Supply Chain Design Models for Cellulosic Ethanol Production Plants: A Study of Mississippi

Dr. Sandra Duni Eksioglu
Department of Industrial & Systems Engineering

Dr. Liam Leightley
Forest & Wildlife Research Center

Biomass South 2008
Raleigh, NC

Motivations

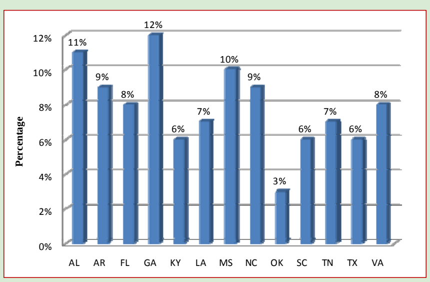
- Energy prices continue to rise
- Increased awareness on environmental issue
- Energy security has become a national priority
- U.S. government granted $385M to six c-ethanol plants in 2007

Opportunities in Southeast

- Vast amount of timber and woody biomass
- Price of pulpwood is declining
- Pulp and paper industry are in decline
- Furniture industry is in decline
- There are marginal agricultural land that can grow woody biomass
- Sept. 2008: Conventional Ethanol - $2.168, Gas - $3.68

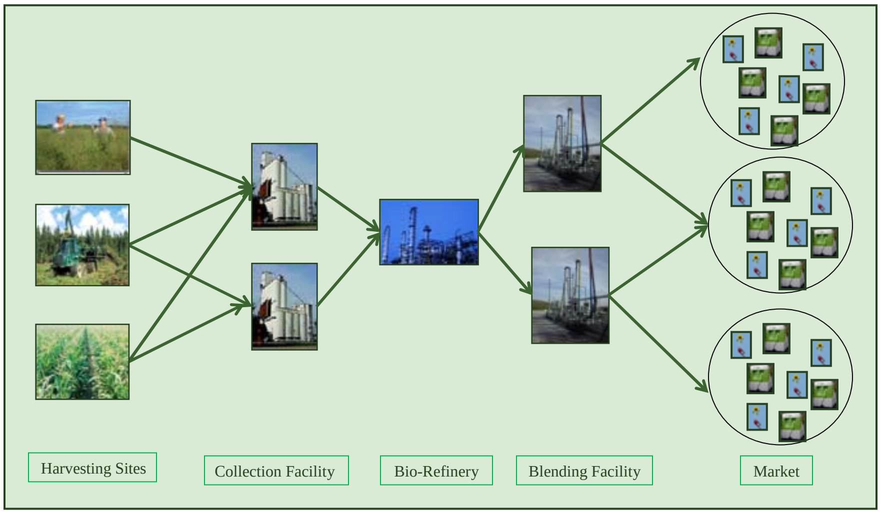
Opportunities in Mississippi

Percentage of Forest Land Contribution in Southeastern U.S. (Source: MIFI & FIA)



- July 15, 2008: Forbes Magazine named Iowa, North Dakota, Georgia, Mississippi and North Carolina the most important state sources of biomass…. Mississippi was named for its 3.6 million tons of logging waste.

Supply Chain of C-Ethanol

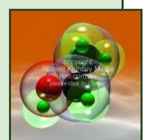


Supply Chain Design – Long-Term Decisions

- SCh Design (long-term decisions)
  - How many bio-refineries should be constructed?
  - What should be the corresponding production capacity?
  - Where should they be located? Location affects transportation costs.
  - Should there be collection facilities located between a harvesting site and a bio-refinery?
    - If yes, how many and where?

Supply Chain Design – Mid- & Short-Term Decisions

- SCh Operations (mid-, short-term decisions)
  - Which harvesting sites will supply a particular collection facility / bio-refinery?
  - What part of the available land will be cultivated with a particular crop (land distribution among cotton, soybeans, rice, corn, etc.)
  - What mode of transportation should be used?
  - How should we manage the inventories? Should we carry biomass, or ethanol, and how much of each?



Challenges with Biomass Supply Chains and Logistics Management

- Supply is constrained by land availability
- Supply is seasonal and uncertain
- High logistics costs:
  - Widely dispersed physical distribution
  - Bulky, and difficult to transport
- High transactions costs
- Biomass looses dry matter with time
- Lack of technical information on biomass SCh design & management

Logistics Cost Analyses

We build a <u>mathematical model</u> that can be used to design the SCh for an c-ethanol production plant

- *Inputs*:
  - the available land
  - production yield
  - unit collection costs
  - unit transportation costs
  - unit inventory costs
  - unit processing costs
  - investment costs
- *Outputs*:
  - Location, size, and number of biorefineries that <u>minimizes delivery costs</u>
  - Location, size, and number of collection facilities that <u>minimizes costs</u>
  - The <u>minimum total delivery cost</u> of c-ethanol: collection, transportation, inventory costs of biomass, processing and distribution costs for c-ethanol

Logistics Cost Analyses

- Sensitivity analyses:
  - How changes in <u>biomass supply</u> affect the delivery cost of c-ethanol?
  - How changes in <u>biomass cost</u> affect the delivery cost of c-ethanol?
  - How changes in the <u>cost of fuel</u> affect the delivery cost of c-ethanol?
  - How changes in <u>yield production</u> affect the delivery cost of c-ethanol?
  - How <u>timing of harvest and storage</u> affects the delivery cost of c-ethanol?
  - How biomass <u>conversion rate</u> affects the delivery cost of c-ethanol?

Case Study

Opportunities for C-Ethanol in Mississippi

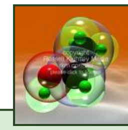
Input Data

- Potential **Demand** for Ethanol in Mississippi

Population	2,921,088 (2005)
Licensed Drivers	1,900,000 (2004)
Gasoline Consumption	1.7 BGY (2005)
Ethanol Blended Consumption	0 (2005)
Potential Ethanol Use (E10)	170 MGY (2005)

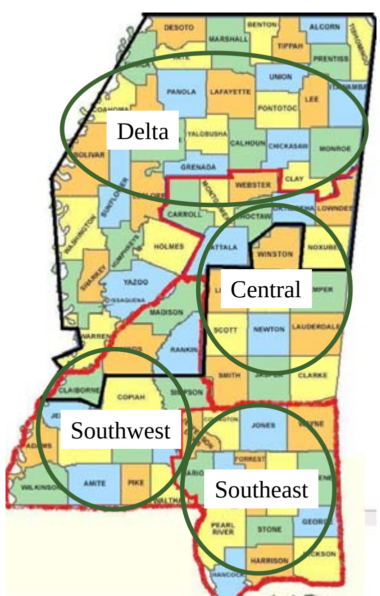
American Coalition for Ethanol Handbook, 2005

Input Data



- Woody Biomass in Mississippi
  - Mississippi Institute for Forest Residues (MIFI)
    - Forest resource inventory: Southeast, Central and Southwest MS (44 counties)
    - The data is presented at the county level
- Corn Stover in Mississippi
  - National Agricultural Statistics Service (NASS) provided by USDA
    - Corn: harvested area, production yield, planting/harvesting periods, historical price, etc.
    - The data is presented at the county and state level
    - 45 out counties are considered (Delta region)
  - Petrolia (2008), Wallace (2005), NREL/TP-510-32438

Input Data

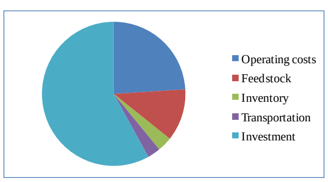


Input Data

- **Investment Costs**
  - MIFI estimates investments costs for a 60MGY plant in south east, MS to be $310 Million
  - Doubling the size of a biorefinery increases the investments costs by a factor of 1.6 (Wallace, 2005)
  - The data is interpolated to derive the rest of investment costs
  - Project life 20 years, discount rate 15%

	Costs	
Size	**Investment**	**Ann. Equivalent**
10 Mill gall/year	87,843,905	14,034,071
20 Mill gall/year	140,972,364	22,521,952
30 Mill gall/year	193,233,409	30,871,254
40 Mill gall/year	226,233,197	36,143,348
60 Mill gall/year	310,102,000	49,542,351

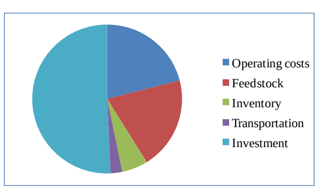
Distribution of Costs per Gallon of C-ethanol



Forest Residues

Costs	$/gallon
Operating costs	0.41
Feedstock	0.20
Inventory	0.06
Transportation	0.05
Investment	0.99
Total	1.71

Source: Based on MIFI's report for the plant in Wiggins using forest residues



Corn Stover

Costs	$/gallon
Operating costs	0.41
Feedstock	0.39
Inventory	0.11
Transportation	0.05
Investment	0.99
Total	1.95

Source: National Renewable Energy Laboratory (NREL/TP – 510 - 32438)

Availability of Biomass Feedstock in Mississippi

	Annual Volume (AV) (dt)	Conversion Rate 50 gl/dt	80 gl/dt
		C-ethanol (MGY)	
Forest Residues (FR)	864,894	43	69
Pulpwood (P)			
10% AV	2,773,810	139	222
1% AV	277,381	14	22
Sawtimber (S)			
10% AV	3,743,926	187	300
1% AV	374,393	19	30
Corn Stover (CS)			
30% AV	645,300	32	51
10% AV	215,100	11	17

C-ethanol potential production in Mississippi :
43 - 642 MGY

Scenarios Analyzed

Supply: Forest Residues → Scenario 1: 40 MGY

Supply: Forest Res. & Stover (Low) → Scenario 2: 50 MGY

Supply: Forest Res. & Pulpwood (Low) → Scenario 3: 55 MGY

Supply: Forest Res. & Pulpwood (High) → Scenario 4: 150 MGY

Supply: Forest Residues, Pulpw. & Sawtimebr (Low) → Scenario 5: 70 MGY

Supply: : Forest Residues, Pulpw. & Sawtimebr (High) → Scenario 6: 170 MGY

Break-Even C-Ethanol Delivery Cost: Scenario 1

Due to increase in transportation & processing costs

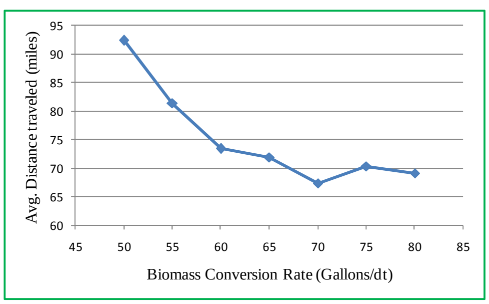
$2.00 - $1.71 = $0.29 due to transportation

Due to increase in investments costs

	Construction Cost per Annual Gallon								
	$1.00	$1.50	$2.00	$2.50	$3.00	$3.50	$4.00	$4.50	$5.00
Gallons/dt	Delivery Cost per Gallon of C-ethanol (in $)								
80	2.00	2.62	3.24	3.86	4.48	5.10	5.71	6.33	6.95
75	2.06	2.68	3.30	3.92	4.54	5.16	5.78	6.40	7.01
70	2.13	2.75	3.37	3.99	4.61	5.23	5.85	6.47	7.09
65	2.21	2.83	3.46	4.08	4.70	5.32	5.94	6.55	7.17
60	2.30	2.93	3.56	4.18	4.80	5.42	6.04	6.66	7.28
55	2.42	3.05	3.68	4.30	4.93	5.55	6.17	6.79	7.41
50	2.58	3.21	3.83	4.46	5.09	5.71	6.34	6.96	7.58

Scenario 1: 40 MGY of C-ethanol produced
Biomass Supply: Forest Residues

Distance Traveled

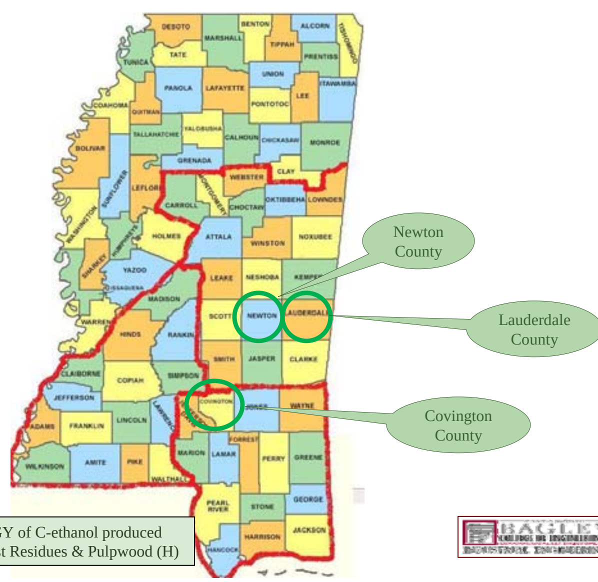


Scenario 1: 40 MGY of C-ethanol produced
Biomass Supply: Forest Residues

Biorefinery Location for Scenario 1

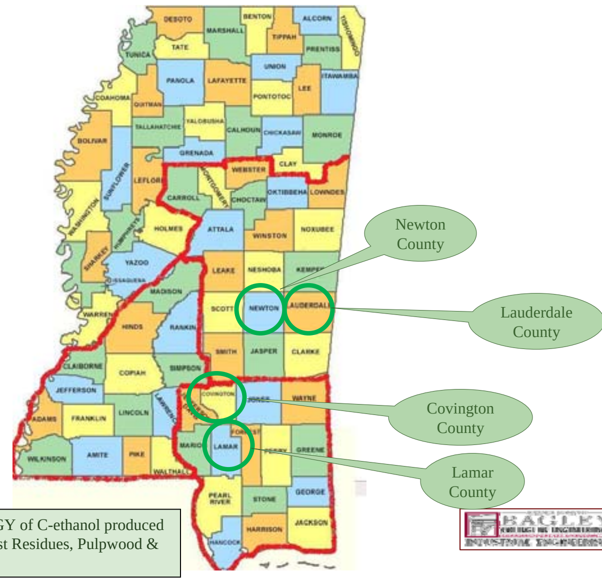
Scenario 1: 40 MGY of C-ethanol produced
Biomass Supply: Forest Residues

Biorefinery Location for Scenario 4



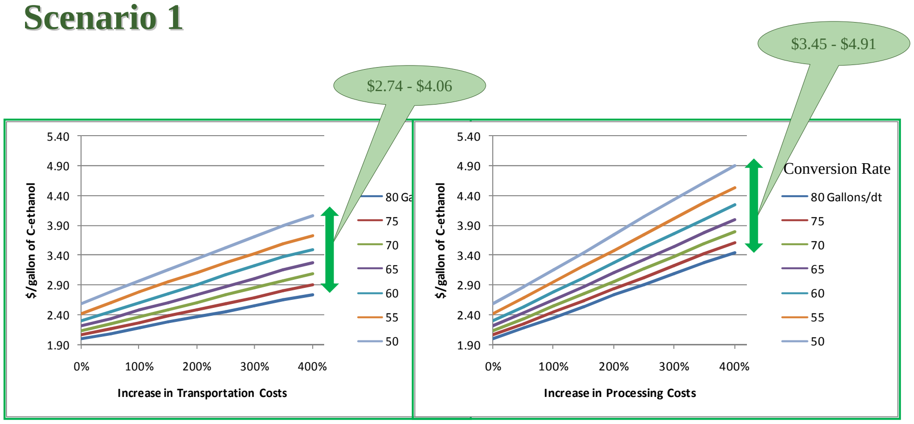
Scenario 4: 150 MGY of C-ethanol produced
Biomass Supply: Forest Residues & Pulpwood (H)

Biorefinery Location for Scenario 6

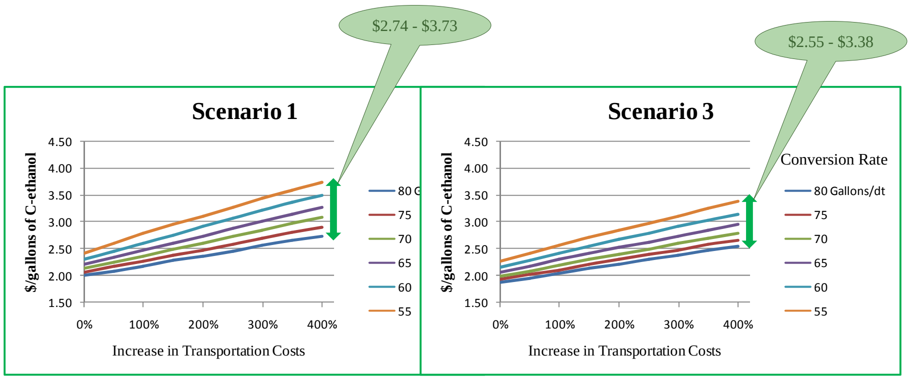


Scenario 6: 170 MGY of C-ethanol produced
Biomass Supply: Forest Residues, Pulpwood & Sawtimber (H)

Impact of Transportation and Processing Costs: Scenario 1



Impact of Biomass Availability on Delivery Cost: Scenario 1 vs 3



Summary

- We developed mathematical models that can be used to identify
  - Locations for biorefineries
  - Estimate the cost of producing one unit of c-ethanol
  - Estimate the impact of different factors (such as, transportation costs, processing costs, investment costs, etc.) on the delivery cost of c-ethanol

Conclusions

- Managing biomass supply is crucial for the success of projects

- Managing biomass supply chain is a challenging problem due to the large number of variables involved

Questions???