CENTRALIZED VERSUS DISTRIBUTED MANUFACTURING: A CONTINUOUS LOCATION-ALLOCATION PROBLEM

Cristiana L. Lara and Ignacio E. Grossmann

Center for Advanced Process Decision-making
Department of Chemical Engineering, Carnegie Mellon University

Modular Manufacturing Workshop
NSF and DOE
January 17 and 18, 2017

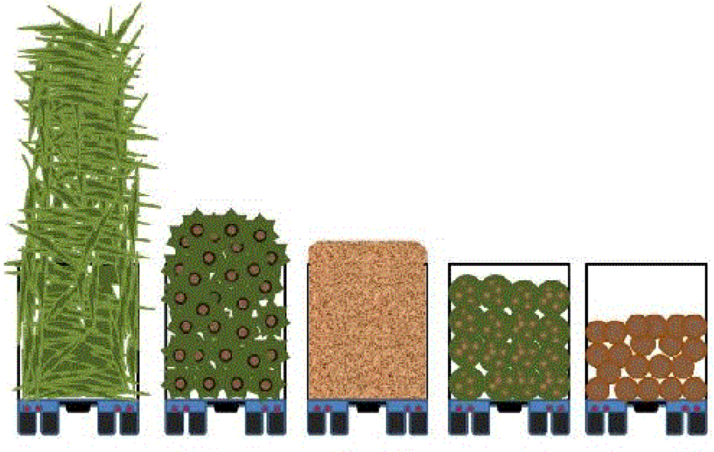
Motivation: Distributed manufacturing

Distributed Manufacturing – geographically distributed network of facilities

- Exploit new technology and <u>**modularity**</u>
- Address new requirements of the market
- Logistical aspects

Potential applications

- Biomass supply chain (ethanol production)[1]
- Shale gas supply chain (gas processing plants)
- Electric power generation (distributed power)



1 F. You and B. Wang, "Life cycle optimization of biomass-to-liquid supply chains with distributed-centralized processing networks,", 2011.

Question: Centralized vs. Distributed Facilities

Tradeoff: Capital cost vs. Transportation Cost

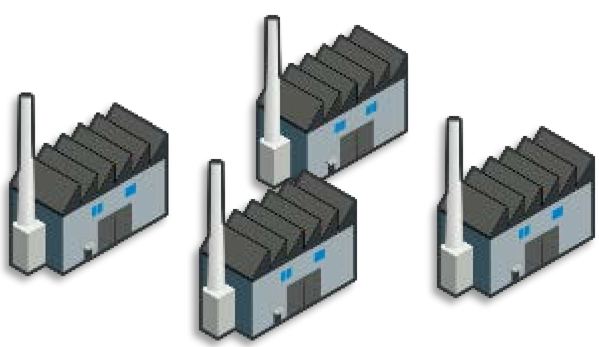
- Modular designs and transportation favors Distributed Manufacturing
- Economy of scale favors large-scale production

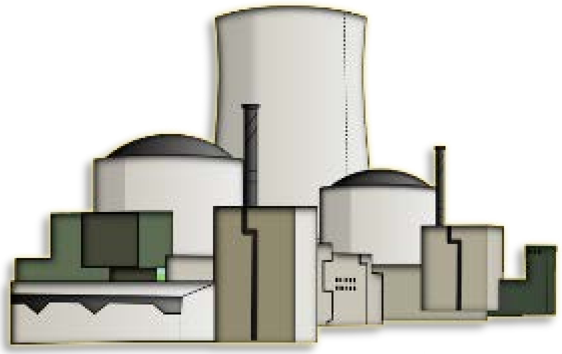
Need for a optimization model that captures the tradeoff and design best network

- Evaluate cost of centralized versus distributed manufacturing
- Address higher level planning problems

Problem formulated as Capacitated Multi-facility Weber problem[2]

- Determine location in continuous 2-D space for new facilities in relation to the location of existing facilities





2 Brimberg, P. Hansen, N. Mladonovic, and S. Salhi, "A survey of solution methods for the continuous location allocation problem,", 2008.

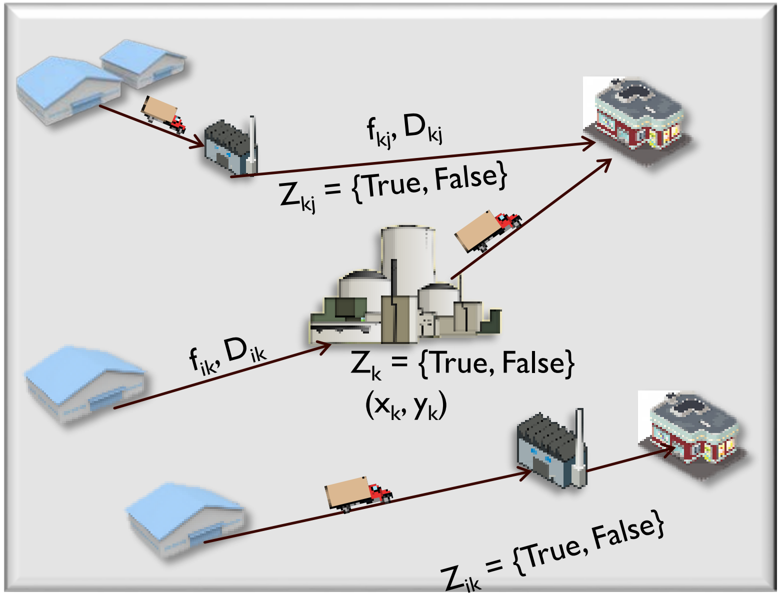
Problem statement

Given:

- A set of suppliers i, a set of consumer markets j, and their respective fixed location, availability and demand
- M potential distributed and N potential centralized set of k single-product facilities, and their corresponding maximum capacity and conversion rate (*unknown location: x_k, y_k,*)
- Investment, operating and transportation costs

Find:

- Number, type and location of facilities to design a manufacturing network that minimizes the cost



Continuous variables: x_k, y_k, f_{ik}, f_{kj}, f_k, D_{ik}, D_{kj}
Boolean variables: Z_k, Z_{ik}, Z_{kj}

General Disjunctive Programming (GDP) Formulation

Objective Function: Total Cost = Investment cost + Transportation Cost

Disjunction 1:
If potential facility k is going to be built or not

Disjunction 2:
If facility k is supplied by supplier i or not

Disjunction 3:
If facility k sells its product to market j or not

Distance between supplier i and facility k

Distance between facility k and market j

Logical Constraints
If facility k is built, there must be at least on connection between this facility and the suppliers, and between this facility and the markets

Maximum availability of raw material in each supplier i

Mass balance

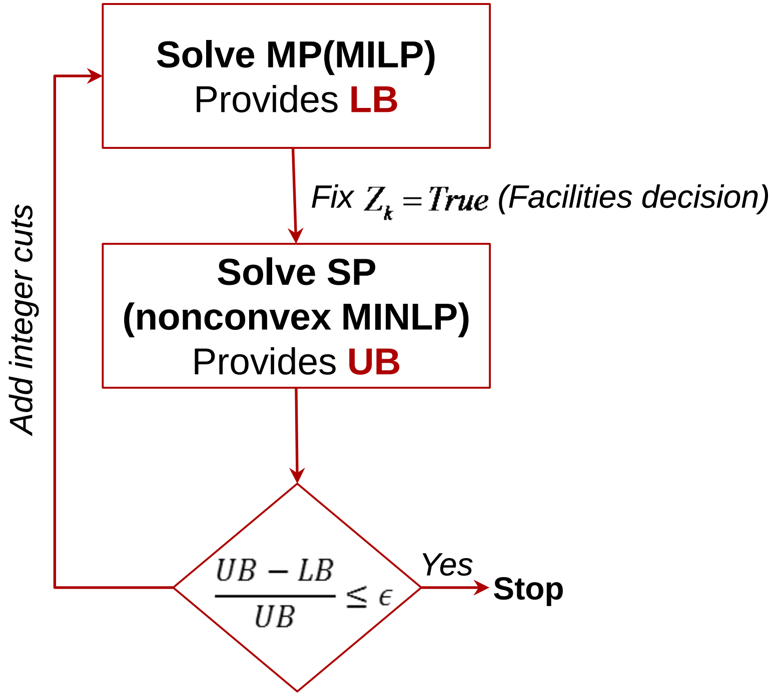
The facilities' production must attend the markets demand

Boolean variables

Variables domain

Bilevel decomposition algorithm

Global Optimization Algorithm



Description

Master problem[11]: linear GDP relaxation provides a lower bound, and the selection of facilities to fix

- Bilinear terms are approximated using Logarithmic Piecewise McCormick[12]
- Distance constraints, which are convex, are linearized for a given discretization of space

Subproblem[11]: For the fixed alternative of facilities, the MINLP is solved with global solver to obtain an upper bound

- Potential links, which involve discrete variables, are still to be determined.

Integer cuts[13] are added to the (MP)

11 F. Trespalacios and I. E. Grossmann, “Cutting planes for improved global logic-based outer-approximation for the synthesis of process networks .,”, 2015.
12 R. Misener, J. P. Thompson, and C. a. Floudas, “Apogee: Global optimization of standard, generalized, and extended pooling problems via linear and logarithmic partitioning schemes,” 2011
13 E. Balas and R. Jeroslow. “Canonical cuts on the unit hypercube”., 1972.

Example problem: bioethanol production

10 switchgrass suppliers

500 kt/year of switchgrass available per supplier

Prices ranging from \$30 to \$40/t (dry basis)[14]

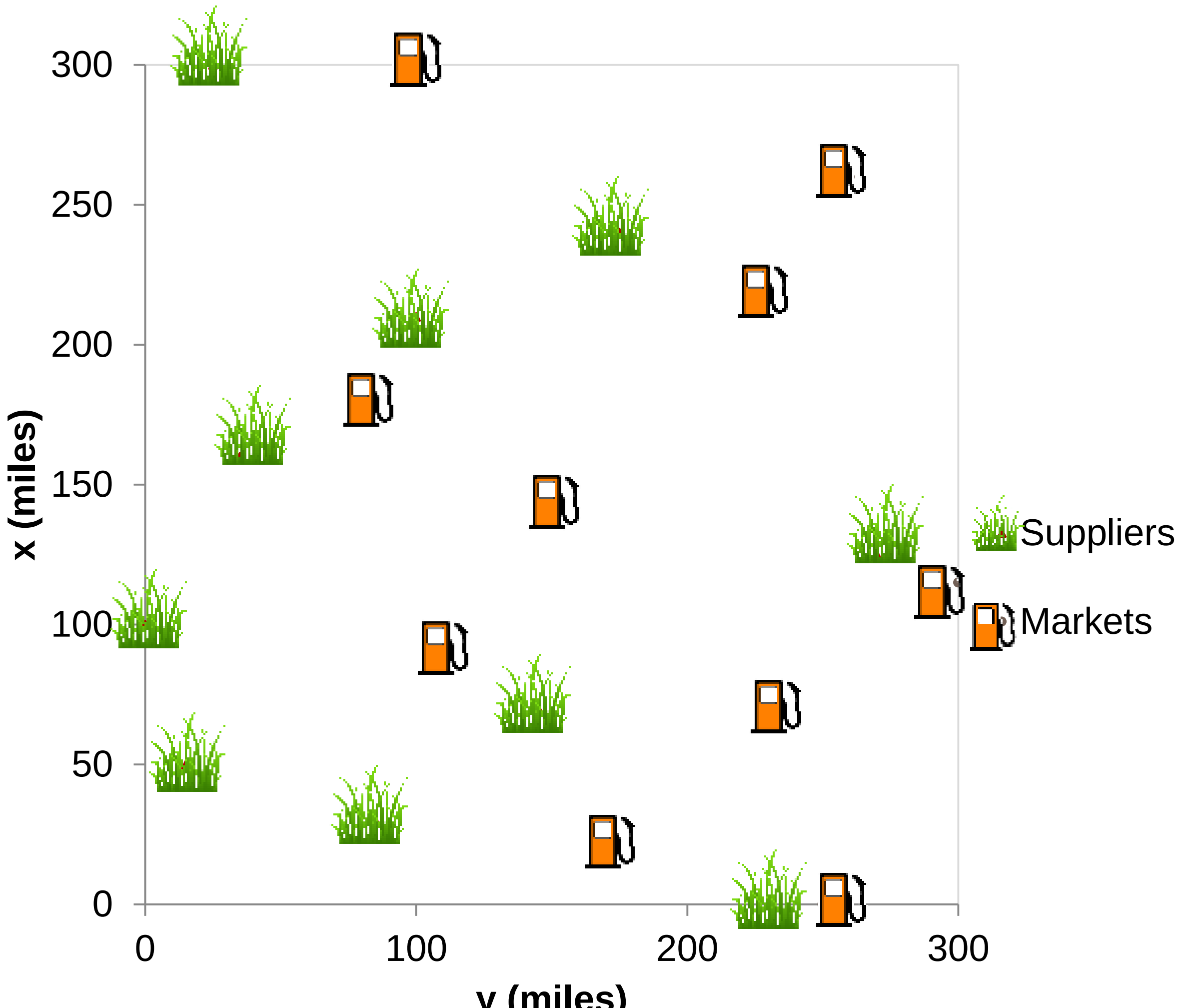
10 ethanol markets

Demand of 40 MGal /year of ethanol per market

12 potential facilities $(cv_k = 26\%)$[14]

10 distributed $\left(mc_m = 40.4 \, {}^{MGal}/_{year}\right)$

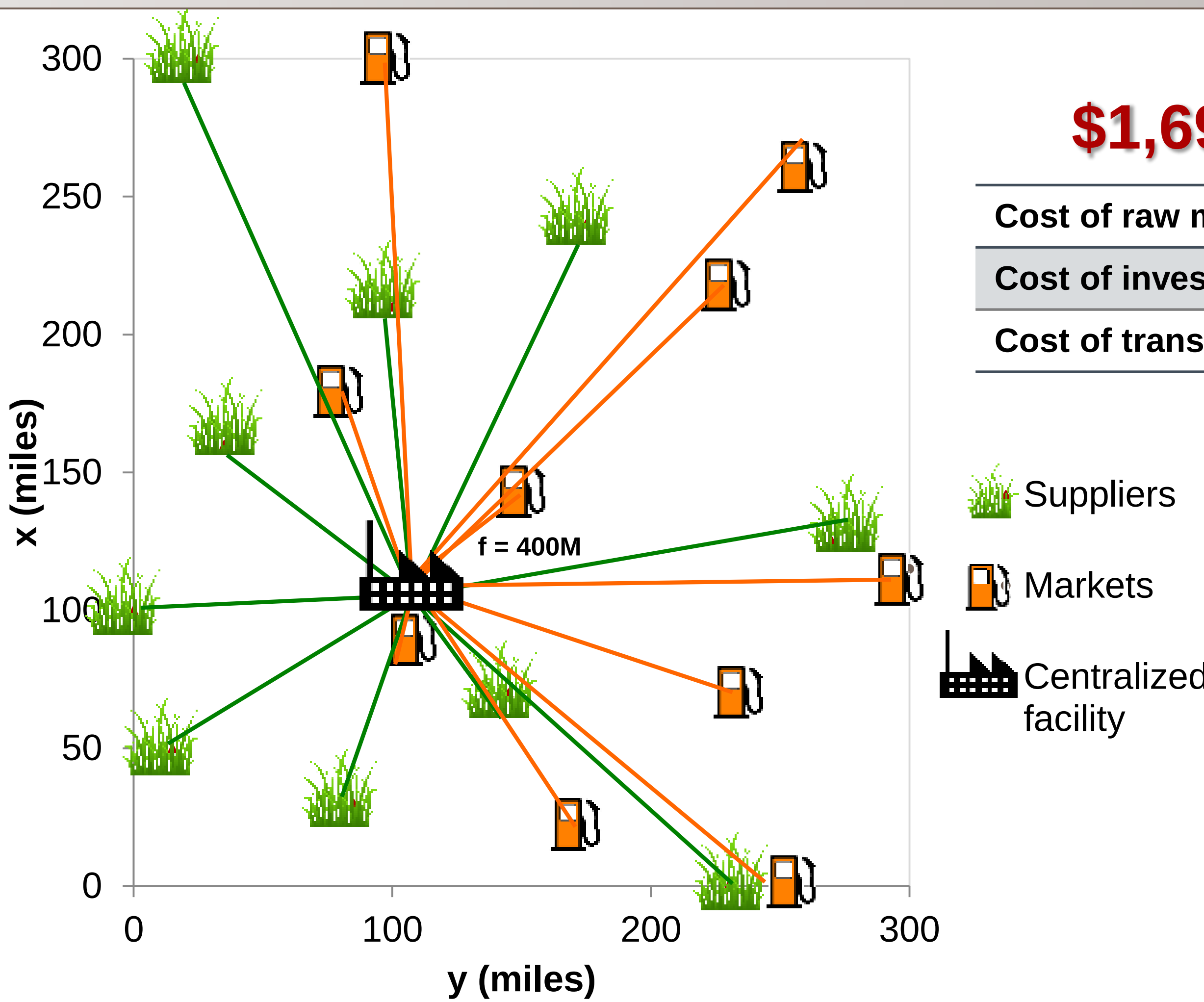
2 centralized $\left(mc_n = 404 \, {}^{MGal}/_{year}\right)$



14 M. Haque and F. M. Epplin, "Cost to produce switchgrass and cost to produce ethanol from switchgrass for several levels of biorefinery investment cost and biomass to ethanol conversion rates" , 2012

Large-scale problem: bioethanol production

1 centralized facility and optimal location

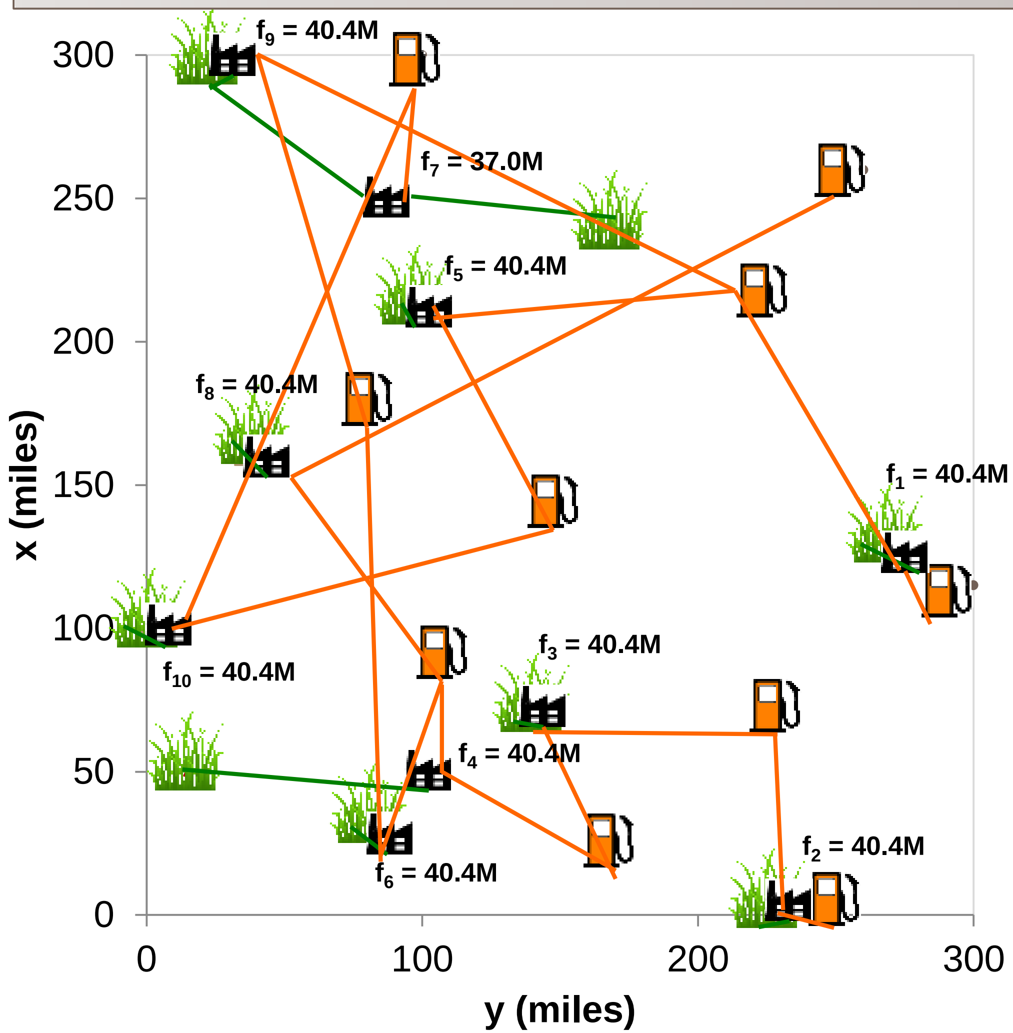


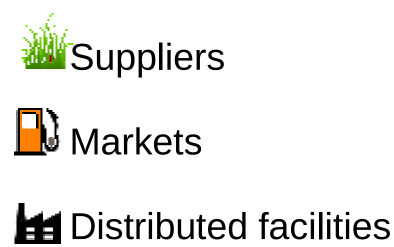
$1,695 million/year

Cost of raw material	$ 160 million/year
Cost of investment	$1,070 million/year
Cost of transportation	$ 464 million/year

Large-scale problem: bioethanol production

10 distributed facilities and their optimal location



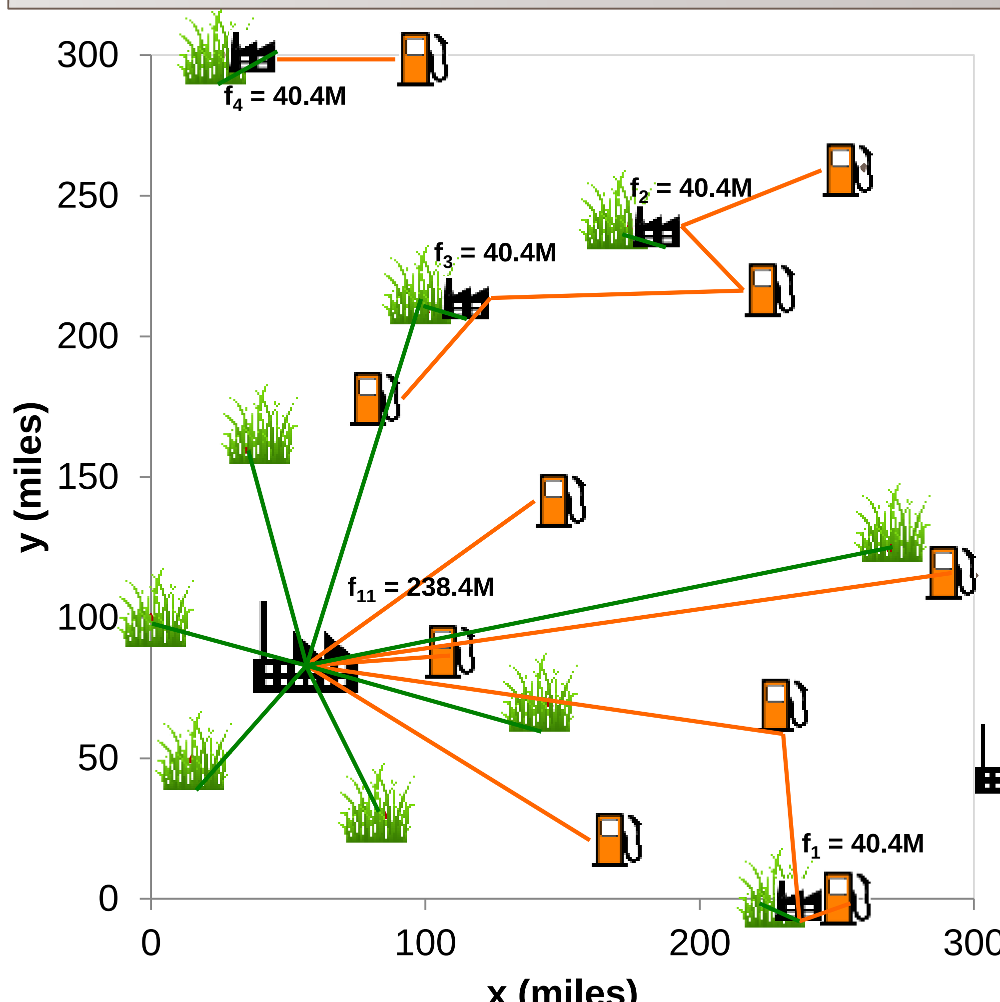


$1,415 million/year

Cost of raw material	$ 158 million/year
Cost of investment	$1,084 million/year
Cost of transportation	$ 173 million/year

Large-scale problem: bioethanol production

Optimal network: 1 centralized, 4 decentralized



$1,404 million/year

vs. $1,415M and $1,695M

Cost of raw material	$ 158 million/year
Cost of investment	$ 793 million/year
Cost of transportation	$ 453 million/year

Large-scale problem: bioethanol production

Computational Results

Model statistics

	Single Equations	Single variables	Discrete variables
Full dimension (nonconvex MINLP)	2,838	769	252
Master Problem (MILP)	10,639	6,769	2,172
Subproblem (nonconvex MINLP)	2,912	757	240

2 major iterations

Global Optimization

METHOD	Cost ($millions/year)	Optimality gap (%)	CPU time (hrs)
BARON	1,491	44.3%	12*
SCIP	1,695	1312.4%	12*
ANTIGONE	1,589	14.6%	12*
Bilevel Decomposition	1,404	7%	3.1

- Exceeded maximum CPU time
- For the Bilevel Decomposition Algorithm, the master problem (MILP) was solved using Gurobi and the subproblem (nonconvex MINLP) was solved using BARON

Conclusions

Nonconvex GDP Centralized vs Distributed:

reformulated as a nonconvex MINLP

Commercial global solvers can solve small problems fairly quickly

Computationally expensive to solve large-scale problems

- ***Bilevel decomposition algorithm***
  - ***Provides superior results in less amount of time***
  - ***Potential to be improved***