the harvesting area is depleted, the sub-model will send a reading data signal to the reading model inputs sub-model to shift to the next available harvesting area. The process goes on until the yearly demand for biomass feedstock at the biorefinery is met.

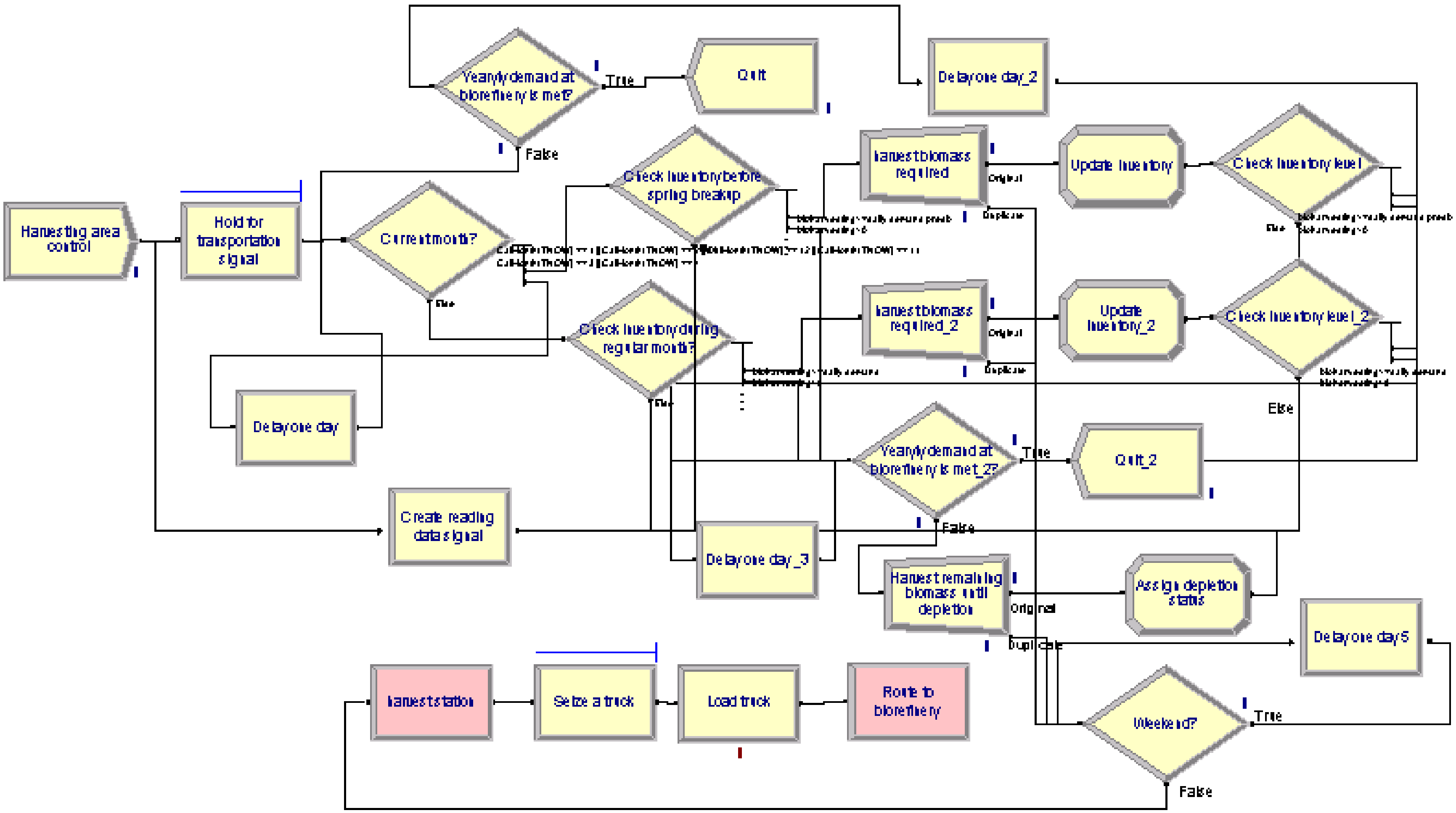


Figure 17 Sub-model Design for Harvesting Areas

At the biorefinery, as trucks arrive they are unloaded and the inventory at the biorefinery is updated. Total truck numbers are also updated as appropriate. The logic for the biorefinery operation is shown in Figure 18.

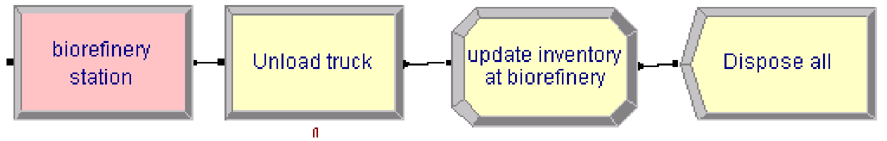


Figure 18 Sub-model Design for Biorefinery Operations

Daily Biomass Processing

This daily biomass processing sub-model (Figure 19) is responsible for dictating the daily biomass demand at a biorefinery. Each day a production target (control entity) is issued and then the biorefinery prepares a certain amount of biomass either from the on-site inventory or using fresh biomass (biomass that is delivered to the biorefinery on the day it is needed) to process based on the daily requirement/production target. If the biorefinery is experiencing a biomass feedstock shortage, the sub-model sends a transportation signal to inform of the supply sub-model of the low inventory situation.

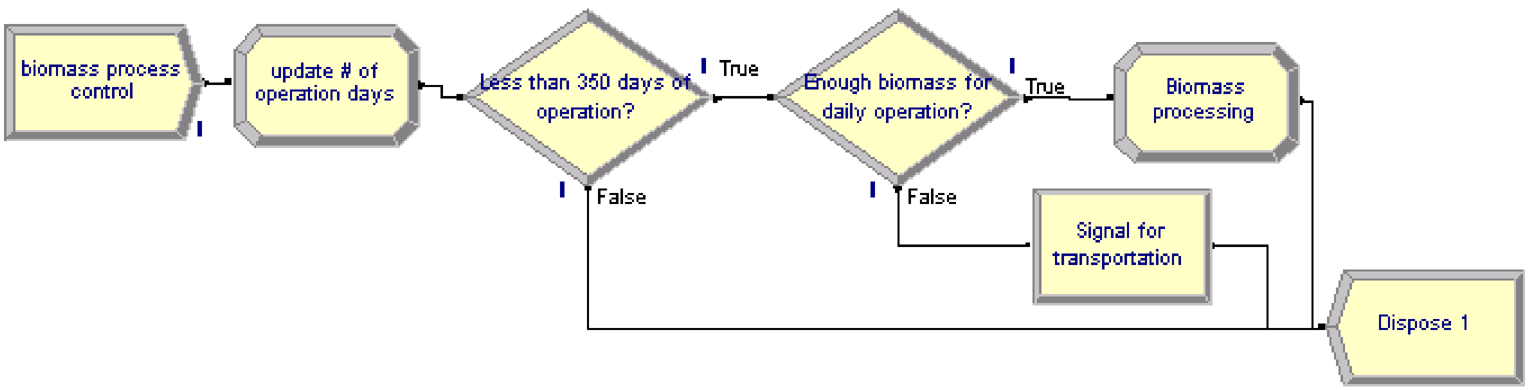


Figure 19 Sub-model Design for Biomass Processing

Screen Shots of Model Input

Parameter Input

An easy-to-use graphical user interface has been developed for the simulation model. The interface (Figure 20) allows users to enter data into one or more of the model parameters before running the model. The model parameters are classified into four categories: cost coefficients, energy intensity coefficients (Btu/ton-mile), GHG emission coefficients (lbs/ton-mile), and biorefinery size options. The first three coefficients are only related to the transportation activity. The transportation cost consists of two parts: fixed cost ($/ton, including loading and unloading cost) and distance-dependent variable cost ($/ton-mile). Users can also select a plant size of 30 MGY, 40 MGY, or 50 MGY.

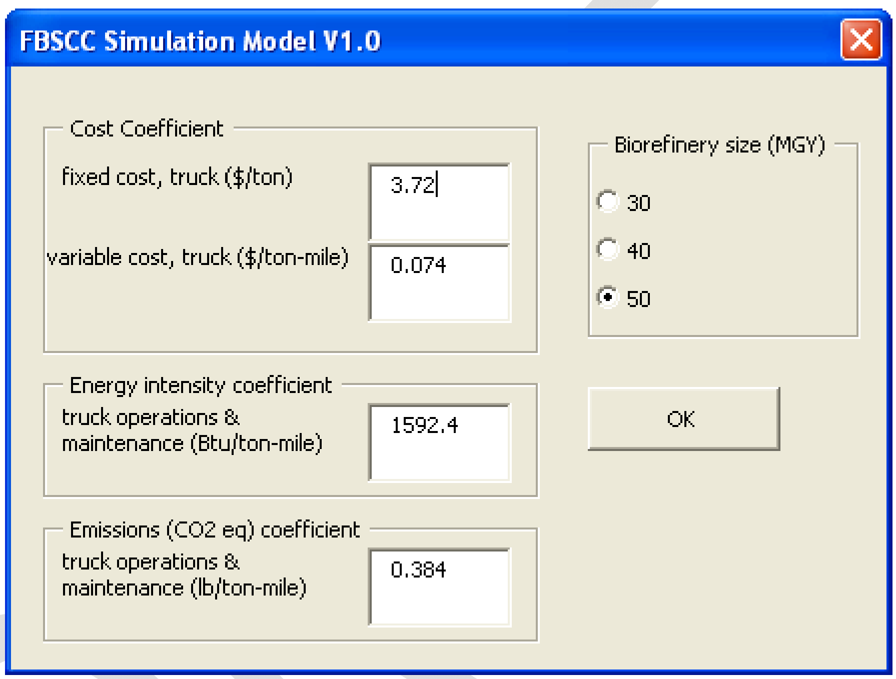


Figure 20 Graphical User Interface

Data Input

The model also reads two types of data for model configuration before beginning the simulation: biomass inventory level at a harvesting area within a given region and the transportation distance from the harvesting area to the biorefinery. The model inputs are organized in macro enabled Microsoft Excel format by harvesting area and by year. As an example, take the input file for the Manton facility location (Table 21). In Table 21, only the first three years' data are shown. The first column contains the 37 potential harvesting areas (suppliers) for the Manton facility ordered by distance. The harvesting areas are specified and will keep the same for 20 years. The transportation distance is derived using the rectilinear distance function. The initial values of the distance are calculated from the center of a harvesting area to the center of the facility location. The amount of biomass available for biofuel production in each harvesting area represents net forest growth each year. Users can enter new data or change the current data for transportation distance and biomass availability. Note that every time users make a change to the distance values for the first year, the table will automatically sort from the smallest to the largest by distance. The distance values from the second year to the 20th year will be filled automatically according to the first year distance value. The two types of inputs for each year (20 years in all) are organized in the same way.

Harvesting Area	year1		year2		year3	
	distance (mile)	biomass (50 tons)	distance (mile)	biomass (50 tons)	distance (mile)	biomass (50 tons)
Wexford	13.862	4911	13.862	4911	13.862	4911
Missaukee	20.151	3868	20.151	3868	20.151	3868
Grand Traverse	25.728	2358	25.728	2358	25.728	2358
Osceola	33.021	2801	33.021	2801	33.021	2801
Kalkaska	34.15	3436	34.15	3436	34.15	3436
Manistee	37.986	4124	37.986	4124	37.986	4124
Roscommon	43.864	2978	43.864	2978	43.864	2978
Benzie	46.018	2027	46.018	2027	46.018	2027
Lake	48.94	4942	48.94	4942	48.94	4942
Antrim	53.136	2697	53.136	2697	53.136	2697
Clare	56.676	3089	56.676	3089	56.676	3089
Leelanau	56.721	978	56.721	978	56.721	978
Mecosta	57.339	3239	57.339	3239	57.339	3239
Crawford	58.042	2416	58.042	2416	58.042	2416
Ogemaw	67.463	2450	67.463	2450	67.463	2450
Mason	70.919	4203	70.919	4203	70.919	4203
Charlevoix	74.514	1935	74.514	1935	74.514	1935
Newaygo	78.924	5875	78.924	5875	78.924	5875
Gladwin	78.994	2418	78.994	2418	78.994	2418
Isabella	81.031	2958	81.031	2958	81.031	2958
Otsego	81.523	5498	81.523	5498	81.523	5498
Oscoda	82.053	4735	82.053	4735	82.053	4735
Montcalm	88.884	3680	88.884	3680	88.884	3680
Iosco	89.638	3187	89.638	3187	89.638	3187
Oceana	96.323	4469	96.323	4469	96.323	4469
Arenac	97.706	2377	97.706	2377	97.706	2377
Emmet	101.01	2780	101.01	2780	101.01	2780
Kent	102.064	3898	102.064	3898	102.064	3898
Midland	103.189	2104	103.189	2104	103.189	2104
Montmorency	105.497	4001	105.497	4001	105.497	4001
Alcona	109.381	4237	109.381	4237	109.381	4237
Muskegon	114.708	4524	114.708	4524	114.708	4524
Cheboygan	115.246	4506	115.246	4506	115.246	4506
Gratiot	117.374	1313	117.374	1313	117.374	1313
Bay	118.366	589	118.366	589	118.366	589
Alpena	131.073	2438	131.073	2438	131.073	2438
Presque Isle	137.05	2972	137.05	2972	137.05	2972

Table 21 Model Inputs for a Manton Facility

Discussion of Results

As main outputs, the simulation model provides estimates of the delivery cost, energy consumption, and greenhouse gas (GHG) emissions for different facility locations and different plant sizes. The delivery cost is a sum of loading cost, transportation cost, and unloading cost. No stumpage and harvesting costs are calculated in this model due to the assumption that all harvesting areas have the same stumpage and harvesting costs. Other important outputs of the model are tracking the inventory level at the biomass processing facility over time, and picking the most preferable harvesting sites for each biofuel facility.

One simulation was run for a biofuel facility of 50 million gallons per year (MGY) in the city of Gaylord, Michigan. The start date for the simulation was set as Nov 1st, 2011 and the model run length was 350 days a year, 20 years in total. The time step during the simulation was set as one day. The inventory (tons) changes as a function of time following the pattern demonstrated in Figure 21. A better look at the first year operation is shown in Figure 22. In Figure 22, it is obvious that there are three phases in the chart. For the first 4 months (Nov 1st to Feb the end), the harvesting areas provide 72% more biomass each day than the daily demand to build up the inventory. Starting with March 1st, the spring thaw starts and no biomass is allowed to be transported. The daily requirement for biomass at the biorefinery is met by pulling biomass from inventory only. When spring breakup ends at the end of April a regular operation plan (daily demand is met by daily transportation) is executed, and the inventory essentially equals to the initial inventory level (25,000 tons). Table 22 shows the eight most preferable harvesting areas (ordered by the distance from a harvesting area to the facility) for supplying the Gaylord plant.

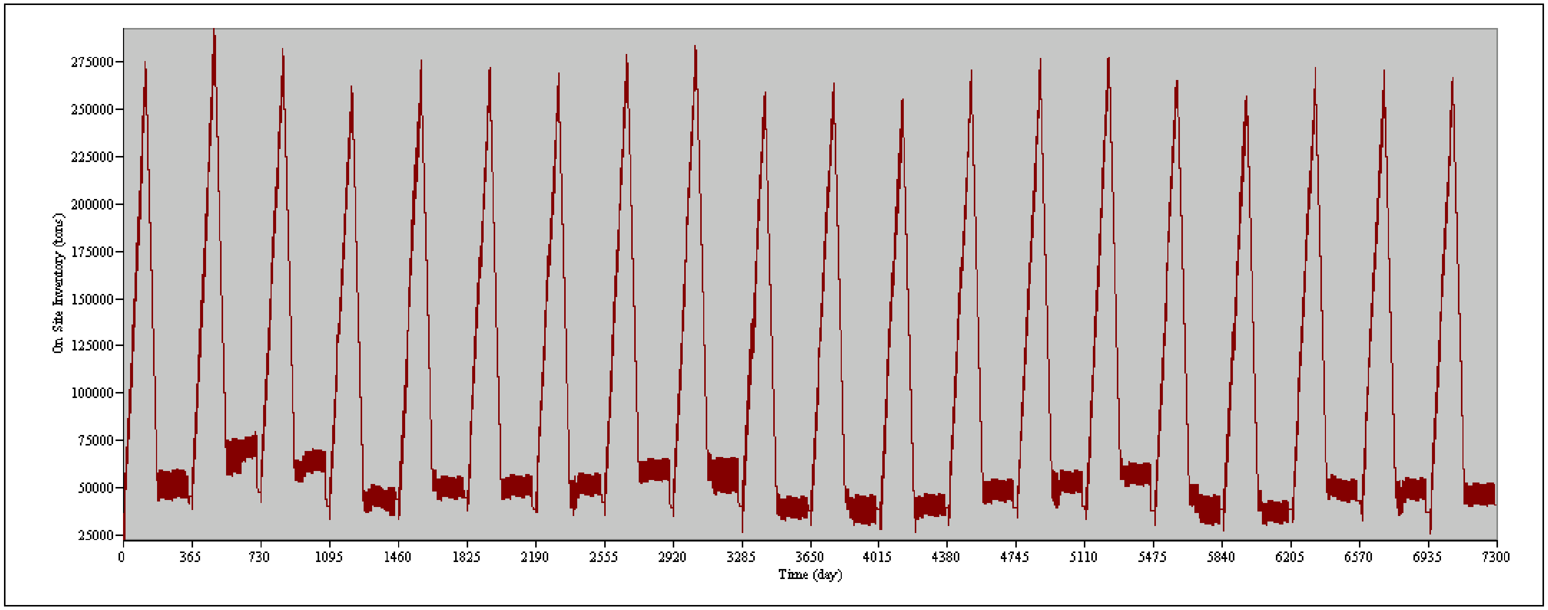


Figure 21 Inventory level for a Facility Size of 50 MGY in Gaylord Operating 20 Years

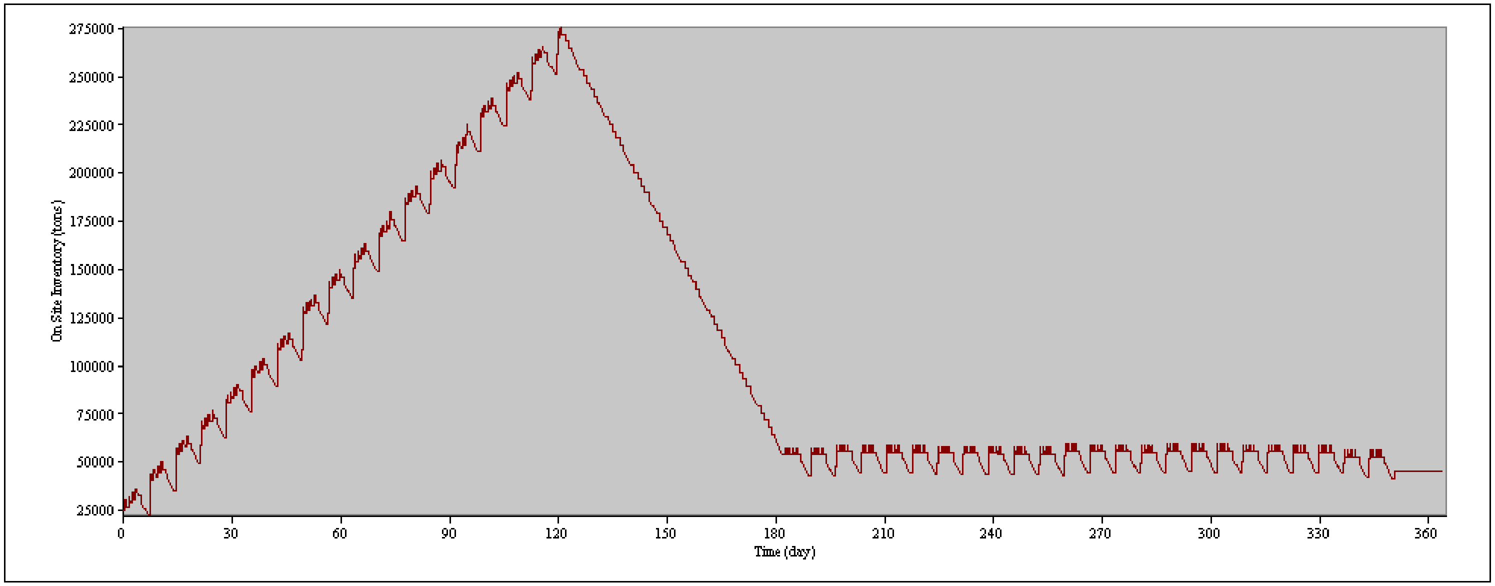


Figure 22 A Better Look at the First Year Operation

Order	Harvesting Area	Rectlinear Distance (mile)	Biomass (green tons)
1	Otsego	4.023	274,920
2	Antrim	24.754	134,827
3	Crawford	27.196	120,789
4	Montmorency	27.607	200,041
5	Cheboygan	37.356	225,280
6	Charlevoix	40.748	96,751
7	Kalkaska	43.740	171,816
8	Emmet	44.968	28,450

Table 22 Eight Most Preferable Harvesting Areas for Supplying Gaylord Plant

A series of simulations were run for each of the nine potential biofuel facility locations. The facilities can have a size of producing 30, 40 or 50 million gallons of biofuel per year. The outputs of the three system performance indicators were shown in Table 23. The tables in the left column are total measurement and the right ones are average measurement. Based on the average measurements, it is obvious that Gaylord is the best facility location due to the lowest unit delivery cost, the lowest unit energy use, and the lowest unit GHG emissions regardless of plant size. Traverse City is the least favorable location to build a biofuel facility of producing 40 or 50 million gallons of biofuel per year, while Boyne City is the least favorable location for a 30 MGY biofuel facility. If a comparison is made among the three different facility sizes at one location, a 30 MGY biofuel facility is the best plant size due to the lowest unit delivery cost, the lowest unit energy use, and the lowest unit GHG emissions.

Gaylord

indicators	total		
	50 MGY	40 MGY	30 MGY
cost (1000 $)	9810.66	7239.59	4882.29
energy use (Mill Btu)	110824	75546	44884
GHG emissions (ton)	13118.72	8942.7	5313.1

Indicator	Average		
	50 MGY	40 MGY	30 MGY
cost ($/ton)	7.8485	7.2396	6.5097
energy use (Mill Btu/ton)	88659	75546	59845
GHG emissions (lb/ton)	20.9900	17.8854	14.1683

Boyne City

indicators	total		
	50 MGY	40 MGY	30 MGY
cost (1000 $)	11318.09	8386.8	5932.23
energy use (Mill Btu)	143418	100356	67477
GHG emissions (ton)	16977.07	11879.68	7987.62

Indicator	Average		
	50 MGY	40 MGY	30 MGY
cost ($/ton)	9.0545	8.3868	7.9096
energy use (Mill Btu/ton)	114734	100356	89969
GHG emissions (lb/ton)	27.1633	23.7594	21.3003

Manton

indicators	total		
	50 MGY	40 MGY	30 MGY
cost (1000 $)	10101.17	7592.22	5286.78
energy use (Mill Btu)	117075	83134	53668
GHG emissions (ton)	13858.75	9840.96	6352.94

Indicator	Average		
	50 MGY	40 MGY	30 MGY
cost ($/ton)	8.0809	7.5922	7.0490
energy use (Mill Btu/ton)	93660	83134	71557
GHG emissions (lb/ton)	22.1740	19.6819	16.9412

Roscommon

indicators	total		
	50 MGY	40 MGY	30 MGY
cost (1000 $)	10472.69	8145.89	5835.68
energy use (Mill Btu)	125226	95192	65400
GHG emissions (ton)	14823.6	11268.37	7741.68

Indicator	Average		
	50 MGY	40 MGY	30 MGY
cost ($/ton)	8.3782	8.1459	7.7809
energy use (Mill Btu/ton)	100181	95192	87200
GHG emissions (lb/ton)	23.7178	22.5367	20.6445

Kingsley

indicators	total		
	50 MGY	40 MGY	30 MGY
cost (1000 $)	10565.57	7900.33	5425.88
energy use (Mill Btu)	127225	89784	56661
GHG emissions (ton)	15060.2	10628.18	6707.26

Indicator	Average		
	50 MGY	40 MGY	30 MGY
cost ($/ton)	8.4525	7.9003	7.2345
energy use (Mill Btu/ton)	101780	89784	75548
GHG emissions (lb/ton)	24.0963	21.2564	17.8860

Kalkaska

indicators	total 50 MGY	total 40 MGY	total 30 MGY
cost (1000 $)	10653.66	7977.31	5364.66
energy use (Mill Btu)	129120	91441	55344
GHG emissions (ton)	15284.58	10824.26	6551.33

Indicator	Average 50 MGY	Average 40 MGY	Average 30 MGY
cost ($/ton)	8.5229	7.9773	7.1529
energy use (Mill Btu/ton)	103296	91441	73792
GHG emissions (lb/ton)	24.4553	21.6485	17.4702

Clare

indicators	total 50 MGY	total 40 MGY	total 30 MGY
cost (1000 $)	10847.44	8140.26	5685.37
energy use (Mill Btu)	133134	95031	62245
GHG emissions (ton)	15759.71	11249.3	7368.25

Indicator	Average 50 MGY	Average 40 MGY	Average 30 MGY
cost ($/ton)	8.6780	8.1403	7.5805
energy use (Mill Btu/ton)	106507	95031	82993
GHG emissions (lb/ton)	25.2155	22.4986	19.6487

West Branch

indicators	total 50 MGY	total 40 MGY	total 30 MGY
cost (1000 $)	10815.45	8125.22	5667.31
energy use (Mill Btu)	132446	94644	61869
GHG emissions (ton)	15678.22	11203.41	7323.67

Indicator	Average 50 MGY	Average 40 MGY	Average 30 MGY
cost ($/ton)	8.6524	8.1252	7.5564
energy use (Mill Btu/ton)	105957	94644	82491
GHG emissions (lb/ton)	25.0852	22.4068	19.5298

Traverse City

indicators	total 50 MGY	total 40 MGY	total 30 MGY
cost (1000 $)	11451.83	8514.55	5779.91
energy use (Mill Btu)	146168	103001	64280
GHG emissions (ton)	17302.59	12192.76	7609.09

Indicator	Average 50 MGY	Average 40 MGY	Average 30 MGY
cost ($/ton)	9.1615	8.5146	7.7065
energy use (Mill Btu/ton)	116934	103001	85706
GHG emissions (lb/ton)	27.6841	24.3855	20.2909

Table 23 System Performance Indicators for Different Facility Locations and Different Plant Sizes

Hardware Requirements

Minimum System Requirements

The minimum system requirements to run the simulation model are (Rockwell Automation, 2011):

- Arena simulation software, version 13 (or newer)
- Hard drive with 1GB free disk space (or more)
- 2GB RAM (or more)
- Intel dual-core processor (or more), 3GHz or faster

Recommended System Requirements

The recommended system requirements to run the simulation model are (Rockwell Automation, 2011):

- Arena simulation software, version 13.0 (or newer)
- Hard drive with 4GB free disk space (or more)
- 4GB RAM (or more)
- Intel dual-core processor (or more), 3GHz or faster

The details can be found at:
http://www.arenasimulation.com/Files/Requirements_13.9.pdf.

Model Constraints/Limitations

The model is a simplification of a biomass supply chain system for biofuel production. A series of assumptions were made to simulate the supply chain system. As a result, some of the processes in the model may not be able to capture all the features in the real world. The limitations produce two types of uncertainties inherent to the model: data uncertainty and model uncertainty (National Research Council, 2007).

- Due to the minimum resolution available for the harvesting areas is county, the assumption of defining a county as one harvesting area introduces uncertainties. In the real world, one county can be split into several harvesting areas;
- The starting point of transportation in real is not the county centroid;
- The amount available from private landowners is largely unknown and subject to a high level of uncertainty and variability. There are numerous factors that impact the availability which were not fully evaluated in this report.
- The conversion factor that defines gallons of biofuel per green ton of biomass could produce varies based on the conversion technology adopted at the biorefinery, the feedstock type used, and so on. And the conversion efficiency may be improved over time. In this model, the assumption of a conversion factor of 40 gallons biofuel per green ton of biomass may introduce uncertainty;
- The assumption of all trucks are initially located at the biorefinery may produce uncertainty. In real, trucks are initially located in transportation companies.
- In the model, no backhaul is considered. In reality, a certain percent of backhaul may be practical;
- Truck breakdown and weather delay are not considered in the model;

- Spring breakup, where road load restrictions are in place, is not calendar based as assumed in the model. It depends on geological locations, weather conditions, soil types and so on.
- Although road weight limits are enforced during spring breakup, transportation can still take place by reducing truck loads;
- The moisture content may keep changing throughout the supply chain;
- Dry matter loss may be caused through the supply chain due to a series of reasons, for example, weight loss during storage due to insect infestation.

Similarities and Differences

The two models (the optimization model discussed in section 6 and the simulation model described in section 7) built for the biofuel supply chain addressed different supply issues, while they also share similarities. Both models can be used to rank the nine potential biofuel facility locations identified in previous sections. In other words, the two models can be used to identify the optimal biofuel facility location in the study area. Both models used the delivered feedstock cost, GHG emissions, and energy consumption as system performance criteria. Both models can be applied to a single location for one year operation. Since both models cannot capture all the features of a supply chain system, a series of assumptions were made to simplify the supply chain and corresponding constraints and limitations applied.

The optimization model is a static, Excel-based application which allows for sensitivity analysis by changing inputs to evaluate different scenarios. The optimization model was demonstrated using single location and three multi-location configurations. For the single location models, cost, emissions, and energy were minimized to optimize the individual attributes. In the case of the multi-location configurations, only cost was evaluated. The optimization model is for a single period of time, but can be applied to multiple years assuming there are no changes in data inputs. Since the optimization model is a static model considering only one year operation, the optimization model cannot evaluate the impacts of spring breakup period on biomass supply and demand, and cannot be used to track inventory level or estimate truck requirements.

Compared with the optimization model, the simulation model represents a more dynamic look at a 20-year operation by considering the impacts associated with building inventory at the biorefinery to address the limited availability of biomass feedstock during the spring breakup period. The simulation model was developed using single location over a 20 year period of time. The assumed starting inventory along with increased inventory prior to spring break up was designed to deal with limited supply during that time period. The number of trucks required per day is estimated and the inventory level all year around was tracked. Also the potential optimal suppliers (harvesting areas) were selected based on the three system performance criteria (the delivered feedstock cost, energy consumption and GHG emissions). Through the exchange of information across different procedures (harvesting procedure, transportation procedure, and biomass feedstock processing procedure), a smooth flow of biomass from harvesting areas to a biofuel facility was implemented.

Compared with existing supply chain models discussed in the literature review section, both models considered different feedstock type, harvesting/preprocessing procedures, transportation modes and plant locations. The both models used roundwood or/and forest residue as biomass feedstock while other types of biomass (energy crops, agriculture residues etc.) can be easily added. The both models did not consider size reduction (chipping) procedures which are assumed to happen at a biorefinery. The truck transportation is the only option considered in the two models due to the lower cost, while existing supply chain models consider multiple transportation modes including water, railway and sometimes pipelines. The two models were applied in the Lower Peninsula of Michigan which is different from existing supply chain models in the literature which considers nationwide or a different study area.

Summary

To reduce carbon emissions and reduce U.S. dependence on imported oil, renewable biofuel production from biomass has received increasing interest. However, due to the distributed nature of biomass feedstock, the cost and complexity of biomass recovery operations result in significant challenges that hinder increased biomass utilization for energy production. To facilitate the exploration of a wide variety of conditions that promise profitable biomass utilization, a supply chain model has been designed and implemented using Arena Simulation Software. The model considers key activities of the supply chain, including biomass harvesting/processing, transportation, and onsite storage. The supply chain is driven by both daily demand for biomass feedstock at a biorefinery and daily biomass recovery at harvesting sites. The model is evaluated using three key performance indicators: the delivered feedstock cost, energy consumption, and GHG emissions. The model also considered road restrictions associated with spring breakup that limit use of truck transportation on certain roads. The utility of the supply chain simulation model has been demonstrated through a series of simulations that considers a supply chain for biomass feedstock for several biorefinery locations in the Lower Peninsula of Michigan.

Future Work

Future work will focus on refining the model to incorporate uncertainties listed in the model limitation section. The graphical user interface needs to be improved as well. Another consideration may include integrating inventory holding cost. The possibility of applying the model (subject to minor revisions) to other regions in the United States may be investigated.

8. Infrastructure Analysis

Overview

An infrastructure analysis was conducted to investigate the feasibility of growing the transportation infrastructure in order to realize the necessary network system needed to transport sufficiently large volumes of biomass in the Lower Peninsula of Michigan. The analysis is conducted on the road transportation network and equipment by examining existing roads and truck fleets as well as comparing with the needs for road and truck infrastructure forecasted for the supply chain model. The capital investment on road and truck infrastructure is also discussed.

Purpose/Objective

Driven by the concern regarding the effects of greenhouse gases on global warming, biofuel production from renewable biomass has been receiving increased attention lately. Growing biofuel requirements pose considerable challenges to the infrastructure needed across all stages of the supply chain, such as biomass feedstock harvesting/processing, and transportation. The purpose of the infrastructure analysis was to address shipment routing decisions or/and biofuel facility location decisions, with the objective to minimize the total cost including the transportation costs and the cost for infrastructure investment. The analysis identifies and evaluates the existing road and truck infrastructure. The information gained through the analysis will provide direction for possible solutions that can incorporate existing transportation networks and technologies and leverage existing investments in the networks and technologies.

Discussion

To reduce carbon emissions and reduce U.S. dependence on imported oil, renewable biofuel production from biomass has received increasing interest. However, due to the distributed nature of biomass feedstock, the complexity of biofuel supply chain result in significant challenges that hinder increased biomass utilization for energy production (Iakovou et al., 2010; Rentizelas et al., 2009). One particular aspect of the biofuel supply chain is that biomass transportation (i.e., routing) should be considered endogenously with biofuel facility location decisions (Bai et al., 2011).

In the biofuel supply design literature, comprehensive mathematical models have been proposed to address shipment routing decisions or/and biofuel facility location decisions, with the objective to minimize the total cost including the transportation costs and the cost for infrastructure investment (Bai et al., 2011). The biomass and ethanol routing problems can be modeled as a traffic assignment problem, which determines traffic flow on a network that achieves certain optimal criteria (e.g., user equilibrium or system optimum) (Bai et al., 2011). Such problems can be solved efficiently by the convex combination method (Frank and Wolfe, 1965; Sheffi, 1985), the disaggregated simplicial decomposition method (Larsson and Patriksson, 1992), the gradient projection method (Jayakrishnan et al., 1994), and the origin-based assignment method (Bar-Gera, 2002), among others. The biofuel facility location problem can be modeled as a fixed-charge facility location problem, which is nonlinear (NP)-hard but can be solved effectively by techniques such as Lagrangian relaxation. Bai et al. (2011) proposed a variety of solution approaches based on combinations of Lagrangian relaxation, liner programming relaxation, branch and bound and convex combination in order to solve the integrated model of addressing both facility location and shipment routing problems.

The mathematical model proposed by Bai et al. (2011) can serve as a basis for the development of supply chain management decision support tools. Bai's model focuses on planning biofuel facility locations where the total system cost for biofuel facility investment, biomass and ethanol transportation and public travel is minimized. Bai's model is similar to our model at finding biofuel facility locations while minimize transportation cost. The difference is our model will only consider biomass shipment routing problem, not considering ethanol distribution issues as Bai's model. Our model may consider other optimal criteria, such as minimizing energy consumption and GHG emissions, other than just transportation cost.

The biofuel facility location decision has been made based on a GIS-based method presented in Section 4: Identification of Candidate Locations. Nine potential biofuel facility locations were identified. Further analysis on ranking the nine candidate locations can be made either by the optimization model in section 6 or the simulation model in section 7. However, as has been noted, latitude and longitude coordinates are used from the related centroid of the harvesting areas to the nine potential biofuel facilities in order to estimate the transportation distances. It is necessary to examine the existing transportation networks to identify whether these infrastructures are sufficient for large volumes of biomass delivery. For the biofuel supply chain, only the road transportation network is considered. Therefore, the existing road (e.g., national highway, major road, and county road) and truck infrastructures are examined. See Appendix B4-B for the maps having information regarding the road transportation network.

In the third quarter report of FBSCC from MTU, the truck fleet size for the State of Michigan has been identified by Task B1: *Evaluation Michigan Biomass Transportation Systems*. The truck fleet was split between the Upper and Lower Peninsula's. From this report, 405 trucks are available within the Lower Peninsula region. As has been noted, to meet the demand for biomass at a biorefinery, which produces 50 million gallons of biofuel per year, 50 trucks (more than 12% of the truck fleet size) are needed on regular working days (May 1st to October 31st) and 61 trucks (more than 15% of the fleet size) needed per day from November 1st through the end of February to prepare the inventory for the coming of spring breakup. The large size of truck fleet required to transport sufficiently large volumes of biomass may be not met using current truck fleet in the Lower Peninsula region. Therefore, new investment may be required on new equipment for biomass transportation. However, the exact number is dependent on the number of roundtrips in a day and distance driven.

There is a significant capital investment that is required by developers of the infrastructure along with the transportation companies supporting the increased volumes. A critical ingredient is to sufficiently identify the optimal costs associated with capital investment along with the required maintenance and operational costs for longer-term viability and sustainability. The capital investment costs will be split between infrastructure (e.g., roads) and equipment (e.g., trucks). Identification of the associate maintenance and operating costs will also be included.

Summary

To expand the biofuel industry, it is important to examine the existing transportation networks and technologies to identify whether they are sufficient for large volumes of biomass delivery for the increasing biofuel industry. Bai's model (2011) was suggested to serve as a basis for the infrastructure analysis in order to investigate the feasibility of growing infrastructure to be able to realize the necessary scales to transport sufficiently large volumes of biomass in the Lower Peninsula of Michigan. The analysis is made on road transportation network and equipment by examining existing roads and truck fleets and comparing with the needs for road and truck infrastructure forecasted for the supply chain model. The capital investment on road and truck infrastructure is also discussed.

9. Overall Summary and Conclusion

Summary

The data and results in this report represent a snapshot in time. Because of the flexibility of the models to accept input as new data becomes available, it allows prospective users to evaluate different scenarios and conduct sensitivity analysis to meet their needs. Each of the sections in the paper outlines the results from the optimization and simulation models. With any study, there are limitations that a decision maker needs to be aware of. The next section outlines some of the potential limitations associated with this study and report.

Limitations

This study was conducted using an aggregated approach. Although the results provide some initial insights into potential locations for a biorefinery plant, the following are limitations of this study:

- Limited to selected locations,
- Aggregate feedstock data and availability,
- Expansion of supply chain,
- Stability of feedstock supply,
- Distance calculations,
- Limited transportation modes,
- Transportation costs,
- Harvest/processing cost and stumpage prices,
- Known and unknown competing uses,
- Preprocessing unknown, and
- Processing technology for fuel production is unknown.

Each of these limitations is discussed below.

Selected Locations

The ideal situation would allow for the selection of a location based on the greatest amount of feedstock available close by. If the evaluation considered only one location, this approach would be feasible. Reviewing multiple locations at the same time required identification of desirable selection criteria for candidate locations. This approach allowed for evaluating multiple locations concurrently but does have its limitation as that the locations are fixed and so are the results from the models.

Aggregate Feedstock Data and Availability

The classification of woody biomass was at an aggregate level of hardwood and softwood without differentiation to different species within each of those classes. Most engineering design studies have indicated specific species of hardwood and processing technologies as desirable for cellulosic ethanol production, if this is the biofuel of choice. An additional factor for consideration is the percentage of each of hardwood or softwood that is roundwood or logs and the percentage of forest residues. This is an option in the entry screens.

Much of the data on historical removals are based on actual removals. The decline in pulp and paper production does allow for sufficient availability for other uses but determining the exact quantities can only be based on historical information. The exact amount of expansion relies heavily on estimates. This information was outlined in an earlier section.

Expansion of supply chain

The woody biomass supply chain is well developed and has been in existence for many years supporting lumber, furniture, pulp and paper, and a number of other industries with fiber. The market has seen some retrenchment because housing starts are down and production in the pulp and paper industry. This has caused a reduced demand and resulted in the lowering of prices for delivered woody biomass. It is anticipated that the biofuels industry will increase demand to exceed prior levels. The question is, "How much can the supply chain expand to reliably meet the growing demand?" It is not a matter of sufficient woody biomass but more of an issue of whether the demand can be met when needed at a price that is affordable and with adequate quality to meet the producers' or refiners' needs.

The harvesting/processing provides two primary products: logs and forest residue. One does not exist without the other. The supply chain for logs is well developed. The supply chain for forest residue is developing as some of the residue will remain in the forests and some would be available for biomass fired electric plants or perhaps in the future, biofuels that can use the forest residues.

Stability of Feedstock Supply

The demand for roundwood and the highest quality fiber is going to initially exceed the demand for forest residues. The expansion and supply is highly dependent on a supply chain of independent operators and private owners. The loggers/transporters represent a large stakeholder in the process and also can make or break the success of the biorefinery industry. The need to develop a supply chain for forest residues that is more formalized would be useful, especially for biomass fired electric plants.

Distance calculations

The distance calculations were based on the rectilinear distance using the latitude and longitude of the centroid of each of the counties to the candidate locations. Because of the number of locations and the limited scope of the project, the results represent an estimate with limited variability. This does represent a close approximation, especially if the road system is in grids. The only possible adjustment would have been to consider adding a tortuosity factor[5] to take into consideration curves in the road. But since each location is unique, this could require multiple factors and many inputs into the model.

[5] The ratio of actual distance travelled to straight line distance.

Limited transportation modes
Exclusive use of truck transportation may be a limiting factor in this study. Prior work had indicated that transportation distances less than 100 miles will be more economically served by truck instead of multimodal truck/rail or rail (Hicks, 2009). Some counties did not have rail access, which poses further limitations. Another possible future consideration may be to consider transport by barge from the Upper Peninsula of Michigan or adjacent states such as Minnesota and Wisconsin.

Transportation costs
The transportation cost is based on a study conducted in 2009 when diesel fuel prices were lower than the current levels (Hicks, 2009). The results contained for the FBSCC study were based on the models provided. However, input cells are available in both models to update these parameters as new information becomes available.

Harvest/processing cost and stumpage prices
Task B2.5 *Select feasible processing technologies* and B2.6 *Analyze supply chain cost of processing technologies* are evaluating the potential costs associated with harvesting and processing

Known and unknown uses
There are two known future uses of woody biomass that were identified earlier in the report. The biorefinery in the eastern portion of the Upper Peninsula of Michigan will be using woody biomass from the upper portion of the Lower Peninsula of Michigan, as indicated as the overlapping area in this study. It is not known if all sources of woody biomass for the planned Mancelona biomass fired electric plant will come from Michigan or from outside of Michigan (i.e., Wisconsin). There are other potential uses that have not been confirmed. For example, there is some indication that in the upper portion of the Lower Peninsula there is consideration for a pellet operation.

Preprocessing unknown
It is likely that preprocessing, such as bark removal, will occur. It is unknown whether this preprocessing will occur at the landing, roadside, or biorefinery location. Other preprocessing such as chipping and shredding could occur. Without knowing this information, it was not included in any evaluation associated with this project.

Processing technology for fuel production is unknown
There are different processing technologies for producing biofuels. Since no specific technology was specifically indicated in this study, attributes or variables associated with processing technologies were not included as a part of this study.

10. Proposed Future Work

The pilot project was limited in scope to the upper portion of the Lower Peninsula of Michigan. Initially the project was planned to encompass the entire state of Michigan but because of the possible size of the project and the limited time span to complete the project, a scope that was appropriate to the time and resource availability was completed. There are several possible expansions of work and include:

1) Differentiating feedstock species,
2) Identifying other possible industries to include beyond biorefineries and look at other related industries such as biomass fired or co-fired power operations,
3) Evaluating the impact on the expansion in the supply chain from a behavioral as well as a quantitative perspective,
4) Determining the maximum resource consumption of forest residues and roundwood that would allow for maintaining sustainable forest management practices,
5) Considering a mix of feedstock, to include agricultural residues such as corn stover,
6) Studying the co-location of a biorefinery with a biomass fired electric plant or pulp and paper operations to determine if there are possible synergies and whether it is feasible,
7) Expanding the scope to the rest of the state of Michigan,
8) Expanding the scope to a Midwestern focused study to include the states of Wisconsin and Minnesota,
9) Expanding the modes of transportation,
10) Identifying if there are additional decision criteria need to determine candidate locations, and
11) Evaluating the potential retooling of former pulp and paper locations that have been closed (i.e., Gaylord).

This represents a possible list of additional work to expand the scope of work. It is not intended to be all-inclusive but to represent a starting point for consideration of future projects to enhance the output from this study.

11. List of Publications and Presentations Associated with Research

1. Johnson, D. M., Zhang, F., Harrison, E., and Hanninen, K., (2011) "Comparative Review of Biofuel Supply Chains," Decision Sciences Institute 42nd Annual Meeting, Boston, MA, USA Nov 19 to 22, 2011 (accepted).
2. Zhang, F., Johnson, D. M., and Sutherland, J. W., (June 2011) "A GIS-Based Method for Identifying the Optimal Location for a Facility to Convert Forest Biomass to Biofuel," Biomass and Bioenergy.
3. Zhang, F., Johnson, D. M., Johnson, M. A., and Sutherland, J. W., (2011) "Development of a Biomass Supply Chain for Biofuel Production," 2011 Industrial Engineering Research Conference, Reno, Nevada May 21-25, 2011.
4. Zhang, F., Handler, R., Johnson, D. M., and Shonnard, D. R., (2011) "Comparative Analysis of Life Cycle Greenhouse Gas Emissions of Supply Chains for Biofuel and Fossil Fuel Production," Production and Operations Management Society (POMS) 22nd Annual Conference, Reno, Nevada, USA April 29 to May 2, 2011.

5. Zhang, F., Johnson, D. M., and Sutherland, J. W., (May 2010) “GIS-based Approach of Identification of the Optimal Pulpwood-to-Biofuel Facility Location in Michigan's Upper Peninsula,” POMS 21st Annual Conference, Vancouver, Canada.

Conference Presentations

6. Johnson, D. M., Zhang, F., and Sutherland, J. W., (May 2010) “GIS-based Approach of Identification of the Optimal Pulpwood-to-Biofuel Facility Location in Michigan's Upper Peninsula,” POMS 21st Annual Conference, Vancouver, Canada.
7. Johnson, D. M., Zhang, F., Handler, R., and Shonnard, D. R., (April 29 to May 2, 2011) “Comparative Analysis of Life Cycle Greenhouse Gas Emissions of Supply Chains for Biofuel and Fossil Fuel Production,” Production and Operations Management Society (POMS) 22nd Annual Conference, Reno, Nevada, USA.
8. Zhang, F., Johnson, D. M., Johnson, M. A., and Sutherland, J. W., (May 21-25, 2011) “Development of a Biomass Supply Chain for Biofuel Production,” 2011 Industrial Engineering Research Conference, Reno, Nevada.

12. **Website Associated with Research**

The public webpage (Figure 23) is a part of the outreach component for the FBSCC project. It includes a page that summarizes the supply chain component of the FBSCC project (Task B4). Basically we summarized the research questions and the approach employed to address the questions. We also have a section for a brief description of the project progress and results, where the literature gap analysis and initial location selection were attached. More details can be found at:
http://biofuels.confidentialdelivery.com/research-project/feedstock-supply-chain-landing-biorefinery

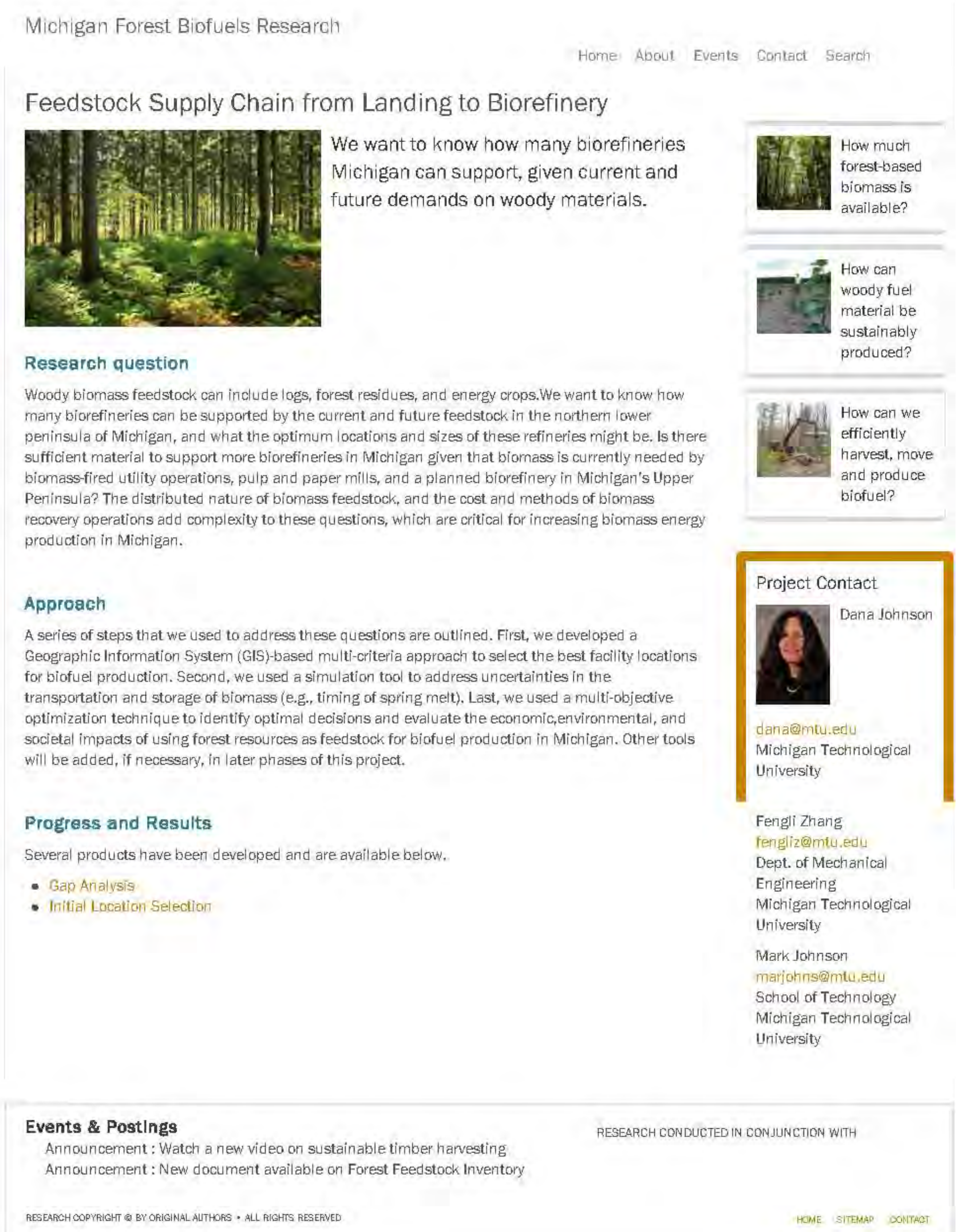


Figure 23 The website for supply chain component of the FBSCC project (Task B4)

References

Aden, A., Ruth, M., Ibsen, K., Jechura, J., Neeves, K., Sheehan, J., Wallace, B., Montague, L., Slayton, A., and Lukas, J., (2002). Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute. Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover NREL Technical Report, National Renewable Energy Laboratory 2002;154pp.

Aerts, D., Ragland, K., (2000). Case study of successful wood-fired co-generation power plant, 1982-1996. Mechanical Engineering Department, University of Wisconsin-Madison, Madison, WI. Available at http:/www.nrp.org/papers/055.pdf

Athanassiadis, D., (2000). Energy consumption and exhaust emissions in mechanized timber harvesting operations in Sweden. Science of the Total Environment, Vol. 255, 135-143.

Athanassiadis, D., Lidestav, G. and Nordfjell, T., (2002). Energy use and emissions due to the manufacture of a forwarder. Resources Conservation and Recycling, Vol. 34, 149-160.

Bai, Y., Hwang, T., Kang, S. and Ouyang, Y., (2011). Biofuel refinery location and supply chain planning under traffic congestion. Transportation Research Part B, 45(1): 162–175.

Bar-Gera H., (2002). Origin-based algorithm for the traffic assignment problem, Transportation Science 36 (4), pp. 398–417.

Biomass Research and Development Board, (2008). National Biofuels Action Plan. Biomass Research & Development Initiative.

Canadian National Railroad Greenhouse Gas Calculator Emission Factors. (2009) [cited; Available from: http://www.cn.ca/en/greenhouse-gas-calculator-emission-factors.htm.

De Mol, R. M., Jogems, M. A. H., Van Beek, P. and Gigler, J. K., (1997). Simulation and optimization of the logistics of biomass fuel collection, Netherlands Journal of Agricultural Science, 45, 219-228.

DOE/NETL-2009/1346. (Nov 26, 2008). Development of baseline data and analysis of life cycle greenhouse gas emissions of petroleum-based fuels.

Frank M. and Wolfe P., (1956). An algorithm for quadratic programming, Naval Research Logistics Quarterly **3** , pp. 95–110.

Frischknecht, R. and Rebitzer, G. (2005). The ecoinvent database system: a comprehensive web-based LCA database. Journal of Cleaner Production, Vol. 13, 1337-1343.

Gunnarsson, H., Ronnqvist, M., and Lundgren, J. T., (2004). Supply chain modeling of forest fuels, European Journal of Operational Research, 158, 103-123.

Gunnarsson, H., (2007). Supply chain optimization in the forest industry (Doctoral Dissertation, Linköping University, 2007). Linköping Studies in Science and Technology, No. 1105.

Gronalt, M. and Rauch, P., (2007). Designing a regional forest fuel supply network, Biomass and Bioenergy, 31, 393-402.

Handler, R. (April 2010). Personal communication and interviews with loggers in the state of Michigan. Results currently unpublished.

Hess, J. R., Wright, C. T., and Kenney, K. L., (2007). Cellulosic biomass feedstocks and logistics for ethanol production. Biofuels, Bioproducts & Biorefining, 181-190.

Hess, R. J., Wright, C. T., Kenney, K. L., and Searcy, E., (2009), Uniform-Format Feedstock Supply System Design: A Commodity-Scale Design to Produce an Infrastructure-Compatible Bulk Solid from Lignocellulosic Biomass. Idaho National Laboratory Biofuels and Renewable Energy, <http://inlportal.inl.gov/portal/server.pt/gateway/PTARGS_0_1829_37189_0_0_18/Executive_Summary_Final_w_cover.pdf> 9 December 2009

Hicks J. (2009). Modeling the Multi-Modal Transport of Logs and the Effects of Changing Fuel Prices Civil and Environmental Engineering Department. Houghton, Michigan Technological University. Master Thesis.

Iakovou, E., Karagiannidis, A., Vlachos, D., Toka, A., and Malamakis, A., (2010), Waste biomass-to-energy supply chain management: A critical synthesis, Waste Management (in press).

Idaho National Laboratory (INL), (2006, October). Bioenergy Technology. Retrieved December 2009, from INL Web site: http://www.inl.gov/bioenergy/projects/d/1006_ch2m.pdf

Jayakrishnan R., Tsai W.K., Prashker J.N. and Rajadhyaksha S., (1994). A faster path-based algorithm for traffic assignment,Transportation Research Record 1443 , pp. 75–83.

Jenkins, T. L., (2008). A GIS Based Analysis for Locating Woody Biomass Ethanol Facilities, Unpublished manuscript, Michigan Technological University, Houghton, MI.

Klvac, R., Ward, S., Owende, P.M.O. and Lyons, J. (2003). Energy audit of wood harvesting systems. Scandinavian Journal of Forest Research,Vol. 18, 176-183.

Larsson, T. and Patriksson, M., (1992). Simplicial decomposition with disaggregated representation for the traffic assignment problem, Transportation Science 26 (1), pp. 4–17.

Leatherberry E. C., and Spencer J. S. Jr. (1996). Michigan Forest Statistics, 1993. Resource Bulletin NC-170. St. Paul, MN: U.S. Dept. of Agriculture, Forest Service, North Central Forest Experiment Station.

Maker, T. M., (2004). Wood-chip heating systems: A guide for institutional and commercial biomass installations. Biomass Energy Resource Center. Montpelier, VT. 76 pp.

Michigan State Police (MSP), (March 4, 2004). That Time of Year Again: Lighten the Load Spring-Like Weather Brings on Weight Restrictions for Roads, http://www.michigan.gov/msp/0,1607,7-123-1586_1710-87560--,00.html.

Microsoft Office. (2009). 2007 Microsoft Office System Requirements. http://www.microsoft.com/officebusiness/products/technical-requirements.aspx (accessed June 13, 2011).

Miles, P. D., (2011). Forest Inventory EVALIDator web-application version 4.01. St.Paul, MN: U.S. Department of Agriculture, Forest Service, Northern Research Station. EVALID=260903; downloaded 03 March 2011, http://fiatools.fs.fed.us/Evalidator401/tmattribute.jsp.

McNeil Technologies, Inc., (2005). Jefferson County Biomass Facility Feasibility Study. Available from: http://frontrangeroundtable.org/uploads/Jeffco_Biomass_Final_Report_01-21-05.pdf.

McWhirter S., 2010, “Mancelona biomass plant awaits utility deal,” http://record-eagle.com/antrim/x794091110/Mancelona-biomass-plant-awaits-utility-deal
National Research Council, (NRC), (2007). Models in environmental regulatory decision making, National Academies Press, Edition.
Ragland, K. W., Aerts D. J., and Baker A. J. (1991). Properties of wood for combustion analysis. Bioresource Technology. 37: 161-168.
Renewable Electric Plant Information System (REPIS), (2003). http://www.nrel.gov/analysis/repis/
Rentizelas, A.A., Tatsiopoulos, I.P., and Tolis, A., (2009), An optimization model for multi-biomass tri-generation energy supply, Biomass and Bioenergy, 33, 223-233.
Reynolds, R. E. (2002). Infrastructure Requirements for an Expanded Fuel Ethanol Industry. South Bend, IN: Oak Ridge National Laboratory Ethanol Project, http://www.ethanolrfa.org/objects/documents/94/dai.pdf.
Rockwell Automation (2011). Arena Simulation Software Version 13.90.00 System Requirements. http://www.arenasimulation.com/Files/Requirements_13.9.pdf (accessed June 13, 2011).
Sandia National Laboratories. (2009). 90 Billion Gallon Biofuel Deployment Study. Sandia National Laboratories Web site. February 10, http://www.sandia.gov/news/publications/white-papers/HITEC_Biofuel%20_Study.pdf (accessed December 9, 2009).
Sheffi, Y., (1985). Urban Transportation Networks: Equilibrium Analysis with Mathematical Programming Methods, Prentice Hall, England Cliffs, NJ.
Sokhansanj, S., Kumar, A., and Turhollow, A. F., (2006). Development and implementation of integrated biomass supply analysis and logistics model (IBSAL). Biomass and Bioenergy, 30,838-847.
U.S. Life-Cycle Inventory Database, (2009). Available from: www.nrel.gov/lci.
Wang, M. GREET 1, version 1.8c.0 - Fuel-cycle model. Argonne National Laboratory.
West, T., Dunphy-Guzman, K., Sun, A., Malczynski, L., Reichmuth, D., Larson, R., Ellison, J., Taylor, R., Tidwell, V., Klebanoff, L., Hough, P., Lutz, A., Shaddix, C., Brinkman, N., Wheeler, C., and O’Toole, D., (August 2009). Feasibility, economics, and environmental impact of producing 90 billion gallons of ethanol per year by 2030. Sandia National Laboratories Web site: http://www.sandia.gov/news/publications/white-papers/90-Billion-Gallon-BiofuelSAND2009-3076J.pdf (accessed December 9, 2009).
White, M. K., Gower, S. T. and Ahl, D. E., (2005). Life cycle inventories of roundwood production in northern Wisconsin: Inputs into an industrial forest carbon budget. Forest Ecology and Management, Vol. 219, 13-28.
Wikipedia (2010). Facts about the Mackinaw Bridge, http://en.wikipedia.org/wiki/Mackinaw_Bridge, accessed 4/11/11
Zhang, F., Johnson, D. M., and Sutherland, J. W., (May 2010) “GIS-based Approach of Identification of the Optimal Pulpwood-to-Biofuel Facility Location in Michigan's Upper Peninsula,” POMS 21st Annual Conference, Vancouver, Canada.
Zhang, F., Handler, R., Johnson, D. M., and Shonnard, D. R., (2011) “Comparative Analysis of Life Cycle Greenhouse Gas Emissions of Supply Chains for Biofuel and Fossil Fuel Production,” Production and Operations Management Society

(POMS) 22nd Annual Conference, Reno, Nevada, USA, April 29 to May 2, 2011.

Zhang, F., Johnson, D. M., and Sutherland, J. W., (June 2011) "A GIS-Based Method for Identifying the Optimal Location for a Facility to Convert Forest Biomass to Biofuel," Biomass and Bioenergy.

Zhang, F., Johnson, D. M., Johnson, M. A., and Sutherland, J. W., (2011) "Development of a Biomass Supply Chain for Biofuel Production," 2011 Industrial Engineering Research Conference, Reno, Nevada May 21-25, 2011.

USER’S DOCUMENTATION – OPTIMIZATION MODEL

Introduction

The optimization model was designed as a user-friendly, Excel-based tool to allow for selected inputs to be modified based on the user's needs. This management decision support tool was also developed to allow for quick and easy sensitivity analysis. The aggregate nature of the tool allows for a macro level view of decisions associated with nine specific potential locations for a biorefinery in the upper portion of the Lower Peninsula of Michigan. It was designed to provide fundamental information regarding optimizing cost, energy, and emissions, as outlined in the earlier sections of the report.

Entry Screen Key

The entry screen key is color coded to help denote the meaning of each of the cells. There are three different types of cells in the key: Input Cells, Calculated Cells, and Model Results. The key is shown in Figure O-1.

KEY:	
	INPUT CELLS
	CALCULATED CELLS
	MODEL RESULTS

Figure O-1 Entry Screen Key

Input Screens

There are a series of input screens. These include:

- Cost
- Energy
- Emissions
- Availability
- Availability Adjustment Factors
- Facility Size, Conversion Rate, and Biomass Feedstock Requirement

Cost

The cost entry screen includes information for stumpage, harvest/processing, and transportation. The transport cost consists of two components: a cost per ton and a cost per ton per mile. At the time of the optimization model development, only transportation cost was available. There are entry boxes for stumpage and harvest.

	Stumpage		Harvest		Transport		Total	
Cost	0.00	$/ton	0.00	$/ton	3.72	$/ton	3.72	$/ton
					0.074	$/ton-mile	0.074	$/ton-mile

Figure O-2 Input Screen for Cost Data

Energy
The energy screen includes information for harvest/processing and transportation energy consumption.

	Stumpage		Harvest			Transport		
Energy			137.4330	1000 Btu/ton		1.5924	1000 Btu/ton-mile	

Figure O-3 Input Screen for Energy Data

Emissions
The emissions screen includes information for harvest/processing and transportation emissions.

	Stumpage		Harvest			Transport		
Emissions			25.6	lb GHG/ton		0.377	lb GHG/ton-mile	

Figure O-4 Input Screen for Emissions Data

Availability
The availability screen includes the region as noted in the map in Figure 10 along with the availability factor for federal, state, and private ownership. These factors can be modified and were provided from Task A1: *Develop a Geospatial Forest Based Biomass Inventory*.

Federal		Region	Factor
Availability	Soft	N	0.93288219
		S	0.93288219
	Hard	N	0.90959717
		S	0.90959717
State		Region	Factor
Availability	Soft	N	0.54210441
		S	0.89363253
	Hard	N	0.48138431
		S	0.88568285
Private		Region	Factor
Availability	Soft	N	0.68544762
		S	0.95282162
	Hard	N	0.56189444
		S	0.75485393

Figure O-5 Input Screen for Availability by General Species and Ownership Type

Availability can further be classified by general characterization of roundwood or forest residues.

Residue	Roundwood	Total
0%	100%	100%
0%	100%	100%
0%	100%	100%
0%	100%	100%
Residue	Roundwood	Total
0%	100%	100%
0%	100%	100%
0%	100%	100%
0%	100%	100%
Residue	Roundwood	Total
0%	100%	100%
0%	100%	100%
0%	100%	100%
0%	100%	100%

Figure O-6 Input Screen to Identify Percentages

The calculation will default the balance to roundwood for total supply of 100%. If residues are entered, the roundwood percentage would be reduced.

Availability Adjustment Factors

The adjustment factors were utilized to adjust for known competing uses that will be coming on line and operational in 2012+ timeframe. FRR stands for Frontier Renewable Resources, a biorefinery being constructed in the Eastern portion of the U.P. in Kinross, MI. FRR plans to purchase woody biomass from the upper portion of the Lower Peninsula of Michigan, and the estimated quantity is included in Figure O-7. This amount can be modified. Additionally, an adjustment factor for the planned operation of a biomass fired electric plant in Mancelona assumed to use softwood so the amount available for other uses is 80% of the softwood. Both the soft and hard wood residue and roundwood can be adjusted to account for competing uses.

FRR	500,000	*tons hardwood (roundwood)*				
Soft adjust	*Species*			**Hard adjust**	*Species*	
	Residue	80%			*Residue*	100%
	Roundwood	80%			*Roundwood*	100%

Figure O-7 Adjustment Factors for Competing Uses

Facility Size, Conversion Rate, and Biomass Feedstock Requirement

In this study we used 50 MGY, 40 MGY, and 30 MGY sized facilities. Both the size and conversion rate (gal/ton) can be modified to compute the required biomass feedstock for a particular location. Each location calculation is independent and not all locations at the same time. Multiple location configurations will be shown later.

Facility	Location	Size (MGY)	Conversion Rate (gal/ton)	Biomass Feedstock
	Manton	30	40	750,000
	Roscommon	30	40	750,000
	Kingsley	30	40	750,000
	Kalkaska	30	40	750,000
	Gaylord	30	40	750,000
	Clare	30	40	750,000
	West Branch	30	40	750,000
	Traverse City	30	40	750,000
	Boyne City	30	40	750,000

Figure O-8 Facility Size

Update Model

Macros and buttons were created to update the calculations in the model. Select one or more buttons to update the related information.

Update Model	Cost	Energy	Emissions

Figure O-9 Buttons to Update Model

Model Output

After updating the model, the Model Output screen will be updated showing average cost (in this example it is for transportation cost only), energy consumption, and emissions.

MODEL OUTPUT

Location	Cost		Energy (1000 Btu)		Emissions (lbs/ton)	
	Total	Average ($/ton)	Total	Average	Total	Average
Manton	$ 5,272,294	7.02973	156,491,043	208.655	31,846,284	42.46171
Roscommon	$ 5,811,741	7.74899	168,099,340	224.132	34,594,543	46.12606
Kingsley	$ 5,399,676	7.19957	159,232,166	212.310	32,495,244	43.32699
Kalkaska	$ 5,338,434	7.11791	157,914,298	210.552	32,183,239	42.91099
Gaylord	$ 4,858,537	6.47805	147,587,434	196.783	29,738,358	39.65114
Clare	$ 5,838,350	7.78447	168,671,944	224.896	34,730,107	46.30681
West Branch	$ 5,656,221	7.54163	164,752,737	219.670	33,802,236	45.06965
Traverse City	$ 5,747,224	7.66297	166,711,018	222.281	34,265,859	45.68781
Boyne City	$ 5,901,027	7.86804	170,020,685	226.694	35,049,421	46.73256

Figure O-10 Model Output Screen

Multiple Locations

There are three examples of possible multiple location configurations shown in Figure O-11. This allows the user to modify the size of the locations as well as the conversion rate for biomass feedstock. This is an advanced function. Given all the possible combinations, if further combinations are required, this will require additional modeling.

MULTIPLE LOCATIONS				
Configuration 1		***Size (MGY)***	***Conversion Rate (gal/tons)***	***Biomass Feedstock (tons)***
	Roscommon	50	40	1,250,000
	Clare	50	40	1,250,000
	Boyne City	50	40	1,250,000
Configuration 2				
	Roscommon	50	40	1,250,000
	Clare	50	40	1,250,000
	Boyne City	50	40	1,250,000
	Traverse City	50	40	1,250,000
Configuration 3				
	Traverse City	50	40	1,250,000
	Kalkaska	50	40	1,250,000
	Kingsley	50	40	1,250,000
	Manton	50	40	1,250,000

Figure O-11 Example Multiple Location Configurations

Update Model

Macros and a button were created to update the calculations in the model. Select the button to update the related information.

Update Model	**Multi Cost**

Figure O-12 Button to Update Model

Model Output for Multiple Locations

After updating the model, the Model Output screen will be updated showing average cost (in this example it is for transportation cost only.

MODEL OUTPUT					
Configuration 1		***Total Cost by Location***	***Average ($/ton)***	***Total Cost by Configuration***	***Average ($/ton)***
	Roscommon	$ 11,609,108	$ 9.28729		
	Clare	$ 11,583,556	$ 9.26684		
	Boyne City	$ 11,354,180	$ 9.08334		
Total Configuration 1				$ 34,546,844	$ 9.21249
Configuration 2					
	Roscommon	$ 11,894,975	$ 9.51598		
	Clare	$ 11,682,077	$ 9.34566		
	Boyne City	$ 12,475,818	$ 9.98065		
	Traverse City	$ 11,905,801	$ 9.52464		
Total Configuration 2				$ 47,958,672	$ 9.59173
Configuration 3					
	Traverse City	$ 15,615,295	$ 12.49224		
	Kalkaska	$ 16,806,034	$ 13.44483		
	Kingsley	$ 15,653,106	$ 12.52248		
	Manton	$ 15,834,518	$ 12.66761		
Total Configuration 3				$ 63,908,953	$ 12.78179

Figure O-13 Results for Multiple Location Configurations

USER'S DOCUMENTATION – SIMULATION MODEL

Introduction
The model is a simulation of the woody biomass supply chain prepared for the FBSCC project. The model simulates the flow of biomass from harvesting areas to the inventory at a biomass processing facility. It consists of three different sub-models for reading model inputs, supplying activities (including harvesting, transportation and storage at the biomass processing facility), and daily biomass processing. As main outputs, the FBSCC simulation model estimates the delivery cost, energy consumption, and greenhouse gas (GHG) emissions for different facility locations and different plant sizes. The model also tracks the inventory level at the biomass processing facility versus time, and picks the most preferable harvesting sites for each plant. The FBSCC simulation model has been developed using the Arena Simulation Software, Version 13, available from Rockwell Automation. Arena Simulation Software is required to run the simulation and can be purchased for approximately $2,495 (per website). This user's guide outlines the setup and running of the model.

Setup
Arena
To run the simulation model, the Arena Simulation Software has to be installed on a computer. The version that has been used to develop the model is Arena 13.0. Old versions of Arena may be not able to run the model due to compatibility issues.
Microsoft Excel
To run the simulation model, the user also needs to have Microsoft Excel 2007 installed. This is for the user's benefit to review or modify the model inputs which are stored in a Microsoft Excel file format.

File Structure
There are two types of files that should be stored in the master simulation. The model file is created using Arena 13.0 and was named FBSCC simulation model.doe. The data input files are in macro-enabled Microsoft Excel format and are identified by city name. The city name represents one of the nine potential biorefinery locations: Boyne City, Clare, Gaylord, Kalkaska, Kingsley, Manton, Roscommon, Traverse City, and West Branch.

The Excel input file for each city is structured the same Take a 3-year input file for the Manton facility location as shown in table S-1 for example. The harvesting areas are specified and remain the same for the entire simulation length of 20 years. The areas are fixed parameters and can't be changed. The transportation distances shown in the file are derived using the rectilinear distance function. The initial values of the distance are calculated from the center of a harvesting area to the center of the facility location. The distance values from the second year to the 20th year are filled automatically according to the first year distance value. The amount of biomass available for biofuel production in each harvesting area represents net forest growth each year and is in 50 ton units. Users can enter new data or change the current data for transportation distance (only the first year) and biomass availability (for all 20 years). Note that every time users make a change to the distance values for the first year, the table will automatically sort from smallest to the largest by distance. To use the auto sort function, users needs to have Macros enabled. Users will see a security warning message when opening an input file.

Users need to click on ‘Options…’ in the message and the Microsoft Office Security Options dialog box will be opened. Users have to have the option of ‘Enable this content’ selected and then click OK to finish.

Harvesting Area	year1		year2		year3	
	distance (mile)	biomass (50 tons)	distance (mile)	biomass (50 tons)	distance (mile)	biomass (50 tons)
Wexford	13.862	4911	13.862	4911	13.862	4911
Missaukee	20.151	3868	20.151	3868	20.151	3868
Grand Traverse	25.728	2358	25.728	2358	25.728	2358
Osceola	33.021	2801	33.021	2801	33.021	2801
Kalkaska	34.15	3436	34.15	3436	34.15	3436
Manistee	37.986	4124	37.986	4124	37.986	4124
Roscommon	43.864	2978	43.864	2978	43.864	2978
Benzie	46.018	2027	46.018	2027	46.018	2027
Lake	48.94	4942	48.94	4942	48.94	4942
Antrim	53.136	2697	53.136	2697	53.136	2697
Clare	56.676	3089	56.676	3089	56.676	3089
Leelanau	56.721	978	56.721	978	56.721	978
Mecosta	57.339	3239	57.339	3239	57.339	3239
Crawford	58.042	2416	58.042	2416	58.042	2416
Ogemaw	67.463	2450	67.463	2450	67.463	2450
Mason	70.919	4203	70.919	4203	70.919	4203
Charlevoix	74.514	1935	74.514	1935	74.514	1935
Newaygo	78.924	5875	78.924	5875	78.924	5875
Gladwin	78.994	2418	78.994	2418	78.994	2418
Isabella	81.031	2958	81.031	2958	81.031	2958
Otsego	81.523	5498	81.523	5498	81.523	5498
Oscoda	82.053	4735	82.053	4735	82.053	4735
Montcalm	88.884	3680	88.884	3680	88.884	3680
Iosco	89.638	3187	89.638	3187	89.638	3187
Oceana	96.323	4469	96.323	4469	96.323	4469
Arenac	97.706	2377	97.706	2377	97.706	2377
Emmet	101.01	2780	101.01	2780	101.01	2780
Kent	102.064	3898	102.064	3898	102.064	3898
Midland	103.189	2104	103.189	2104	103.189	2104
Montmorency	105.497	4001	105.497	4001	105.497	4001
Alcona	109.381	4237	109.381	4237	109.381	4237
Muskegon	114.708	4524	114.708	4524	114.708	4524
Cheboygan	115.246	4506	115.246	4506	115.246	4506
Gratiot	117.374	1313	117.374	1313	117.374	1313
Bay	118.366	589	118.366	589	118.366	589
Alpena	131.073	2438	131.073	2438	131.073	2438
Presque Isle	137.05	2972	137.05	2972	137.05	2972

Table S-1 Model Inputs for a Manton Facility

Running the Model

- Launch the model
    - Double click on the model file of FBSCC simulation model.doe to start the model.
    - Or first start Arena 13.0 from the Windows Start menu and navigate to Program > Rockwell Software > Arena. The Arena modeling environment will open with a new model window. Go to File > Open, the Open dialog box will open. Navigate to the path where the FBSCC simulation model.doe file is stored and select it to open.
- Specify replication parameters

  Open the Run Setup dialog box (Figure S-1) by using the Run > Setup menu item and clicking the Replication Parameters tab.
    - # of replications
    - Start data and time
    - Replication length
    - Hours per day
    - Base time units

  Click OK to close the dialog box.

Note:

1. Replication length is set as the (# of years * 365) -1 in days. In this example, the # of years equals 20 resulting in a replication length as 7299 days;
2. All the time units are in days;
3. Hours per day is suggested to set as 24 because a biofuel facility usually operates 24/7.

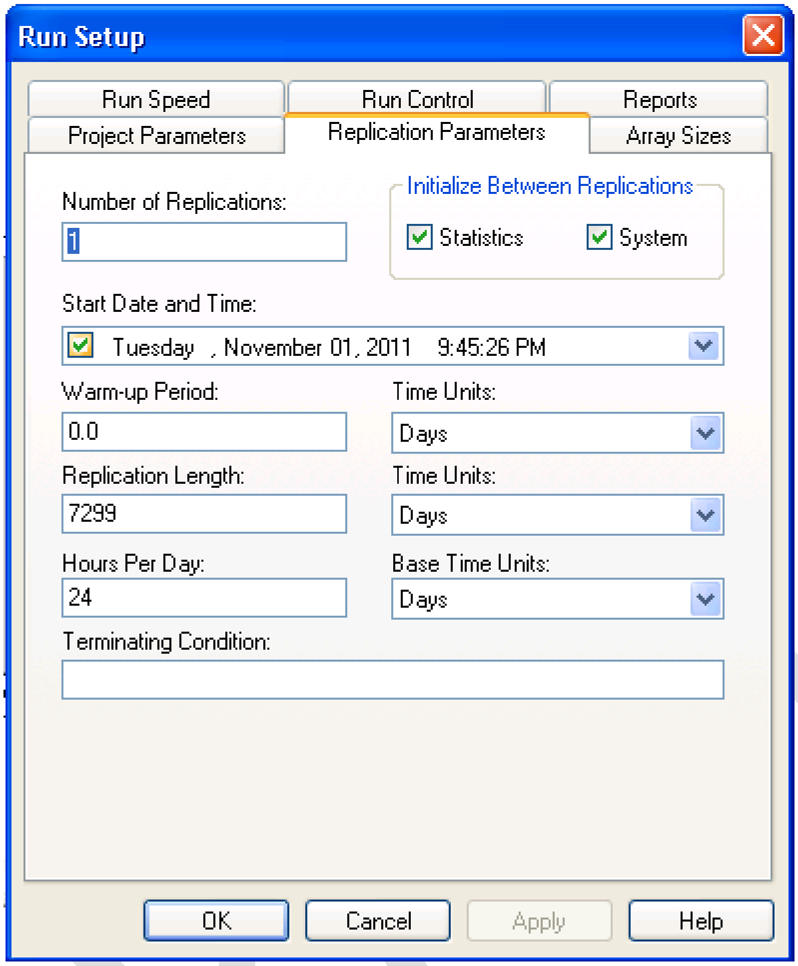


Figure S-1 Project Parameters Dialog Box

- Select an input file

Users can select an input file by clicking the file module in the Advanced Process panel (Figure S-2). Within the file module, users can select an input file under the Operating System File Name box. To select a file, users will need to click on the small button to the right of the input file name box. After clicking the button, a dialog box of Browse for File will appear. Users will need to click the arrow to the right of the Files of Type box and select All Files. A list of input files will appear (Figure S-3). Users can select one file as the input file.

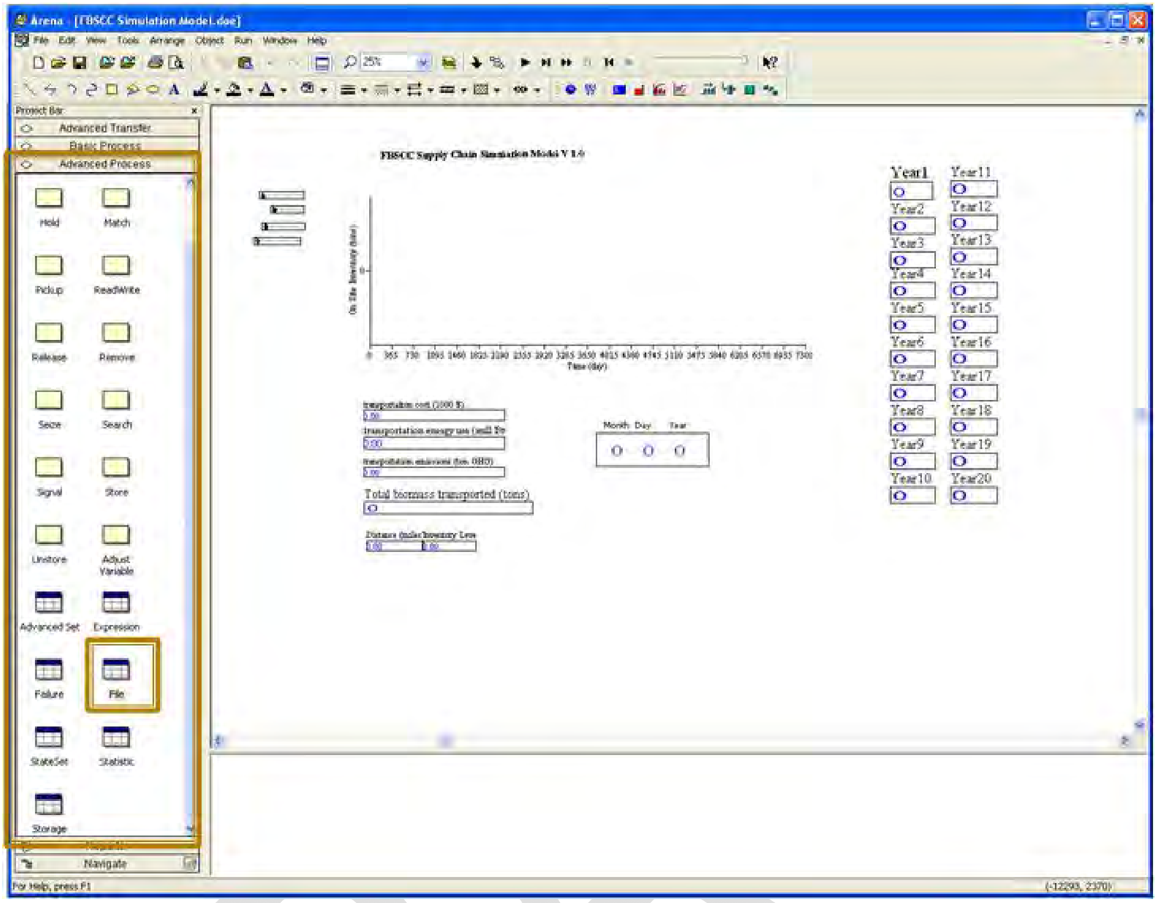


Figure S-2 File Module in the Advanced Process Panel

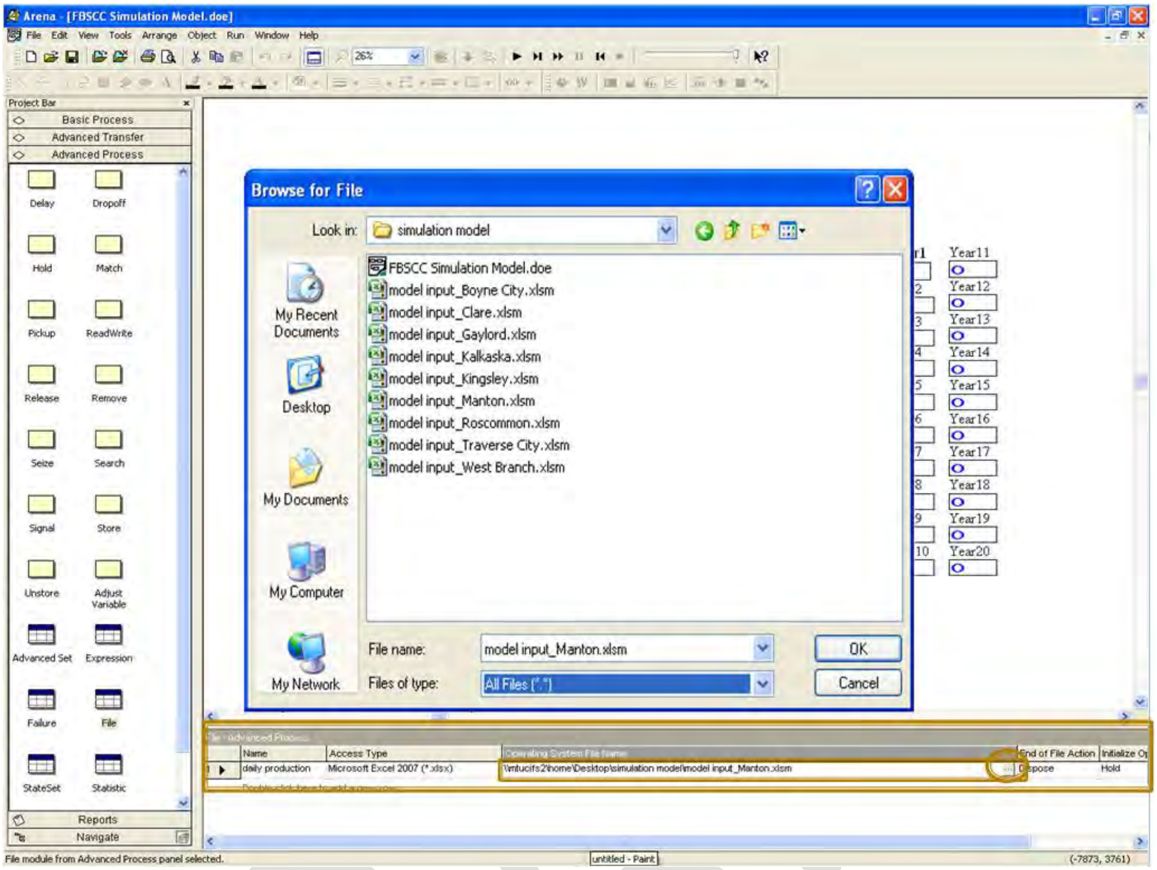


Figure S-3 Select an Input file within the File Module

- Start a simulation run

Click the Go button (Figure S-4) in the main toolbar or clicking the Run > Go menu item. The input screen (Figure S-5) will open. Users can specify cost, energy use and GHG emissions coefficients, and specify the facility size in million gallons per year of 30, 40 and 50. Click OK by finishing up input.

Go
Button

Figure S-4 Go Button in the Main Toolbar

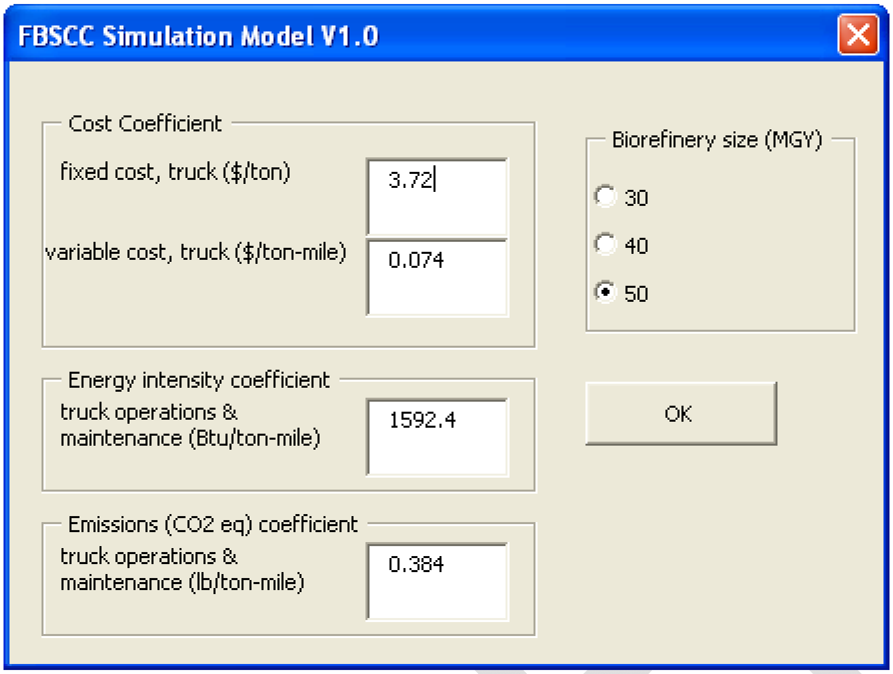


Figure S-5 Input Screen

- To speed up the simulation

  Users can speed up a simulation by adjusting the animation scale factor. For this users have two choices:
  - Use the slide bar in the main toolbar (Figure S-6). Move the slider to the left to slow down the animation; move the slider to the right to speed up the animation; or
  - Click the Fast-Forward button in the main toolbar (Figure S-6).
- Pause the simulation

Click the Pause button in the main toolbar (Figure S-6) or press the Esc key.

- Step through the simulation

Pause the simulation and then click the Step button in the main toolbar (Figure S-6) or press F10 key. Note that if a simulation is running, users have to pause the model first before stepping through it.

- Stop button

Users can stop a simulation anytime by pressing the stop button in the main toolbar (Figure S-6).

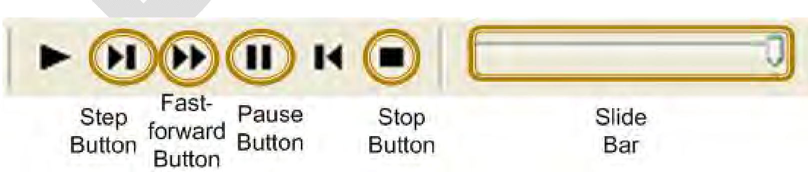


Figure S-6 Main Toolbar

View Model Outputs

At the end of each run, users will see the output window. Outputs of the model include (Figure S-7):

- End date of a simulation;
- Inventory level at the biomass processing facility against time;

- Delivery cost, energy consumption and greenhouse gas (GHG) emissions, total biomass transported in tons, and real time tracking of transportation distance and inventory level;
- The most preferable harvesting sites.

  The numbers of the most preferable harvesting sites are displayed as an output. The name of the most preferable harvesting sites can be obtained by comparing those numbers with the corresponding input file.

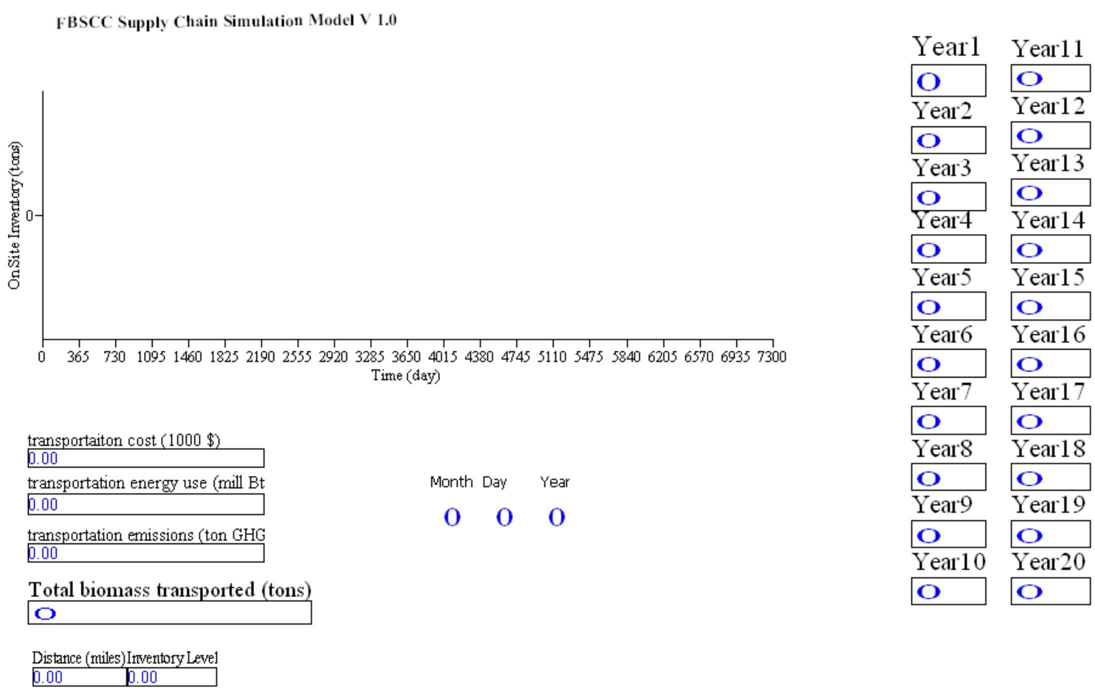


Figure S-7 output Window of the Simulation Model

TUTORIAL – OPTIMIZATION MODEL

Tutorial for the optimization model is available and is complimentary to the user documentation.

TUTORIAL – SIMULATION MODEL

Tutorial for the simulation model is available and is complimentary to the user documentation.

APPENDICES

APPENDIX B4-A DETAILED LITERATURE SUMMARY

Introduction

The literature review examined research to date on producing biofuel from lignocellulosic biomass and identified the gap where new research can focus. The review was organized into seven categories. In each category, a series of critical points were examined. The seven categories included the investigation of existing biomass supply chains, different types and forms of feedstock for the supply chains, key drivers of the supply chain, policy related constraints, mathematical models that have been developed for supply chains, infrastructure requirement for an expended fuel ethanol industry and methodologies used to identify the best facility location for biofuel production. Each category has its own heading with the summaries of the corresponding literature following the heading.

Existing supply chain systems for ethanol

This section investigated the different existing supply chain systems available for ethanol. The first existing system is the National Biofuels Plan created by the Biomass Research and Development Board (BRDB) that developed a plan to reach government biofuel goals. The second system discussed involves different research studies with the uniform-format feedstock supply system produced by the Idaho National Laboratory. The third system discussed was created by Sandia National Laboratories which performed a feasibility analysis for large scale production of biofuels.

National Biofuels Plan (hereafter referred to as 'plan')

This Biomass Research and Development Board (2008) developed a plan that discusses specific government legislation affecting the amount of biofuels required to be in use over the next few years; 36 billion gallons per year (BGY) of biofuels by 2022. In order to accomplish this, a group called the BRDB was established. The BRDB outlined its plan of action in the study and discussed the required steps needed to reach the government goals. The first area of focus for the BRDB is sustainability.

Sustainability

The first area of action outlined by the Biomass R&D Board is to evaluate the sustainability of biofuels production and use. The plan must try to enhance economic and environmental benefits of biofuels through a successful implementation of an efficient feedstock supply chain. The board suggested to do this by reducing greenhouse gases from the different feedstocks, requiring biofuel production to not adversely impact the environment, focusing on developing cellulosic and other feedstocks that promote sustainability, and stipulating that the EPA assess and report to Congress on environmental impacts.

Feedstock Production

The second action area outlined in the plan is to review feedstock production. The plan outlined different generations of feedstock production. The first generation is ethanol and biodiesel made from corn and soybeans. The second is using residues and "left-overs" from crops and forests as feedstock for the process. The third is using R&D to develop specific types of energy crops that have high yields for biofuels. The board is reviewing factors such as a long-term integrated feedstock research plan, information and research into new energy crops, and the promotion of knowledge sharing between select government groups and agencies involved.

Feedstock Logistics

The third action area of the plan is feedstock logistics which can count for as much as 20% of the cost of finished ethanol. However, Hess et al. (2007) reported transportation and handling compose nearly 30% of annual cost. Among the areas of focus inside this plan that relate to the project are storage facilities, preprocessing/grinding equipment, and transportation of feedstock. The board will focus on collaborating the development and deployment of logistics systems, while including the private sector as well.

Conversion Science and Technology

The fourth action area is conversion science and technology in which the need to develop a more economically viable conversion process if biofuels are going to compete in the marketplace is revealed. The board is establishing groups to investigate the different conversion processes that will lead to cost-effective and commercially viable options.

Distribution Infrastructure

The fifth area of action for the plan is the distribution infrastructure, which focuses on the need for transporting biofuels, mainly from the Midwest, to areas on the east and west coasts. If this is going to be done via pipeline, the board suggests that research is needed to know the effects of ethanol on pipeline components (e.g. gasket and sealing materials) and the cost.

Blending

The sixth area of action for the plan is blending, in which the issue of increasing the acceptable level of blended ethanol in gasoline is addressed. The board stated that research on the effects of ethanol on air quality, automobiles, and pipeline components is needed before increased blending can occur.

Environment, Health, and Safety

The seventh action area of the plan includes environment, health, and safety issues, in which the board stated that it will inventory related Federal government activities, as well as review and summarize related potential issues that may arise from the life-cycle of biofuel. The action plan ends by stating that the critical near term areas of action for biofuel success are feedstock production and logistics, conversion, and distribution and end use.

Idaho National Laboratory (INL)

Hess et al. (2009) performed a research study that identifies the need for a uniform-format, commodity driven supply system for biomass. This is to meet the goals of displacing 30% of the United States' gasoline consumption in 2004 with biofuels by 2030. In order to do this economically, the feedstock supply system cannot account for more than 25% of the total cost of biofuel production. This report introduced two types of supply systems:

- the conventional bale feedstock supply system, representing current practice, and
- the uniform-format supply system, moving preprocessing to early stages of the system so that the biomass is a commodity.

Hess et al. (2007) discussed the pioneer feedstock supply system using cellulosic biomass. An advanced feedstock supply system would be targeted. In order to economically produce ethanol from biomass at a national level, the discussion described the different conversion processes for ethanol at the biorefinery: biochemical and thermo chemical conversion. It then described the current feedstock supply system.

Feedstock Supply System

A challenge in a feedstock supply system highlighted in the research by Hess et al. (2007) is that each supply system tends to be unique for each biorefinery based on factors like location, size, and harvesting procedures. The costs that make up the minimum cost for ethanol can be broken into feedstock costs and conversion costs. Grower payment, efficiency/capacity, and quality are all aspects of feedstock costs. The research stated that the two main challenges for the feedstock supply system are:

- Improving feedstock logistics mainly though efficiency and capacity operations; and
- Developing a uniform commodity-scale feedstock supply system that can use diverse cellulosic feedstock with standardized supply system infrastructures and biorefinery conversion processes.

From the feedstock supply system, the research introduces a pioneer supply system that can make the supply chain be more economically viable at the national level.

Pioneer Supply System

Hess et al. (2007) discusses the pioneer supply system using wheat straw as an example throughout. It begins with production where the largest variable is due to the different demands for a variety of products that compete with the amount of feedstock available for energy production. The harvesting and collection describes common practices. Storage of the biomass feedstock variables includes shrinkage and material degradation. Preprocessing occurs to enable transportation and handling in a similar fashion by all of the equipment involved. After the pioneer supply system, an advanced feedstock supply system was introduced.

Advanced Feedstock Supply System

The advanced feedstock supply system is described by Hess et al. (2007) states that technological advancement will occur in the harvesting and collection processes. This will improve the efficiency, allowing for increased and overall supply system costs can be reduced. More research is in progress to identify losses that occur during storage so that the losses can be prevented in the advanced model. Next there is a discussion regarding the advances in preprocessing equipment. This will allow transportation and handling problems to be minimized. The product is more uniform. The study reports that transporting and material handling account for nearly 30% of the annual cost for a feedstock assembly system. Evaluating new methods can possibly eliminate the need for certain types of equipment used, thus lower costs.

INL (2006) reviewed a previously written study that describes a biomass feedstock system for wheat and barley straw. Some critical success factors identified for the feedstock model include:

- Ability to contract straw from a specified distance,
- Capability to field grind straw to customer's specifications,
- Capability to transport ground straw to meet demand, and
- Ability to design a transfer facility that can accommodate inflow of material and refinery demand.

The aspects of the INL (2006) study included harvesting, transporting and handling, inventory management, and quality assurance. Some areas of concern were highlighted in the study. These were:

- Cost of straw will increase as the demand increases substantially after the plant is operational,
- Logistics of moving the straw are very complicated,
- Storing the straw may be subject to a variety of fire codes,
- Unloading the truck and transferring the feedstock into and out of storage may not have a practical design, and
- Field fueling issues may arise so equipment might need day tanks that they can be fueled once per day at each site.

Sandia National Laboratories

A joint biofuels system analysis project, "90-Billion Gallon Biofuel Deployment Study", was conducted by Sandia National Laboratories (SNL) and General Motors' Research and Development Center between March and November 2008 (SNL, 2009; West et al., 2008). The project assessed the feasibility, implications, limitations, and enablers of large-scale production of biofuels in the United States. A 'Seed to Station' system dynamics model, Biofuels Deployment Model (BDM), was developed to explore the feasibility of producing 90 billion gallons of biofuels in US. This is a linear programming distribution optimization model. The inputs of the model were derived from previous research and imported into the model. The inputs were categorized into four major groups, including conversion yield, capital investment/annual capacity per cellulosic plant, energy prices, and feedstock yield improvements.

Sensitivity analyses were conducted to identify the most influential factors that impact the feasibility, cost-competitiveness, and greenhouse gas impact of large-scale ethanol production. Three major matrices were generated: the total volume of ethanol production by 2030; the difference of accumulated cost between the ethanol produced over the life of the simulation and the displaced gasoline; and the difference between the GHG emissions associated with ethanol production over the life of the simulation and those associated with the gasoline that it replaced. Several steps were involved to perform the sensitivity analyses: importance screening, interaction screening, and fine-tuning of the last step.

A reference/base case was set as the baseline in the sensitivity analyses. A series of assumptions were made in the reference case, such as conversion yield is 90 gallons/ dry ton and short rotation woody crops (SRWC) are available for cellulosic ethanol production and so on. The results of the sensitivity analysis were discussed. For the first metric of ethanol production volume, conversion yield and the availability of SRWC play an important role in achieving the goal. The examination of the combined influence of the two most important factors on ethanol production demonstrated that the goal of producing 90-billion gallon of ethanol per year by 2030 in U.S. is feasible over the range of the conversion yield from 74 gallons/dry ton to 115 gallons/dry ton. When SRWC and/or energy crops are not available, the goal cannot be achieved, even at the highest conversion yield. For the second metric of cost-competitiveness of ethanol relative to gasoline, energy prices were demonstrated as the most influential parameter. It was also identified that the price of crude oil influences the most of the price of energy. However, the competitiveness of price is only valid when the price of crude oil is over $90/barrel.

Further examination shows that the capital cost, conversion yield, and feedstock cost also impact significantly the cost-competitiveness of ethanol with gasoline. For the third metric of GHG gas emission savings relative to gasoline, it was identified that the conversion yield and the boiler efficiency have the largest influence. An increase of the conversion yield at 10 gallons/dry ton would result in about a 3% increase of GHG gas emission savings while a 6% improvement in the boiler efficiency (which reduces the amount of energy generation needed) results in a similar percentage of GHG gas emission savings.

Different feedstock types involved in supply chains

This section investigates the use of different feedstocks for biomass supply chains such as agricultural residues, woodchips, forest residues, and energy crops. Searcy et al. (2007) examined two types of biomass: woodchips and agriculture residues, including stover and straw. Aden et al. (2002) developed a process design for producing ethanol using corn stover and conducted related cost estimation analysis.

Blackwelder and Wilkerson (2008) highlight the different aspects and associated supply costs (harvesting, handling, transporting, and preprocessing) for using different types of feedstocks including slash, forest thinnings, and commercial energy wood as biomass.

Slash

Blackwelder and Wilkerson (2008) describe slash as the leftover tree tops and limbs from commercial harvesting. It states that 20-30% of the total volume of woody biomass is leftover as slash when harvested. Through model simulation and estimates, the predicted cost of supplying one bone dry ton (bdt) to the plant is $20.50 per bdt. The assumed transportation procedure for this process is to place the slash into a chipper with a loader and from there, the chipped slash gets loaded into a truck trailer. The trailer is then brought to the plant gate and unloaded so the conversion process can begin. This scenario does not require an incremental cost of piling the slash because that process is a byproduct of commercial harvesting.

Forest Thinning

Forest thinning, which involves the removal of certain trees that are small or undesirable for commercial harvesting, was also analyzed by Blackwelder and Wilkerson (2008) for supply costs. The projected cost for the plant using forest thinning was $51.85 per bdt. The assumed procedure for moving the woody biomass is after the harvesting has occurred and the logs are moved with a forwarder. Then a loader is used to load the logs into a chipper which puts the chips directly into a truck bed. Next, the woody biomass get transported to the plant gate and unloaded so the conversion process can begin.

Energy Crops

The third option analyzed by Blackwelder and Wilkerson (2008) was plantation energy crops that are grown specifically for high potential biofuel yield and quick growth. The supply cost associated with this method was found to be $30.52-$34.63 per bdt. The transportation procedures are very similar to the ones outlined in the forest thinnings section.

Stokes (1992) described the background of each country for using forest residue and small trees as energy and relative harvesting technologies at that time. Countries involved in this activity were Denmark, Finland, Norway, Sweden, United Kingdom, Italy, Switzerland, New Zealand, Canada and United States. Harvesting system databases and transportation database were built with the activity. To increase the use of forest residues and small tree for energy production, the fossil fuel price and the political decisions impacted significantly.

Forest residues

Harvesting systems for forest residues differ depending on where the forest residuals were concentrated. For residues on cutover areas, stand mobile chippers were the most popularly used because the residues had characteristics of widely spread, small size and non-uniform shapes which are difficult to compact. For residues that were more concentrated distributed, e.g., on roadsides, drum chippers, and tub grinders were commonly used for size reduction.

Small trees

Small trees were much easier to harvest compared to forest residues. Small trees can be harvested in three periods: thinnings, preharvests and postharvests of conventional forest products. Preharvestings were more efficient than the other two and harvested more materials too. The least expensive harvesting technologies involved mechanical felling and bunching, skidding of whole trees and chipping at roadside. Stand-mobile chippers were commonly used in Denmark and the United Kingdom for smaller harvest volumes. In Sweden, drum delimber/debarkers were employed, called tree-section method, to separate high value pulp chip from low value fuel products.

Mitchell (2005) reviewed two types of integrating biomass harvest system, one-pass and two-pass harvesting. The one-pass harvesting was defined as the felling and skidding of energy wood are operated at the same time when the conventional roundwood products are removed. The two-pass harvesting method involves two operations. Energy wood is felled, skidded and chipped first and merchantable roundwood products are harvested afterwards. The comparison of the two methods showed that the one-pass method is more efficient. Mitchell (2005) also presented the impact of different production. Slash and stems, which are longer portions of forest residues, are easy to grapple. The shorter limbs and tops are not easy to carry with grapplers. Mitchell (2005) also created a table to show the productivity and cost using different combination machines depending on the production type. The study also presents a new technology of bundling and a new type of machine caller bundler. Mitchell (2005) discussed the low transporting efficiency due to the physical characters of forest residues. At last, the value of the forest residues was estimated and compared with traditional fuels.

Key drivers of the supply chain
This section discusses research involved in areas that are key drivers of the supply chain. These areas include information management, transportation, and supply chain enablers.

Information Management
Cachon and Fisher (2000) investigate, through mathematical equations, the cost effects that full information sharing versus a traditional, non-information sharing policy has on supply chain.

Supply Chain Inventory Management
The purpose of this investigation is to address the general belief in industry that capturing real-time demand information is important for improving supply chain performance. The study defines traditional information sharing is where the supplier only observes the orders, and full information sharing is where the supplier has instant access to inventory data. The investigation goes into addressing the question of how information technology improves supply chain performance, not necessarily if it does. This can be related to woody biomass systems in which the logger, the supplier, would have orders from the ethanol plant. The traditional information sharing would provide full access to all of the inventory data for the ethanol plant.

Modeling
The equations used to model the different scenarios are discussed in detail, as well as the results. The mean cost benefit that a full information policy has over the traditional policy on the supply chain is 2.2% in supply chain cost savings. The study concludes from the results that there are savings from lead time and batch size reductions, which are both caused by the implementation of information technology. Information sharing could have a much larger effect on the supply chain. If the demand of the product was unknown, full information could be used to detect shifts in the demand process. The research assumed demand was known, retailers were identical, one source of inventory, no constraints on capacity, firms could not create conflict between other supply chain firms based on incentives, and that the firms were rational in their ordering practices.

Transportation
Mahmudi and Flynn (2006) observe the cost savings between a single transportation system for straw or wood biomass via truck or rail versus a transshipment method that combines the two.

Single Shipment of Biomass
The study states that rail transportation has higher fixed cost than trucks. This is because there are both supplier and carrier components to consider for rail transportation. However, the variable costs are lower for rail than trucks. This means if a transshipment method is to be used for transporting biomass to a facility; the distance has to be such that the saving in variable costs from the second mode of transportation must be able to offset

the increase in fixed costs for the system.

Transshipment of Biomass

Mahmudi and Flynn (2006) state there is an optimum number of transshipment terminals that minimize shipping costs. There are tradeoffs between fixed and variable costs as the number of terminals increases. The study found the optimal rate of biomass per terminal to be 100,000 dry tons of boreal forest harvest residue (FHR) wood chips. The study also highlights that the minimum economic rail shipping distance for boreal FHR wood chips is 145 km (also in parenthesis include the conversion of miles). In the study, power plants in Canada that were an economic size (130 MW) and were economically capable of using transshipment were analyzed. Transshipment from truck to rail was indeed found to be an economically viable option if rail lines existed that led to the plant.

Supply chain enablers

Edward (2008) discussed the four supply chain enablers: organizational infrastructure, technology, strategic alliances, and human resources management. A group of professionals were interviewed to rank the four enablers and the associated attributes of each enabler. The results of the survey show that organizational infrastructure and its associated attributes topped the list for being the most important enabler of successful supply chain implementation.

For organizational infrastructure enabler, the attribute –a business strategy that aligns business units toward the same goal—was more significant than other attributes. The second important attribute was considered to be the need to have a sound process-management methodology in place. A top-management process flow chart was presented to illustrate how the first two important attributes are implemented in a company. The technology enabler was analyzed in two parts: IT and manufacturing and material-management technology. For IT, a list of eight categories was used to define the scope of IT in supply chain. The ready availability of coordinated internal data on operations, marketing, and logistics were pointed out to be the first important attribute. When it comes to manufacturing and material-management technology, a list of four categories was used to define the scope of the physical technologies. The design of products and physical processes for supply chain efficiencies topped the list of attributes. For strategic alliances enabler, the attribute –having expectations clearly stated, understood, and agreed to up front—was more significant than other attributes. For human resources management enabler, the most challenging enabling attribute is finding practitioners knowledgeable in supply chain management and finding facilitators to lead the implementation change process.

Policy related constraints

The following section will highlight different policies that can create constraints in a supply chain. The first area discussed is forest policies. Next, environmental policy will be reviewed. The third area of discussion relates to different public policies.

Forest Policies

Cubbage and Newman (2006) describe the reformation of forest policy over time. They suggest that forest policy is developed through a mixture of implementing reasoned laws and decisions to resolve identified fundamental issues, making small incremental changes to existing policies as time goes on, and making short-term incremental changes while implementing new policy based on social innovation.

International Forestry

Cubbage and Newman (2006) discuss how international forestry and trade has enhanced sustainable forest management. International agreements have been developed to clearly define seven agreed upon criteria for sustainable forest management. The seven criteria include "(1) conservation of biological diversity, (2) maintenance of the productive capacity of forest ecosystems, (3) maintenance of forest ecosystem health and vitality, (4) conservation and maintenance of soil and water resources, (5) maintenance of forest contribution to global carbon cycles, (6) maintenance and enhancement of long-term socio-economic benefits to meet the needs of societies, and (7) development of the legal, institutional, and economic framework for forest conservation and sustainable management (Cubbage and Newman, 2006, pg. 263)". Combined with international agreements, market based-incentives for producing green products have increased the use of sustainable practices.

"Green" Policies

Cubbage and Newman (2006) also describe how intense public pressure to ensure sustainable forest practices is causing a corporate "green" revolution. There are two major U.S. certification programs, the Forest Stewardship Council (FSC) and the Sustainable Forestry Initiative (SFI). The research highlights that there are no federal or state forests that are certified by these programs. It begins to discuss the expansions being made at the federal and state level on the topic of forests.

Federal and State Policies

Cubbage and Newman (2006) highlight some of the legislation that has been passed over the past decades, such as the initiative to reduce unneeded paperwork for thinning and harvesting to take place. The topic of different state forest policy was addressed and the idea of how corporations have actively pursued environmental agendas on their own that exceed government regulations was highlighted. The future of forest policy developers have the challenge of meeting widely accepted economic, social, and environmental goals of sustainable development without decreasing the ability of forests to provide for the needs of people.

Environmental Policy

Gallagher et al. (2004) proposes three different possible scenarios for the future of the fuel industry:

- Implementing a renewable fuel standard (RFS),
- Imposing a national ban on the additive MTBE and replace with ETBE, and
- Removing oxygen standards for reformulated fuel.

These scenarios are modeled through simulation and the effects of each change are documented and compared against a baseline scenario which uses existing EPA policies. The research provides an introduction to the three natural resources used in fuel processing: petroleum, natural gas, and biomass. It also investigates the existing emission standards and what each formulation of fuel does to the environment.

Implementing a renewable fuel standard

The implementing renewable fuel standards scenario's simulation shows growth in the additives market by 56%, specifically with growth in refined gasoline output at 20%. The ethanol industry also grows in this simulation.

National ban

Under the scenario where there is a ban on MTBE, gasoline prices are predicted to rise and ethanol demand is projected to rise moderately as well. Long-run welfare gains for corn-producers and processors raise slightly based on the slight increase in ethanol demand.

Removing Oxygen Standards

The third scenario, removing oxygen standards while still banning MTBE, efficiency is improved some while summer reformulated gasoline prices return to baseline levels. In all three scenarios, gasoline additives will continue to grow, which includes the production of ethanol. The economic costs associated with this growth are more than offset by the environmental improvement. The research states that issue leads to the potential expansion of biofuels in the future.

Public Policy

Sissine (2007) summarized the major provisions included in the Energy Independence and Security Act of 2007 and presented the legislative actions under each of the titles in the law. Three key provisions were included in the law: the Corporate Average Fuel Economy (CAFE) Standards, the Renewable Fuel Standard (RFS), and the Appliance and Lighting Efficiency Standards (Sissine, 2007). The CAFÉ provision involves a setting of an average fuel economy goal at 35miles per gallon for the combined fleet of light trucks and cars by 2020. The RFS law is about setting standards for the availability of renewable fuels. By 2020, 36 billions of biofuels will be available arising from 9.0 billions from 2008. Especially, 21-billion out of the 36-billion biofuels are cellulosic ethanol and other advanced biofuels. The Appliance and Lighting Efficiency Standards set requirements for residential and commercial appliance equipment.

Mathematical models for supply chains

Many existing mathematical models were reviewed and summarized in the following section. The first specific area that will be discussed are simulation and optimization models. The second area involves full supply chain models that have been developed. The next section discussed focuses on models that have been developed involving the specific individual drivers of supply chain, such as transportation. The last section reviews mathematical models for different processing methods.

Simulation and Optimization

De Mol et al. (1997) discuss the results and differences in simulation models versus optimization models for the logistics of biomass fuel collection. The report first describes how the network structure is set up for the supply system.

Network Structure

The network structure is defined by De Mol et al. (1997) as having nodes, which correspond to source locations, collection sites, transshipment sites, pre-treatment sites, and the energy plant itself. There are also arcs connecting the nodes which are modes of transportation like road, water, or rail. The study also discusses how there are losses during storage that can be positive, like moisture loses, or negative like dry matter losses. All of this information was defined in a database where the simulation and optimization could be performed from. The research uses numerous different combinations of the described network structures to find the optimal design through simulation and optimization.

Simulation Model

For the simulation model by De Mol et al. (1997), the network structure is fixed, and different parameters like transportation costs, storage losses, and seasonal supply or demand are inputs into the simulation. The biomass flows for certain time periods are simulated and cost figures of variances are calculated from the results. The simulation model follows a pull model where each lot orders stock from the preceding lot to maintain at least the minimum safety level that can be used to provide for the lot that is next in line. Results of the simulation model include input and output of biomass, costs for transportation and handling, energy consumption for transportation and handling, and number of transports needed to supply the energy plant.

Optimization Model

The optimization model by De Mol et al. (1997) combines different types of biomass, different nodes, and pre-treatments situations to develop the optimal network structure. While the simulation model takes losses into account for the biomass, the optimization model does not because it only gives annual flows. It is also hard to include time-dependent effects in the optimization model like the simulation model can. The research also states that optimization of logistics structure is hard with the simulation model. The results of the modeling by De Mol et al. (1997) are as followed.

Results of the modeling

- The simulation model showed that the truck is cheapest for short distances, chipping should be done at the plant, and that costs and energy consumption from logistics is a major part of the cost for biomass fuel.
- The optimization model's results were similar to the simulation model previously listed.
- The research states that the optimization model is best for selecting what type of network structure to use when there is a lot of variation, and that the simulation model works best when the network structure is fixed or has a small number of possible variations in it.
- The research also mentions that simulation gives more detailed results on biomass logistics, and can be further detailed to make operational decisions from it.

Mathematical models for the supply chain

Gronalt and Rauch (2007) discuss the design of a forest fuel network for a region. It incorporates delivering the products to multiple energy plants, with the use of storage terminals. Different scenarios of how many terminals and where each one is located are simulated to find the most optimal network. Also, the point at which the lumber gets chipped is studied as a central location, as well as on-site chipping. Since bioenergy has to compete in harvesting the forests with logs for pulp, paper, and wood manufacturing industries, the first step for designing a regional forest fuel supply network is to identify the target forests and determine how much wood could be used as forest fuel.

Supply network for forest fuel

Gronalt and Rauch (2007) state that for Austria only 54% of the areas where mechanized harvesting systems could reach could be utilized economically for forest fuels. This is due to lumber claims on certain forests, as well as the inability to harvest specific areas.

The research states that the next step is to calculate expected demand of forest fuel for the specific region. Once demand is known, the costs associated with the network including transportation to terminal, terminal costs, and transportation cost to the plants are necessary to design an optimal supply network. Based on the costs as well as the supply and demand, the network can be designed to find the best spatial allocation for the terminals that minimizes both transportation and chipping costs associated with the network. The study proposes this stepwise heuristic approach as a way to solve forest fuel supply network design problems.

Gunnarsson et al. (2004) propose a solution to the supply chain problem involved with a forest fuel network structure through a large mixed integer linear programming model. The main product used is forest fuel, which are mainly forest residues in harvest areas or from byproducts from sawmills. The destination for the forest fuel is a heat plant. The same research also raises the issues of forests that are owned by the heat plant in which the product would not have to be purchased as opposed to contracted forests in which it would have to be purchased.

Mathematical Model

The mathematical model for Gunnarsson et al. (2004) incorporates the issues associated with chipping forest residues in the forest which is more expensive than doing it at a terminal. It is cheaper to transport chipped wood and it could be delivered directly to the heating plants. Non-chipped residues can be stored at a variety of locations, but it is more expensive to transport them. The model also incorporates locations and numbers of terminals involved in the network. The demand for heat from the plant over the year can be calculated. Based on the calculations, the model shows how much wood to acquire and deliver from each terminal. The model then shows whether or not the wood should be chipped in the forest or at specific terminal locations for transportation purposes. Scenarios for Sweden were computed using the mathematical model by Gunnarsson et al. (2004). This provided the best alternatives for transportation and chipping methods of the forest fuel to the plant. This model can be used to support tactical planning and strategic analysis for the supply of forest fuel to multiple heating plants.

Models involving specific drivers of the supply chain

Kumar et al. (2006) evaluate different collection and transportation systems for biomass feedstock systems using a method called preference ranking organization method for enrichment and evaluations (PROMETHEE).

Mathematical Models
The model developed by Kumar et al. (2006) integrates economic, social, environmental, and technical factors in order to rank alternatives for collection and transportation methods of biomass feedstock. The three collection systems analyzed using PROMETHEE model were baling, loafing, and chopping & ensiling. The collection systems were analyzed using the following criteria: delivery costs, quality of material, emissions, energy consumed, and the maturity of technology. After the analysis was performed, loafing was shown to be the best alternative for collection.
For biomass transportation systems, truck, rail, and pipeline were analyzed. The evaluation criteria included cost, emissions, traffic congestion caused, and maturity of technology. Based on the analysis, rail was shown to be the best alternative for the specific criteria.

Transportation cost model
Searcy et al. (2007) estimated transportation costs for two types of biomass and two types of energy production systems from biomass transported using different modes and unique transport distances. The two types of biomass examined were woodchips and agriculture residues, including stover and straw. The two types of energy were electricity power and ethanol. Transportation modes for biomass involved truck for short distance transportation, and any combination of truck plus rail, truck plus ship and truck plus pipelines for long distance transportation. Transportation modes for ethanol involved truck and pipeline. The transportation cost model comprises two components: Distance Fixed Costs (DFC) and Distance Variable Costs (DVC). DFC included loading and unloading costs which has nothing to do with the distance traveled and DVC depends on the travel distance. The transportation cost models were built by Searcy et al. (2007) based on previous research. Transportation cost factors for each case were generated from the models and relative transportation costs were compared between each case. The results show that truck, rail, and ship have a negligible economy of scale while pipeline has a higher one. Rail and ship are not economical transportation modes until a longer distance are traveled due to the high costs incurred by transshipment. Pipeline does not show its advantage over truck until a higher production rate of ethanol is met per day. It is always a good idea to build a conversion plant closer to the biomass than to a population center or a transmission grid.

Processing models
To estimate ethanol selling price, a series of process design and plant design assumptions were made by Aden et al. (2002). To evaluate the affect of plant size, a tradeoff was examined between the savings resulting from increasing plant size/economies of scale and the increased transportation cost due to increased collect distance of biomass. A formula was presented to illustrate the relationship between plant size and area to collect biomass. The results of the formula also show the impact of the assumed availability of harvesting acres and the yield of corn stover per acre per year.

Infrastructure requirement analysis
Reynolds (2002) investigated the feasibility of expanding the ethanol industry by studying two cases. Each case identified the potential ethanol plant location information and then estimated the demand volume of the ethanol markets. Finally, composite freight rates were developed.

Market uncertainties analysis
Market uncertainties, resulting from a series of issues that impacted the demand for ethanol and the production of ethanol, were examined. Relevant public policy issues and regulatory barriers included:

- The legislation banning the use of methyl tertiary butyl ether (MTBE) increased the opportunities of the use of ethanol as a substitute.
- U.S. Environmental Protection Agency/California Air Resources Board (USEPA/CARB) models effect on ethanol's value as a blending component could also potentially affect the demand and production of ethanol.
- Whether the tax exemption of ethanol blends sustain affects the demand for ethanol and the production of ethanol.
- Energy policy encouraged the use of renewable fuels.
- The availability and competition of cellulosic biomass affected the production of ethanol.
- The concern of reducing GHG emissions increased the use of ethanol.
- The different state regulations may affect the ethanol use positively or negatively.

Optimization model
A mathematical model that integrates spatial and temporal dimensions was proposed for strategic planning of ethanol supply chain systems. A snap shot of a bioethanol supply chain is shown in Figure 1 (Huang et al.). This model incorporates dynamics issues in long-term strategic planning of biofuel systems. In previous literature, advanced mathematical models have been proposed but seldom consider system dynamics and uncertainties. This model also considered the entire biofuel supply chain as a whole which has not been widely adopted in renewable energy planning literature (Huang et al.).

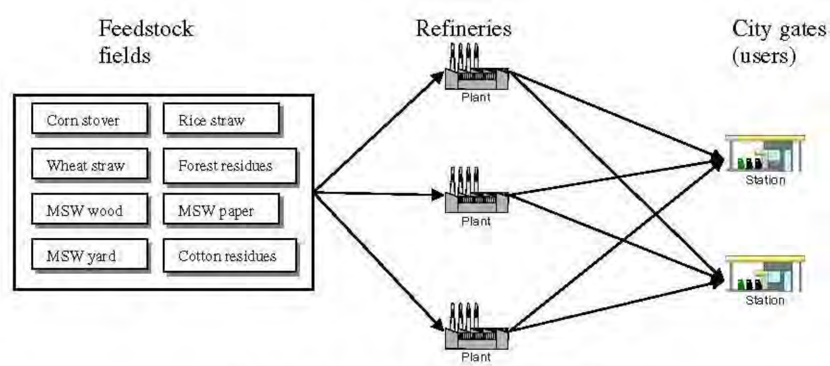


Fig. 1. A snap shot of a bioethanol supply chain.

Figure 1 A snap shot of a bioethanol supply chain (Huang et al.)

The spatial dimension represents the geographic distribution of the feedstock resources, the fuel demands and the production and transportation infrastructure (Huang et al.). The temporal dimension focuses on long-term biofuel system planning. The production and distribution infrastructure system will have to be expanded over time in response to the growing demand. To achieve an overall effectiveness of the systems expansion, the dynamics of such an evolving process needs to be taken into consideration in the system planning (Huang et al.).

The objective of the model was to minimize the cost of the entire supply chain of biofuel from biowaste feedstock field to end users. The key research questions of this study were (Huang et al.):

- Is cellulosic biofuel an economically viable solution?
- What are the infrastructure requirements to support such a biofuel supply chain system?

The model was used to evaluate the economic potential and infrastructure requirements for bioethanol production from eight waste biomass resources in California as a case study. It concluded that biowaste-based ethanol production can be sustained at a compatible cost around $1.1 per gallon (Huang et al.).

A mathematical model was developed to design biomass-to-biorefinery supply chain and manage the logistics of a biorefinery (Eksioglu et al., 2009). Decisions about supply chain design are long-term decisions which are made every 5-10 years, or even more. These decisions related to identifying (Eksioglu et al., 2009):

- The number, capacity and location of biorefineries needed to make use of the biomass available in the region;
- The number and location of biomass collection facilities;
- Harvesting sites that serve a particular collection facility;
- Collection facilities that serve a particular biorefinery; and
- Blending facilities used by a particular biorefinery.

On the other hand, managing the logistics of a biorefinery consists of mid-term to short-term decisions. These decisions related to identifying (Eksioglu et al., 2009):

- The amount of biomass collected in a time period;
- The amount of biomass shipped in a time period to a collection facility (or directly to a biorefinery) from each harvesting site;
- The amount of biomass shipped to a biorefinery in a time period;
- The amount of biofuel shipped in a time period from a biorefinery to a blending facility
- The amount of biomass processed in a time period in a biorefinery; and
- The amount of inventory of biomass in a facility, etc.

Due to the high transportation cost, biorefineries prefer to get their supply of biomass from within 50 miles of radius. This is the reason why 76% of ethanol produced in the USA comes from small sized biorefineries located in four major corn producing states in the Midwest (Eksioglu et al., 2009).

There is a vast literature on the area of supply-chain design and supply-chain management for industrial products. However, due to the nature of biomass, these models do not directly apply. For example, biomass supply is uncertain, seasonal, and constrained by land availability. Supply-chain design and management models for industrial products consider mainly demand (rather than supply) uncertainties, consider

demand (rather than supply) seasonality, and focus on satisfying demand (rather than making good use of the supply). The literature related to supply chain management for biomass supply provides models that estimate the cost of collecting, handling and hauling biomass to biorefineries, compare different modes of delivering biomass, and identify supply chain options for biobased businesses. To our knowledge, the work of Tembo, Epplin, and Hunke (2003) is the only study that takes an integrated view of biomass harvesting, inventory, transportation processes and biorefinery location. However, the structure of the supply chain considered is different (Eksioglu et al., 2009).
The supply chain is modeled as a network design problem with additional constraints. Figure 2 gives a network representation of a supply chain model consisting of two harvesting sites, two potential locations for collection facilities, two potential locations for biorefineries, and two blending facilities. Each time period can be taken as a layer. Within each layer, nodes represent potential locations for harvesting sites, collection facilities, or biorefineries. Arcs in solid lines are transportation pathway, while the dash lines that connect the same facility in two consecutive time periods represent inventory arcs. The model assumed no inventory of biomass was held in the field side. The network representation allows modeling the dynamic nature of decisions related to supply chain design and logistics management of a biorefinery. In this network, a time period t could be as long as a day, a week, or a month. The length of the whole horizon T could be as long as one year. Decreasing the length of a time period t increases the size of the problem. Due to the availability of the data, the length of a time period used in the computational analyses is one week, and the planning horizon is one year (Eksioglu et al., 2009).

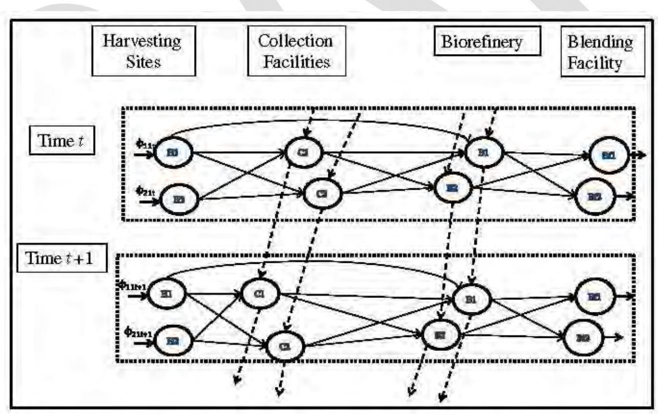


Fig. 4. Network representation of the supply chain model.

Figure 2 Network representation of the supply chain model (Eksioglu et al., 2009)

This study aims to identify the number, size and location of collection facilities and biorefineries needed to process the biomass availability in a particular region. The objective function is to minimize the annual cost of harvesting, storing, transporting and processing biomass; storing and transporting ethanol; and locating and operating biorefineries. A mixed integer programming (MIP) model was developed and the CPLEX optimization software was used to solve the problem (Eksioglu et al., 2009). The objective was to minimize the annual cost of harvesting, storing and transporting ethanol as well as locating and operating biorefineries.

Two significant bottlenecks that hinder the increased biomass utilization for energy production are the cost and complexity of its logistics operations (Iakovou et al.). Figure 3 is a graphical representation of a waste biomass supply chain.

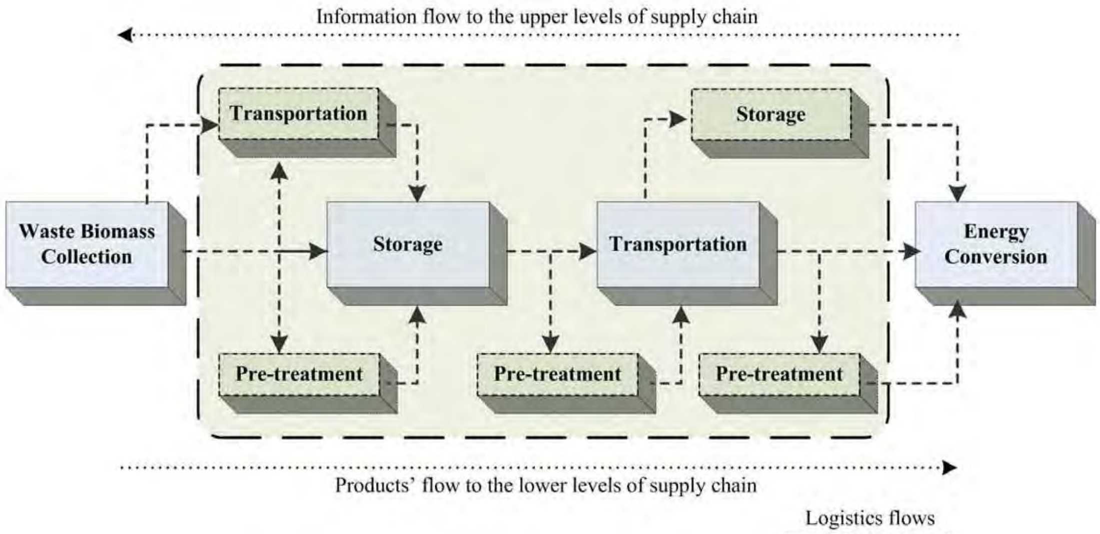


Fig. 1. Graphical representation of a waste biomass supply chain (WSBC).

Figure 3 Graphical representation of a waste biomass supply chain (WSBC) (Iakovou et al.)

The economic potential and infrastructure requirements of hydrogen production from agricultural residues were examined by Parker et al. (2010). In general, a biorefinery pathway includes all the facilities and operations involved in the supply chain of biorefinery from the raw feedstock supply to the end users. The efficiency of the entire pathway depends on the geography of the feedstock resources, the layout and operation of the biorefineries, and the cost of accessing the energy market. These factors are not independent of each other. In order to achieve the most efficient and economic production of hydrogen, individual components of bio-hydrogen pathway, the supplies, the production, and the delivery systems, need to be designed simultaneously as an integrated supply chain system. However, an integrated system analysis for the entire hydrogen pathway from biomass waste is still lacking in the literature (Parker et al.).

Fig. 1. A simple example of biohydrogen pathway.

Figure 4 A simple example of biohydrogen pathway (Parker et al.)

The integrated model was developed based on GIS and mathematical programming to evaluate the economic potential and infrastructure requirements of hydrogen production from agricultural residues. The model answered the two following questions (Parker et al.):

- Is bio-hydrogen production economically sustainable?
- How should we plan the production and delivery infrastructure system involved in the bio-hydrogen supply chain and allocate available biomass resources to achieve the best economic performance?

The objective is to maximize profit generated from biohydrogen production. It depends on the capacities of the infrastructure built as well as the quantities delivered or produced at each node and along each link. A mixed integer non-linear programming (MINLP) model with real word GIS data was developed. The objective was to maximize the profit generated from biohydrogen production. It is dependent on the infrastructure capacity as well as the quantities delivered or produced at each node and along each link. The model described the optimal behavior of an industry to supply vehicular hydrogen from agricultural residues in a steady-state system of hydrogen demand, selling price, and feedstock supply. If hydrogen from agricultural residues can be delivered to the refueling stations for less than the given selling price then it is profitable for the industry to supply that hydrogen and the infrastructure is built to reap that profit. Model assumptions include (Parker et al.):

- The optimality is measured by the annualized profit from hydrogen production. Most supply chain model chooses minimizing total cost as the objective. The advantage of choosing profit maximization lie in that it reflects the profit-driven industrial operation and it allows infrastructure design to respond to price differentials between demand centers.
- Hydrogen is produced from rice straw via a gasification process with co-production of a small amount of electricity. The technologies for rice straw harvest and delivery remain unchanged from current practice. Hydrogen is delivered to refueling stations using one of three modes: gaseous truck, liquid truck or via pipeline (new). The refueling stations dispense hydrogen to vehicles with 5000 psi onboard storage tanks.
- Hydrogen demand will be concentrated in areas of high population density and will be evenly distributed in those areas.
- Model parameters remain constant in the one-year study period. This model is a deterministic model (demand, supply, and technology are stabilized in the long run) which can serve as the basis for more advanced stochastic models. For example, sensitivity analysis of the deterministic model can help identify important model parameters that may need stochastic treatment.

  The inputs of the model include (Parker et al.):

- GIS-based data describing biomass feedstock availability;
- Geographic distribution and projection for future hydrogen demand; and
- Engineering economic sub models for computing the production and transportation costs under different technology assumptions.

The outputs of the model include (Parker et al.):

- The maximum profit generated from biohydrogen production;
- The optimal locations and sizes of biohydrogen production plants;
- The optimal allocation of biomass resources to production plants; and

- The optimal transportation infrastructure configuration and operation for biomass and produced hydrogen.

The objective is to build an industry that will maximize profit with given demands, supplies, and hydrogen market price. Figure 5 is a network representation of biohydrogen pathway. Three types of constraints are considered, including (Parker et al.),

- Capacity constraints which restrict quantities not to exceed the maximum allowed by the built or given capacities;
- Flow conservation constraints which require that at each node the quantities going in must equal the quantities going out plus (or minus) the quantities supplied (or consumed) at the node; and
- Non-negative constraints which require that all physical quantities be positive as they cannot be negative.

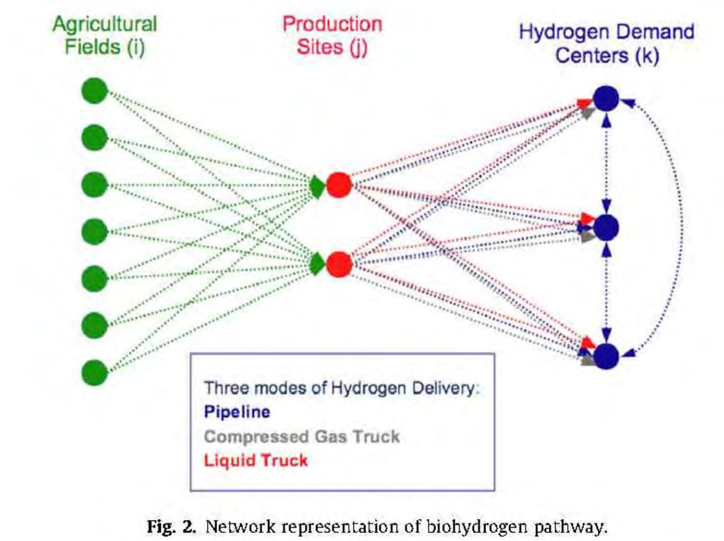


Figure 5 Network representation of biohydrogen pathway (Parker et al.)

A multi-biomass supply chain model for tri-generation energy (electricity, heating and cooling) production was built and optimized to maximize the financial yield of the investment for investors (Rentizelas et al., 2009). The consideration of multi-biomass supply chain presents significant potential for cost reduction, by allowing spreading of capital costs and reducing warehousing requirement, especially when seasonal biomass types are concerned (Rentizelas et al., 2009).

One of the most important barriers in increased biomass utilization in energy supply is the cost of the respective supply chain and the technology to convert biomass into useful forms of energy (electricity, heating, etc.). It is therefore natural that many attempts have been made to date to simulate and optimize a specific biomass supply chain on the understanding that significant cost reductions could originate from more efficient logistics operations (Rentizelas et al., 2009).

Two of the major characteristics of the model are (Rentizelas et al., 2009):

- Multi-biomass supply chain approach which leads to increased efficiencies in the biomass supply chain, especially when biomass types with high seasonality are concerned, according to several researchers; and

- System-wide modeling and optimization approach which ensuring that the global optimum design and operational characteristics for the system are defined.

The model aims to provide investor with optimal answers concerning the following investment issues (Rentizelas et al., 2009):

- Which is the best location to establish the biomass-to-energy facility?
- Which is the optimal relative size of the base-load CHP unit and the peak-load boiler?
- Which amount of each locally available biomass type should be used and from where should it be collected?

The simulation and the optimization model were developed in Matlab by Mathworks. The objective function to be maximized is the net present value (NPV) of the investment for the project's lifetime. NPV was chosen not only because it is the most frequently used investment appraisal criterion in co-generation plant investment, but also as it is considered theoretically superior to other criteria (Rentizelas et al., 2009).

The constraints considered include (Rentizelas et al., 2009):

- Energy demand constraints
- Warehousing constraints
    - A safety stock constraint was considered. The biomass safety stock in the warehouse was set as the amount of biomass adequate for at least 20 days of full load operation.
    - Another constraint is introduced, due to the rolling horizon of the model: the finishing season stock must be at least as much as the starting season stock.
- Legislation constraints
    - The legislation in Greece requires that a co-generation project may receive subsidy on investment only if at least 65% of the heat generated is exploited.
- Social constraints
    - The bioenergy conversion facility must be located at least a safety distance away from the customer's location.
- Logic constraints
    - non-negative or upper bounds constraints

In order to overcome the limitations of using a specific non-liner method, a hybrid method was applied in the model. This means that firstly, one optimization method is employed to define a good solution to the problem. This solution is used as the starting point of the second optimization method that bears the task to enhance further the solution found at the first step. The optimization method used for the first step is a genetic algorithm (GA). A sequential quadratic programming (SQP) optimization method was applied at the second step to define the optimum (Rentizelas et al., 2009).

Lam et al. (2010) proposed a novel methodology for regional energy targeting and supply chain synthesis. It is a two-level methodology. The first is a top-level supply chain network with lowest Carbon Footprint (CFP) generated. It consists of a number of zone clusters. The zones can be a village or a town. Each zone was considered as a unit. At the second level is a supply chain synthesis carried out by P-graph (process graph) based optimization with each cluster (Lam et al.).

The objective of the paper is to minimize the CFP generated in the biomass supply chain. The CFP is mainly caused by processing, transportation and burning. Especially transportation activities could contribute the major part of the CFP in the supply chain. The typical locations of biomass sources (farms, forest, etc.), the relatively low energy density, and the distributed nature of the sources require extensive infrastructure and huge transport capacities for implementing the biomass supply network. For regional biomass supply chain road transportation is the usual mode for collection and transportation. This tends to increase the CFP of the biomass based energy (Lam et al.).

This paper focused on a detailed technical design combining with economic and environmental analysis of a lignocellulosic feedstock (LCF) biorefinery producing ethanol, power and high-value chemicals (succinic acid and acetic acid). The results of the economic analysis showed that the designed refinery has great potential compared to the single-output ethanol plant. The LCF biorefinery showed better environmental performance mainly in global warming potential due to CO_2 fixation during acid fermentation (Luo et al.).

Design of the biorefinery

The LCF biorefinery used corn stover as feedstock and produce multiple outputs, including ethanol, power and high-value chemicals (succinic acid and acetic acid). The stover is collected with an 80 km (50 miles) radius around the biorefinery. The harvested stover was transported by lorries. The biorefinery was designed to operate 24 hours per day, and 335 days (11 months) per year continuously. The remaining one month was used for cleaning-up and restarting the operations. As crop residues are harvested and transported at different time of the year, long-term storage is required to provide feedstocks to the plant year-round. The lifetime of the biorefinery was assumed to be 20 years. The capacity of the biorefinery was also defined from literature study (Luo et al.).

On-site short-term storage was provided equivalent to 72 hours of production at an outside storage area. The stored material provides a short-term supply for weekends, holidays, and when normal direct delivery of material into the process is interrupted. The material will be rotated continuously, with a first-in, first-out inventory management strategy (Luo et al.).

Economic analysis

The economic analysis was conducted to estimate the net present value (NPV) and internal rate of return (IRR), which is based on the capital investment, and on the variable and fixed operating costs of the refinery. The discount rate was set at 10%. The construction period of the biorefinery was assumed to be three years. The first year expense is the engineering, construction and contingency costs. In the second year, 80% of the total capital investment is assumed to be made and the investment is finished in the third year. It is assumed that the refinery starts to be operated at 75% capacity in the third year, and at full capacity (11 months per year) in the rest of the life time. The results of the economic analysis were compared with the ones from the ethanol plant designed by Aden et al. (2002) from NREL. Sensitivity analyses were conducted on the capital investment, the market price of both succinic acid and ethanol, and the purchase price of the feedstock (Luo et al.).

References

Aden A, Ruth M, Ibsen K, Jechura J, Neeves K, Sheehan J, Wallace B, Montague L, Slayton A, Lukas J. Lignocellulosic Biomass to Ethanol Process Design and Economics Utilizing Co-Current Dilute. Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover NREL Technical Report, National Renewable Energy Laboratory 2002;154pp.

Biomass Research and Development Board. *National Biofuels Action Plan.* Biomass Research & Development Initiative, (2008).

Blackwelder, D. B., and E. Wilkerson. "Supply System Costs of Slash, Forest Thinnings, and Commercial Energy Wood Crops." *INL Biofuels and Renewable Energy Web site.*September2008. https://inlportal.inl.gov/portal/server.pt/gateway/PTARGS_0_1829_30968_0_0_18/TM2008-008-0%20Supply%20System%20Costs%20of%20Slash,%20Forest%20Thinnings,%20and%20Commercial%20Energy%20Wood%20Crops.pdf (accessed December 9, 2009).

Cachon, G.P. and M. Fisher, "Supply chain inventory management and the value of shared information", Management Science, 46 (2000) 1032-1048.

Cheng EWL and Li H, Exploring quantitative methods for project location selection, Building and Environment, vol. 39, pp. 1467-1476, 2004.

Chopra, S. and P. Meindl, Supply Chain Management: Strategy, Planning, and Operation, Pearson-Prentice Hall: Upper Saddle River, NJ (2007).

Cubbage, F.W. and Newman, D.H., (2006), Forest policy reformed: a United States perspective, Forest Policy and Economics, Vol. 9, pp. 261-273.

De Mol, R.M., M.A.H. Jogems, P. Van Beek and J.K. Gigler, "Simulation and optimization of the logistics of biomass fuel collection", Netherlands Journal of Agricultural Science, 45 (1997) 219-228.

Eksioglu SD, Acharya A, Leightley LE, Arora S (2009) Analyzing the design and management of biomass-to-biorefinery supply chain. Computers & Industrial Engineering 57: 1342-1352.

Gallagher, P.W., Shapouri, H., Price, J., Schamel, G., and Brubaker, H., (2003), Some long-run effects of growing markets and renewable fuel standards on additives markets and the U.S. ethanol industry, Journal of Policy Modeling, Vol. 25, pp. 585-608.

Gronalt, M. and P. Rauch, "Designing a regional forest fuel supply network", Biomass and Bioenergy, 31 (2007) 393-402.

Gunnarsson, H., M. Ronnqvist and J.T. Lundgren, "Supply chain modeling of forest fuels", European Journal of Operational Research, 158 (2004) 103-123.

Hess, J. R., C. T. Wright, and K. L. Kenney. "Cellulosic biomass feedstocks and logistics for ethanol production." Biofuels, Bioproducts & Biorefining, (2007) 181-190.

Hess, R. J., C. T. Wright, K. L. Kenney, and E. Searcy. "Uniform-Format Feedstock Supply System Design: A Commodity-Scale Design to Produce an Infrastructure-Compatible Bulk Solid from Lignocellulosic Biomass." INL Biofuels and Renewable Energy Web site. April 2009. https://inlportal.inl.gov/portal/server.pt/gateway/PTARGS_0_1829_37189_0_0_18/Executive_Summary_Final_w_cover.pdf (accessed December 9, 2009).

Huang Y, Chen C-W, Fan Y Multistage optimization of the supply chains of biofuels. Transportation Research Part E: Logistics and Transportation Review In Press, Corrected Proof.

Iakovou E, Karagiannidis A, Vlachos D, Toka A, Malamakis A Waste biomass-to-energy supply chain management: A critical synthesis. Waste Management In Press, Corrected Proof.

Idaho National Laboratory (INL). (2006, October). Bioenergy Technology. Retrieved December 2009, from INL Web site: http://www.inl.gov/bioenergy/projects/d/1006_ch2m.pdf

Kahraman C, Ruan D, and Dogan I, Fuzzy group decision-making for facility location selection, Information Sciences, vol. 157, pp. 135-153, 2003.

Kallali H, Anane M, Jellali S, andTarhouni J, GIS-based multi-criteria analysis for potential wastewater aquifer recharge sites, Desalination, vol. 215, pp. 111-119, 2007.

Kumar, A., S. Sokhansanj and P.C. Flynn, "Development of a Multicriteria Assessment Model for Ranking Biomass Feedstock Collection and Transportation Systems", Applied Biochemistry and Biotechnology, 129-132 (2006) 71-78.

Lam HL, Varbanov PS, Klemes JJ Optimisation of regional energy supply chains utilising renewables: P-graph approach. Computers & Chemical Engineering 34: 782-792.

Luo L, van der Voet E, Huppes G Biorefining of lignocellulosic feedstock - Technical, economic and environmental considerations. Bioresource Technology 101: 5023-5032Mahmudi, H. and P.C. Flynn, "Rail vs. Truck Transport of Biomass", Applied Biochemistry and Biotechnology, 129-132 (2006) 88-103.

Marien, Edward J. "The Four Supply Chain Enablers." *Supply Chain Management Review*, (March/April 2000), 60-68.

Mitchell, D. Assessment of Current Technologies for Communition of Forest Residues. ASAE, (2005).

Muttiah RS, Engel BA, and Jones DD, Waste disposal site selection using GIS-based simulated annealing, Computers & Geosciences, vol. 22, pp. 1013-1017, 1996.

Noon CE, Zhan FB, Graham RL. GIS-Based Analysis of Marginal Price Variation with an Application in the Identification of Candidate Ethanol Conversion Plant Locations. Networks and Spatial Economics 2002;2(1):79-93.

Noorollahi Y, Itoi R, Fujii H, and Tanaka T, GIS integration model for geothermal exploration and well siting, Geothermics, vol. 37, pp. 107-131, 2008.

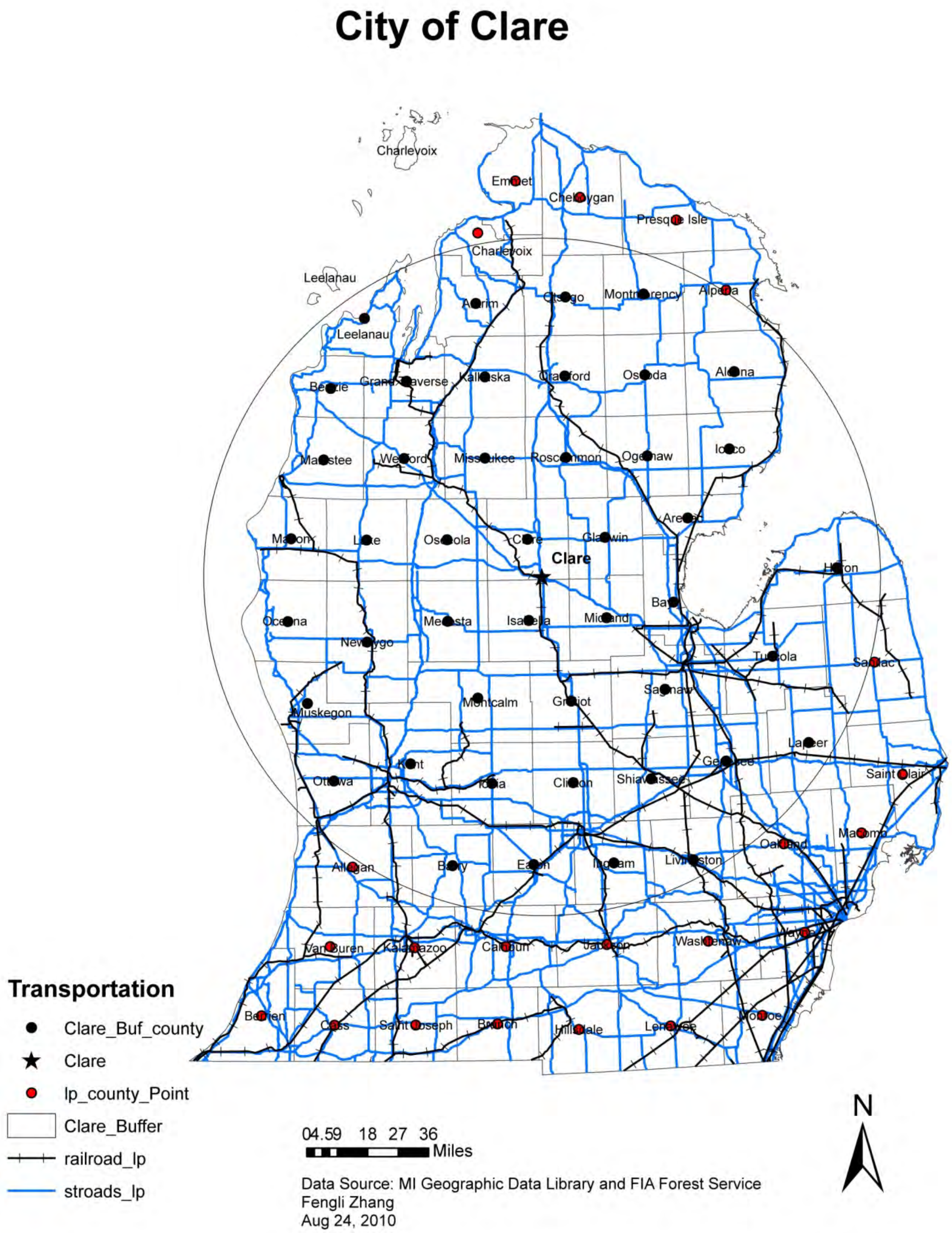
Ocalir EV, Ercoskun OY, and Tur R. An integrated model of GIS and fuzzy logic (FMOTS) for location decisions of taxicab stands, Expert Systems with Applications, vol. 37, pp. 4892-4901, 2010.

Panichelli L, Gnansounou E. GIS-based approach for defining bioenergy facilities location: A case study in Northern Spain based on marginal delivery costs and resources competition between facilities. Biomass and Bioenergy 2008;32(4):289-300.Reynolds, R. E. Infrastructure Requirements for an Expanded Fuel Ethanol Industry. South Bend, IN: Oak Ridge National Laboratory Ethanol Project, (2002). http://www.ethanolrfa.org/objects/documents/94/dai.pdf.

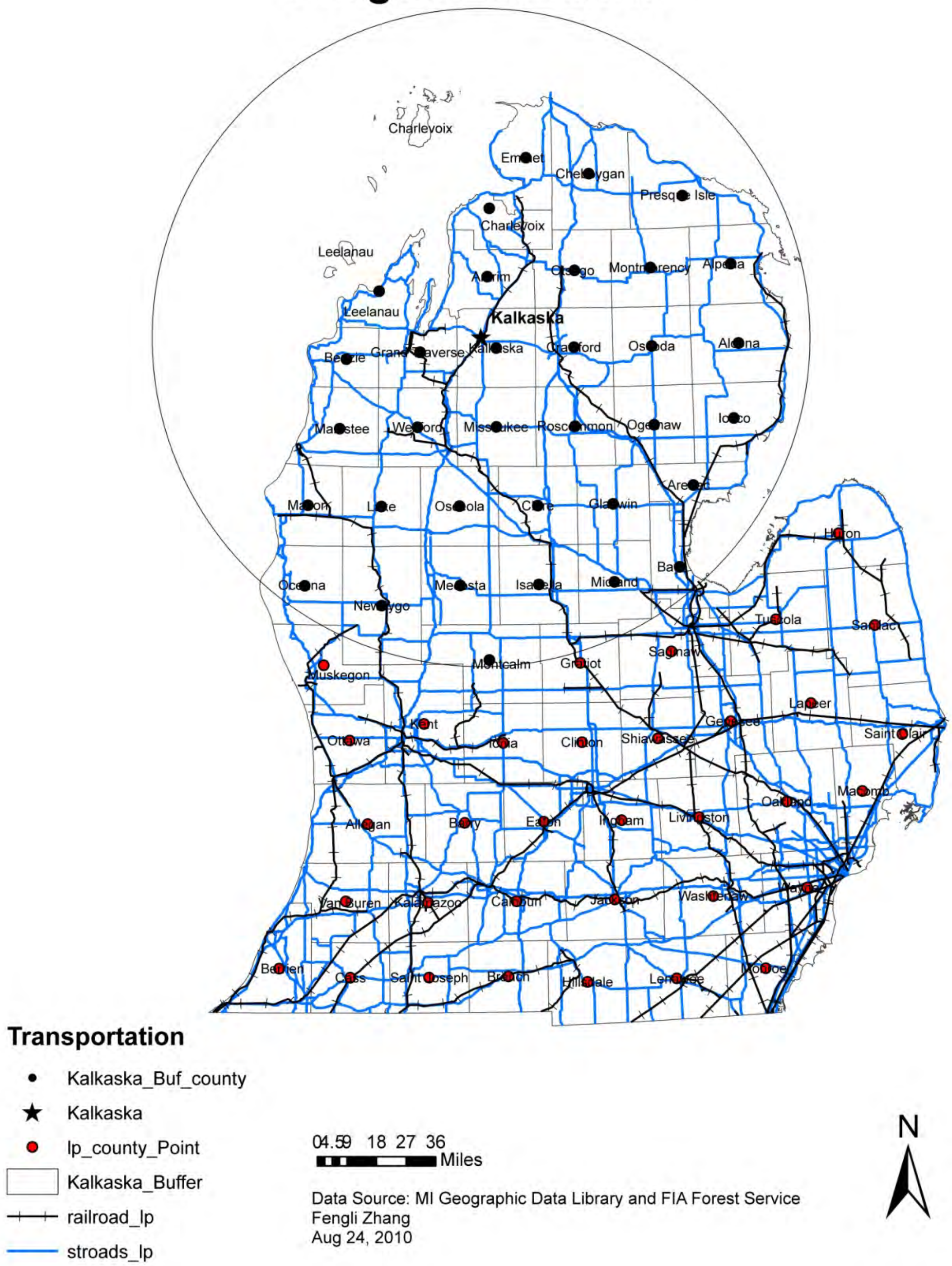
Parker N, Fan Y, Ogden J From waste to hydrogen: An optimal design of energy production and distribution network. Transportation Research Part E: Logistics

and Transportation Review 46: 534-545.
Perpiñá C, Alfonso D, Pérez-Navarro A, Peñalvo E, Vargas C, Cárdenas R. Methodology based on Geographic Information Systems for biomass logistics and transport optimisation. Renewable Energy 2009;34(3):555-565.
Rentizelas AA, Tatsiopoulos IP, Tolis A (2009) An optimization model for multi-biomass tri-generation energy supply. Biomass and Bioenergy 33: 223-233Sandia National Laboratories. "90 Billion Gallon Biofuel Deployment Study." Sandia National Laboratories Web site. February 10, 2009. http://www.sandia.gov/news/publications/white-papers/HITEC_Biofuel%20_Study.pdf (accessed December 9, 2009).
Sandia National Laboratories. "90 Billion Gallon Biofuel Deployment Study." Sandia National Laboratories Web site. February 10, 2009. http://www.sandia.gov/news/publications/white-papers/HITEC_Biofuel%20_Study.pdf (accessed December 9, 2009).
Searcy, E. and P. Flynn. The Impact of Biomass Availability and Processing Cost on Optimum Size and Processing Technology Selection. Edmonton, AB: Humana Press, (2008).
Searcy, E., P. Flynn, E. Ghafoori, and A. Kumar. "The Relative Cost of Biomass Energy Transport." Applied Biochemistry and Biotechnology, 136-140, (2007) 639-652.
Sissine, F. (2007), Energy Independence and Security Act of 2007: a summary of major provisions, Congressional Research Service Report for Congress, Order Code RL34294, Washington, D.C.
Stokes, Bryce J. "Harvesting small trees and forest residues." Biomass and Bioenergy, 2, (1992) 131-147.
Tabari M, Kaboli A, Aryanezhad MB, Shahanaghi K, and Siadat A, A new method for location selection: A hybrid analysis, Applied Mathematics and Computation, vol. 206, pp. 598-606, 2008.
West, T., et al. "Feasibility, economics, and environmental impact of producing 90 billion gallons of ethanol per year by 2030." Sandia National Laboratories Web site. August 2009. http://www.sandia.gov/news/publications/white-papers/90-Billion-Gallon-BiofuelSAND2009-3076J.pdf (accessed December 9, 2009).
Yeh AG-O and Chow MH, An integrated GIS and location-allocation approach to public facilities planning--An example of open space planning, Computers, Environment and Urban Systems, vol. 20, pp. 339-350, 1996.
Zamorano M., Molero E., Hurtado, Grindlay A, and Ramos Á, Evaluation of a municipal landfill site in Southern Spain with GIS-aided methodology, Journal of Hazardous Materials, vol. 160, pp. 473-481, 2008.
Zhan FB, Chen X, Noon CE, Wu G. A GIS-enabled comparison of fixed and discriminatory pricing strategies for potential switchgrass-to-ethanol conversion facilities in Alabama. Biomass and Bioenergy 2005;28(3): 295-306.

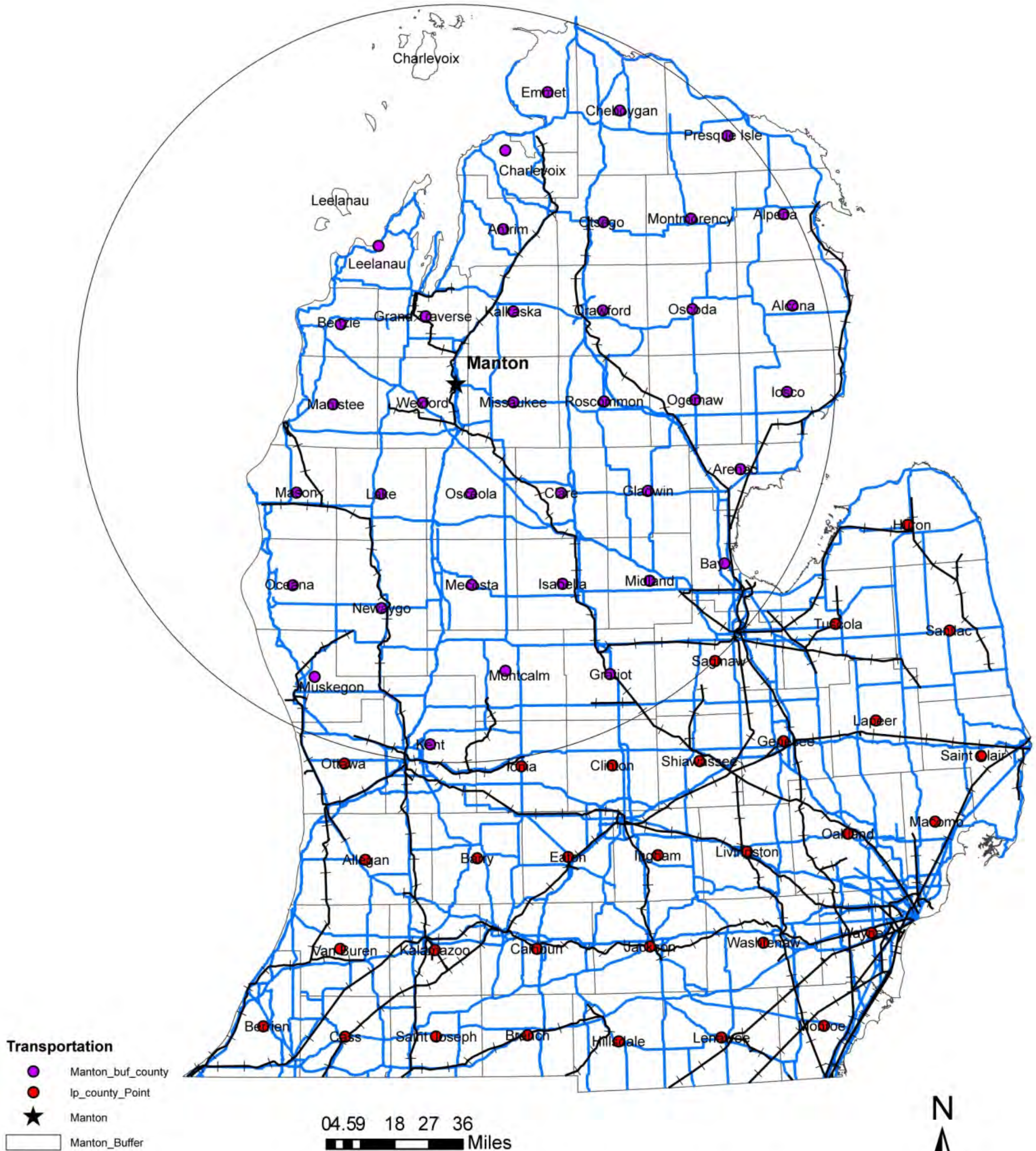
Appendix B4-B Maps of Each of the Nine Locations and 100 Mile Radius



Village of Kalkaska

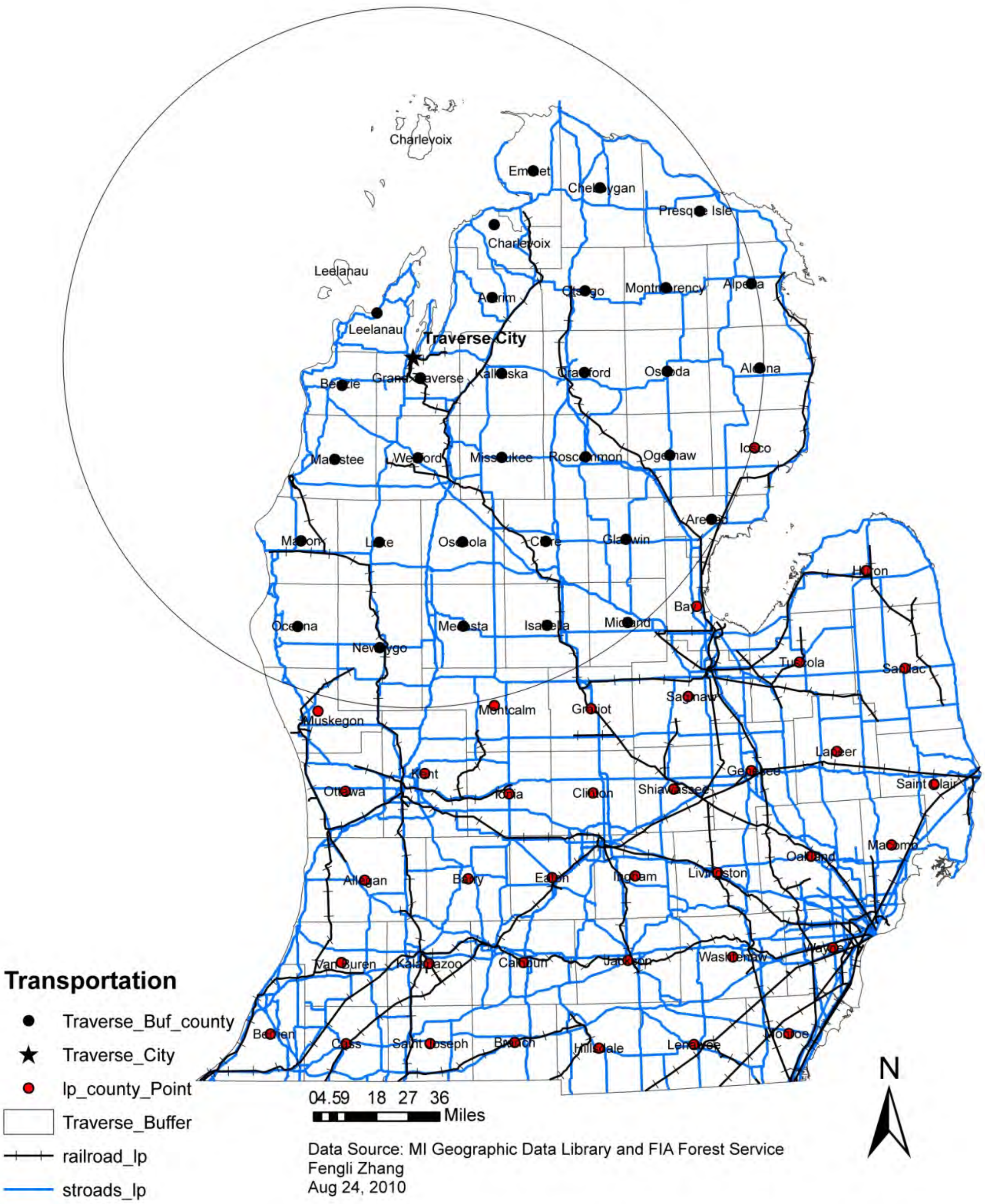


City of Manton

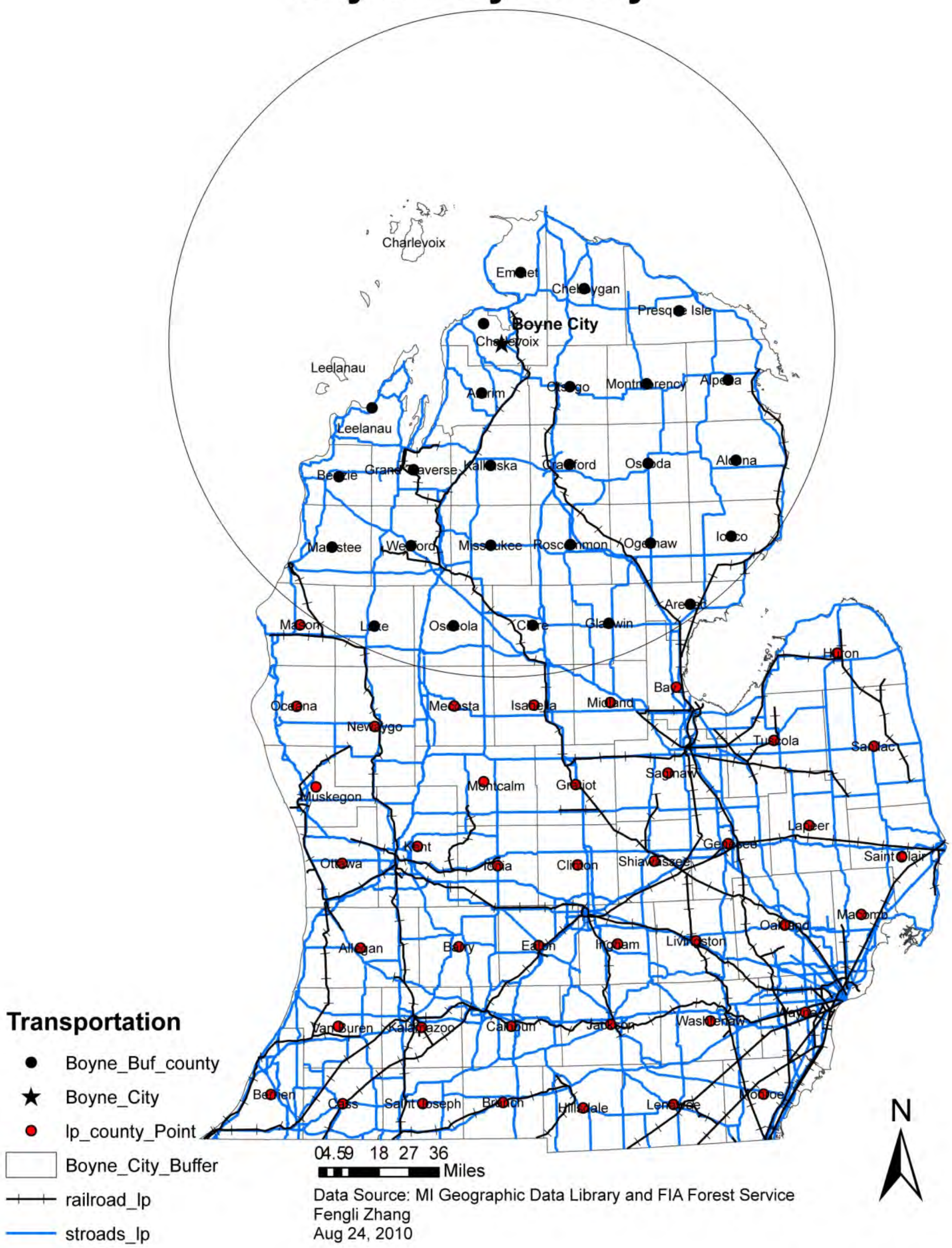


Data Source: MI Geographic Data Library and FIA Forest Service
Fengli Zhang
Aug 24, 2010

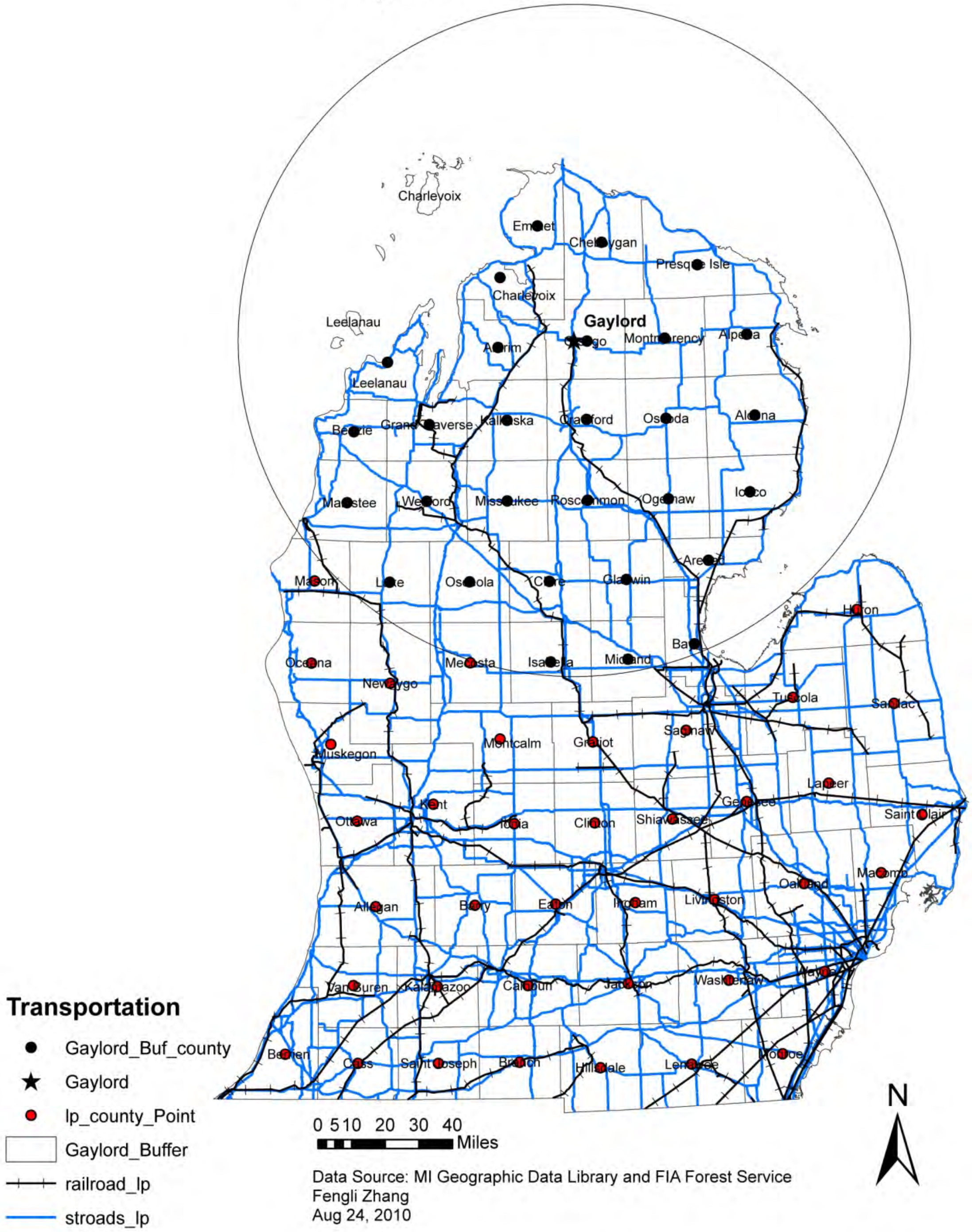
City of Traverse City



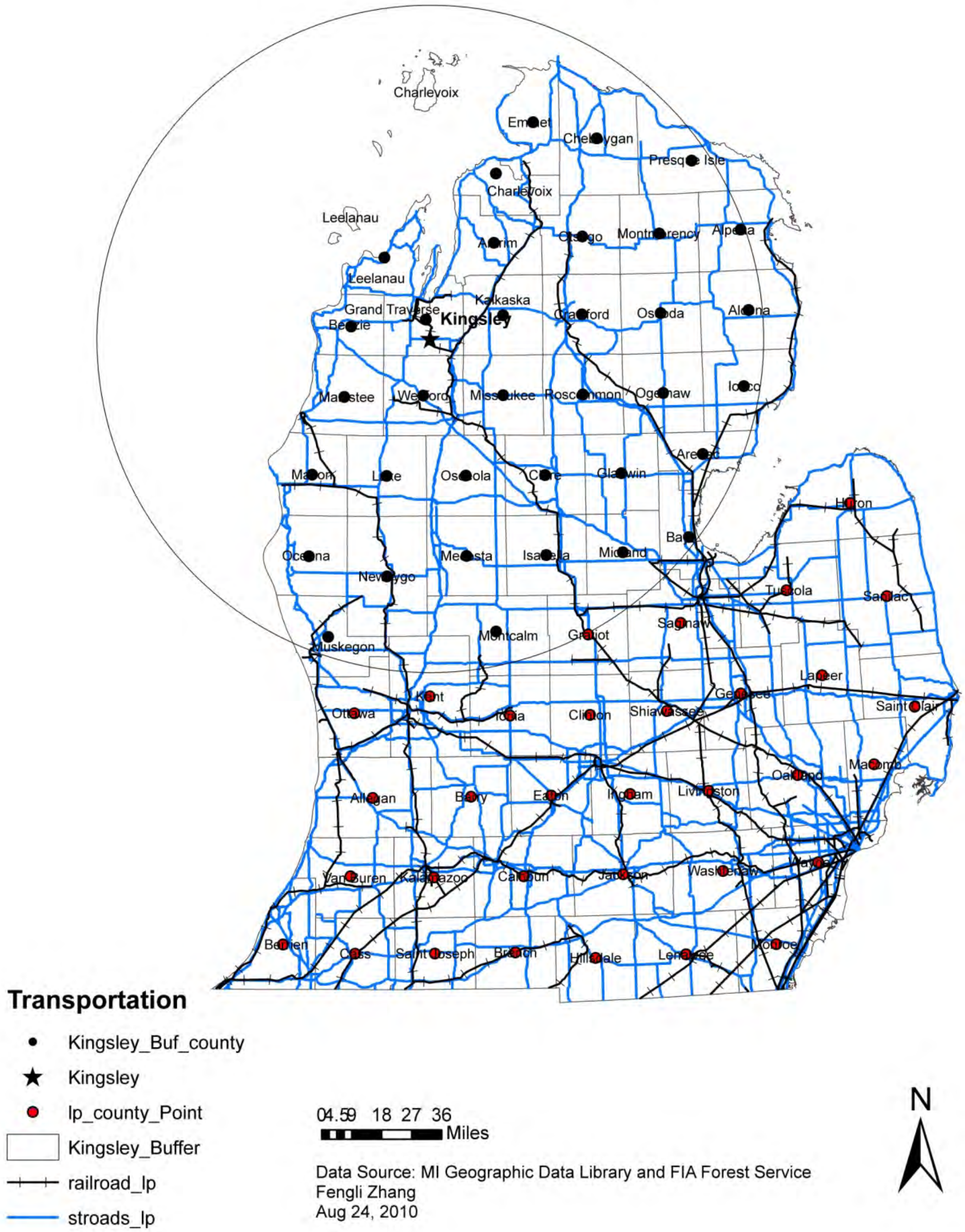
City of Boyne City



City of Gaylord

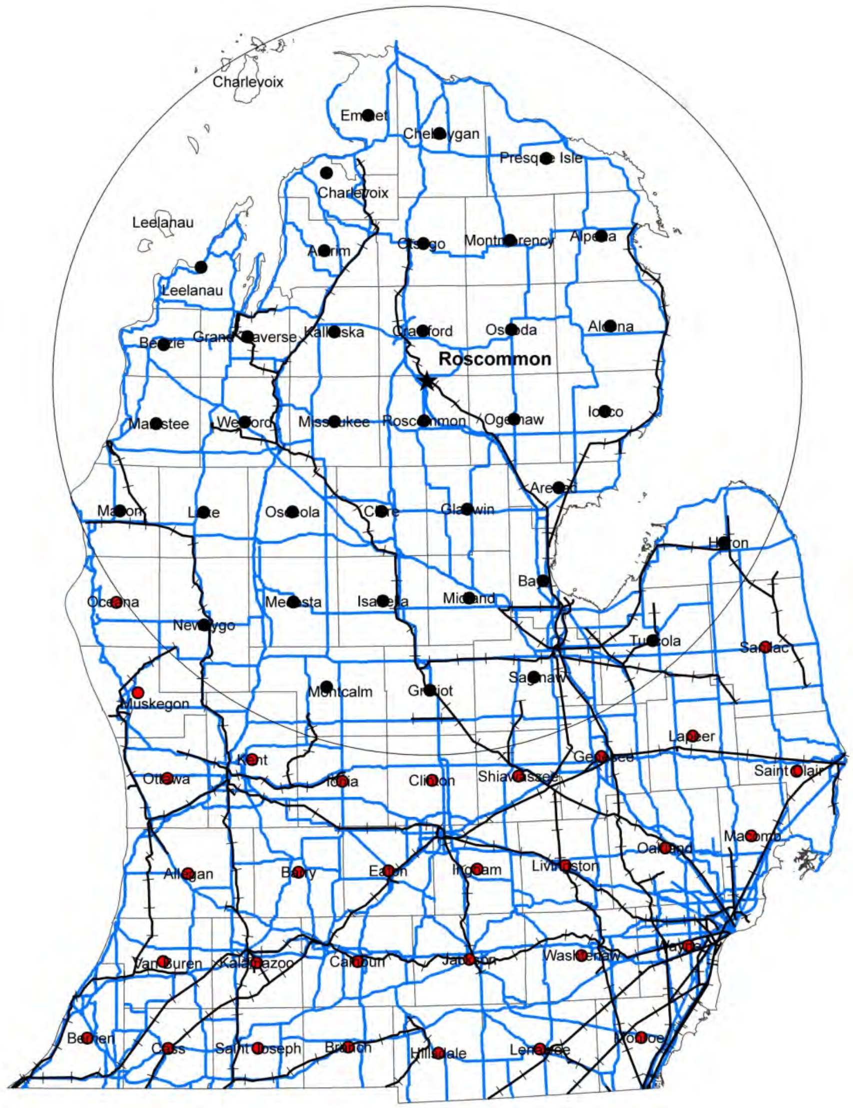


Village of Kingsley



Data Source: MI Geographic Data Library and FIA Forest Service
Fengli Zhang
Aug 24, 2010

Village of Roscommon



Transportation

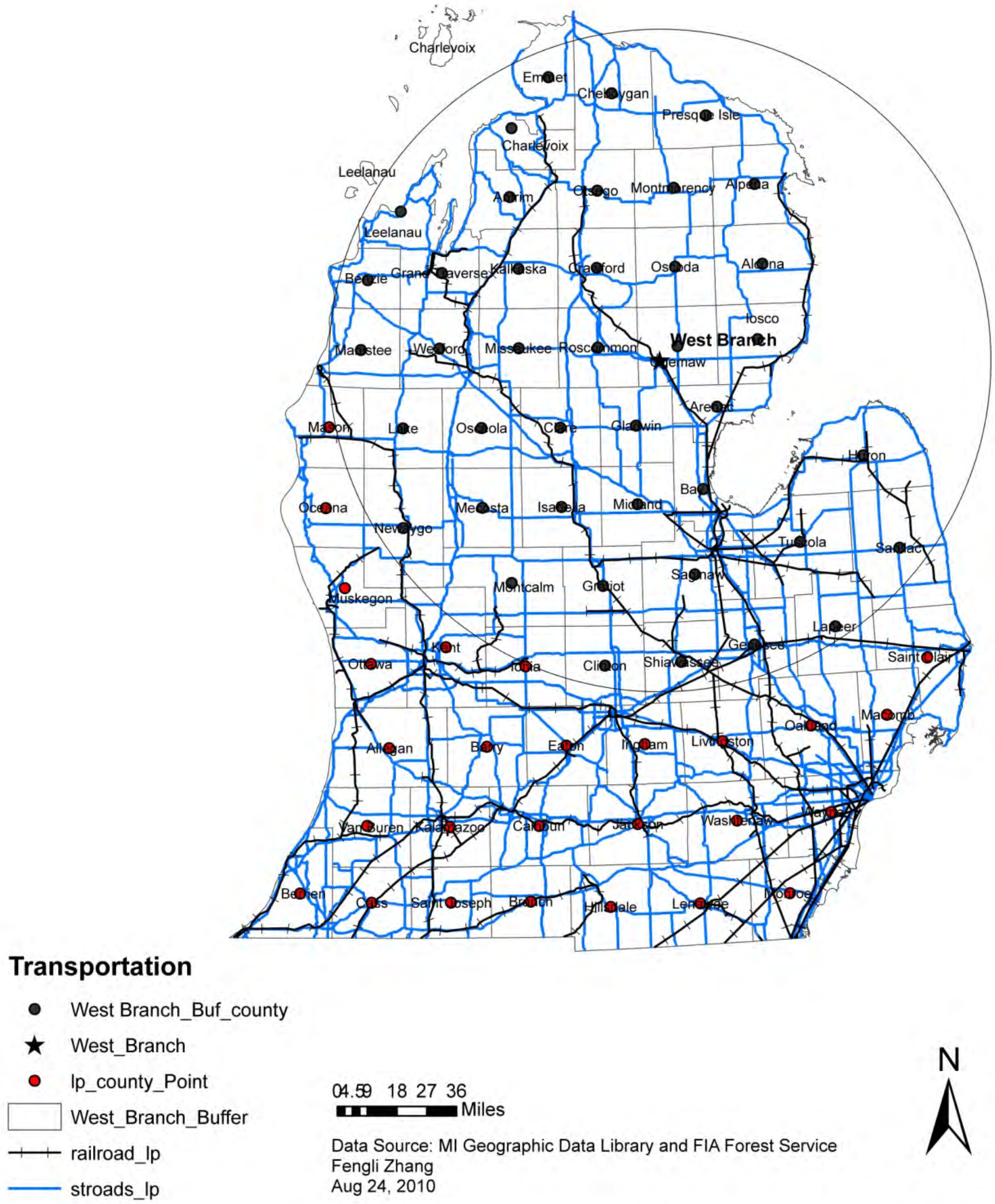
- Roscommon_Buf_county
- Roscommon
- lp_county_Point
- Roscommon_Buffer
- railroad_lp
- stroads_lp

0 4.5 9 18 27 36 Miles

N

Data Source: MI Geographic Data Library and FIA Forest Service
Fengli Zhang
Aug 24, 2010

City of West Branch



Appendix B4-C – Counties within 100 mile radius of each location (we excluded UP)

County (supplier)	Railway going through the county (YES/NO)	Biorefinery location (demand site)								
		Manton	Roscommon	Kingsley	Kalkaska	Gaylord	Clare	West Branch	Traverse City	Boyne City
Barry	NO						X			
Benzie	NO	X	X	X	X	X	X	X	X	X
Cheboygan	NO	X	X	X	X	X		X	X	X
Gladwin	NO	X	X	X	X	X	X	X	X	X
Leelanau	NO	X	X	X	X	X	X	X	X	X
Mecosta	NO	X	X	X	X		X	X	X	
Montmorency	NO	X	X	X	X	X	X	X	X	X
Oceana	NO	X		X	X		X		X	
Oscoda	NO	X	X	X	X	X	X	X	X	X
Presque Isle	NO	X	X	X	X	X		X	X	X
Alcona	YES	X	X	X	X	X	X	X	X	X
Alpena	YES	X	X	X	X	X		X	X	X
Antrim	YES	X	X	X	X	X	X	X	X	X
Arenac	YES	X	X	X	X	X	X	X	X	X
Bay	YES	X	X	X	X	X	X	X		
Charlevoix	YES	X	X	X	X	X		X	X	X
Clare	YES	X	X	X	X	X	X	X	X	X
Clinton	YES						X	X		
Crawford	YES	X	X	X	X	X	X	X	X	X
Eaton	YES						X			
Emmet	YES	X	X	X	X	X		X	X	X
Genesee	YES						X	X		
Grand Traverse	YES	X	X	X	X	X	X	X	X	X
Gratiot	YES	X	X				X	X		
Huron	YES		X				X	X		
Ingham	YES						X			
Ionia	YES						X			
Iosco	YES	X	X	X	X	X	X	X		X
Isabella	YES	X	X	X	X	X	X	X	X	
Kalkaska	YES	X	X	X	X	X	X	X	X	X
Kent	YES	X					X			
Lake	YES	X	X	X	X	X	X	X	X	X
Lapeer	YES						X	X		
Livingston	YES						X			
Manistee	YES	X	X	X	X	X	X	X	X	X
Mason	YES	X	X	X	X		X		X	
Midland	YES	X	X	X	X	X	X	X	X	
Missaukee	YES	X	X	X	X	X	X	X	X	X
Montcalm	YES	X	X	X	X		X	X		
Muskegon	YES	X		X			X			
Newaygo	YES	X	X	X	X		X	X	X	
Ogemaw	YES	X	X	X	X	X	X	X	X	X
Osceola	YES	X	X	X	X	X	X	X	X	X
Otsego	YES	X	X	X	X	X	X	X	X	X
Ottawa	YES						X			
Roscommon	YES	X	X	X	X	X	X	X	X	X
Saginaw	YES		X				X	X		
Sanilac	YES							X		
Shiawassee	YES						X	X		
Tuscola	YES		X				X	X		
Wexford	YES	X	X	X	X	X	X	X	X	X

NOTE: X means the county is a potential supplier for the biorefinery.

Appendix B4-D Michigan Department of Transportation Spring Break Up Maps


1-31-06


2-1-06am


2-6-06am


3-1-06


3-3-06


3-6-06


03-06-062


3-7-06


3-8-06


3-8-06a


30806c


30906a


31006a


31006b


31306a


31306b


32306


32806


32806b


32806c


33006a


33006b


33106a


040306a


040306b


040306c


040406a


040406b


040506a


040706


040906


041206a


041206b


041306a


041306b


41706a

41806a

42106a

42406a

042506

042806

050306

050306b

050406

050806a

051006

051006

051606

051706

051706b

051906

052306

052306b

062106


2_20_07am

2_21_07pm

2_21_07pm_2

2_22_07

2_23_07am

2_24_07am

2_26_07am

2_26_07am

2_26_07am2

2_26_07pm

2_26_07pm2

2_27_07am

2_28_07am2

3_1_07am

3_2_07am

3_2_07am2

3_2_07pm

3_5_07am

3_5_07am2

3-5-07pm

3_9_07

3_12_07am

3_13_07am

3_13_07am2

3_13_07am3

3_14_07am

3_15_07

3_22_07

3-26-07am

3_28_07

3_29_07

3_30_07am

4_2_07am

4_2_07pm

4_3_07am


4_4_07 am


4_5_07am


4_6_07am


4_9_07am


4_9_07pm


4_10_07am


4_10_07pm


4_13_07am


4_16_07am


4_16_07am2


4_18_07am


4_19_07pm


4_20_07pm


4_23_07am


4_23_07am2


4_23_07pm


4_26_07am


4_30_07pm


5_1_07am


5_2_07pm


5_4_07am


5_7_07pm


5_11_07pm


5_14_07pm


5-18-07am


5_25_2007


6_12_07


6_14_07am


4-18-08

4-18-08-2

4-18-08-3

4-18-08-4

4-21-08

4-22-08

4-22-08-2

4-23-08

4-25-08

4-28-08

4-28-08

4-29-08

5-5-08

5-6-08

5-8-08

5-12-08

5-13-08

5-15-08

5-15-08-2

5-16-08

5-16-08-2

5-19-08

5-22-08

5-23-08

6-2-08

6-10-08

7-28-08

1_09_08

1-21-08

2-25-08

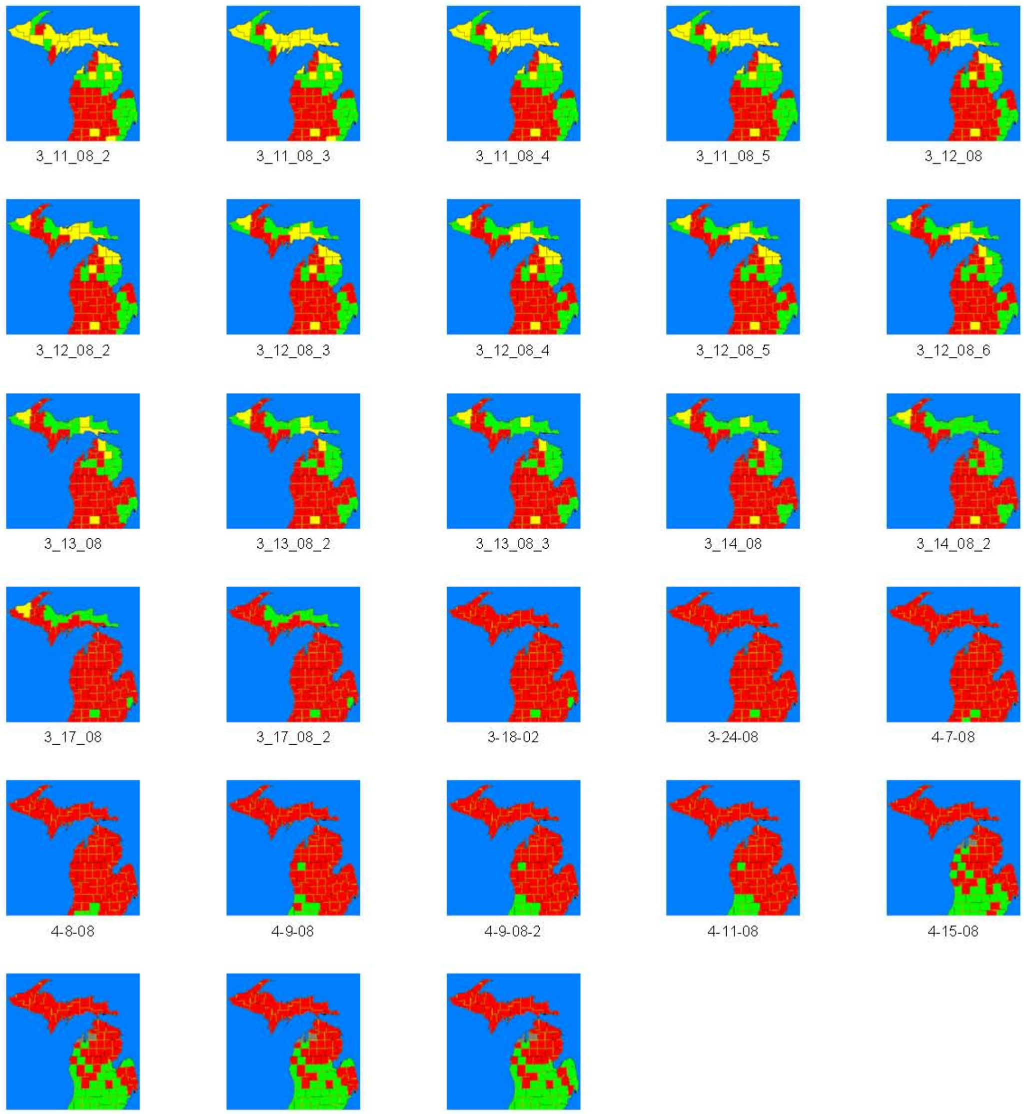
3_3_08

3_04_08

3-7-08

3_10_08

3_11_08



3_11_08_2 3_11_08_3 3_11_08_4 3_11_08_5 3_12_08

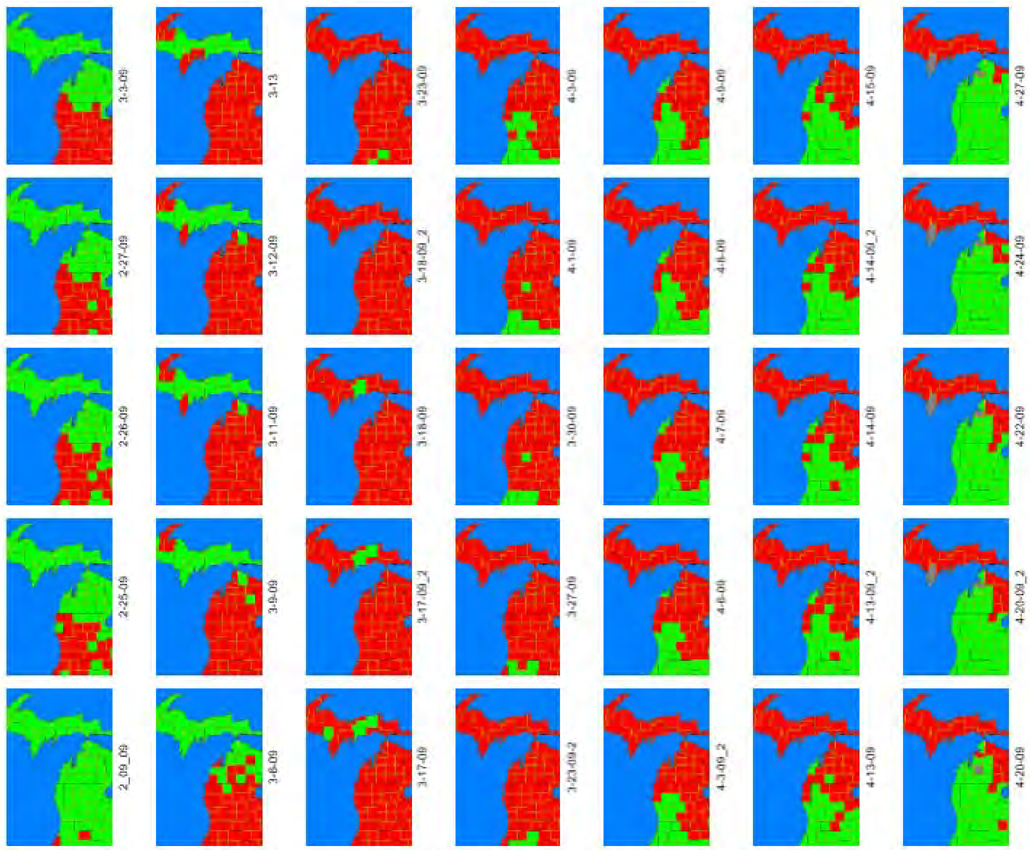
3_12_08_2 3_12_08_3 3_12_08_4 3_12_08_5 3_12_08_6

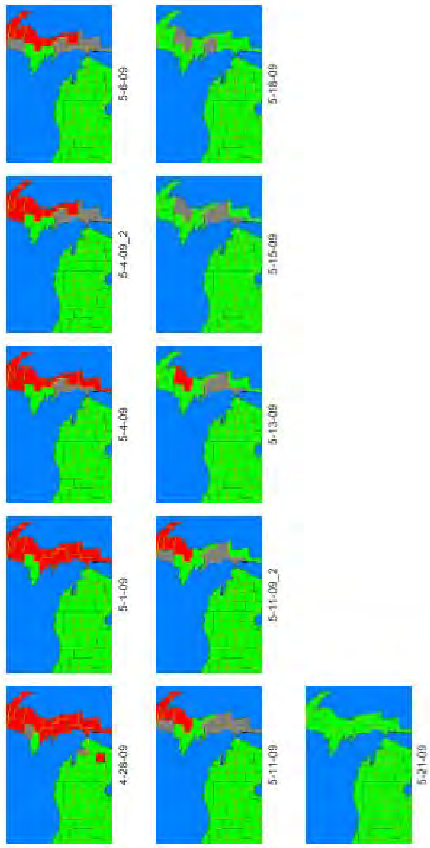
3_13_08 3_13_08_2 3_13_08_3 3_14_08 3_14_08_2

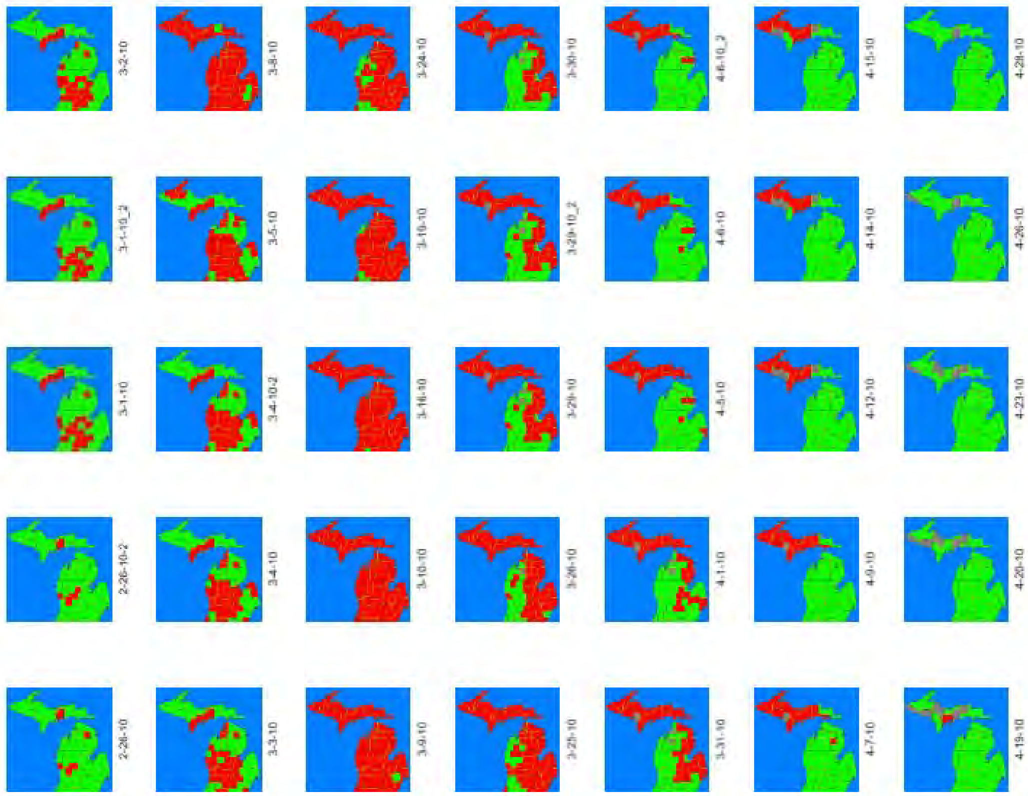
3_17_08 3_17_08_2 3-18-02 3-24-08 4-7-08

4-8-08 4-9-08 4-9-08-2 4-11-08 4-15-08

4-16-08 4-16-08-2 4-17-08


2_09_09
2-25-09
2-26-09
2-27-09
3-3-09
3-6-09
3-9-09
3-11-09
3-12-09
3-13
3-17-09
3-17-09_2
3-18-09
3-18-09_2
3-23-09
3-23-09-2
3-27-09
3-30-09
4-1-09
4-3-09
4-3-09_2
4-6-09
4-7-09
4-8-09
4-9-09
4-13-09
4-13-09_2
4-14-09
4-14-09_2
4-15-09
4-20-09
4-20-09_2
4-22-09
4-24-09
4-27-09


4-28-09
5-1-09
5-4-09
5-4-09_2
5-6-09
5-11-09
5-11-09_2
5-13-09
5-15-09
5-18-09
5-21-09



2-26-10
2-26-10-2
3-1-10
3-1-10_2
3-2-10
3-3-10
3-4-10
3-4-10-2
3-5-10
3-8-10
3-9-10
3-10-10
3-16-10
3-24-10
3-25-10
3-26-10
3-29-10
3-29-10_2
3-30-10
3-31-10
4-1-10
4-5-10
4-6-10
4-6-10_2
4-7-10
4-9-10
4-12-10
4-14-10
4-15-10
4-19-10
4-20-10
4-23-10
4-26-10
4-28-10

Appendix B4-E MDOT Spring Break Up Data

County	2006			2007			2008			2009			2010		
	start	end	# of days	start	end	# of days	start	end	# of days	start	end	# of days	start	end	# of days
Alcona	9-Mar	13-Apr	36	12-Mar	23-Apr	43	17-Mar	25-Apr	40	9-Mar	24-Apr	47	8-Mar	6-Apr	30
Alpena	8-Mar	13-Apr	37	12-Mar	20-Apr	40	17-Mar	22-Apr	37	9-Mar	22-Apr	45	8-Mar	1-Apr	25
Antrim	6-Mar	9-Apr	35	9-Mar	2-Apr	25	11-Mar	18-Apr	39	9-Mar	15-Apr	38	3-Mar	25-Mar	23
Arenac	13-Mar	7-Apr	26	5-Mar	20-Apr	47	14-Mar	18-Apr	36	6-Mar	15-Apr	41	8-Mar	1-Apr	25
Barry	1-Feb	28-Mar	56	26-Feb	3-Apr	37	10-Mar	9-Apr	31	25-Feb	1-Apr	37	2-Mar	25-Mar	24
Bay	6-Mar	12-Apr	38	28-Feb	16-Apr	48	10-Mar	15-Apr	37	6-Mar	15-Apr	41	3-Mar	26-Mar	24
Benzie	8-Mar	23-Mar	16	9-Mar	29-Mar	21	12-Mar	18-Apr	38	9-Mar	6-Apr	29	5-Mar	16-Mar	12
Charlevoix	6-Mar	17-Apr	42	24-Feb	18-Apr	54	10-Mar	18-Apr	40	9-Mar	15-Apr	38	3-Mar	26-Mar	24
Cheboygan	8-Mar	13-Apr	37	12-Mar	16-Apr	36	17-Mar	22-Apr	37	13-Mar	24-Apr	43	8-Mar	1-Apr	25
Clare	10-Mar	7-Apr	29	13-Mar	10-Apr	30	10-Mar	18-Apr	40	25-Feb	15-Apr	51	3-Mar	31-Mar	29
Clinton	6-Mar	31-Mar	26	26-Feb	6-Apr	40	10-Mar	11-Apr	33	3-Mar	13-Apr	42	1-Mar	1-Apr	32
Crawford	6-Mar	9-Apr	35	22-Mar	20-Apr	40	12-Mar	18-Apr	38	6-Mar	15-Apr	41	8-Mar	26-Mar	19
Eaton	1-Mar	3-Apr	34	1-Mar	6-Apr	37	3-Mar	11-Apr	40	25-Feb	13-Apr	49	2-Mar	1-Apr	31
Emmet	1-Mar	4-Apr	34	1-Mar	29-Mar	29	10-Mar	18-Apr	40	9-Mar	15-Apr	38	2-Mar	26-Mar	25
Genesee	6-Feb	9-Apr	63	9-Mar	16-Apr	39	12-Mar	11-Apr	31	25-Feb	9-Apr	45	8-Mar	1-Apr	25
Gladwin	6-Mar	13-Apr	39	9-Mar	20-Apr	43	12-Mar	23-Apr	43	26-Feb	22-Apr	57	5-Mar	31-Mar	27
Grand Traverse	6-Mar	28-Mar	23	5-Mar	30-Mar	26	14-Mar	11-Apr	29	9-Mar	15-Apr	38	8-Mar	19-Mar	12
Gratiot	6-Mar	4-Apr	30	26-Feb	4-Apr	38	10-Mar	11-Apr	33	25-Feb	9-Apr	45	3-Mar	1-Apr	30
Huron	31-Jan	13-Apr	75	22-Mar	16-Apr	36	11-Mar	15-Apr	36				4-Mar	31-Mar	28
Ingham	9-Mar	13-Mar	5	5-Mar	3-Apr	30	10-Mar	11-Apr	33	25-Feb	9-Apr	45	1-Mar	1-Apr	32
Ionia	6-Mar	30-Mar	25	26-Feb	4-Apr	38	4-Mar	11-Apr	39	25-Feb	8-Apr	44	1-Mar	25-Mar	25
Iosco	10-Mar	7-Apr	29	12-Mar	20-Apr	40	17-Mar	23-Apr	38	9-Mar	20-Apr	43	8-Mar	1-Apr	25
Isabella	6-Mar	7-Apr	33	28-Feb	10-Apr	42	7-Mar	16-Apr	41	25-Feb	14-Apr	50	3-Mar	30-Mar	28
Kalkaska	6-Mar	12-Apr	38	12-Mar	23-Apr	43	17-Mar	22-Apr	37	6-Mar	15-Apr	41	8-Mar	25-Mar	18
Kent	6-Mar	28-Mar	23	26-Feb	30-Mar	33	3-Mar	18-Apr	47	25-Feb	1-Apr	37	26-Feb	25-Mar	28
Lake	8-Mar	30-Mar	23	5-Mar	30-Mar	26	10-Mar	8-Apr	30	25-Feb	7-Apr	43	3-Mar	26-Mar	24
Lapeer	6-Mar	3-Apr	29	9-Mar	16-Apr	39	12-Mar	21-Apr	41				19-Mar	1-Apr	14
Leelanau	8-Mar	28-Mar	21	9-Mar	19-Apr	42	12-Mar	22-Apr	42	6-Mar	3-Apr	29	8-Mar	16-Mar	9
Livingston	1-Mar	23-Mar	23	24-Feb	5-Apr	41	10-Mar	11-Apr	33	25-Feb	6-Apr	42	1-Mar	31-Mar	31
Manistee	10-Mar	30-Mar	21	5-Mar	30-Mar	26	10-Mar	11-Apr	33	26-Feb	14-Apr	49	2-Mar	19-Mar	18
Mason	6-Mar	28-Mar	23	5-Mar	9-Apr	36	10-Mar	18-Apr	40	25-Feb	13-Apr	49	4-Mar	19-Mar	16
Mecosta	8-Mar	31-Mar	24	9-Mar	6-Apr	29	10-Mar	11-Apr	33	25-Feb	27-Mar	32	4-Mar	19-Mar	16
Midland	6-Mar	7-Apr	33	28-Feb	16-Apr	48	10-Mar	15-Apr	37	25-Feb	15-Apr	51	1-Mar	5-Apr	36
Missaukee	6-Mar	4-Apr	30	12-Mar	2-Apr	22	12-Mar	18-Apr	38	6-Mar	9-Apr	35	5-Mar	19-Mar	15
Montcalm	6-Mar	30-Mar	25	26-Feb	30-Mar	33	3-Mar	18-Apr	47	25-Feb	1-Apr	37	26-Feb	25-Mar	28
Montmorency	1-Mar	7-Apr	38	1-Mar	30-Mar	30	17-Mar	18-Apr	33	6-Mar	28-Apr	54	26-Feb	26-Mar	29
Muskegon	6-Mar	30-Mar	25	26-Feb	30-Mar	33	3-Mar	15-Apr	44	25-Feb	1-Apr	37	26-Feb	29-Mar	32
Newaygo	9-Mar	30-Mar	22	1-Mar	6-Apr	37	10-Mar	17-Apr	39	25-Feb	1-Apr	37	2-Mar	19-Mar	18
Oceana	9-Mar	3-Apr	26	9-Mar	6-Apr	29	3-Mar	11-Apr	40	26-Feb	15-Apr	50	1-Mar	24-Mar	24
Ogemaw	8-Mar	7-Apr	31	9-Mar	13-Apr	36	17-Mar	23-Apr	38	6-Mar	22-Apr	48	8-Mar	1-Apr	25
Osceola	8-Mar	30-Mar	23	5-Mar	9-Apr	36	10-Mar	17-Apr	39	9-Mar	9-Apr	32	3-Mar	25-Mar	23
Oscoda	13-Mar	13-Apr	32	13-Mar	23-Apr	43	17-Mar	25-Apr	40	11-Mar	24-Apr	45	8-Mar	7-Apr	31
Otsego	9-Mar	9-Apr	32	9-Mar	2-Apr	25	12-Mar	18-Apr	38	9-Mar	15-Apr	38	8-Mar	26-Mar	19
Ottawa	6-Mar	13-Mar	39	26-Feb	29-Mar	32	10-Mar	11-Apr	33	25-Feb	1-Apr	37	3-Mar	25-Mar	23
Presque Isle	7-Mar	13-Apr	38	9-Mar	18-Apr	41	17-Mar	23-Apr	38	9-Mar	27-Apr	50	5-Mar	1-Apr	28
Roscommon	8-Mar	7-Apr	31	9-Mar	16-Apr	39	17-Mar	17-Apr	32	9-Mar	15-Apr	38	5-Mar	26-Mar	22
Saginaw	6-Mar	7-Apr	33	9-Mar	16-Apr	39	10-Mar	15-Apr	37	27-Feb	15-Apr	49	1-Mar	1-Apr	32
Sanilac	3-Mar	7-Apr	36	12-Mar	16-Apr	36	12-Mar	16-Apr	36				4-Mar	31-Mar	28
Shiawassee	1-Mar	30-Mar	30	26-Feb	16-Apr	50	10-Mar	17-Apr	39	25-Feb	9-Apr	45	2-Mar	31-Mar	30
Tuscola	6-Mar	7-Apr	33	12-Mar	16-Apr	36	13-Mar	18-Apr	37	3-Mar	15-Apr	44	8-Mar	31-Mar	24
Wexford	13-Mar	3-Apr	22	13-Mar	6-Apr	26	13-Mar	17-Apr	36	9-Mar	15-Apr	38	5-Mar	29-Mar	25

Source: Michigan Department of Transportation (MDOT)

Methodology

The start and end dates are colored in the maps we got from MDOT. The start was identified as the day one county is colored. The end date were identified as the last day the weight restriction is in effect (through 2006-2010). The duration of spring breakup were calculated by plus one to the difference between start and end dates.

Appendix B4-F Federal Forest Biomass Data

County code and name	LP/UP	N/S or E/W	Total	Softwoods	Hardwoods	soft_avail	hard_avail	soft_vol_ava	hard_vol_avail	soft_GT_avail	hard_GT_avail
26001 MI Alcona	LP	N	3,610,146	1,182,724	2,427,422	0.93288219	0.90959717	1,103,342	2,207,976	28,386	83,301
26007 MI Alpena	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26009 MI Antrim	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26011 MI Arenac	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26015 MI Barry	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26017 MI Bay	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26019 MI Benzie	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26029 MI Charlevoix	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26031 MI Cheboygan	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26035 MI Clare	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26037 MI Clinton	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26039 MI Crawford	LP	N	1,529,259	590,142	939,117	0.93288219	0.90959717	550,533	854,218	14,164	32,227
26045 MI Eaton	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26047 MI Emmet	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26049 MI Genesee	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26051 MI Gladwin	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26055 MI Grand Traverse	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26057 MI Gratiot	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26063 MI Huron	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26065 MI Ingham	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26067 MI Ionia	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26069 MI Iosco	LP	N	3,546,112	2,803,665	742,447	0.93288219	0.90959717	2,615,489	675,328	67,289	25,478
26073 MI Isabella	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26079 MI Kalkaska	LP	N	17,379	17,379	0	0.93288219	0.90959717	16,213	0	417	0
26081 MI Kent	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26085 MI Lake	LP	N	3,800,713	1,723,244	2,077,470	0.93288219	0.90959717	1,607,584	1,889,661	41,359	71,292
26087 MI Lapeer	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26089 MI Leelanau	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26093 MI Livingston	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26101 MI Manistee	LP	N	3,342,112	929,228	2,412,884	0.93288219	0.90959717	866,860	2,194,752	22,302	82,802
26105 MI Mason	LP	N	2,798,640	1,570,618	1,228,021	0.93288219	0.90959717	1,465,202	1,117,004	37,696	42,142
26107 MI Mecosta	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26111 MI Midland	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26113 MI Missaukee	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26117 MI Montcalm	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26119 MI Montmorency	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26121 MI Muskegon	LP	S	369,587	176,465	193,122	0.93288219	0.90959717	164,621	175,663	4,235	6,627
26123 MI Newaygo	LP	N	3,221,786	1,439,903	1,781,883	0.93288219	0.90959717	1,343,260	1,620,796	34,558	61,148
26127 MI Oceana	LP	N	2,233,111	975,326	1,257,785	0.93288219	0.90959717	909,864	1,144,078	23,408	43,163
26129 MI Ogemaw	LP	N	823,775	356,258	467,516	0.93288219	0.90959717	332,347	425,251	8,550	16,044
26133 MI Osceola	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26135 MI Oscoda	LP	N	6,278,618	3,352,508	2,926,110	0.93288219	0.90959717	3,127,495	2,661,581	80,462	100,414
26137 MI Otsego	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26139 MI Ottawa	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26141 MI Presque Isle	LP	N	0	0	0	0.93288219	0.90959717	0	0	0	0
26143 MI Roscommon	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26145 MI Saginaw	LP	S	683,156	0	683,156	0.93288219	0.90959717	0	621,397	0	23,444
26151 MI Sanilac	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26155 MI Shiawassee	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26157 MI Tuscola	LP	S	0	0	0	0.93288219	0.90959717	0	0	0	0
26165 MI Wexford	LP	N	4,680,902	2,101,463	2,579,439	0.93288219	0.90959717	1,960,417	2,346,250	50,436	88,518

Appendix B4-G State Forest Biomass Data

County code and name	LP/UP	N/S or E/W	Total	Softwoods	Hardwoods	soft_avail	hard_avail	soft_vol_ava	hard_vol_ava	soft_GT_avail	hard_GT_avail
26001 MI Alcona	LP	N	839,538	130,601	708,937	0.54210441	0.48138431	70,799	341,271	1821	12875
26007 MI Alpena	LP	N	1,567,513	1,023,803	543,710	0.54210441	0.48138431	555,008	261,733	14279	9874
26009 MI Antrim	LP	N	3,145,318	1,076,762	2,068,556	0.54210441	0.48138431	583,717	995,770	15017	37568
26011 MI Arenac	LP	N	625,930	88,609	537,321	0.54210441	0.48138431	48,035	258,658	1236	9758
26015 MI Barry	LP	S	876,142	260,052	616,090	0.89363253	0.88568285	232,391	545,660	5979	20586
26017 MI Bay	LP	N	234,995	0	234,995	0.54210441	0.48138431	0	113,123	0	4268
26019 MI Benzie	LP	N	3,182,835	949,901	2,232,934	0.54210441	0.48138431	514,946	1,074,899	13248	40553
26029 MI Charlevoix	LP	N	500,281	338,935	161,346	0.54210441	0.48138431	183,738	77,669	4727	2930
26031 MI Cheboygan	LP	N	4,751,606	1,511,757	3,239,849	0.54210441	0.48138431	819,530	1,559,612	21084	58840
26035 MI Clare	LP	N	1,494,315	638,650	855,665	0.54210441	0.48138431	346,215	411,904	8907	15540
26037 MI Clinton	LP	S	356,296	10,372	366,668	0.89363253	0.88568285	9,269	324,752	238	12252
26039 MI Crawford	LP	N	4,277,009	2,106,357	2,170,652	0.54210441	0.48138431	1,141,865	1,044,918	29377	39422
26045 MI Eaton	LP	N	209,943	0	209,943	0.54210441	0.48138431	0	101,063	0	3813
26047 MI Emmet	LP	N	2,665,256	1,130,362	1,534,894	0.54210441	0.48138431	612,774	738,874	15765	27876
26049 MI Genesee	LP	S	1,646,423	0	1,646,423	0.89363253	0.88568285	0	1,458,209	0	55014
26051 MI Gladwin	LP	N	2,497,107	368,529	2,128,577	0.54210441	0.48138431	199,781	1,024,664	5140	38658
26055 MI Grand Traverse	LP	N	1,728,621	771,223	957,399	0.54210441	0.48138431	418,083	460,877	10756	17388
26057 MI Gratiot	LP	S	219,986	0	219,986	0.89363253	0.88568285	0	194,838	0	7351
26063 MI Huron	LP	S	516,384	0	516,384	0.89363253	0.88568285	0	457,352	0	17255
26065 MI Ingham	LP	S	2,395,246	467,774	1,927,471	0.89363253	0.88568285	418,018	1,707,128	10754	64405
26067 MI Ionia	LP	S	2,090,294	0	2,090,294	0.89363253	0.88568285	0	1,851,338	0	69846
26069 MI Iosco	LP	N	370,824	201,494	169,330	0.54210441	0.48138431	109,231	81,513	2810	3075
26073 MI Isabella	LP	N	301,435	0	301,435	0.54210441	0.48138431	0	145,106	0	5474
26079 MI Kalkaska	LP	N	6,457,381	3,173,387	3,283,994	0.54210441	0.48138431	1,720,307	1,580,863	44259	59642
26081 MI Kent	LP	S	1,057,177	26,396	1,030,781	0.89363253	0.88568285	23,588	912,945	607	34443
26085 MI Lake	LP	N	2,018,012	970,798	1,047,214	0.54210441	0.48138431	526,274	504,112	13540	19019
26087 MI Lapeer	LP	S	287,692	14,375	273,317	0.89363253	0.88568285	12,846	242,072	330	9133
26089 MI Leelanau	LP	N	51,984	119,727	171,711	0.54210441	0.48138431	64,905	82,659	1670	3118
26093 MI Livingston	LP	S	592,829	7,604	585,225	0.89363253	0.88568285	6,795	518,324	175	19555
26101 MI Manistee	LP	N	1,008,053	349,266	658,788	0.54210441	0.48138431	189,339	317,130	4871	11964
26105 MI Mason	LP	N	420,665	230,698	189,967	0.54210441	0.48138431	125,062	91,447	3218	3450
26107 MI Mecosta	LP	N	431,641	0	431,641	0.54210441	0.48138431	0	207,785	0	7839
26111 MI Midland	LP	N	436,750	117,186	319,564	0.54210441	0.48138431	63,527	153,833	1634	5804
26113 MI Missaukee	LP	N	5,282,587	3,289,677	1,992,910	0.54210441	0.48138431	1,783,348	959,356	45881	36194
26117 MI Montcalm	LP	S	845,695	97,409	748,286	0.89363253	0.88568285	87,048	662,744	2240	25004
26119 MI Montmorency	LP	N	5,011,178	1,613,008	3,398,170	0.54210441	0.48138431	874,419	1,635,826	22496	61715
26121 MI Muskegon	LP	S	1,008,942	153,137	855,805	0.89363253	0.88568285	136,848	757,972	3521	28596
26123 MI Newaygo	LP	N	187,483	42,811	230,294	0.54210441	0.48138431	23,208	110,860	597	4182
26127 MI Oceana	LP	N	577,691	125,261	452,430	0.54210441	0.48138431	67,905	217,793	1747	8217
26129 MI Ogemaw	LP	N	2,713,088	1,023,469	1,689,619	0.54210441	0.48138431	554,827	813,356	14274	30686
26133 MI Osceola	LP	N	1,058,297	205,884	852,413	0.54210441	0.48138431	111,611	410,338	2871	15481
26135 MI Oscoda	LP	N	1,550,748	786,867	763,881	0.54210441	0.48138431	426,564	367,720	10974	13873
26137 MI Otsego	LP	S	4,105,273	2,249,565	1,855,708	0.89363253	0.88568285	2,010,284	1,643,569	51719	62007
26139 MI Ottawa	LP	N	261,688	43,461	218,227	0.54210441	0.48138431	23,560	105,051	606	3963
26141 MI Presque Isle	LP	N	2,211,446	1,398,746	812,700	0.54210441	0.48138431	758,266	391,221	19508	14760
26143 MI Roscommon	LP	S	4,260,801	2,039,244	2,221,557	0.89363253	0.88568285	1,822,335	1,967,595	46884	74232
26145 MI Saginaw	LP	S	131,429	44,773	86,656	0.89363253	0.88568285	40,011	76,750	1029	2896
26151 MI Sanilac	LP	S	594,126	0	594,126	0.89363253	0.88568285	0	526,207	0	19852
26155 MI Shiawassee	LP	S	276,188	34,481	241,708	0.89363253	0.88568285	30,813	214,077	793	8077
26157 MI Tuscola	LP	S	968,921	51,102	917,820	0.89363253	0.88568285	45,666	812,897	1175	30668
26165 MI Wexford	LP	N	2,575,447	1,421,017	1,154,430	0.54210441	0.48138431	770,340	555,724	19819	20966

Appendix B4-H Private Ownership Forest Biomass Data

County code and name	LP/UP	N/S or E/W	Total	Softwoods	Hardwoods	soft_avail	hard_avail	soft_vol_ava	hard_vol_ava	soft_GT_avail	hard_GT_avail
26001 MI Alcona	LP	N	6,570,977	2,055,367	4,515,610	0.68544762	0.56189444	1,408,846	2,537,296	36246	95725
26007 MI Alpena	LP	N	6,334,734	2,550,725	3,784,009	0.68544762	0.56189444	1,748,388	2,126,214	44981	80216
26009 MI Antrim	LP	N	5,299,749	340,356	4,959,393	0.68544762	0.56189444	233,296	2,786,655	6002	105133
26011 MI Arenac	LP	N	5,481,396	1,144,137	4,337,260	0.68544762	0.56189444	784,246	2,437,082	20177	91944
26015 MI Barry	LP	S	6,208,383	324,330	5,884,052	0.95282162	0.75485393	309,029	4,441,600	7950	167569
26017 MI Bay	LP	N	1,221,787	98,372	1,123,415	0.68544762	0.56189444	67,429	631,241	1735	23815
26019 MI Benzie	LP	N	3,386,431	635,114	2,751,316	0.68544762	0.56189444	435,337	1,545,949	11200	58324
26029 MI Charlevoix	LP	N	5,220,430	284,295	4,936,135	0.68544762	0.56189444	194,869	2,773,587	5013	104640
26031 MI Cheboygan	LP	N	9,709,089	3,054,729	6,654,360	0.68544762	0.56189444	2,093,857	3,739,048	53869	141064
26035 MI Clare	LP	N	6,664,000	1,337,892	5,326,108	0.68544762	0.56189444	917,055	2,992,710	23593	112907
26037 MI Clinton	LP	S	1,644,130	156,282	1,487,848	0.95282162	0.75485393	148,909	1,123,108	3831	42372
26039 MI Crawford	LP	N	1,652,232	660,802	991,430	0.68544762	0.56189444	452,945	557,079	11653	21017
26045 MI Eaton	LP	N	4,978,306	11,812	4,966,494	0.68544762	0.56189444	8,097	2,790,645	208	105283
26047 MI Emmet	LP	N	6,089,221	999,283	5,089,938	0.68544762	0.56189444	684,956	2,860,008	17622	107900
26049 MI Genesee	LP	S	3,645,186	87,016	3,558,170	0.95282162	0.75485393	82,911	2,685,899	2133	101332
26051 MI Gladwin	LP	N	3,931,523	734,654	3,196,869	0.68544762	0.56189444	503,567	1,796,303	12955	67770
26055 MI Grand Traverse	LP	N	5,995,581	2,976,889	3,018,692	0.68544762	0.56189444	2,040,501	1,696,186	52497	63992
26057 MI Gratiot	LP	S	2,047,095	0	2,047,095	0.95282162	0.75485393	0	1,545,258	0	58298
26063 MI Huron	LP	S	3,563,020	235,105	3,327,915	0.95282162	0.75485393	224,013	2,512,090	5763	94774
26065 MI Ingham	LP	S	1,939,039	62,954	1,876,085	0.95282162	0.75485393	59,984	1,416,170	1543	53428
26067 MI Ionia	LP	S	4,617,704	251,086	4,366,618	0.95282162	0.75485393	239,240	3,296,159	6155	124355
26069 MI Iosco	LP	N	4,807,607	1,353,276	3,454,331	0.68544762	0.56189444	927,600	1,940,969	23865	73227
26073 MI Isabella	LP	N	6,635,358	50,351	6,685,709	0.68544762	0.56189444	34,513	3,756,663	888	141729
26079 MI Kalkaska	LP	N	5,342,214	2,016,093	3,326,121	0.68544762	0.56189444	1,381,926	1,868,929	35553	70510
26081 MI Kent	LP	S	6,047,706	1,383,804	4,663,902	0.95282162	0.75485393	1,318,518	3,520,565	33922	132821
26085 MI Lake	LP	N	6,380,319	3,155,819	3,224,500	0.68544762	0.56189444	2,163,149	1,811,829	55652	68355
26087 MI Lapeer	LP	S	3,047,789	217,481	2,830,307	0.95282162	0.75485393	207,221	2,136,468	5331	80603
26089 MI Leelanau	LP	N	2,597,974	157,135	2,440,839	0.68544762	0.56189444	107,708	1,371,494	2771	51743
26093 MI Livingston	LP	S	2,321,003	316,326	2,004,677	0.95282162	0.75485393	301,402	1,513,238	7754	57090
26101 MI Manistee	LP	N	6,533,656	2,472,914	4,060,742	0.68544762	0.56189444	1,695,053	2,281,708	43609	86083
26105 MI Mason	LP	N	6,567,168	1,043,683	5,523,485	0.68544762	0.56189444	715,390	3,103,616	18405	117091
26107 MI Mecosta	LP	N	8,199,916	2,782,436	5,417,480	0.68544762	0.56189444	1,907,214	3,044,052	49067	114844
26111 MI Midland	LP	N	4,695,521	205,595	4,489,926	0.68544762	0.56189444	140,925	2,522,864	3626	95181
26113 MI Missaukee	LP	N	7,664,063	2,217,001	5,447,062	0.68544762	0.56189444	1,519,638	3,060,674	39096	115471
26117 MI Montcalm	LP	S	5,769,736	800,226	4,969,511	0.95282162	0.75485393	762,473	3,751,255	19616	141525
26119 MI Montmorency	LP	N	8,014,460	2,773,795	5,240,665	0.68544762	0.56189444	1,901,291	2,944,701	48915	111096
26121 MI Muskegon	LP	S	6,772,527	910,922	5,861,604	0.95282162	0.75485393	867,946	4,424,655	22330	166930
26123 MI Newaygo	LP	N	11,120,084	5,000,686	6,119,398	0.68544762	0.56189444	3,427,708	3,438,456	88186	129724
26127 MI Oceana	LP	N	7,816,973	2,017,992	5,823,777	0.68544762	0.56189444	1,383,228	3,272,348	35587	123457
26129 MI Ogemaw	LP	N	3,995,161	1,301,409	2,693,752	0.68544762	0.56189444	892,048	1,513,604	22950	57104
26133 MI Osceola	LP	N	6,292,884	1,571,219	4,721,665	0.68544762	0.56189444	1,076,988	2,653,077	27708	100093
26135 MI Oscoda	LP	N	4,173,132	1,193,189	2,979,943	0.68544762	0.56189444	817,869	1,674,413	21042	63171
26137 MI Otsego	LP	S	8,048,753	1,850,996	6,197,756	0.95282162	0.75485393	1,763,669	4,678,400	45374	176503
26139 MI Ottawa	LP	N	3,077,321	398,748	3,476,069	0.68544762	0.56189444	273,321	1,953,184	7032	73688
26141 MI Presque Isle	LP	N	7,380,021	2,514,124	4,865,897	0.68544762	0.56189444	1,723,300	2,734,120	44336	103151
26143 MI Roscommon	LP	S	2,155,717	191,913	1,963,804	0.95282162	0.75485393	182,859	1,482,385	4704	55926
26145 MI Saginaw	LP	S	4,749,511	227,164	4,522,347	0.95282162	0.75485393	216,447	3,413,711	5569	128790
26151 MI Sanilac	LP	S	3,111,512	335,663	2,775,849	0.95282162	0.75485393	319,827	2,095,361	8228	79052
26155 MI Shiawassee	LP	S	918,447	0	918,447	0.95282162	0.75485393	0	693,293	0	26156
26157 MI Tuscola	LP	S	3,913,234	420,931	3,492,303	0.95282162	0.75485393	401,072	2,636,179	10318	99456
26165 MI Wexford	LP	N	6,092,443	2,338,198	3,754,245	0.68544762	0.56189444	1,602,712	2,109,489	41233	79585

Appendix B4-I Distance Data

County (supplier)	Rectilinear Distance (miles)								
	Manton	Roscommon	Kingsley	Kalkaska	Gaylord	Clare	West Branch	Traverse City	Boyne City
Alcona	109.381	63.45	104.17	79.97	75.95	117.35	60.19	101.94	105.33
Alpena	131.073	85.14	125.86	98.35	53.18	0.00	81.88	117.54	78.89
Antrim	53.136	62.16	47.92	20.41	24.75	100.29	94.71	39.60	20.92
Arenac	97.71	63.79	116.33	109.42	105.40	60.43	31.24	131.39	134.78
Barry	0.00	0.00	0.00	0.00	0.00	111.73	0.00	0.00	0.00
Bay	118.37	84.45	136.99	130.08	126.06	46.32	51.90	0.00	0.00
Benzie	46.02	79.94	27.39	47.56	92.72	118.07	112.49	28.37	88.89
Charlevoix	74.514	82.36	69.30	41.79	40.75	0.00	114.92	60.98	11.37
Cheboygan	115.246	69.31	110.03	82.52	37.36	0.00	95.24	101.71	41.19
Clare	56.68	47.11	75.30	68.39	79.06	15.37	50.37	90.36	93.75
Clinton	0.00	0.00	0.00	0.00	0.00	69.99	108.73	0.00	0.00
Crawford	58.04	14.42	52.83	31.22	27.20	66.01	46.97	53.18	56.57
Eaton	0.00	0.00	0.00	0.00	0.00	87.40	0.00	0.00	0.00
Emmet	101.01	86.58	95.80	68.28	44.97	0.00	119.14	87.48	26.95
Genesee	0	0	0	0	0	108.79	114.37	0	0
Gladwin	78.99	45.08	97.62	90.71	86.69	30.27	26.89	112.68	116.07
Grand Traverse	25.73	59.65	7.10	23.03	68.19	97.78	92.20	7.96	64.36
Gratiot	117.37	83.46	0.00	0.00	0.00	45.32	85.23	0.00	0.00
Huron	0.00	122.61	0.00	0.00	0.00	89.91	90.05	0.00	0.00
Ingham	0.00	0.00	0.00	0.00	0.00	105.71	0.00	0.00	0.00
Ionia	0.00	0.00	0.00	0.00	0.00	75.79	0.00	0.00	0.00
Iosco	89.64	55.72	108.26	101.36	97.33	93.12	35.96	0.00	126.71
Isabella	81.03	70.68	99.66	92.75	102.64	16.78	73.94	114.72	0.00
Kalkaska	34.15	37.79	28.94	7.84	43.74	75.92	70.34	29.81	39.91
Kent	102.06	0.00	0.00	0.00	0.00	94.10	0.00	0.00	0.00
Lake	48.94	94.87	54.15	81.67	126.83	62.65	98.13	62.47	123.00
Lapeer	0.00	0.00	0.00	0.00	0.00	127.71	133.29	0.00	0.00
Leelanau	56.721	90.64	38.10	45.00	62.06	128.77	123.19	23.04	58.22
Livingston	0	0	0	0	0	128.32	0	0	0
Manistee	37.99	83.92	43.20	70.71	115.88	99.01	93.43	51.52	112.04
Mason	70.92	116.85	76.13	103.65	0.00	85.35	0.00	84.45	0.00
Mecosta	57.34	94.88	75.96	81.67	0.00	40.98	98.14	91.02	0.00
Midland	103.19	69.27	121.81	114.91	110.89	31.14	50.15	136.87	0.00
Missaukee	20.15	35.71	38.78	31.87	67.67	51.90	46.32	53.84	63.83
Montcalm	88.88	108.68	107.51	100.60	0.00	54.78	111.94	0.00	0.00
Montmorency	105.497	59.56	100.28	72.77	27.61	113.47	56.30	91.97	55.60
Muskegon	114.71	0.00	119.92	0.00	0.00	106.74	0.00	0.00	0.00
Newaygo	78.92	124.86	84.14	111.65	0.00	70.96	128.12	92.46	0.00
Oceana	96.32	0.00	101.54	129.05	0.00	88.36	0.00	109.86	0.00
Ogemaw	67.46	33.54	86.09	79.18	75.16	66.80	9.64	101.15	104.54
Osceola	33.02	71.03	51.65	57.82	102.98	39.03	74.29	66.71	99.15
Oscoda	82.053	36.12	76.84	54.54	50.52	90.02	32.86	76.50	79.89
Otsego	81.523	37.59	76.31	48.80	4.02	89.49	70.14	67.99	33.40
Ottawa	0	0	0	0	0	121.76	0	0	0
Presque Isle	137.05	91.12	131.84	104.32	59.16	0.00	87.86	123.52	62.99
Roscommon	43.86	11.56	62.49	55.58	51.56	42.34	22.61	77.55	80.94
Saginaw	0.00	107.70	0.00	0.00	0.00	69.57	75.15	0.00	0.00
Sanilac	0.00	0.00	0.00	0.00	0.00	0.00	129.01	0.00	0.00
Shiawassee	0.00	0.00	0.00	0.00	0.00	91.87	97.45	0.00	0.00
Tuscola	0.00	129.69	0.00	0.00	0.00	91.56	97.14	0.00	0.00
Wexford	13.86	59.80	19.08	46.59	91.75	75.74	70.16	30.00	87.92

Appendix B4-J Cost Data

County (supplier)	Cost Intensity ($/ton)								
	Manton	Roscommon	Kingsley	Kalkaska	Gaylord	Clare	West Branch	Traverse City	Boyne City
Alcona	19.9084	13.1103	19.1369	15.5559	14.9607	21.0877	12.6278	18.8070	19.3088
Alpena	23.1188	16.3207	22.3473	18.2752	11.5911	999.0000	15.8382	21.1161	15.3963
Antrim	11.5841	12.9195	10.8126	6.7405	7.3836	18.5629	17.7372	9.5814	6.8163
Arenac	18.1805	13.1605	20.9370	19.9146	19.3195	12.6633	8.3428	23.1657	23.6676
Barry	999.0000	999.0000	999.0000	999.0000	999.0000	20.2563	999.0000	999.0000	999.0000
Bay	21.2382	16.2182	23.9947	22.9723	22.3772	10.5748	11.4005	999.0000	999.0000
Benzie	10.5307	15.5507	7.7742	10.7590	17.4432	21.1941	20.3684	7.9182	16.8759
Charlevoix	14.7481	15.9097	13.9765	9.9045	9.7507	999.0000	20.7274	12.7453	5.4026
Cheboygan	20.7764	13.9783	20.0049	15.9328	9.2487	999.0000	17.8148	18.7737	9.8160
Clare	12.1080	10.6915	14.8645	13.8422	15.4212	5.9954	11.1740	17.0933	17.5951
Clinton	999.0000	999.0000	999.0000	999.0000	999.0000	14.0778	19.8114	999.0000	999.0000
Crawford	12.3102	5.8540	11.5387	8.3401	7.7450	13.4895	10.6717	11.5912	12.0931
Eaton	999.0000	999.0000	999.0000	999.0000	999.0000	16.6545	999.0000	999.0000	999.0000
Emmet	18.6695	16.5343	17.8980	13.8259	10.3753	999.0000	21.3520	16.6667	7.7090
Genesee	999.0000	999.0000	999.0000	999.0000	999.0000	19.8211	20.6468	999.0000	999.0000
Gladwin	15.4111	10.3911	18.1676	17.1452	16.5501	8.1997	7.7002	20.3963	20.8982
Grand Traverse	7.5277	12.5478	4.7712	7.1280	13.8121	18.1911	17.3655	4.8975	13.2448
Gratiot	21.0914	16.0713	999.0000	999.0000	999.0000	10.4280	16.3333	999.0000	999.0000
Huron	999.0000	21.8657	999.0000	999.0000	999.0000	17.0265	17.0480	999.0000	999.0000
Ingham	999.0000	999.0000	999.0000	999.0000	999.0000	19.3646	999.0000	999.0000	999.0000
Ionia	999.0000	999.0000	999.0000	999.0000	999.0000	14.9365	999.0000	999.0000	999.0000
Iosco	16.9864	11.9664	19.7429	18.7205	18.1254	17.5021	9.0422	999.0000	22.4735
Isabella	15.7126	14.1806	18.4691	17.4467	18.9103	6.2033	14.6631	20.6978	999.0000
Kalkaska	8.7742	9.3131	8.0027	4.8811	10.1935	14.9565	14.1308	8.1322	9.6262
Kent	18.8255	999.0000	999.0000	999.0000	999.0000	17.6462	999.0000	999.0000	999.0000
Lake	10.9631	17.7612	11.7346	15.8067	22.4908	12.9928	18.2437	12.9659	21.9236
Lapeer	999.0000	999.0000	999.0000	999.0000	999.0000	22.6214	23.4471	999.0000	999.0000
Leelanau	12.1147	17.1347	9.3582	10.3806	12.9044	22.7781	21.9524	7.1295	12.3372
Livingston	999.0000	999.0000	999.0000	999.0000	999.0000	22.7106	999.0000	999.0000	999.0000
Manistee	9.3419	16.1400	10.1135	14.1855	20.8696	18.3738	17.5481	11.3447	20.3024
Mason	14.2160	21.0141	14.9875	19.0596	999.0000	16.3517	999.0000	16.2187	999.0000
Mecosta	12.2062	17.7622	14.9627	15.8078	999.0000	9.7849	18.2447	17.1914	999.0000
Midland	18.9920	13.9720	21.7485	20.7261	20.1310	8.3286	11.1416	23.9772	999.0000
Missaukee	6.7023	9.0051	9.4588	8.4365	13.7347	11.4011	10.5754	11.6876	13.1674
Montcalm	16.8748	19.8051	19.6313	18.6089	999.0000	11.8277	20.2876	999.0000	999.0000
Montmorency	19.3336	12.5355	18.5620	14.4900	7.8058	20.5128	12.0530	17.3308	11.9491
Muskegon	20.6968	999.0000	21.4683	999.0000	999.0000	19.5175	999.0000	999.0000	999.0000
Newaygo	15.4008	22.1988	16.1723	20.2443	999.0000	14.2215	22.6813	17.4035	999.0000
Oceana	17.9758	999.0000	18.7473	22.8194	999.0000	16.7965	999.0000	19.9785	999.0000
Ogemaw	13.7045	8.6845	16.4610	15.4386	14.8435	13.6068	5.1470	18.6898	19.1916
Osceola	8.6071	14.2318	11.3636	12.2774	18.9615	9.4963	14.7143	13.5923	18.3942
Oscoda	15.8638	9.0658	15.0923	11.7913	11.1962	17.0431	8.5833	15.0424	15.5443
Otsego	15.7854	9.2836	15.0139	10.9418	4.3154	16.9647	14.1013	13.7827	8.6635
Ottawa	999.0000	999.0000	999.0000	999.0000	999.0000	21.7406	999.0000	999.0000	999.0000
Presque Isle	24.0034	17.2053	23.2319	19.1598	12.4757	999.0000	16.7228	22.0007	13.0430
Roscommon	10.2119	5.4313	12.9684	11.9460	11.3509	9.9860	7.0658	15.1971	15.6990
Saginaw	999.0000	19.6599	999.0000	999.0000	999.0000	14.0165	14.8422	999.0000	999.0000
Sanilac	999.0000	999.0000	999.0000	999.0000	999.0000	999.0000	22.8130	999.0000	999.0000
Shiawassee	999.0000	999.0000	999.0000	999.0000	999.0000	17.3171	18.1427	999.0000	999.0000
Tuscola	999.0000	22.9147	999.0000	999.0000	999.0000	17.2713	18.0970	999.0000	999.0000
Wexford	5.7716	12.5697	6.5431	10.6152	17.2993	14.9289	14.1032	8.1597	16.7320

Note: where 999.00 is indicated that means the county is not available to supply feedstock to that specific location.

Appendix B4-K Energy Data

County	Energy Intensity (1000 Btu/ton)								
(supplier)	Manton	Roscommon	Kingsley	Kalkaska	Gaylord	Clare	West Branch	Traverse City	Boyne City
Alcona	485.790	339.502	469.187	392.128	379.322	511.166	329.120	462.088	472.888
Alpena	554.874	408.587	538.272	450.645	306.810	99999.000	398.204	511.778	388.695
Antrim	306.661	335.397	290.058	202.432	216.270	456.837	439.069	263.564	204.062
Arenac	448.607	340.582	507.924	485.923	473.117	329.884	236.910	555.884	566.684
Barry	99999.000	99999.000	99999.000	99999.000	99999.000	493.277	99999.000	99999.000	99999.000
Bay	514.405	406.380	573.722	551.721	538.915	284.940	302.708	99999.000	99999.000
Benzie	283.991	392.016	224.674	288.905	432.740	513.456	495.688	227.773	420.533
Charlevoix	374.745	399.743	358.143	270.516	267.207	99999.000	503.414	331.648	173.641
Cheboygan	504.468	358.181	487.866	400.240	256.404	99999.000	440.737	461.372	268.612
Clare	317.935	287.453	377.252	355.251	389.230	186.396	297.835	425.212	436.011
Clinton	99999.000	99999.000	99999.000	99999.000	99999.000	360.321	483.704	99999.000	99999.000
Crawford	322.285	183.355	305.683	236.853	224.047	347.662	287.026	306.813	317.613
Eaton	99999.000	99999.000	99999.000	99999.000	99999.000	415.769	99999.000	99999.000	99999.000
Emmet	459.130	413.183	442.527	354.901	280.647	99999.000	516.854	416.033	223.273
Genesee	99999.000	99999.000	99999.000	99999.000	99999.000	483.911	501.679	99999.000	99999.000
Gladwin	389.013	280.988	448.330	426.329	413.523	233.831	223.082	496.290	507.090
Grand Traverse	219.372	327.397	160.055	210.769	354.605	448.836	431.068	162.771	342.397
Gratiot	511.246	403.220	99999.000	99999.000	99999.000	281.781	408.858	99999.000	99999.000
Huron	99999.000	527.909	99999.000	99999.000	99999.000	423.775	424.237	99999.000	99999.000
Ingham	99999.000	99999.000	99999.000	99999.000	99999.000	474.089	99999.000	99999.000	99999.000
Ionia	99999.000	99999.000	99999.000	99999.000	99999.000	378.799	99999.000	99999.000	99999.000
Iosco	422.912	314.887	482.229	460.228	447.422	434.008	251.962	99999.000	540.989
Isabella	395.501	362.535	454.817	432.817	464.311	190.871	372.917	502.777	99999.000
Kalkaska	246.194	257.790	229.592	162.418	276.736	379.229	361.461	232.378	264.529
Kent	462.486	99999.000	99999.000	99999.000	99999.000	437.110	99999.000	99999.000	99999.000
Lake	293.297	439.585	309.899	397.526	541.361	336.973	449.967	336.394	529.154
Lapeer	99999.000	99999.000	99999.000	99999.000	99999.000	544.170	561.938	99999.000	99999.000
Leelanau	318.078	426.103	258.761	280.762	335.072	547.543	529.775	210.801	322.865
Livingston	99999.000	99999.000	99999.000	99999.000	99999.000	546.091	99999.000	99999.000	99999.000
Manistee	258.411	404.698	275.013	362.640	506.475	452.766	434.998	301.508	494.268
Mason	363.296	509.583	379.898	467.525	99999.000	409.252	99999.000	406.393	99999.000
Mecosta	320.046	439.607	379.363	397.548	99999.000	267.943	449.989	427.323	99999.000
Midland	466.069	358.044	525.386	503.386	490.580	236.604	297.138	573.346	99999.000
Missaukee	201.610	251.162	260.927	238.926	352.939	302.721	284.953	308.887	340.732
Montcalm	420.511	483.567	479.828	457.827	99999.000	311.903	493.949	99999.000	99999.000
Montmorency	473.420	327.132	456.817	369.191	225.356	498.796	316.750	430.323	314.514
Muskegon	502.755	99999.000	519.357	99999.000	99999.000	477.379	99999.000	99999.000	99999.000
Newaygo	388.790	535.078	405.393	493.019	99999.000	363.414	545.460	431.887	99999.000
Oceana	444.202	99999.000	460.805	548.431	99999.000	418.826	99999.000	487.299	99999.000
Ogemaw	352.289	244.264	411.606	389.605	376.799	350.187	168.141	459.566	470.366
Osceola	242.598	363.637	301.915	321.578	465.413	261.733	374.019	349.875	453.206
Oscoda	398.755	252.468	382.153	311.119	298.313	424.132	242.086	381.080	391.879
Otsego	397.067	257.156	380.465	292.839	150.245	422.444	360.828	353.971	243.812
Ottawa	99999.000	99999.000	99999.000	99999.000	99999.000	525.217	99999.000	99999.000	99999.000
Presque Isle	573.910	427.622	557.307	469.681	325.846	99999.000	417.240	530.813	338.053
Roscommon	277.131	174.259	336.448	314.447	301.641	272.271	209.432	384.408	395.208
Saginaw	99999.000	480.442	99999.000	99999.000	99999.000	359.003	376.771	99999.000	99999.000
Sanilac	99999.000	99999.000	99999.000	99999.000	99999.000	99999.000	548.294	99999.000	99999.000
Shiawassee	99999.000	99999.000	99999.000	99999.000	99999.000	430.027	447.795	99999.000	99999.000
Tuscola	99999.000	550.482	99999.000	99999.000	99999.000	429.043	446.811	99999.000	99999.000
Wexford	181.581	327.868	198.183	285.810	429.645	378.637	360.869	232.971	417.437

Note: where 99999.00 is indicated that means the county is not available to supply feedstock to that specific location.

Appendix B4-L Emissions Data

County (supplier)	GHG Emissions Intensity (lb/ton)								
	Manton	Roscommon	Kingsley	Kalkaska	Gaylord	Clare	West Branch	Traverse City	Boyne City
Alcona	108.0733	73.4398	104.1427	85.8989	82.8671	114.0811	70.9818	102.4620	105.0188
Alpena	124.4290	89.7956	120.4984	99.7529	65.7000	999.0000	87.3375	114.2259	85.0861
Antrim	65.6645	72.4679	61.7339	40.9884	44.2645	101.2187	97.0121	55.4614	41.3744
Arenac	99.2703	73.6954	113.3136	108.1049	105.0731	71.1627	49.1512	124.6681	127.2249
Barry	999.0000	999.0000	999.0000	999.0000	999.0000	109.8459	999.0000	999.0000	999.0000
Bay	114.8480	89.2730	128.8912	123.6826	120.6507	60.5223	64.7288	999.0000	999.0000
Benzie	60.2976	85.8725	46.2543	61.4610	95.5139	114.6233	110.4167	46.9880	92.6238
Charlevoix	81.7836	87.7017	77.8530	57.1074	56.3240	999.0000	112.2459	71.5804	34.1722
Cheboygan	112.4955	77.8620	108.5649	87.8193	53.7664	999.0000	97.4072	102.2924	56.6565
Clare	68.3337	61.1172	82.3770	77.1683	85.2127	37.1920	63.5752	93.7314	96.2883
Clinton	999.0000	999.0000	999.0000	999.0000	999.0000	78.3687	107.5794	999.0000	999.0000
Crawford	69.3637	36.4719	65.4331	49.1376	46.1058	75.3715	61.0161	65.7007	68.2576
Eaton	999.0000	999.0000	999.0000	999.0000	999.0000	91.4958	999.0000	999.0000	999.0000
Emmet	101.7615	90.8836	97.8309	77.0854	59.5059	999.0000	115.4278	91.5584	45.9226
Genesee	999.0000	999.0000	999.0000	999.0000	999.0000	107.6284	111.8350	999.0000	999.0000
Gladwin	85.1615	59.5866	99.2047	93.9961	90.9643	48.4221	45.8773	110.5592	113.1160
Grand Traverse	44.9989	70.5738	30.9557	42.9624	77.0153	99.3246	95.1180	31.5988	74.1252
Gratiot	114.1000	88.5251	999.0000	999.0000	999.0000	59.7743	89.8597	999.0000	999.0000
Huron	999.0000	118.0449	999.0000	999.0000	999.0000	93.3914	93.5007	999.0000	999.0000
Ingham	999.0000	999.0000	999.0000	999.0000	999.0000	105.3031	999.0000	999.0000	999.0000
Ionia	999.0000	999.0000	999.0000	999.0000	999.0000	82.7434	999.0000	999.0000	999.0000
Iosco	93.1871	67.6121	107.2303	102.0217	98.9898	95.8140	52.7146	999.0000	121.1416
Isabella	86.6974	78.8927	100.7406	95.5320	102.9883	38.2514	81.3508	112.0951	999.0000
Kalkaska	51.3491	54.0944	47.4185	31.5151	58.5800	82.8452	78.6386	48.0782	55.6899
Kent	102.5563	999.0000	999.0000	999.0000	999.0000	96.5484	999.0000	999.0000	999.0000
Lake	62.5008	97.1342	66.4314	87.1769	121.2298	72.8411	99.5923	72.7039	118.3397
Lapeer	999.0000	999.0000	999.0000	999.0000	999.0000	121.8948	126.1014	999.0000	999.0000
Leelanau	68.3676	93.9426	54.3244	59.5330	72.3910	122.6933	118.4868	42.9699	69.5009
Livingston	999.0000	999.0000	999.0000	999.0000	999.0000	122.3495	999.0000	999.0000	999.0000
Manistee	54.2414	88.8749	58.1720	78.9176	112.9705	100.2550	96.0485	64.4446	110.0804
Mason	79.0729	113.7064	83.0035	103.7491	999.0000	89.9531	999.0000	89.2761	999.0000
Mecosta	68.8336	97.1395	82.8769	87.1822	999.0000	56.4982	99.5976	94.2313	999.0000
Midland	103.4045	77.8296	117.4478	112.2391	109.2073	49.0788	63.4101	128.8022	999.0000
Missaukee	40.7939	52.5253	54.8371	49.6285	76.6209	64.7318	60.5253	66.1916	73.7308
Montcalm	92.6185	107.5470	106.6618	101.4532	999.0000	66.9056	110.0050	999.0000	999.0000
Montmorency	105.1447	70.5113	101.2141	80.4686	46.4157	111.1526	68.0532	94.9416	67.5239
Muskegon	112.0898	999.0000	116.0204	999.0000	999.0000	106.0820	999.0000	999.0000	999.0000
Newaygo	85.1087	119.7422	89.0393	109.7849	999.0000	79.1008	122.2002	95.3118	999.0000
Oceana	98.2275	999.0000	102.1581	122.9037	999.0000	92.2197	999.0000	108.4307	999.0000
Ogemaw	76.4671	50.8922	90.5104	85.3017	82.2699	75.9695	32.8701	101.8648	104.4217
Osceola	50.4978	79.1536	64.5411	69.1963	103.2492	55.0279	81.6116	75.8956	100.3591
Oscoda	87.4680	52.8345	83.5374	66.7201	63.6883	93.4758	50.3764	83.2833	85.8401
Otsego	87.0683	53.9444	83.1377	62.3922	28.6333	93.0762	78.4886	76.8652	50.7851
Ottawa	999.0000	999.0000	999.0000	999.0000	999.0000	117.4078	999.0000	999.0000	999.0000
Presque Isle	128.9357	94.3022	125.0051	104.2595	70.2066	999.0000	91.8442	118.7326	73.0967
Roscommon	58.6735	34.3185	72.7167	67.5081	64.4762	57.5229	42.6457	84.0712	86.6280
Saginaw	999.0000	106.8073	999.0000	999.0000	999.0000	78.0565	82.2631	999.0000	999.0000
Sanilac	999.0000	999.0000	999.0000	999.0000	999.0000	999.0000	122.8713	999.0000	999.0000
Shiawassee	999.0000	999.0000	999.0000	999.0000	999.0000	94.8715	99.0781	999.0000	999.0000
Tuscola	999.0000	123.3893	999.0000	999.0000	999.0000	94.6385	98.8451	999.0000	999.0000
Wexford	36.0519	70.6854	39.9826	60.7281	94.7810	82.7049	78.4984	48.2185	91.8909

Note: where 999.00 is indicated that means the county is not available to supply feedstock to that specific location.

Appendix B4-M Data Requirements Summary Tables

Components of the Supply Chain Model	Inputs	Information Requests from Other Team Members (Tentative Data Needs)	Used in Simulation Model?	Used in Optimization Model?	Subtask Responsible	Notes
Harvesting/Processing	Harvest areas	Total feedstock availability by county, by type of ownership	X	X	Task A1~4	Ownership type refers to federal, state, private - company, private individual landowner; assumption is aggregate feedstock and from the centroid of the county.
	Seasonal factors	Length of spring breakup by county (historical trends)	X		Task B4	Using the lower peninsula counties and after statistically analyzing the data, it would appear that using the two month timeframe indicated at the MDOT website would be the most reliable.
	Energy consumption rates	Btu/ton-km	X	X	Task B5	Robert Handler provided
	Emissions rates	lbs GHG/ton-km	X	X	Task B5	Robert Handler provided
	Production (demand)	Average daily production requirement at biorefinery	X		Task B4	Assumed yearly annual production of 30, 40, and 50 million and a 50 weeks per year will allow for weekly and daily average production. It is assumed to be constant
Feedstock Inventory and Availability (Supply)	Competing purchasers of feedstock supply	Total feedstock consumed by other users such as biomass CHP and pulp mills	X	X	Task A3	We have a list of the biomass fired power plants existing and one that has been permitted. We do not have a list of the pulp mills. The total other consumption will reduce the total availability for the biorefinery(ies).
	Feedstock availability	Timing of harvesting and spring break-up considerations	X		Task B4	Assumed two month period starting March 1 and ending April 30.
	Target Supply	Target supply at biorefinery	X	X	Task B4	Demand at biorefinery

Transportation	Location and network connectivity	Location of harvesting areas	X		Task B4	Assumed to be entroid of each county
	Distances	Harvest area to biorefinery	X	X	Task B1	Preliminary is based on the rectalinear distance using latitutde and longitude.
	Travel Time	Harvest area to biorefinery	X		Task B1	Based on the average road speed for truck
	Vehicle capacity	Batch size per truck	X		Task B1	Status report 1
	Vehicle capacity	Trucks/day	X		Task B4	Calculated
	Vehicles required	Maximum number of trucks	X		Task B4	Calculated
	Truck capacity	Tons of feedstock/truck	X		Task B1	Status report 1
	Transportation cost for truck	Truck transportation cost per ton by origin to destination	X	X	Task B1	Robert Handler provided
	Transportation cost	Transportation cost per mile by truck (per ton)	X	X	Task B1	Robert Handler provided
	Loading/unloading cost	Loading cost for truck	X	X	Task B1	Robert Handler provided
	Loading/unloading cost	Unloading cost for truck	X	X	Task B1	Robert Handler provided
	Energy consumption rates	Btu/ton-km	X	X	Task B5	Robert Handler provided
	Emissions rates	lbs/ton-km	X	X	Task B5	Robert Handler provided
	Feedstock availability	Federal forest management plans and state harvest plans	X	X	Task A1~4	
	Spring weight restrictions	Road restrictions associated with the spring thaw that limit use of truck transport	X		Task B4	Documented the policy
	Regulations and policies	Load restrictions by class of road/vehicle weight restrictions	X		Task B1	Same as above - MDOT
	Land restrictions	Identify counties with federal and state land restrictions for harvesting (i.e. dune areas etc.)	X	X	Task A1-A4	

Appendix B4-N Cost Optimization Results and Supply Locations for 50 MGY

MANTON COST OPTIMIZATION - 50MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Benzie	$10.53066	26,195	101,329
Grand Traverse	$ 7.52774	117,902	117,902
Kalkaska	$ 8.77420	171,816	171,816
Manistee	$ 9.34193	206,185	206,185
Missaukee	$ 6.70235	193,406	193,406
Osceola	$ 8.60711	140,038	140,038
Roscommon	$10.21187	148,910	148,910
Wexford	$ 5.77158	245,548	245,548
Feedstock Demand		1,250,000	
Total Transportation Cost			$ 10,036,544.95
Transportation Cost Per Ton			$ 8.02924

ROSCOMMON COST OPTIMIZATION - 50MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Crawford	$183.35463	120,789	120,789
Kalkaska	$257.78978	152,750	171,816
Missaukee	$251.16221	193,406	193,406
Ogemaw	$244.26393	122,488	122,488
Oscoda	$252.46798	236,738	236,738
Otsego	$257.15600	274,920	274,920
Roscommon	$174.25884	148,910	148,910
Feedstock Demand		1,250,000	
Total Transportation Cost			$ 10,442,290.00
Transportation Cost Per Ton			$ 8.35383

KINGSLEY COST OPTIMIZATION - 50MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	$10.81260	134,827	134,827
Benzie	$ 7.77416	101,329	101,329
Grand Traverse	$ 4.77124	117,902	117,902
Kalkaska	$ 8.00268	171,816	171,816
Leelanau	$ 9.35821	48,922	48,922
Manistee	$10.11345	206,185	206,185
Missaukee	$ 9.45885	193,406	193,406
Osceola	$11.36361	30,064	140,038
Wexford	$ 6.54310	245,548	245,548
Feedstock Demand		1,250,000	
Total Transportation Cost			$ 10,503,858
Transportation Cost Per Ton			$ 8.40309

KALKASKA COST OPTIMIZATION - 50MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	$ 6.74053	134,827	134,827
Benzie	$ 10.75903	101,329	101,329
Charlevoix	$ 9.90448	96,751	96,751
Crawford	$ 8.34012	120,789	120,789
Grand Traverse	$ 7.12800	117,902	117,902
Kalkaska	$ 4.88106	171,816	171,816
Leelanau	$ 10.38059	48,922	48,922
Missaukee	$ 8.43646	193,406	193,406
Otsego	$ 10.94181	18,710	274,920
Wexford	$ 10.61517	245,548	245,548
Feedstock Demand		1,250,000	
Total Transportation Cost			$ 10,594,473
Transportation Cost Per Ton			$ 8.47558

GAYLORD COST OPTIMIZATION - 50MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	$ 7.38359	134,827	134,827
Charlevoix	$ 9.75070	96,751	96,751
Cheboygan	$ 9.24869	225,280	225,280
Crawford	$ 7.74501	120,789	120,789
Emmet	$ 10.37526	25,576	138,994
Kalkaska	$ 10.19352	171,816	171,816
Montmorency	$ 7.80584	200,041	200,041
Otsego	$ 4.31540	274,920	274,920
Feedstock Demand		1,250,000	
Total Transportation Cost			$ 9,722,602.31
Transportation Cost Per Ton			$ 7.77808

CLARE COST OPTIMIZATION - 50MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Bay	$ 10.57477	29,471	29,471
Clare	$ 5.99535	154,447	154,447
Gladwin	$ 8.19966	120,904	120,904
Gratiot	$ 10.42795	65,649	65,649
Isabella	$ 6.20329	147,913	147,913
Mecosta	$ 9.78489	161,937	161,937
Midland	$ 8.32857	105,192	105,192
Missaukee	$ 11.40105	175,539	193,406
Osceola	$ 9.49629	140,038	140,038
Roscommon	$ 9.98602	148,910	148,910
Feedstock Demand		1,250,000	
Total Transportation Cost			$ 11,109,941
Transportation Cost Per Ton			$ 8.88795

WEST BRANCH COST OPTIMIZATION - 50MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Arenac	$ 8.34278	118,833	118,833
Crawford	$ 10.67171	120,789	120,789
Gladwin	$ 7.70016	120,904	120,904
Iosco	$ 9.04223	159,343	159,343
Midland	$ 11.14161	28,591	105,192
Missaukee	$ 10.57536	193,406	193,406
Ogemaw	$ 5.14702	122,488	122,488
Oscoda	$ 8.58328	236,738	236,738
Roscommon	$ 7.06584	148,910	148,910
Feedstock Demand		1,250,000	
Total Transportation Cost			$ 10,730,698
Transportation Cost Per Ton			$ 8.58456

TRAVERSE CITY COST OPTIMIZATION - 50MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	$ 9.58139	134,827	134,827
Benzie	$ 7.91817	101,329	101,329
Crawford	$ 11.59123	120,789	120,789
Grand Traverse	$ 4.89749	117,902	117,902
Kalkaska	$ 8.13218	171,816	171,816
Leelanau	$ 7.12948	48,922	48,922
Manistee	$ 11.34466	206,185	206,185
Missaukee	$ 11.68758	102,682	193,406
Wexford	$ 8.15970	245,548	245,548
Feedstock Demand		1,250,000	
Total Transportation Cost			$ 11,360,514
Transportation Cost Per Ton			$ 9.08841

BOYNE CITY COST OPTIMIZATION - 50MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	$ 6.81631	134,827	134,827
Charlevoix	$ 5.40261	96,751	96,751
Cheboygan	$ 9.81597	225,280	225,280
Crawford	$ 12.09310	7,370	120,789
Emmet	$ 7.70904	138,994	138,994
Kalkaska	$ 9.62624	171,816	171,816
Montmorency	$ 11.94910	200,041	200,041
Otsego	$ 8.66350	274,920	274,920
Feedstock Demand		1,250,000	
Total Transportation Cost			$ 11,239,737
Transportation Cost Per Ton			$ 8.99179

Appendix B4-O Cost Optimization Results and Supply Locations for 40 MGY

MANTON COST OPTIMIZATION - 40MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Grand Traverse	$ 7.52774	117,902	117,902
Kalkaska	$ 8.77420	171,816	171,816
Manistee	$ 9.34193	131,290	206,185
Missaukee	$ 6.70235	193,406	193,406
Osceola	$ 8.60711	140,038	140,038
Wexford	$ 5.77158	245,548	245,548
Feedstock Demand		1,000,000	
Total Transportation Cost			$ 7,540,381.27
Transportation Cost Per Ton			$ 7.54038

ROSCOMMON COST OPTIMIZATION - 40MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Crawford	$ 183.35463	120,789	120,789
Missaukee	$ 251.16221	193,406	193,406
Ogemaw	$ 244.26393	122,488	122,488
Oscoda	$ 252.46798	236,738	236,738
Otsego	$ 257.15600	177,670	274,920
Roscommon	$ 174.25884	148,910	148,910
Feedstock Demand		1,000,000	
Total Transportation Cost			$ 8,116,887.00
Transportation Cost Per Ton			$ 8.11689

KINGSLEY COST OPTIMIZATION - 40MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Benzie	$ 7.77416	101,329	101,329
Grand Traverse	$ 4.77124	117,902	117,902
Kalkaska	$ 8.00268	171,816	171,816
Leelanau	$ 9.35821	48,922	48,922
Manistee	$ 10.11345	121,077	206,185
Missaukee	$ 9.45885	193,406	193,406
Wexford	$ 6.54310	245,548	245,548
Feedstock Demand		1,000,000	
Total Transportation Cost			$ 7,843,646.00
Transportation Cost Per Ton			$ 7.84365

KALKASKA COST OPTIMIZATION - 40MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	$ 6.74053	134,827	134,827
Charlevoix	$ 9.90448	96,751	96,751
Crawford	$ 8.34012	120,789	120,789
Grand Traverse	$ 7.12800	117,902	117,902
Kalkaska	$ 4.88106	171,816	171,816
Leelanau	$ 10.38059	48,922	48,922
Missaukee	$ 8.43646	193,406	193,406
Wexford	$ 10.61517	115,586	245,548
Feedstock Demand		1,000,000	
Total Transportation Cost			$ 7,919,992.00
Transportation Cost Per Ton			$ 7.91999

GAYLORD COST OPTIMIZATION - 40MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	$ 7.38359	134,827	134,827
Charlevoix	$ 9.75070	44,143	96,751
Cheboygan	$ 9.24869	225,280	225,280
Crawford	$ 7.74501	120,789	120,789
Montmorency	$ 7.80584	200,041	200,041
Otsego	$ 4.31540	274,920	274,920
Feedstock Demand		1,000,000	
Total Transportation Cost			$ 7,192,869.81
Transportation Cost Per Ton			$ 7.19287

CLARE COST OPTIMIZATION - 40MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Clare	$ 5.99535	154,447	154,447
Gladwin	$ 8.19966	120,904	120,904
Gratiot	$ 10.42795	20,659	65,649
Isabella	$ 6.20329	147,913	147,913
Mecosta	$ 9.78489	161,937	161,937
Midland	$ 8.32857	105,192	105,192
Osceola	$ 9.49629	140,038	140,038
Roscommon	$ 9.98602	148,910	148,910
Feedstock Demand		1,000,000	
Total Transportation Cost			$ 8,327,808.00
Transportation Cost Per Ton			$ 8.32781

WEST BRANCH COST OPTIMIZATION - 40MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Arenac	$ 8.34278	118,833	118,833
Gladwin	$ 7.70016	120,904	120,904
Iosco	$ 9.04223	159,343	159,343
Missaukee	$ 10.57536	92,785	193,406
Ogemaw	$ 5.14702	122,488	122,488
Oscoda	$ 8.58328	236,738	236,738
Roscommon	$ 7.06584	148,910	148,910
Feedstock Demand		1,000,000	
Total Transportation Cost			$ 8,059,031.00
Transportation Cost Per Ton			$ 8.05903

TRAVERSE CITY COST OPTIMIZATION - 40MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	$ 9.58139	134,827	134,827
Benzie	$ 7.91817	101,329	101,329
Grand Traverse	$ 4.89749	117,902	117,902
Kalkaska	$ 8.13218	171,816	171,816
Leelanau	$ 7.12948	48,922	48,922
Manistee	$ 11.34466	179,656	206,185
Wexford	$ 8.15970	245,548	245,548
Feedstock Demand		1,000,000	
Total Transportation Cost			$ 8,459,354.00
Transportation Cost Per Ton			$ 8.45935

BOYNE CITY COST OPTIMIZATION - 40MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	$ 6.81631	134,827	134,827
Charlevoix	$ 5.40261	96,751	96,751
Cheboygan	$ 9.81597	182,691	225,280
Emmet	$ 7.70904	138,994	138,994
Kalkaska	$ 9.62624	171,816	171,816
Otsego	$ 8.66350	274,920	274,920
Feedstock Demand		1,000,000	
Total Transportation Cost			$ 8,342,249.00
Transportation Cost Per Ton			$ 8.34225

Appendix B4-P Cost Optimization Results and Supply Locations for 30 MGY

MANTON COST OPTIMIZATION - 30MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Grand Traverse	$ 7.52774	117,902	117,902
Kalkaska	$ 8.77420	53,106	171,816
Missaukee	$ 6.70235	193,406	193,406
Osceola	$ 8.60711	140,038	140,038
Wexford	$ 5.77158	245,548	245,548
Feedstock Demand		750,000	
Total Transportation Cost			$ 5,272,294.46
Transportation Cost Per Ton			$ 7.02973

ROSCOMMON COST OPTIMIZATION - 30MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Crawford	$ 183.35463	120,789	120,789
Missaukee	$ 251.16221	193,406	193,406
Ogemaw	$ 244.26393	122,488	122,488
Oscoda	$ 252.46798	164,407	236,738
Roscommon	$ 174.25884	148,910	148,910
Feedstock Demand		750,000	
Total Transportation Cost			$ 5,811,741.00
Transportation Cost Per Ton			$ 7.74899

KINGSLEY COST OPTIMIZATION - 30MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Benzie	$ 7.77416	101,329	101,329
Grand Traverse	$ 4.77124	117,902	117,902
Kalkaska	$ 8.00268	171,816	171,816
Leelanau	$ 9.35821	48,922	48,922
Missaukee	$ 9.45885	64,483	193,406
Wexford	$ 6.54310	245,548	245,548
Feedstock Demand		750,000	
Total Transportation Cost			$ 5,399,676.00
Transportation Cost Per Ton			$ 7.19957

KALKASKA COST OPTIMIZATION - 30MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	$ 6.74053	134,827	134,827
Charlevoix	$ 9.90448	11,260	96,751
Crawford	$ 8.34012	120,789	120,789
Grand Traverse	$ 7.12800	117,902	117,902
Kalkaska	$ 4.88106	171,816	171,816
Missaukee	$ 8.43646	193,406	193,406
Feedstock Demand		750,000	
Total Transportation Cost			$ 5,338,434.00
Transportation Cost Per Ton			$ 7.11791

GAYLORD COST OPTIMIZATION - 30MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	$ 7.38359	134,827	134,827
Cheboygan	$ 9.24869	19,424	225,280
Crawford	$ 7.74501	120,789	120,789
Montmorency	$ 7.80584	200,041	200,041
Otsego	$ 4.31540	274,920	274,920
Feedstock Demand		750,000	
Total Transportation Cost			$ 4,858,537.19
Transportation Cost Per Ton			$ 6.47805

CLARE COST OPTIMIZATION - 30MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Clare	$ 5.99535	154,447	154,447
Gladwin	$ 8.19966	120,904	120,904
Isabella	$ 6.20329	147,913	147,913
Mecosta	$ 9.78489	81,505	161,937
Midland	$ 8.32857	105,192	105,192
Osceola	$ 9.49629	140,038	140,038
Feedstock Demand		750,000	
Total Transportation Cost			$ 5,838,350.00
Transportation Cost Per Ton			$ 7.78447

WEST BRANCH COST OPTIMIZATION - 30MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Arenac	$ 8.34278	118,833	118,833
Gladwin	$ 7.70016	120,904	120,904
Iosco	$ 9.04223	2,128	159,343
Ogemaw	$ 5.14702	122,488	122,488
Oscoda	$ 8.58328	236,738	236,738
Roscommon	$ 7.06584	148,910	148,910
Feedstock Demand		750,000	
Total Transportation Cost			$ 5,656,221.00
Transportation Cost Per Ton			$ 7.54163

TRAVERSE CITY COST OPTIMIZATION - 30MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	$ 9.58139	64,483	134,827
Benzie	$ 7.91817	101,329	101,329
Grand Traverse	$ 4.89749	117,902	117,902
Kalkaska	$ 8.13218	171,816	171,816
Leelanau	$ 7.12948	48,922	48,922
Wexford	$ 8.15970	245,548	245,548
Feedstock Demand		750,000	
Total Transportation Cost			$ 5,747,224.00
Transportation Cost Per Ton			$ 7.66297

BOYNE CITY COST OPTIMIZATION - 30MGY			
County	*Cost/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	$ 6.81631	134,827	134,827
Charlevoix	$ 5.40261	96,751	96,751
Emmet	$ 7.70904	138,994	138,994
Kalkaska	$ 9.62624	104,508	171,816
Otsego	$ 8.66350	274,920	274,920
Feedstock Demand		750,000	
Total Transportation Cost			$ 5,901,027.00
Transportation Cost Per Ton			$ 7.86804

Appendix B4-Q Energy Optimization Results and Supply Locations for 50 MGY

MANTON ENERGY OPTIMIZATION - 50MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Benzie	283.991	26195	101329
Grand Traverse	219.372	117902	117902
Kalkaska	246.194	171816	171816
Manistee	258.411	206185	206185
Missaukee	201.610	193406	193406
Osceola	242.598	140038	140038
Roscommon	277.131	148910	148910
Wexford	181.581	245548	245548
Feedstock Demand		1,250,000	
Total Energy in 1000 Btus			287,703,874
Total Energy Per Ton			230.163

ROSCOMMON ENERGY OPTIMIZATION - 50MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Crawford	183.355	120,789	120,789
Kalkaska	257.790	152,750	171,816
Missaukee	251.162	193,406	193,406
Ogemaw	244.264	122,488	122,488
Oscoda	252.468	236,738	236,738
Otsego	257.156	274,920	274,920
Roscommon	174.259	148,910	148,910
Feedstock Demand		1,250,000	
Total Energy in 1000 Btus			296,435,065
Total Energy Per Ton			237.148

KINGSLEY ENERGY OPTIMIZATION - 50MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	290.058	134,827	134,827
Benzie	224.674	101,329	101,329
Grand Traverse	160.055	117,902	117,902
Kalkaska	229.592	171,816	171,816
Leelanau	258.761	48,922	48,922
Manistee	275.013	206,185	206,185
Missaukee	260.927	193,406	193,406
Osceola	301.915	30,064	140,038
Wexford	198.183	245,548	245,548
Feedstock Demand		1,250,000	
Total Energy in 1000 Btus			297,759,956
Total Energy Per Ton			238.208

KALKASKA ENERGY OPTIMIZATION - 50MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	202.432	134,827	134,827
Benzie	288.905	101,329	101,329
Charlevoix	270.516	96,751	96,751
Crawford	236.853	120,789	120,789
Grand Traverse	210.769	117,902	117,902
Kalkaska	162.418	171,816	171,816
Leelanau	280.762	48,922	48,922
Missaukee	238.926	193,406	193,406
Otsego	292.839	18,710	274,920
Wexford	285.810	245,548	245,548
Feedstock Demand		1,250,000	
Total Energy in 1000 Btus			299,709,893
Total Energy Per Ton			239.768

GAYLORD ENERGY OPTIMIZATION - 50MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	216.270	134,827	134,827
Charlevoix	267.207	96,751	96,751
Cheboygan	256.404	225,280	225,280
Crawford	224.047	120,789	120,789
Emmet	280.647	25,576	138,994
Kalkaska	276.736	171,816	171,816
Montmorency	225.356	200,041	200,041
Otsego	150.245	274,920	274,920
Feedstock Demand		1,250,000	
Total Energy Green Ton Delivered (Btus)			280,948,168
Energy Per Green Ton Delivered (Btus)			224.759

CLARE ENERGY OPTIMIZATION - 50MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Bay	284.940	29,471	29,471
Clare	186.396	154,447	154,447
Gladwin	233.831	120,904	120,904
Gratiot	281.781	65,649	65,649
Isabella	190.871	147,913	147,913
Mecosta	267.943	161,937	161,937
Midland	236.604	105,192	105,192
Missaukee	302.721	175,539	193,406
Osceola	261.733	140,038	140,038
Roscommon	272.271	148,910	148,910
Feedstock Demand		1,250,000	
Total Energy in 1000 Btus			310,802,186
Total Energy Per Ton			248.642

WEST BRANCH ENERGY OPTIMIZATION - 50MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Arenac	236.910	118,833	118,833
Crawford	287.026	120,789	120,789
Gladwin	223.082	120,904	120,904
Iosco	251.962	159,343	159,343
Midland	297.138	28,591	105,192
Missaukee	284.953	193,406	193,406
Ogemaw	168.141	122,488	122,488
Oscoda	242.086	236,738	236,738
Roscommon	209.432	148,910	148,910
Feedstock Demand		1,250,000	
Total Energy in 1000 Btus			302,641,296
Total Energy Per Ton			242.113

TRAVERSE CITY ENERGY OPTIMIZATION - 50MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	263.56382	134,827	134,827
Benzie	227.77304	101,329	101,329
Crawford	306.81340	120,789	120,789
Grand Traverse	162.77127	117,902	117,902
Kalkaska	232.37826	171,816	171,816
Leelanau	210.80124	48,922	48,922
Manistee	301.50753	206,185	206,185
Missaukee	308.88671	102,682	193,406
Wexford	232.97063	245,548	245,548
Feedstock Demand		1,250,000	
Total Energy in 1000 Btus			316,194,255
Total Energy Per Ton			252.955

BOYNE CITY ENERGY OPTIMIZATION - 50MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	204.062	134,827	134,827
Charlevoix	173.641	96,751	96,751
Cheboygan	268.612	225,280	225,280
Crawford	317.613	7,370	120,789
Emmet	223.273	138,994	138,994
Kalkaska	264.529	171,816	171,816
Montmorency	314.514	200,041	200,041
Otsego	243.812	274,920	274,920
Feedstock Demand		1,250,000	
Total Energy in 1000 Btus			313,595,256
Total Energy Per Ton			250.876

Appendix B4-R Energy Optimization Results and Supply Locations for 40 MGY

MANTON ENERGY OPTIMIZATION - 40MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Grand Traverse	219.372	117,902	117,902
Kalkaska	246.194	171,816	171,816
Manistee	258.411	131,290	206,185
Missaukee	201.610	193,406	193,406
Osceola	242.598	140,038	140,038
Wexford	181.581	245,548	245,548
Feedstock Demand		1,000,000	
Total Energy in 1000 Btus			219,643,475
Total Energy Per Ton			219.643

ROSCOMMON ENERGY OPTIMIZATION - 40MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Crawford	183.355	120,789	120,789
Missaukee	251.162	193,406	193,406
Ogemaw	244.264	122,488	122,488
Oscoda	252.468	236,738	236,738
Otsego	257.156	177,670	274,920
Roscommon	174.259	148,910	148,910
Feedstock Demand		1,000,000	
Total Energy in 1000 Btus			262,049,255
Total Energy Per Ton			232.049

KINGSLEY ENERGY OPTIMIZATION - 40MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Benzie	224.674	101,329	101,329
Grand Traverse	160.055	117,902	117,902
Kalkaska	229.592	171,816	171,816
Leelanau	258.761	48,922	48,922
Manistee	275.013	121,077	206,185
Missaukee	260.927	193,406	193,406
Wexford	198.183	245,548	245,548
Feedstock Demand		1,000,000	
Total Energy in 1000 Btus			226,169,398
Total Energy Per Ton			226.169

KALKASKA ENERGY OPTIMIZATION - 40MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	202.432	134,827	134,827
Charlevoix	270.516	96,751	96,751
Crawford	236.853	120,789	120,789
Grand Traverse	210.769	117,902	117,902
Kalkaska	162.418	171,816	171,816
Leelanau	280.762	48,922	48,922
Missaukee	238.926	193,406	193,406
Wexford	285.810	115,586	245,548
Feedstock Demand		1,000,000	
Total Energy in 1000 Btus			227,812,297
Total Energy Per Ton			227.812

GAYLORD ENERGY OPTIMIZATION - 40MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	216.270	134,827	134,827
Charlevoix	267.207	44,143	96,751
Cheboygan	256.404	225,280	225,280
Crawford	224.047	120,789	120,789
Montmorency	225.356	200,041	200,041
Otsego	150.245	274,920	274,920
Feedstock Demand		1,000,000	
Total Energy in 1000 Btus			7,192,870
Total Energy Per Ton			7.193

CLARE ENERGY OPTIMIZATION - 40MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Clare	186.396	154,447	154,447
Gladwin	233.831	120,904	120,904
Gratiot	281.781	20,659	65,649
Isabella	190.871	147,913	147,913
Mecosta	267.943	161,937	161,937
Midland	236.604	105,192	105,192
Osceola	261.733	140,038	140,038
Roscommon	272.271	148,910	148,910
Feedstock Demand		1,000,000	
Total Energy in 1000 Btus			236,588,055
Total Energy Per Ton			236.558

WEST BRANCH ENERGY OPTIMIZATION - 40MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Arenac	236.910	118,833	118,833
Gladwin	223.082	120,904	120,904
Iosco	251.962	159,343	159,343
Missaukee	284.953	92,785	193,406
Ogemaw	168.141	122,488	122,488
Oscoda	242.086	236,738	236,738
Roscommon	209.432	148,910	148,910
Feedstock Demand		1,000,000	
Total Energy in 1000 Btus			230,804,250
Total Energy Per Ton			230.804

TRAVERSE CITY ENERGY OPTIMIZATION - 40MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	263.56382	134,827	134,827
Benzie	227.77304	101,329	101,329
Grand Traverse	162.77127	117,902	117,902
Kalkaska	232.37826	171,816	171,816
Leelanau	210.80124	48,922	48,922
Manistee	301.50753	179,656	206,185
Wexford	232.97063	245,548	245,548
Feedstock Demand		1,000,000	
Total Energy in 1000 Btus			239,418,777
Total Energy Per Ton			239.419

BOYNE CITY ENERGY OPTIMIZATION - 40MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	204.062	134,827	134,827
Charlevoix	173.641	96,751	96,751
Cheboygan	268.612	182,691	225,280
Emmet	223.273	138,994	138,994
Kalkaska	264.529	171,816	171,816
Otsego	243.812	274,920	274,920
Feedstock Demand		1,000,000	
Total Energy in 1000 Btus			236,898,802
Total Energy Per Ton			236.899

Appendix B4-S Energy Optimization Results and Supply Locations for 30 MGY

MANTON ENERGY OPTIMIZATION - 30MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Grand Traverse	219.372	117,902	117,902
Kalkaska	246.194	53,106	171,816
Missaukee	201.610	193,406	193,406
Osceola	242.598	140,038	140,038
Wexford	181.581	245,548	245,548
Feedstock Demand		750,000	
Total Energy in 1000 Btus			156,491,043
Total Energy Per Ton			208.655

ROSCOMMON ENERGY OPTIMIZATION - 30MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Crawford	183.355	120,789	120,789
Missaukee	251.162	193,406	193,406
Ogemaw	244.264	122,488	122,488
Oscoda	252.468	164,407	236,738
Roscommon	174.259	148,910	148,910
Feedstock Demand		750,000	
Total Energy in 1000 Btus			168,099,340
Total Energy Per Ton			224.132

KINGSLEY ENERGY OPTIMIZATION - 30MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Benzie	224.674	101,329	101,329
Grand Traverse	160.055	117,902	117,902
Kalkaska	229.592	171,816	171,816
Leelanau	258.761	48,922	48,922
Missaukee	260.927	64,483	193,406
Wexford	198.183	245,548	245,548
Feedstock Demand		750,000	
Total Energy in 1000 Btus			159,232,166
Total Energy Per Ton			212.310

KALKASKA ENERGY OPTIMIZATION - 30MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	202.432	134,827	134,827
Charlevoix	270.516	11,260	96,751
Crawford	236.853	120,789	120,789
Grand Traverse	210.769	117,902	117,902
Kalkaska	162.418	171,816	171,816
Missaukee	238.926	193,406	193,406
Feedstock Demand		750,000	
Total Energy in 1000 Btus			157,914,298
Total Energy Per Ton			210.552

GAYLORD ENERGY OPTIMIZATION - 30MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	216.270	134,827	134,827
Cheboygan	256.404	19,424	225,280
Crawford	224.047	120,789	120,789
Montmorency	225.356	200,041	200,041
Otsego	150.245	274,920	274,920
Feedstock Demand		750,000	
Total Energy in 1000 Btus			147,587,434
Total Energy Per Ton			196.783

CLARE ENERGY OPTIMIZATION - 30MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Clare	186.396	154,447	154,447
Gladwin	233.831	120,904	120,904
Isabella	190.871	147,913	147,913
Mecosta	267.943	81,505	161,937
Midland	236.604	105,192	105,192
Osceola	261.733	140,038	140,038
Feedstock Demand		750,000	
Total Energy in 1000 Btus			168,671,944
Total Energy Per Ton			224.869

WEST BRANCH ENERGY OPTIMIZATION - 30MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Arenac	236.910	118,833	118,833
Gladwin	223.082	120,904	120,904
Iosco	251.962	2,128	159,343
Ogemaw	168.141	122,488	122,488
Oscoda	242.086	236,738	236,738
Roscommon	209.432	148,910	148,910
Feedstock Demand		750,000	
Total Energy in 1000 Btus			164,752,737
Total Energy Per Ton			219.670

TRAVERSE CITY ENERGY OPTIMIZATION - 30MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	263.56382	64,483	134,827
Benzie	227.77304	101,329	101,329
Grand Traverse	162.77127	117,902	117,902
Kalkaska	232.37826	171,816	171,816
Leelanau	210.80124	48,922	48,922
Wexford	232.97063	245,548	245,548
Feedstock Demand		750,000	
Total Energy in 1000 Btus			166,711,018
Total Energy Per Ton			222.281

BOYNE CITY ENERGY OPTIMIZATION - 30MGY			
County	*1000 Btus/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	204.062	134,827	134,827
Charlevoix	173.641	96,751	96,751
Emmet	223.273	138,994	138,994
Kalkaska	264.529	104,508	171,816
Otsego	243.812	274,920	274,920
Feedstock Demand		750,000	
Total Energy in 1000 Btus			170,020,685
Total Energy Per Ton			226.694

Appendix B4-T Emission Optimization Results and Supply Locations for 50 MGY

MANTON EMISSIONS OPTIMIZATION - 50MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Benzie	60.29757	26195	101329
Grand Traverse	44.99891	117902	117902
Kalkaska	51.34910	171816	171816
Manistee	54.24144	206185	206185
Missaukee	40.79385	193406	193406
Osceola	50.49783	140038	140038
Roscommon	58.67346	148910	148910
Wexford	36.05195	245548	245548
Feedstock Demand		1,250,000	
Total Emissions (in lbs.)			59,442,263
Total Emissions Per Ton			47.55381

ROSCOMMON EMISSIONS OPTIMIZATION - 50MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Crawford	36.4719	120789	120789
Kalkaska	54.0944	152750	171816
Missaukee	52.5253	193406	193406
Ogemaw	50.8922	122488	122488
Oscoda	52.8345	236738	236738
Otsego	53.9444	274920	274920
Roscommon	34.3185	148910	148910
Feedstock Demand		1,250,000	
Total Emissions (in lbs.)			61,509,368
Total Emissions Per Ton			49.20749

KINGSLEY EMISSIONS OPTIMIZATION - 50MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	61.73394	134,827	134,827
Benzie	46.25432	101,329	101,329
Grand Traverse	30.95566	117,902	117,902
Kalkaska	47.41850	171,816	171,816
Leelanau	54.32438	48,922	48,922
Manistee	58.17205	206,185	206,185
Missaukee	54.83710	193,406	193,406
Osceola	64.54108	30,064	140,038
Wexford	39.98255	245,548	245,548
Feedstock Demand		1,250,000	
Total Emissions (in lbs.)			61,823,036
Total Emissions Per Ton			49.458

KALKASKA EMISSIONS OPTIMIZATION - 50MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	40.98839	134826.91	134826.908
Benzie	61.46099	101328.75	101328.746
Charlevoix	57.1074	96751.322	96751.3222
Crawford	49.13762	120788.72	120788.717
Grand Traverse	42.96236	117902.29	117902.286
Kalkaska	31.51513	171816.43	171816.431
Leelanau	59.53302	48922.09	48922.0901
Missaukee	49.62847	193405.96	193405.958
Otsego	62.39218	18709.712	274919.592
Wexford	60.72811	245547.83	245547.829
Feedstock Demand		1,250,000	
Total Emissions (in lbs.)			62,284,682
Total Emissions Per Ton			49.82775

GAYLORD EMISSIONS OPTIMIZATION - 50MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	44.26452	134,827	134,827
Charlevoix	56.32399	96,751	96,751
Cheboygan	53.76642	225,280	225,280
Crawford	46.10578	120,789	120,789
Emmet	59.50587	25,576	138,994
Kalkaska	58.57996	171,816	171,816
Montmorency	46.41568	200,041	200,041
Otsego	28.63334	274,920	274,920
Feedstock Demand		1,250,000	
Total Emissions Green Ton Delivered (lbs)			57,842,852
Emissions Per Green Ton Delivered (lbs)			46.27428

CLARE EMISSIONS OPTIMIZATION - 50MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Bay	60.52226	29,471	29,471
Clare	37.19200	154,447	154,447
Gladwin	48.42207	120,904	120,904
Gratiot	59.77430	65,649	65,649
Isabella	38.25137	147,913	147,913
Mecosta	56.49817	161,937	161,937
Midland	49.07881	105,192	105,192
Missaukee	64.73185	175,539	193,406
Osceola	55.02787	140,038	140,038
Roscommon	57.52285	148,910	148,910
Feedstock Demand		1,250,000	
Total Emissions (in lbs.)			64,910,778
Total Emissions Per Ton			51.92865

WEST BRANCH EMISSIONS OPTIMIZATION - 50MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Arenac	49.15119	118,833	118,833
Crawford	61.01613	120,789	120,789
Gladwin	45.87732	120,904	120,904
Iosco	52.71459	159,343	159,343
Midland	63.41008	28,591	105,192
Missaukee	60.52528	193,406	193,406
Ogemaw	32.87007	122,488	122,488
Oscoda	50.37644	236,738	236,738
Roscommon	42.64568	148,910	148,910
Feedstock Demand		1,250,000	
Total Emissions (in lbs.)			62,978,691
Total Emissions Per Ton			50.38295

TRAVERSE CITY EMISSIONS OPTIMIZATION - 50MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	55.46142	134,827	134,827
Benzie	46.98796	101,329	101,329
Crawford	65.70074	120,789	120,789
Grand Traverse	31.59882	117,902	117,902
Kalkaska	48.07825	171,816	171,816
Leelanau	42.96990	48,922	48,922
Manistee	64.44457	206,185	206,185
Missaukee	66.19159	102,682	193,406
Wexford	48.21849	245,548	245,548
Feedstock Demand		1,250,000	
Total Emissions (in lbs.)			66,187,348
Total Emissions Per Ton			52.94988

BOYNE CITY EMISSIONS OPTIMIZATION - 50MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	41.37443	134,827	134,827
Charlevoix	34.17223	96,751	96,751
Cheboygan	56.65651	225,280	225,280
Crawford	68.25755	7,370	120,789
Emmet	45.92256	138,994	138,994
Kalkaska	55.68988	171,816	171,816
Montmorency	67.52391	200,041	200,041
Otsego	50.78511	274,920	274,920
Feedstock Demand		1,250,000	
Total Emissions (in lbs.)			65,572,036
Total Emissions Per Ton			52.45763

Appendix B4-U Emission Optimization Results and Supply Locations for 40 MGY

MANTON EMISSIONS OPTIMIZATION - 40MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Grand Traverse	44.99891	117,902	117,902
Kalkaska	51.34910	171,816	171,816
Manistee	54.24144	131,290	206,185
Missaukee	40.79385	193,406	193,406
Osceola	50.49783	140,038	140,038
Wexford	36.05195	245,548	245,548
Feedstock Demand		1,000,000	
Total Emissions (in lbs.)			45,063,294
Total Emissions Per Ton			46.06329

ROSCOMMON EMISSIONS OPTIMIZATION - 40MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Crawford	36.4719	120,789	120,789
Missaukee	52.5253	193,406	193,406
Ogemaw	50.8922	122,488	122,488
Oscoda	52.8345	236,738	236,738
Otsego	53.9444	177,670	274,920
Roscommon	34.3185	148,910	148,910
Feedstock Demand		1,000,000	
Total Emissions (in lbs.)			48,000,357
Total Emissions Per Ton			48.00036

KINGSLEY EMISSIONS OPTIMIZATION - 40MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Benzie	46.25432	101,329	101,329
Grand Traverse	30.95566	117,902	117,902
Kalkaska	47.41850	171,816	171,816
Leelanau	54.32438	48,922	48,922
Manistee	58.17205	121,077	206,185
Missaukee	54.83710	193,406	193,406
Wexford	39.98255	245,548	245,548
Feedstock Demand		1,000,000	
Total Emissions (in lbs.)			46,608,303
Total Emissions Per Ton			46.60830

KALKASKA EMISSIONS OPTIMIZATION - 40MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	40.98839	134,827	134,827
Charlevoix	57.1074	96,751	96,751
Crawford	49.13762	120,789	120,789
Grand Traverse	42.96236	117,902	117,902
Kalkaska	31.51513	171,816	171,816
Leelanau	59.53302	48,922	48,922
Missaukee	49.62847	193,406	193,406
Wexford	60.72811	115,586	245,548
Feedstock Demand		1,000,000	
Total Emissions (in lbs.)			46,997,259
Total Emissions Per Ton			46.99726

GAYLORD EMISSIONS OPTIMIZATION - 40MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	44.26452	134,827	134,827
Charlevoix	56.32399	44,143	96,751
Cheboygan	53.76642	225,280	225,280
Crawford	46.10578	120,789	120,789
Montmorency	46.41568	200,041	200,041
Otsego	28.63334	274,920	274,920
Feedstock Demand		1,000,000	
Total Emissions (in lbs.)			212,165,404
Total Emissions Per Ton			212.165

CLARE EMISSIONS OPTIMIZATION - 40MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Clare	37.19200	154,447	154,447
Gladwin	48.42207	120,904	120,904
Gratiot	59.77430	20,659	65,649
Isabella	38.25137	147,913	147,913
Mecosta	56.49817	161,937	161,937
Midland	49.07881	105,192	105,192
Osceola	55.02787	140,038	140,038
Roscommon	57.52285	148,910	148,910
Feedstock Demand		1,000,000	
Total Emissions (in lbs.)			49,074,916
Total Emissions Per Ton			49.07492

WEST BRANCH EMISSIONS OPTIMIZATION - 40MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Arenac	49.15119	118,833	118,833
Gladwin	45.87732	120,904	120,904
Iosco	52.71459	159,343	159,343
Missaukee	60.52528	92,785	193,406
Ogemaw	32.87007	122,488	122,488
Oscoda	50.37644	236,738	236,738
Roscommon	42.64568	148,910	148,910
Feedstock Demand		1,000,000	
Total Emissions (in lbs.)			47,705,603
Total Emissions Per Ton			47.70560

TRAVERSE CITY EMISSIONS OPTIMIZATION - 40MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	55.46142	134,827	134,827
Benzie	46.98796	101,329	101,329
Grand Traverse	31.59882	117,902	117,902
Kalkaska	48.07825	171,816	171,816
Leelanau	42.96990	48,922	48,922
Manistee	64.44457	179,656	206,185
Wexford	48.21849	245,548	245,548
Feedstock Demand		1,000,000	
Total Emissions (in lbs.)			49,745,088
Total Emissions Per Ton			49.74509

BOYNE CITY EMISSIONS OPTIMIZATION - 40MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	41.37443	134,827	134,827
Charlevoix	34.17223	96,751	96,751
Cheboygan	56.65651	182,691	225,280
Emmet	45.92256	138,994	138,994
Kalkaska	55.68988	171,816	171,816
Otsego	50.78511	274,920	274,920
Feedstock Demand		1,000,000	
Total Emissions (in lbs.)			49,148,485
Total Emissions Per Ton			49.14848

Appendix B4-V Emission Optimization Results and Supply Locations for 30 MGY

MANTON EMISSIONS OPTIMIZATION - 30MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Grand Traverse	44.99891	117,902	117,902
Kalkaska	51.34910	53,106	171,816
Missaukee	40.79385	193,406	193,406
Osceola	50.49783	140,038	140,038
Wexford	36.05195	245,548	245,548
Feedstock Demand		750,000	
Total Emissions (in lbs.)			31,846,284
Total Emissions Per Ton			42.46171

ROSCOMMON EMISSIONS OPTIMIZATION - 30MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Crawford	36.4719	120,789	120,789
Missaukee	52.5253	193,406	193,406
Ogemaw	50.8922	122,488	122,488
Oscoda	52.8345	164,407	236,738
Roscommon	34.3185	148,910	148,910
Feedstock Demand		750,000	
Total Emissions (in lbs.)			34,594,543
Total Emissions Per Ton			46.12606

KINGSLEY EMISSIONS OPTIMIZATION - 30MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Benzie	46.25432	101,329	101,329
Grand Traverse	30.95566	117,902	117,902
Kalkaska	47.41850	171,816	171,816
Leelanau	54.32438	48,922	48,922
Missaukee	54.83710	64,483	193,406
Wexford	39.98255	245,548	245,548
Feedstock Demand		750,000	
Total Emissions (in lbs.)			32,495,244
Total Emissions Per Ton			43.32699

KALKASKA EMISSIONS OPTIMIZATION - 30MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	40.98839	134,827	134,827
Charlevoix	57.1074	11,260	96,751
Crawford	49.13762	120,789	120,789
Grand Traverse	42.96236	117,902	117,902
Kalkaska	31.51513	171,816	171,816
Missaukee	49.62847	193,406	193,406
Feedstock Demand		750,000	
Total Emissions (in lbs.)			32,183,239
Total Emissions Per Ton			42.91099

GAYLORD EMISSIONS OPTIMIZATION - 30MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	44.26452	134,827	134,827
Cheboygan	53.76642	19,424	225,280
Crawford	46.10578	120,789	120,789
Montmorency	46.41568	200,041	200,041
Otsego	28.63334	274,920	274,920
Feedstock Demand		750,000	
Total Emissions (in lbs.)			29,738,358
Total Emissions Per Ton			39.65114

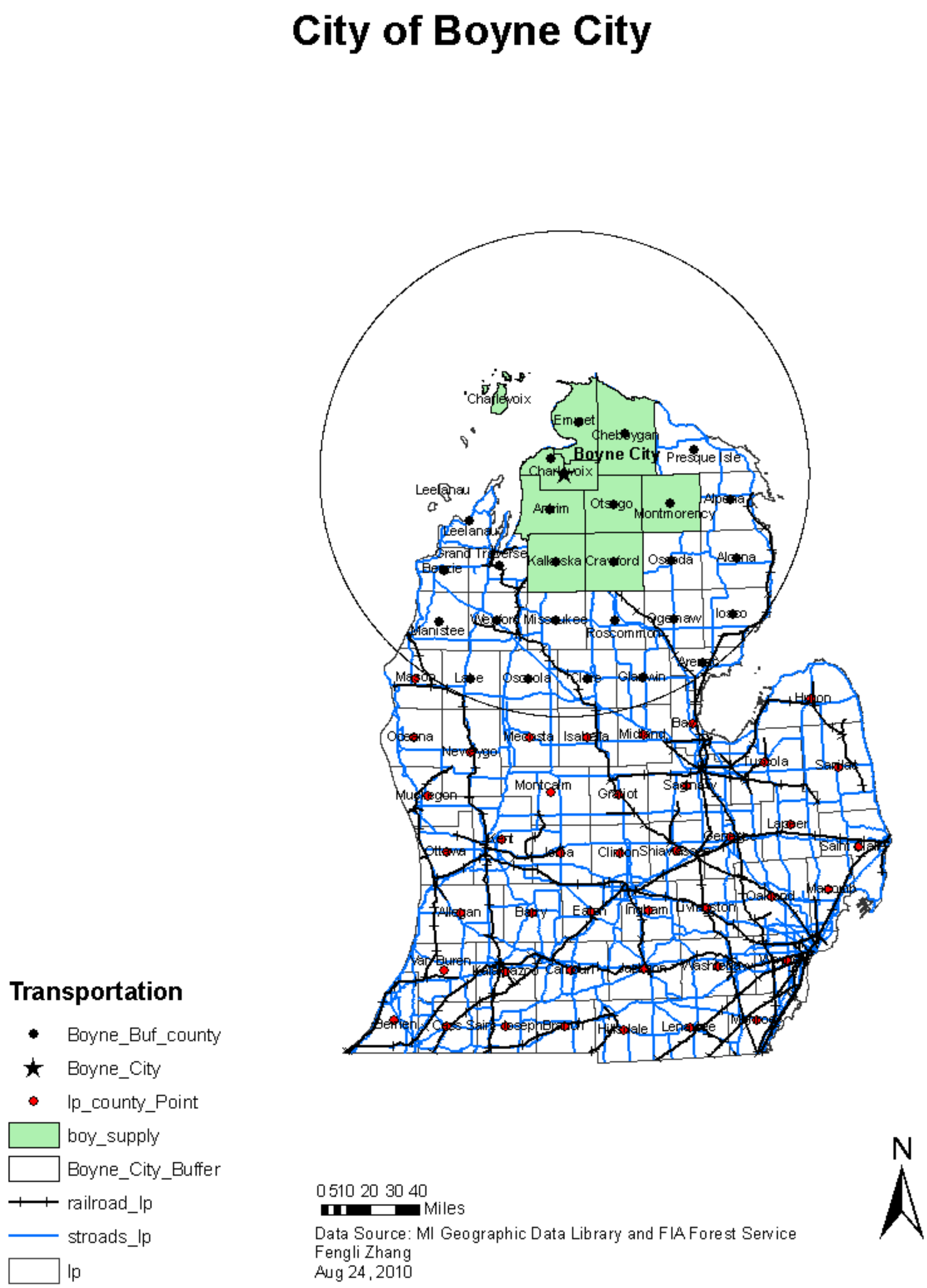
CLARE EMISSIONS OPTIMIZATION - 30MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Clare	37.19200	154,447	154,447
Gladwin	48.42207	120,904	120,904
Isabella	38.25137	147,913	147,913
Mecosta	56.49817	81,505	161,937
Midland	49.07881	105,192	105,192
Osceola	55.02787	140,038	140,038
Feedstock Demand		750,000	
Total Emissions (in lbs.)			34,730,107
Total Emissions Per Ton			46.30681

WEST BRANCH EMISSIONS OPTIMIZATION - 30MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Arenac	49.15119	118,833	118,833
Gladwin	45.87732	120,904	120,904
Iosco	52.71459	2,128	159,343
Ogemaw	32.87007	122,488	122,488
Oscoda	50.37644	236,738	236,738
Roscommon	42.64568	148,910	148,910
Feedstock Demand		750,000	
Total Emissions (in lbs.)			33,802,236
Total Emissions Per Ton			45.06965

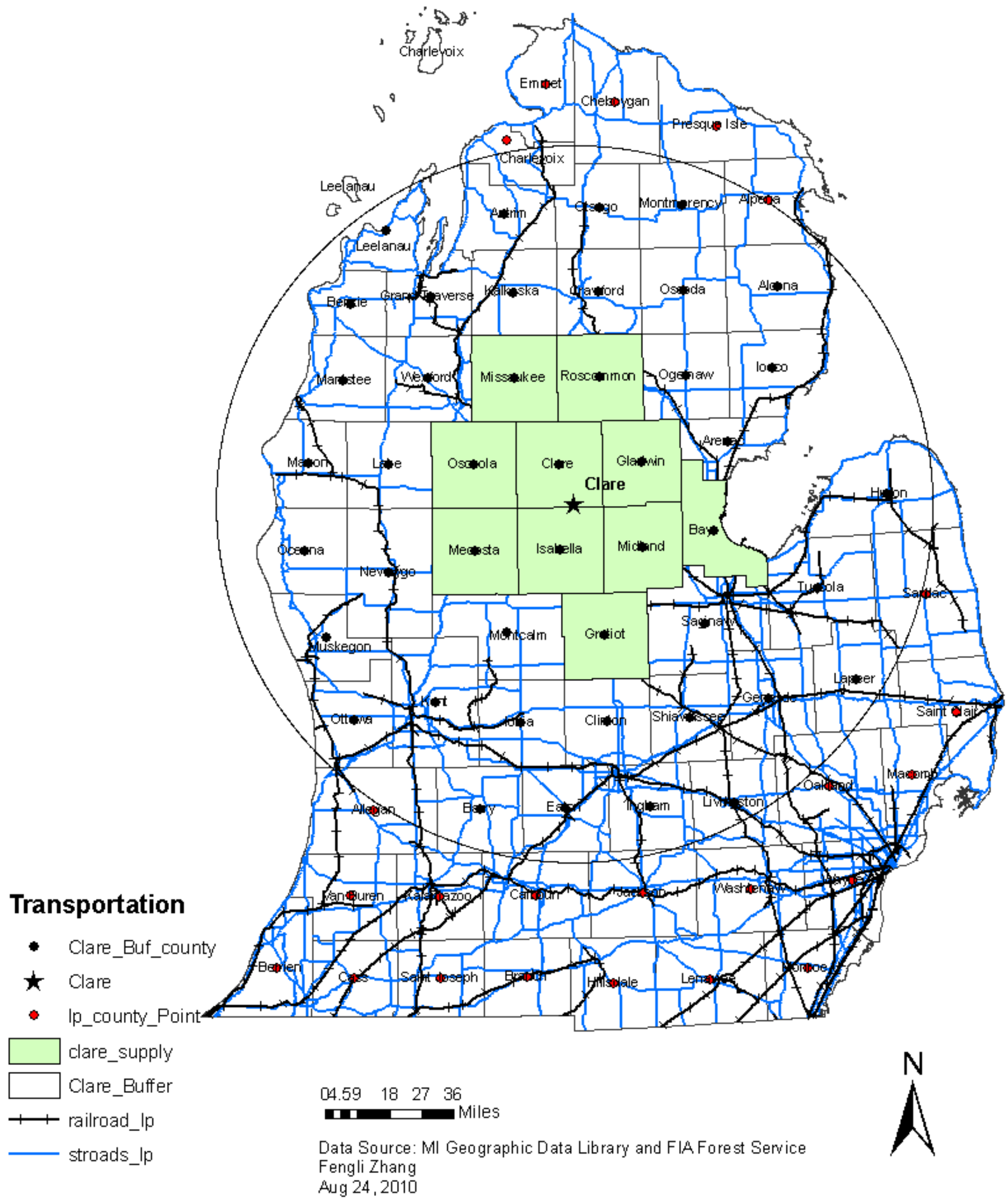
TRAVERSE CITY EMISSIONS OPTIMIZATION - 30MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	55.46142	64,483	134,827
Benzie	46.98796	101,329	101,329
Grand Traverse	31.59882	117,902	117,902
Kalkaska	48.07825	171,816	171,816
Leelanau	42.96990	48,922	48,922
Wexford	48.21849	245,548	245,548
Feedstock Demand		750,000	
Total Emissions (in lbs.)			34,265,859
Total Emissions Per Ton			45.68781

BOYNE CITY EMISSIONS OPTIMIZATION - 30MGY			
County	*Lbs/Ton*	*Optimal Supply*	*Maximum Supply*
Antrim	41.37443	134,827	134,827
Charlevoix	34.17223	96,751	96,751
Emmet	45.92256	138,994	138,994
Kalkaska	55.68988	104,508	171,816
Otsego	50.78511	274,920	274,920
Feedstock Demand		750,000	
Total Emissions (in lbs.)			35,049,421
Total Emissions Per Ton			46.73256

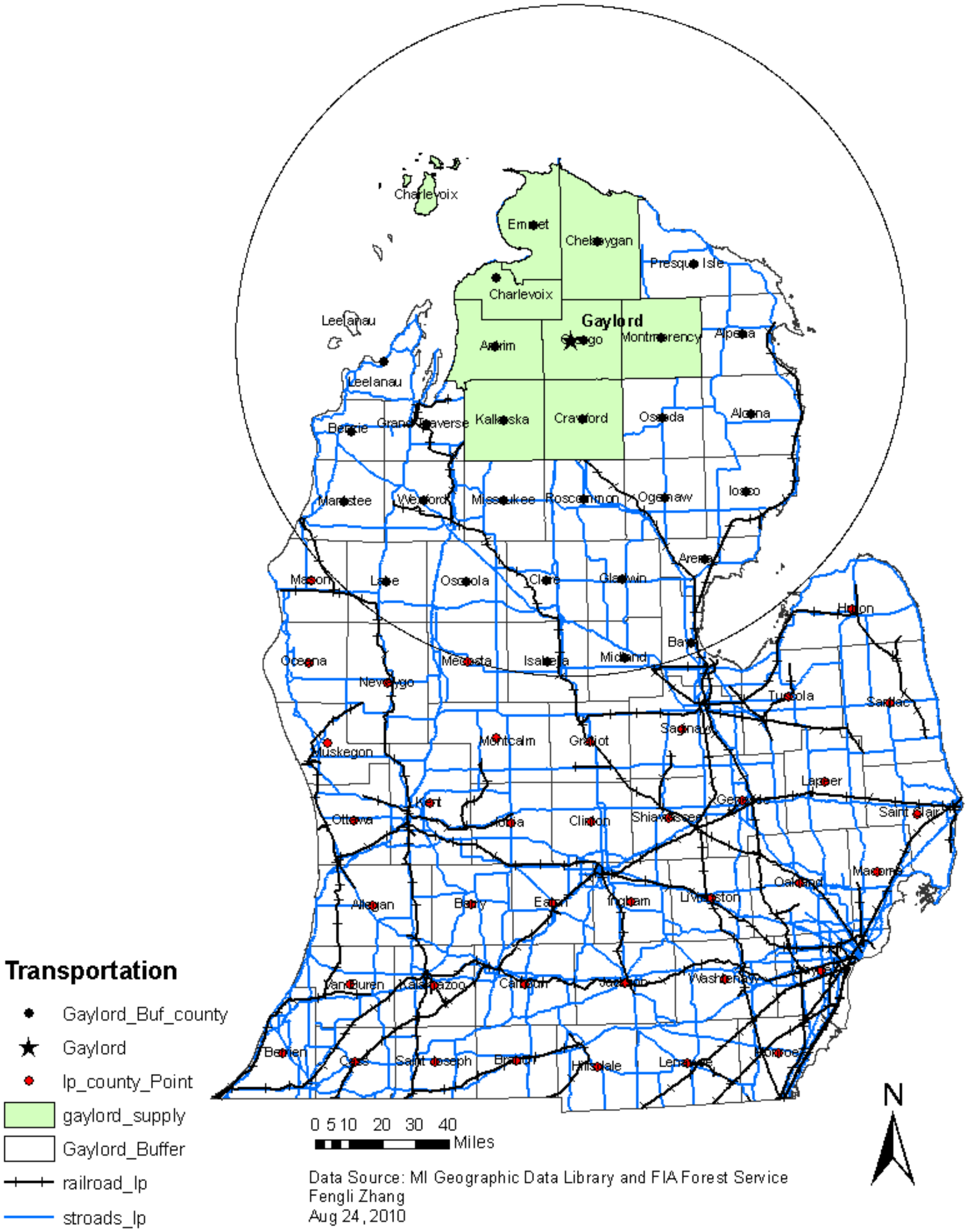
Appendix B4-W Visual Depiction of Counties to Supply Each Candidate Location for a 50 MGY Per Year Production



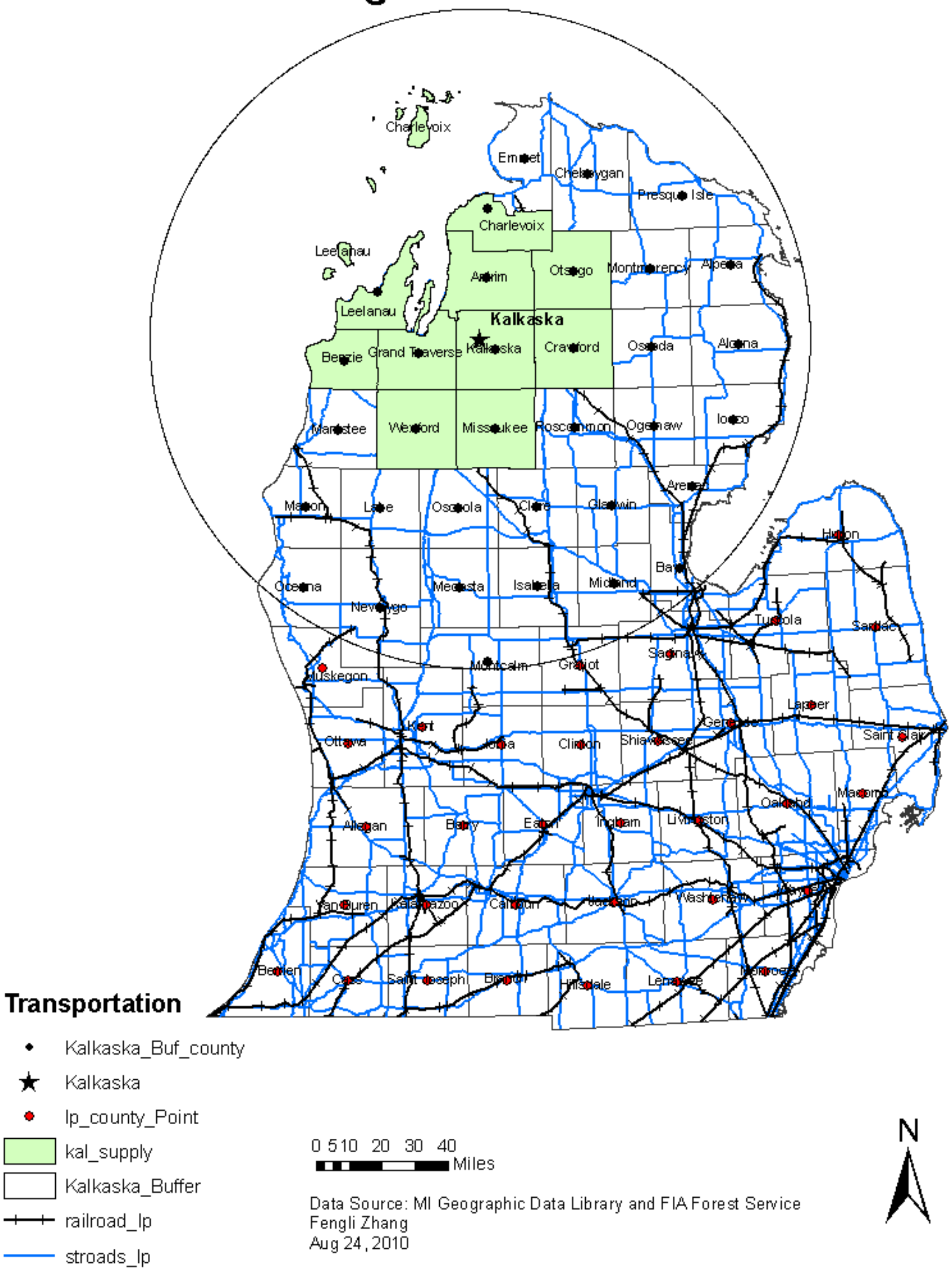
City of Clare



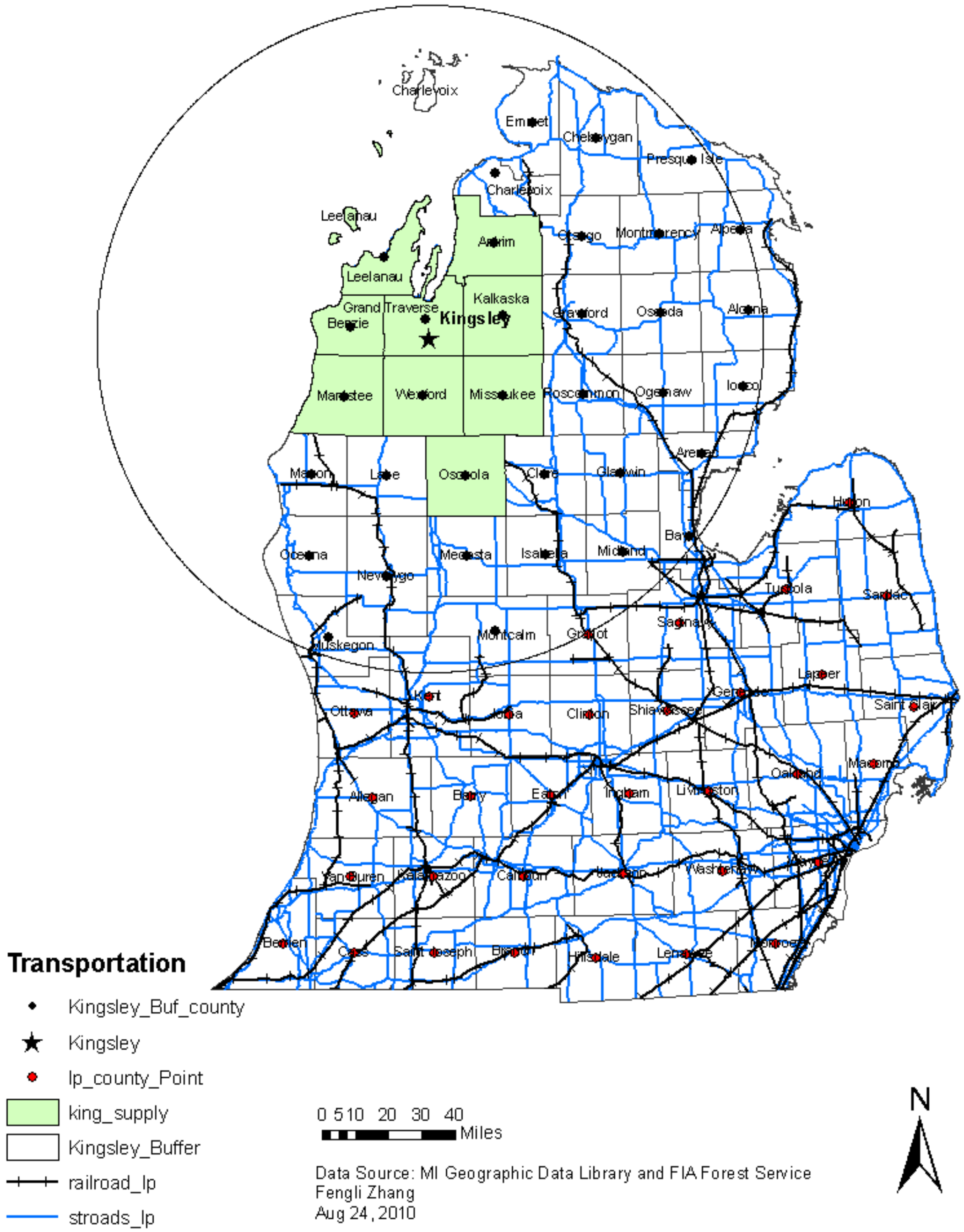
City of Gaylord



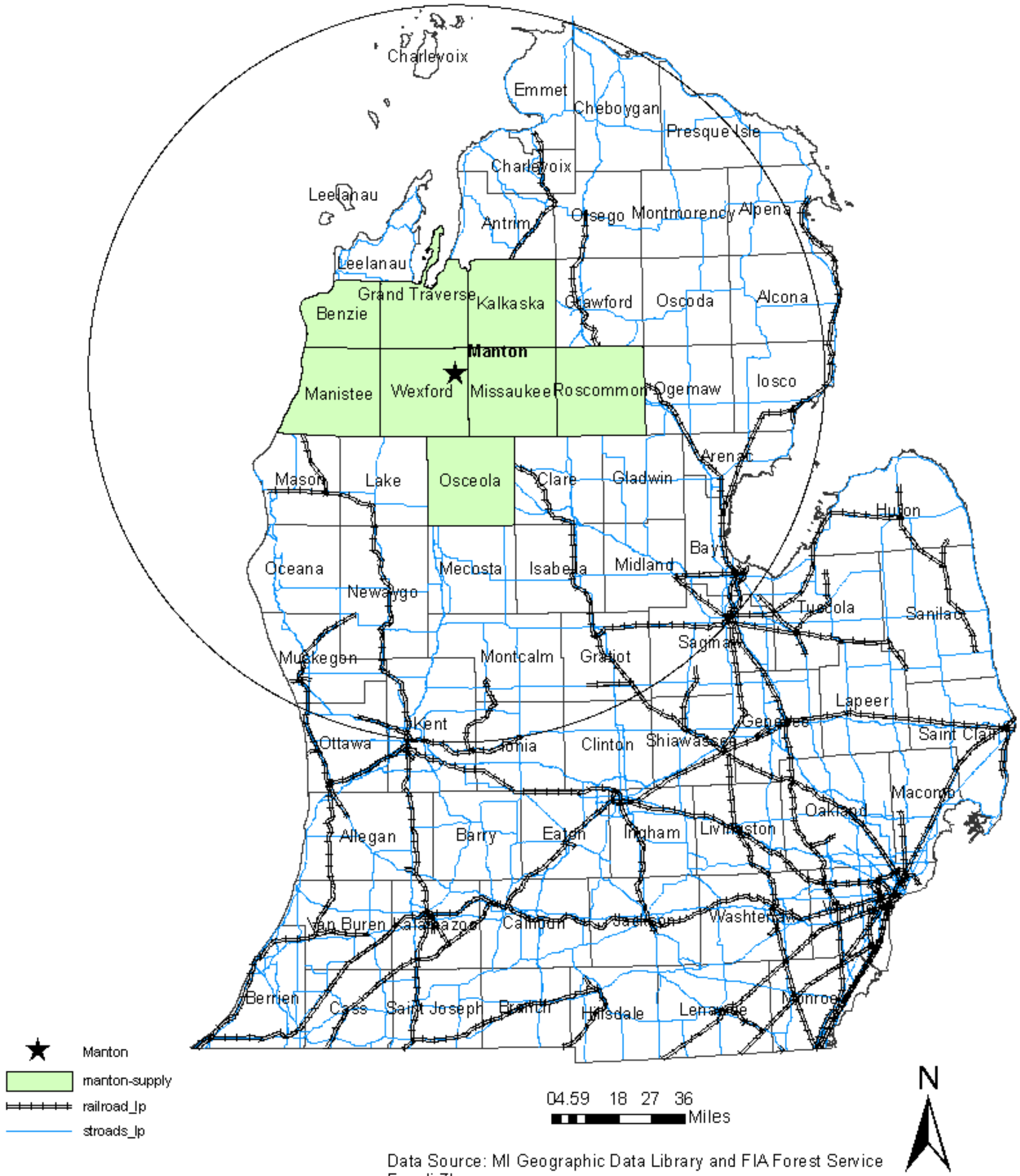
Village of Kalkaska



Village of Kingsley

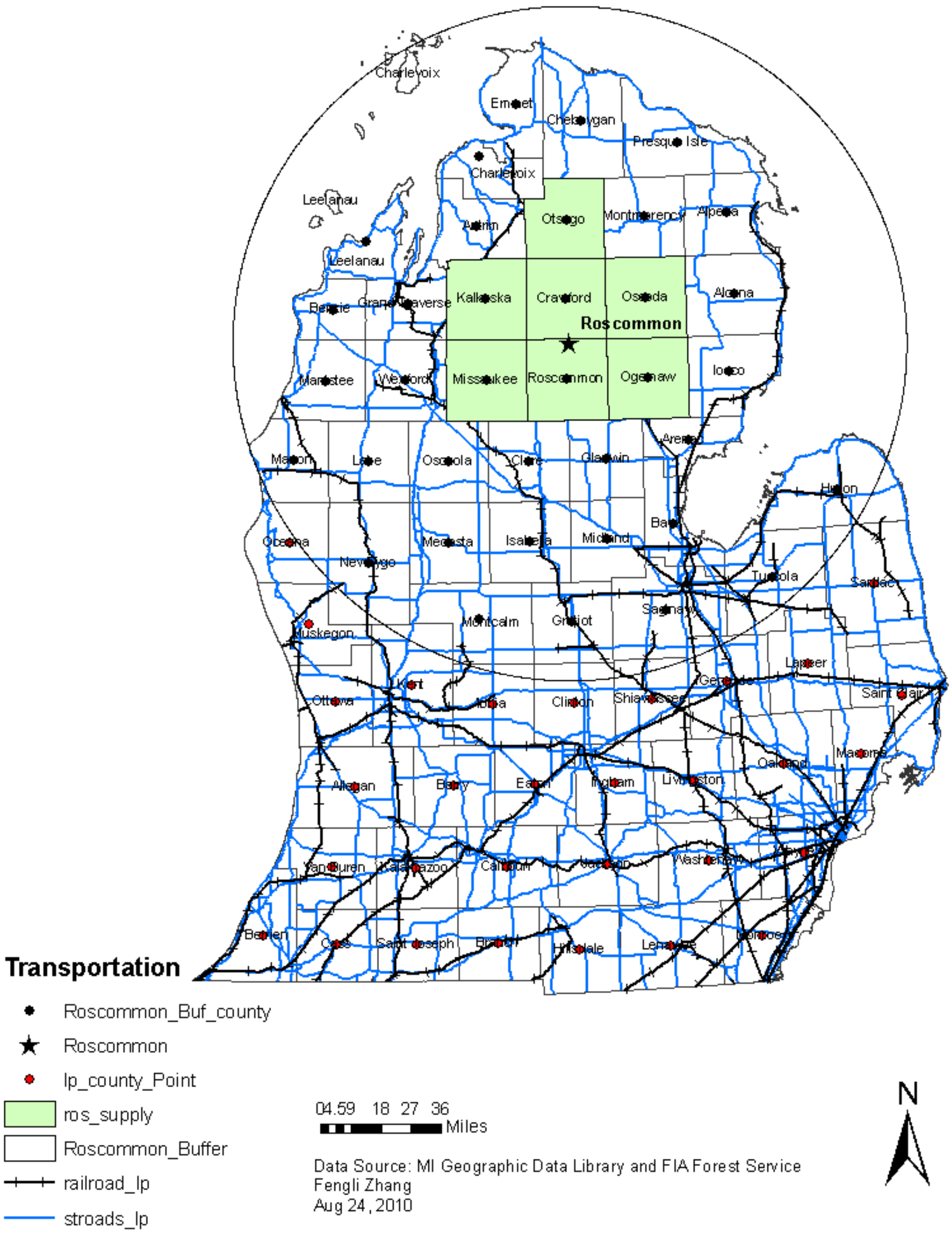


City of Manton

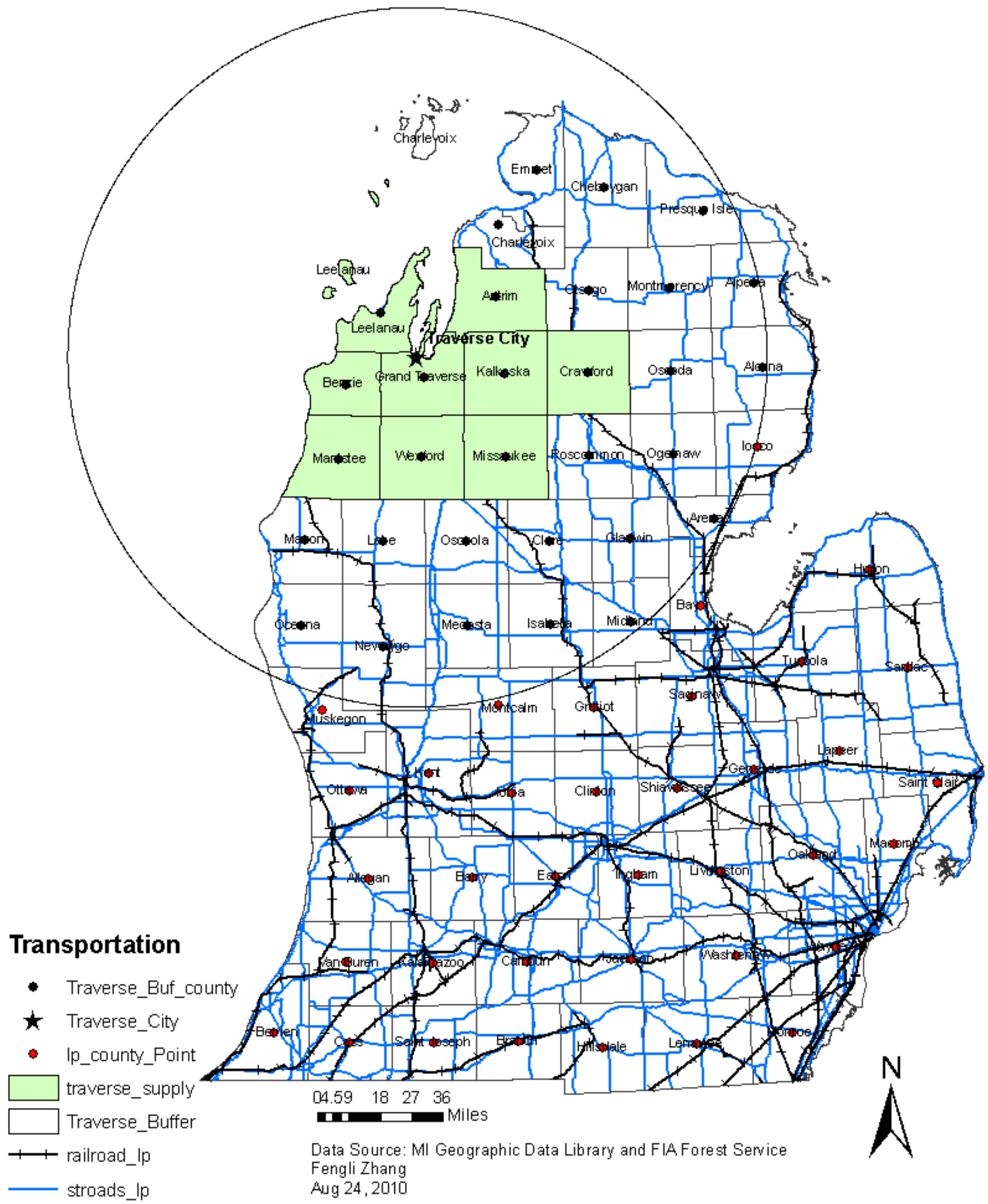


Data Source: MI Geographic Data Library and FIA Forest Service
Fengli Zhang
Aug 24, 2010

Village of Roscommon



City of Traverse City



City of West Branch