Project 001(F) Alternative Jet Fuel Supply Chain Analysis

Techno-Market Analysis of US Biorefinery Supply Chains from Feedstock to Alternative Jet Fuels

University of Tennessee

Project Lead Investigator

Timothy Rials
Professor and Director
Center for Renewable Carbon
University of Tennessee
2506 Jacob Dr. Knoxville, TN 37996
865-946-1130
trials@utk.edu

University Participants

University of Tennessee

- P.I.(s): Burton English, Professor; Tim Young, Professor
- FAA Award Number: 13-C-AJFE-UTenn-002, 11712069
- Period of Performance: August 18, 2014 to January, 31, 2016
- Task(s):
    1. Task 1.1: Assess and inventory regional forest and agricultural biomass feedstock options.
    2. Task 1.2: Delineate the sustainability impacts associated with various feedstock choices including land use effects.
    3. Task 4: Biorefinery Infrastructure and Siting (Supporting Role)

Project Funding Level

Total Estimated Project Funding: $205,000
Total Federal and Non-Federal Funds: $400,000
Faculty salary will be provided by The University of Tennessee, Institute of Agriculture in support of the project.

Investigation Team

- Tim Rials – Project Director(s)/Principal Investigator (PD/PI)
- Burton English – Co-Principal Investigator (Co PD/PI)
- Tim Young – Co-Principal Investigator (Co PD/PI)
- Chris Clark – Faculty (1.2)
- Lixia He – Other Professional (1.1)
- Kim Jensen – Faculty (1.1)
- Dayton Lambert – Faculty (1.1,1.2)
- Jim Larson – Faculty (1.1)
- Ed Yu – Faculty (1.1,1.2)
- Olga Khaliukova – Research Associate (1.1,4)
- Evan Markel – Graduate Student (1.1,1.2)
- Brad Wilson – GIS programmer (1.1,1.2)

Project Overview

The University of Tennessee is leading the Feedstock Production (Task 1) component of the project. This component targets the need to assess and inventory regional forest and agricultural biomass feedstock options (1.1); and, the goal to delineate the sustainability impacts associated with various feedstock choices, including land use effects. Additionally, The University of Tennessee is supporting activities in Task 4 (Biorefinery Infrastructure and Siting) with information and insights on regional demand centers for aviation fuels and current supply chain infrastructure, as required.

Task 1.1: Assess and inventory regional forest and agricultural biomass feedstock options

University of Tennessee

Objective(s)

As the markets for lignocellulosic biomass (LCB) feedstock, i.e. grasses, short-rotation woody crops, and agricultural residues, are currently not well established, it is important to evaluate the feasibility of supplying those LCB feedstocks. The opportunity cost of converting the current agricultural lands to LCB feedstocks production will be estimated. In addition, the production, harvest, storage and transportation cost of the feedstocks are included in the assessment. A variety of potential crop and biomass sources will be considered in the feedstock path including:

Oilseed crops: Potentials include: Mustard/Crambe (*Sinapsis alba/Crambe abyssinicia*); Rapeseed/Canola (*Brassica napus/B. campestris*); Safflower (*Carthamus tinctorius*); Sunflower (*Helianthus spp.*); Soybean (*Glycine max*); camelina (*Camelina sativa*)

Perennial grasses: Switchgrass (*Panicum virgatum*); Miscanthus (*Miscanthus sinensis*); Energy Cane (*Saccharum complex*)

Short-rotation woody crops: Poplar (*Populus species*); Willow (*Salix species*); Loblolly pine (*Pinus taeda*); Sweetgum (*Liquidambar styraciflua*); Sycamore (*Plantanus occidentalis*)

Agricultural residue: Wheat straw; Corn stover

Forest residue: Logging and Processing Residue

POLYSYS will be used to estimate and assess the supply and availability of these feedstock options at regional and national levels. This U.S. agricultural sector model forecasts changes in commodity prices and net farm income over time. BioSAT data will be used to aggregate data on woody biomass resources.

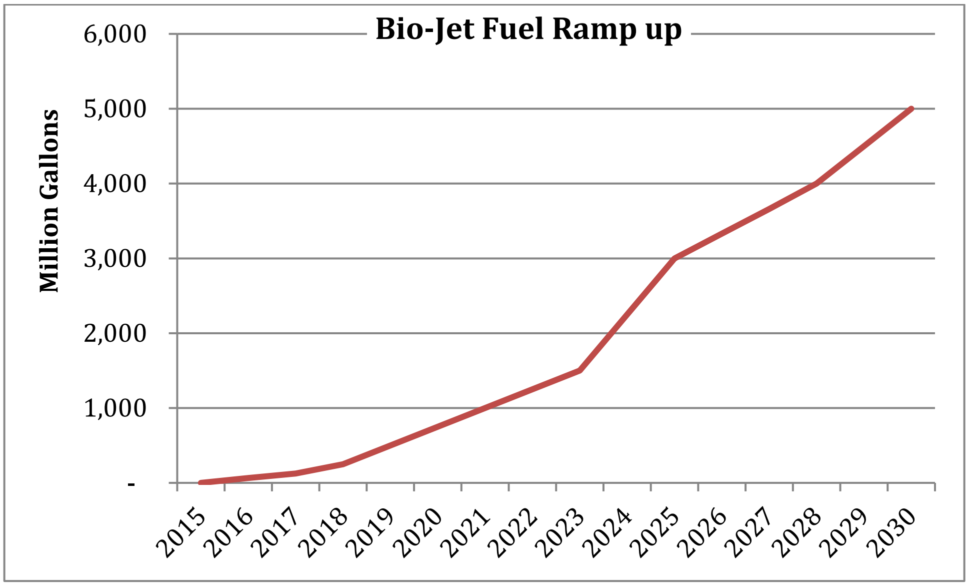
County level estimates of all-live total woody biomass, as well as average annual growth, removals, and mortality will be obtained from the Forest Inventory and Analysis Database (FIADB). Mill residue data will be obtained from the USFS FIA Timber Product Output (TPO) data. The Subregional Timber Supply (SRTS) model will be used to estimate and predict logging residues. SRTS uses U.S. Forest Service FIA data to project timber supply trends based on current conditions and the economic responses in timber markets[20]. Specific tasks related to this objective are outlined below. These supply curves will be placed in POLYSYS and estimates into the future will be made.

Research Approach

1. Using an existing model, POLYSYS, annual demand targets were developed. Analysis conducted for alternative cellulosic feedstocks – dedicated energy crops (DEC), short rotation woody crops (SRWC), forest residues (FR), and Crop residues (CR). A combined solution and individual solutions were estimated for the bio-jet fuel ramp up of 5 billion gallons by 2030. The feedstock streams were placed in ASCENT 1's Database. Present before research team. Pass feedstock info to other team members.
2. Began to develop Pennycress information. Send graduate student to workshop. Develop fact sheet on Pennycress (attached). Develop budget and yield maps.
3. Address comments from 1 and develop new target pathway

Target (1)

1. Demand for Jet fuel 1 Billion gallons by 2021 and 5 Billion by 2025
2. Conversion process was fast pyrolysis with hydrogen purchase
3. Conversion rate 43.3 gallons jet fuel /ton biomass plus other energy fuels
4. Each plant will require 645,000 dry tons of biomass/year
5. Each facility will produce 27.9 million gallons of jet fuel plus other energy fuels

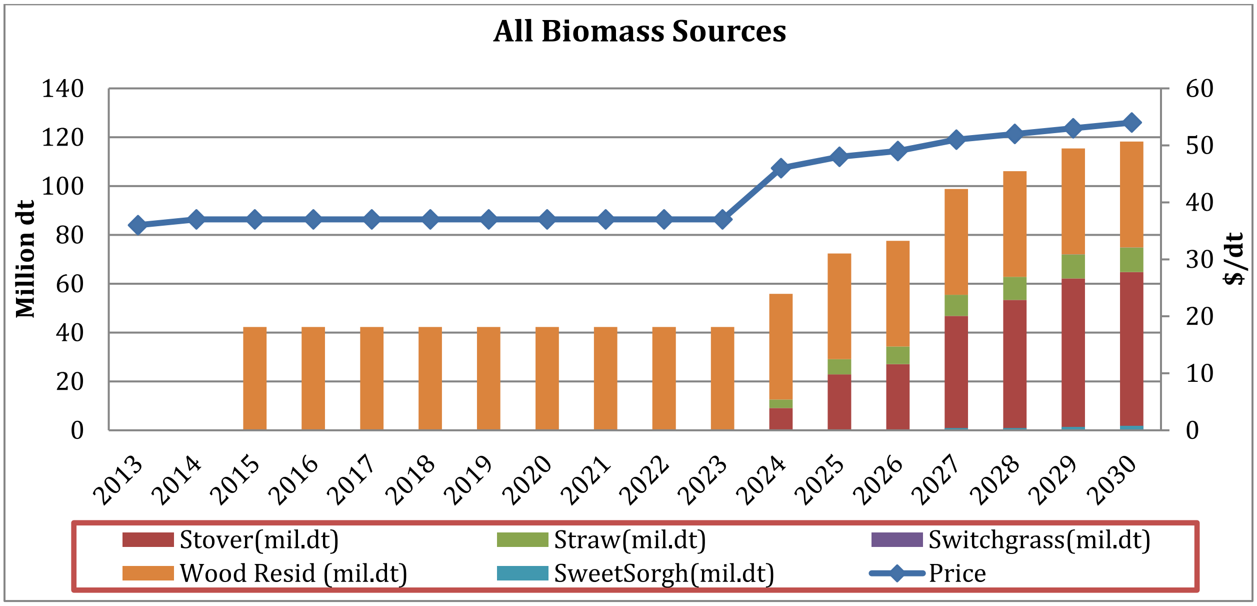


Additional Assumptions

1. Used cost and yield assumptions in the Billion Ton Update for biomass types including Stover, Straw, Switchgrass, Miscanthus, Poplars, Willows, Sweet Sorghum, Energy Cane, and Forest Residues.
2. Forest residue supply curves by county estimated with ForSEAM and then further develop by ORNL. Using data developed from Lixia He, Burton C. English, Daniel G. De La Torre Ugarte, and Donald G. Hodges. (2014). "Woody biomass potential for energy feedstock in United States." Journal of Forest Economics 20: 174-191.
3. Pasture land can be converted to dedicated bioenergy, with an assumption that remaining pasturelands will be more intensively grazed at an increased cost. This conversion is limited to 50% of a county.
4. There is no biofuel mandate assumed other than what was assumed in the USDA Baseline.

Findings (1)

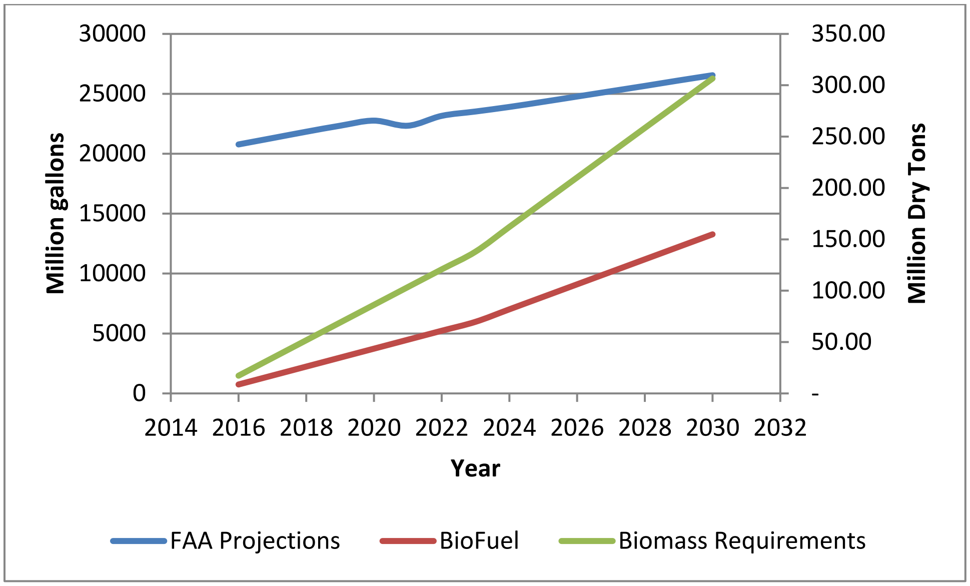
- Feedstock potential include: corn stover; straw from wheat, barley, and oats; dedicated energy crops including: switchgrass, miscanthus, poplars, willows, sweet sorghum, energy cane, and algae; and wood residue.
- Biomass price for forest residues (tops and limbs) enter in at $37/dry ton. In 2019, crop residues enter into the solution with biomass at $46/dry ton. Dedicated energy crops do not enter the solution until biomass price is at $49/dry ton for sweet sorghum and $53/ton for dedicated energy crops.



- Harvesting corn stover or straw on 25.1 million acres producing 76 million dt of biomass (31% of the 2014 corn + wheat acreage). Only have 110 thousand acres of dedicated energy crops. 43.3 million tons of wood residues enter the solution first at about $37.0/dt.
- Taking an average of commodity prices over the 19 year, changed very little. A decrease in commodity prices for grain oats, barley, and wheat of $0.07/bu, $0.14/bu, and $0.05/bu, respectively. Soybeans decrease by $0.13/bu.

13 Billion Gallon Scenario (3)

1. Demand for Jet fuel 4.5 Billion gallons by 2021 and 13 Billion by 2025
2. Conversion process was fast pyrolysis with hydrogen purchase
3. Conversion rate 43.3 gallons jet fuel /ton biomass plus other energy fuels
4. Each plant will require 645,000 dry tons of biomass/year
5. Each facility will produce 27.9 million gallons of jet fuel plus other energy fuels
6. Used cost and yield assumptions in the Billion Ton Update for biomass types including Stover, Straw, Switchgrass, Miscanthus, Poplars, Willows, Sweet Sorghum, Energy Cane, and Forest Residues.
7. Forest residue supply curves by county estimated with ForSEAM and then further develop by ORNL. Using data developed from Lixia He, Burton C. English, Daniel G. De La Torre Ugarte, and Donald G. Hodges. (2014). "Woody biomass potential for energy feedstock in United States." Journal of Forest Economics 20: 174-191.
8. Pastureland can be converted to dedicated bioenergy, with an assumption that remaining pasturelands will be more intensively grazed at an increased cost. This conversion is limited to 50% of a county.
9. There is no biofuel mandate assumed other than what was assumed in the USDA Baseline.
10. Info required to run new scenario



Year	Million Gallons Aviation Fuel	Million Gallons of BioJet	Million Tons of biomass
2030	26551	13,275.5	306.59
2029	26114	12,232.8	282.51
2028	25658	11,190.1	258.43
2027	25218	10,147.4	234.35
2026	24775	9,104.6	210.27
2025	24334	8,061.9	186.19
2024	23906	7,019.2	162.11
2023	23525	5,976.5	138.03
2022	23161	5,229.4	120.77
2021	22338	4,482.4	103.52
2020	22763	3,735.3	86.27
2019	22338	2,988.3	69.01
2018	21837	2,241.2	51.76
2017	21305	1,494.1	34.51
2016	20777	747.1	17.25

Milestone(s)

- Generated data passed on to ASCENT 1 database for five billion gallon run.
- 13 Billion Gallon pathway developed
- Pennycress fact sheet under review.

Major Accomplishments

- The datasets for the 5 Billion Gallon pathway have been uploaded to Box and are available for team use.
- The 13 Billion Gallon scenario has been developed, POLYSYS analysis has been completed and is under review.
- Preliminary maps have been developed for the pennycress growth and yield based on climate data.

Outreach Efforts

Burton C. English, Alternative Jet Fuel Supply Chain Analysis: ASCENT 1 (Feedstock) April 13, 2015. Weekly meeting Webinar.

Awards

None

Student Involvement

We have a PhD student, Evan Markel, working on this project. He is gathering information on pennycress, and developing an analysis looking at pennycress as a feedstock.

Plans for Next Period

Complete pennycress analysis for incorporation into the alternative jet fuel supply chain.

Publications

None

Task 1.2: Delineate the sustainability impacts associated with various feedstock choices including land use effects

University of Tennessee

Objective(s)

Environmental Sustainability – Regarding environmental sustainability, the impacts associated with LCB feedstock production, such as greenhouse gas (GHG) flux, water use and quality, and soil erosion will be estimated based on local geographic characteristics. The GHG flux related to land use change and LCB feedstock production is analyzed using the DAYCENT model along with EPIC crop management files, to simulate the daily GHG emissions changes over time between the cropping systems. The DAYCENT model also estimates the water use by source (e.g. rain fall, irrigation) for different feedstock production systems. Given the water use and yield of feedstock, an indicator of water use efficiency can be generated. Different agricultural land use systems have varied effects on soil erosion or soil loss. The impact on soil erosion from different LCB feedstock productions is simulated with the Universal Soil Loss Equation incorporating the soil parameters generated from Environmental Policy Integrated Climate (EPIC) model.

This SPARROW module will generate ex ante forecasts of the impacts land use changes have on water quality. The geographic resolution is flexible, and can be expanded to model all 48 contiguous states. Input from the deterministic models (POLYSYS and BioFLAME) will provide data for the SPARROW analysis. The approach we use is entirely general, and readily extended to encompass urban growth dynamics, increased water demand by the non-agricultural sector, and possibly other policy-informed land use interventions on water quality[21]. The SPARROW model has been calibrated to analyze changes in water quality as determined by land use driven by demand for cellulosic bioenergy in the Southeast. This project will expand that effort to the nation.

Economic/Social Sustainability – The IO analysis provides estimates of output, employment and income multipliers, which measure the response of the economy to a change in demand or production[9, 22]. The economic multipliers measure the indirect and induced effects of a change in final demand (direct effects) for a particular industry (for example, the introduction of biorefineries and preprocessing facilities in a region). The indirect effects are the secondary effects or production changes when input demands change due to the impact of the directly-affected industry (for example, construction sector, agriculture producers, and transportation sectors). The induced effects represent the response by all local industries caused by changes in expenditures by households and inter-institutional transfers generated from the direct and indirect effects of the change in final demand. Projections of changes in jobs (job creation), economic activity, labor income and state/local taxes to the region both directly from growth in the aviation biofuel industry itself and through multiplier effects will be projected using IMPLAN.

Research Approach

Develop impact analysis for economic and environmental parameters. Develop post analysis of POLYSYS output that use ACCESS databases and queries to estimate impact on environmental parameters (fertilizer expenditures, herbicide expenditures, soil erosion estimates) These estimates along with land use change will be used in SPARROW a water quality model to examine surface water impact.

IO Analysis

We are in the process of estimating the economic impacts of the 5 Billion Gallon scenario. We have developed the transactions required for investment and annual operations of the biorefinery assumed in the 5 Billion Gallon scenario. The conversion process was fast pyrolysis with hydrogen purchase, it has a conversion rate 43.3 gallons jet fuel /ton biomass plus other energy fuels; each plant will require 645,000 dry tons of biomass/year; and each facility will produce 27.9 million gallons of jet fuel plus other energy fuels.

Milestone(s)

None

Major Accomplishments

Environmental indicators including Fertilizer (Nitrogen, Phosphorous, and Potassium) and chemical (Herbicides, Insecticides, etc.) expenditures and Soil erosion coefficients have been developed. Datasets containing these estimates for the 5 billion ton run are under review. Work on Sparrow is pending an internal review. Through a USDA AFRI project, SPARROW was used to estimate environmental impacts of industry development in the south. Erosion coefficients when using cover crop (Pennycress) is under development; however, insufficient experimental work has been found to develop a C-factor for a soybean/corn-pennycress rotation.

Outreach Efforts

None

Awards

None

Student Involvement

None

Plans for Next Period

- Develop impact analysis for economic and environmental parameters. Expand sedimentation impact model for 5 and 13 Billion Gallon scenarios. .
- SPARROW needs to be updated and expanded through the rest of the nation.
- Forest residues (and the environmental impact on removing) sector in Billion Ton was not completed until this month. This allows work on sustainability to accelerate.

Task 4: Biorefinery Infrastructure and Siting (Supporting Role)

Washington State University

Objective(s)

The University of Tennessee team plays a supporting role in this task. Several models are available to contribute to the effort, including: 1) BioSAT (currently available for the **35 Eastern and Midwest** states), 2) BioFLAME (we hope to expand its geographic scope from its current southeast U.S. regional focus to the contiguous 48 states).

Research Approach

Database development using the enhanced database structure of the BioSAT model is being expanded to include the Pacific Northwest and Central Plains regions. Enhancement of the database includes socio-economic and USFS/USDA/EPA biomass data allocated to the U.S. Census Bureau 5-digit ZCTA level boundaries using forest and crop land cover imagery in the context of geo-spatial analysis. Examples of database enhancements at this higher level of resolution include: 1) socio-economic data, such as population density, median income, farm income, road network density, etc.; 2) biomass data, such as merchantable and non-merchantable forest biomass tonnage and agricultural-residue data; 3) public ownership constraints, such as, parks, preserves, national forest, military installations, etc.; 4) EPA-defined eco-region limitations for forests; and 5) competition for the forest resource given active mill locations. The aforementioned enhancements to existing databases will improve estimates and POLYSYS projections for modeling woody biomass availability.

Geo-spatial Analysis

Geo-spatial economic analyses are being performed and updated for the 48 continental United States. The supply chain supporting the BioSAT model for multiple feedstocks has three main cost components: resource, harvesting, and transportation. All USFS inventory and USDA NASS data are allocated to 5-digit “zip code tabulation areas” (ZCTAs) based on area proportionality. Microsoft© MapPoint® 2009 is used to provide the shortest travel time and distance routes between the demand and supply ZCTAs. Road networks are a combination of the Geographic Data Technology, Inc. (GDT) and Navteq data. The harvesting cost models generate production costs on a per dry-ton basis for five harvesting systems dependent on ecoregions. Geospatial layers including public reserved land, population density and EPA Level-III ecoregions are part of the update, *i.e.,* ZCTAs that are not suitable for sustainable fiber supply are removed from the supply procurement zones of the model (Figures 1 and 2).

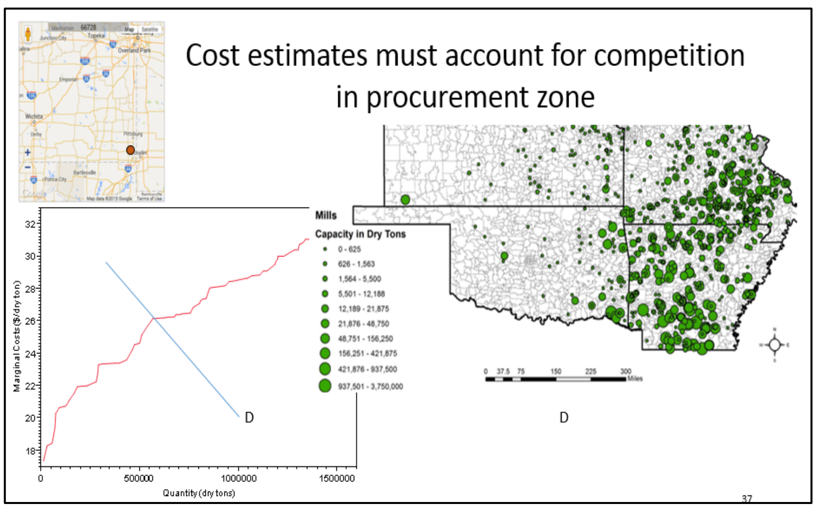


Figure 1. Illustration of competition for resources as accounted in the BioSAT model.

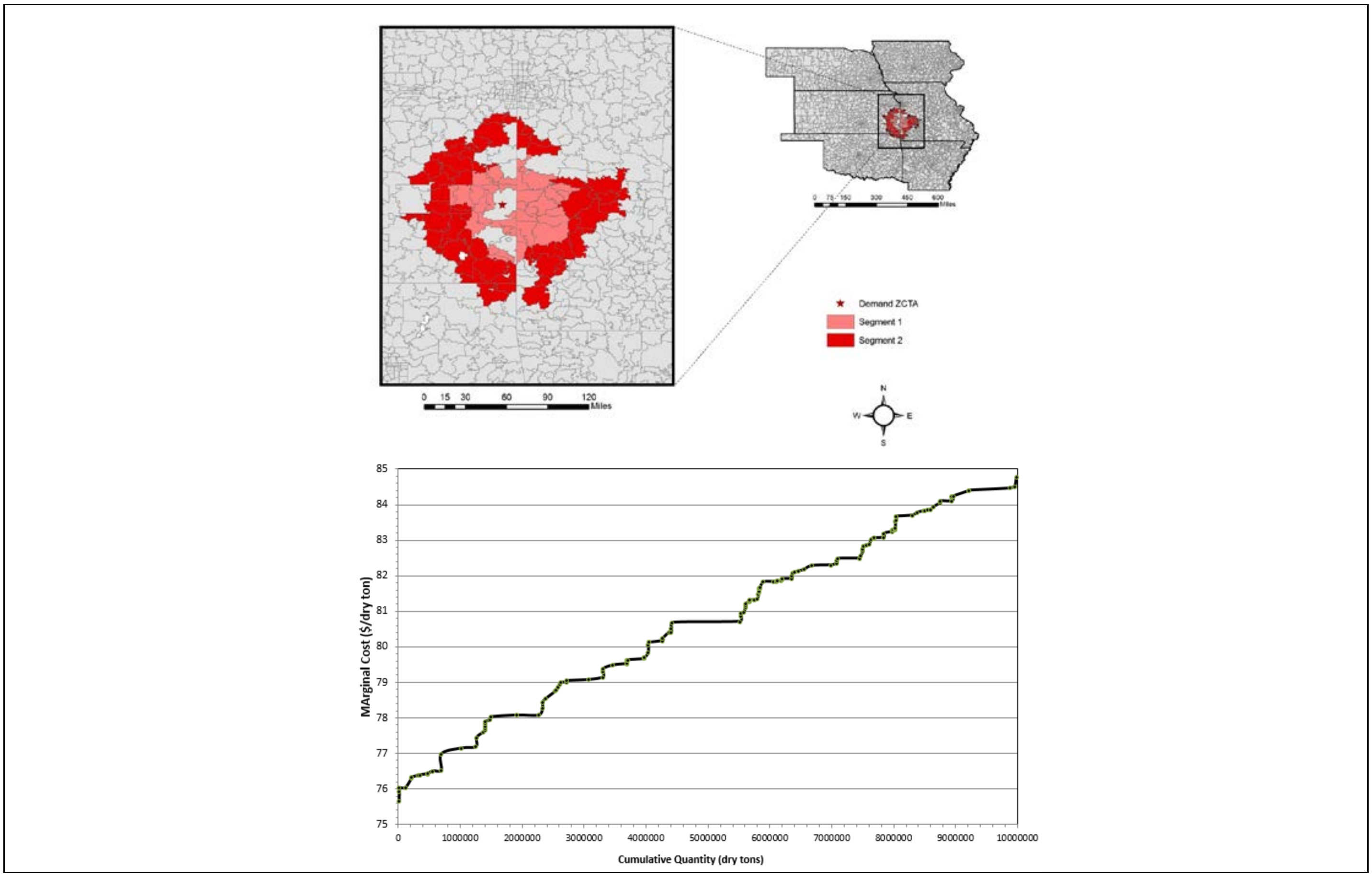


Figure 2. Marginal Cost Curve Comparison for ZCTA 66701 for "Upland Hardwood Pulpwood Total Inventory" 200-mile maximum roundtrip haul distance.

Milestone(s)
Database has supply curves for individual feedstocks assuming 5 billion gallons.

Major Accomplishments
None

Publications
Young, T.M., Y. Wang, F.M. Guess, M. Fly, D. Hodges, and N. Pouydal. 2015. Understanding the characteristics of non-industrial private forest landowners that harvest trees. Small-Scale Forestry. 14(3):273-285. DOI: 10.1007/s11842-015-9287-9.

Outreach Efforts
None

Awards
None

Student Involvement
None

Plans for Next Period
Provide feedstocks for 13 billion gallon scenario.

Publications
None