Forestry Biofuel Statewide Collaboration Center

Supply Chain Model:
Optimization Models – Cost, Energy, Emissions

Thursday, August 25th, 2011

Presenter: Dana M. Johnson, Ph.D.
Collaborators: Fengli Zhang, Mark A. Johnson, Ph.D.

Overview

- Project Requirements
- Review of Existing Models
- Identification of Candidate Locations
- Assumptions
- Methodology
- Summary and Location Rankings
  - Transportation Cost Per Green Ton Delivered
  - Energy Per Green Ton Delivered
  - Emissions Per Green Ton Delivered
- Gaylord Example
  - Cost Optimization
  - Energy Optimization
  - Emissions Optimization
- Comparative Summary
- Multiple Locations Analysis

FBSCC – Task B4: Supply Chain Model

The supply chain models were designed as a pilot for a more comprehensive statewide model to encompass all forest regions in Michigan. The pilot focus area was the upper portion of the lower peninsula of the State of Michigan. There were two types of models developed: (1) optimization model with a one-year timeframe, and (2) simulation model with a twenty year time frame. The models evaluated nine potential locations that were pre-selected based on geographic information system (GIS) criteria. The models sought to minimize transportation cost, emissions, and energy consumption to identify the optimal location for a biorefinery. The purpose was to provide user friendly plug and play models that could be accessed through the website at:

http://michiganforestbiofuels.org/research-project/feedstock-supply-chain-landing-biorefinery

Comparative Models

Comparative Models

Identification of Candidate Locations

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:

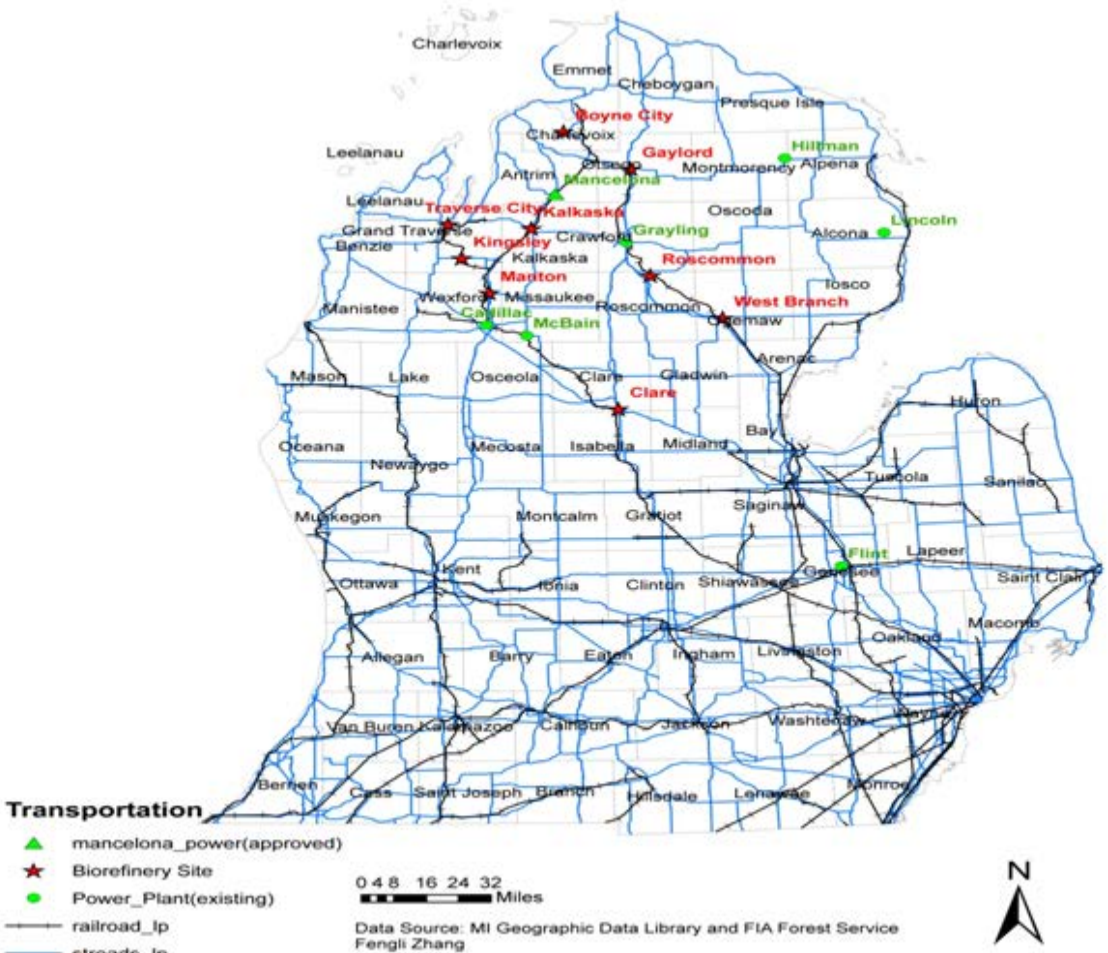
- Location within one mile of a major state road (Jenkins, 2008);
- Location within one mile of railway (Jenkins, 2008);
- Location within a community size of at least 1,000 (Jenkins, 2008);
- Location within ¼ mile of a water body (rivers, lakes, etc.);
- The minimum residues within a 100 mile radius 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[a]) to support a facility producing 50 million gallons of fuel each year; and
- Location does not have a co-fired power plant around (there are co-fired power plants in Grayling, Mancelona and Cadillac).

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

Potential Site for Biorefinery in Lower Peninsula of Michigan

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

Nine Potential Locations



Cost, Energy, and Emission Inputs

- The centroid of the county is the measurement for distance to the designated location.
- Transportation cost
  - Variable cost = 0.074 $/ton-mile; Fixed cost = 3.72 $/ton
- Energy – harvest
  - Energy Intensity = 137.4330 per 1,000 Btus/ton
- Energy - transportation
  - Energy Intensity = 1.68 MJ/ton-mile =1.5924 per 1,000 Btus/ton/mile
- Emissions – harvest
  - Emissions Intensity = 25.6 lb GHG/ton
- Emissions - transportation
  - Emissions Intensity = 0.171 kg GHG/ton-mile =0.377 lb GHG/ton/mile

Details provided by Dr. Robert Handler and Dr. David Shonnard
Refer to Life Cycle Analysis presentation for more details

Assumptions

Assumptions for biorefinery operation

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

Assumptions for transportation

- Radius is less than 100 miles;
- Centroid of the county is origin for feedstock to facility location; and
- Truck carrying capacity is 50 tons.

Assumptions

Assumptions for biomass availability and inventory

- Land area within 100-mile radius subdivided into harvesting areas - county level information;
- Harvest areas target size that allows balance between detailed information about the resource locations;
- Woody biomass feedstock includes logs and forest residues;

Assumptions

Assumptions for biomass availability and inventory

- One green ton to produce 40 gallons of biofuel
  - 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 transported over the Mackinaw Bridge (hereafter referred to as "bridge". Feedstock in the Upper Peninsula not available for transport over the bridge and consumed by others in the Upper Peninsula; and
- Reduced by a percentage to be determined based on the biomass consumption for combined heat and power facilities and mill consumption for operations that are not currently consumers of feedstock.
  - Frontier Renewable Resources biorefinery,
  - Planned Mancelona, MI 36MW combined heat and power plant planned, and
  - Estimated combined total of approximately 800,000 green tons per year for steady-state operation of both operations

Methodology

- Optimization models to minimize:
  - Cost
  - Energy
  - Emissions
- Network optimization methods employed
- Assumed linear models
- Assumed non-negativity
- Excel based of user-friendly application

Summary of Transportation Cost Per Green Ton

	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

Transportation Cost Location Ranking

	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

Summary of Energy Per Green Ton and Location Ranking

	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

Energy Location Ranking

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

Summary of Emissions Per Green Ton and Location Ranking

	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

Emissions Location Ranking

	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

Gaylord Cost Optimization

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

Gaylord Energy Optimization

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

Gaylord Emissions Optimization

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

Overall Ranking

		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

Multiple Locations

- At maximum capacity of 50 MGY
- Four possible locations
- Some combinations
  - Roscommon, Clare, Boyne City
  - Roscommon, Clare, Boyne City, Traverse City
  - Traverse City, Kalkaska, Kingston, Manton
- Unlimited combinations but maximum would be four at maximum capacity for each
- Can apply to biorefinery or biomass fired power plants

Future Work

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*, and
10. Identifying if there are *additional decision criteria* need to determine candidate locations.

Researcher Acknowledgement

- We would like to acknowledge several researchers for their support in our project work:
  - Tim Jenkins, ME-EM provided some of the initial GIS selection criteria
  - Dr. Robert Froese, SFRES, for feedstock data and availability information from FIA EVALidator
  - Dr. Robert Handler, SFI, for information related to emissions and energy consumption
  - Dr. Pasi Lautala, CEE, and graduate student Justin Hicks, CEE, for their transportation cost estimates
  - Donna LaCourt, MEDC, Project Sponsor, for her insights and preliminary feedback on model development

References

- Biomass Research and Development Board (BRDB). National Biofuels Action Plan. Biomass Research & Development Initiative, (2008).
- 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.
- Gunnarsson, H., M. Ronnqvist and J.T. Lundgren, "Supply chain modeling of forest fuels", European Journal of Operational Research, 158 (2004) 103-123.
- Gronalt, M. and P. Rauch, "Designing a regional forest fuel supply network", Biomass and Bioenergy, 31 (2007) 393-402.
- Hess, J. R., C. T. Wright, and K. L. Kenney. "Cellulosic biomass feedstocks and logistics for ethanol production." Biofuels, Bioproducts & Biorefining, (2007) 181-190.
- 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
- 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).
- 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.
- 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).

Acknowledgement

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