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Department of Building Construction Management

Optimization of BioRefinery Capacity for the Production of BioFuels.

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Abstract

With increasing energy demands, decreasing oil supplies, and increased concern about global climate change interest in the efficient, environmental, and economical conversion of lignocellulosic biomass materials to ethanol and other liquid biofuels has never been greater. There are several different methods for the conversion of biomass to ethanol; thermo-chemical, acid hydrolysis, and enzymatic hydrolysis, with some of the most basic issues facing the commercialization of these technologies including the collection, transport, and delivery of bulky, high moisture, low density biomass feedstocks for processing. The larger the capacity of a biorefinery the more land, storage area, and transport is required for feedstock- thus increasing f.o.b. (free on board) input costs. Conversely, in liquid chemical processing plants there exists an increasing returns to scale in terms of per unit of capacity capital and operating costs. This research plans to examine these conflicting returns to scale to give a range of economically and environmentally optimal biorefinery capacity under different conditions, assumptions, and feedstocks through techno-economic and spatial process modeling.

1 Problem Statement

What is the **tradeoff** between cellulosic ethanol (EtOH) **plant size** and the **land area** from which the plant is drawing feedstock and natural resources?

→ **Optimization** across
Space
Time

How do you balance the increasing returns to scale to larger facilities against the increased cost of transport, storage, and logistics of the biomass feedstock?

2 Hypothesis

There has been a trend in the corn ethanol industry towards ever larger plants (100+ mgy) because of the increasing returns to scale, but due to the differences in feedstock (grain / biomass) cellulosic EtOH plants are under different constraints than corn EtOH plants.

Since cellulosic feedstocks are less dense, produce less ethanol per ton, and have a higher moisture content than corn:

→ **We hypothesize that cellulosic EtOH plants will be smaller in capacity in order to keep feedstock transportation and storage costs down relative to production costs**

7 References

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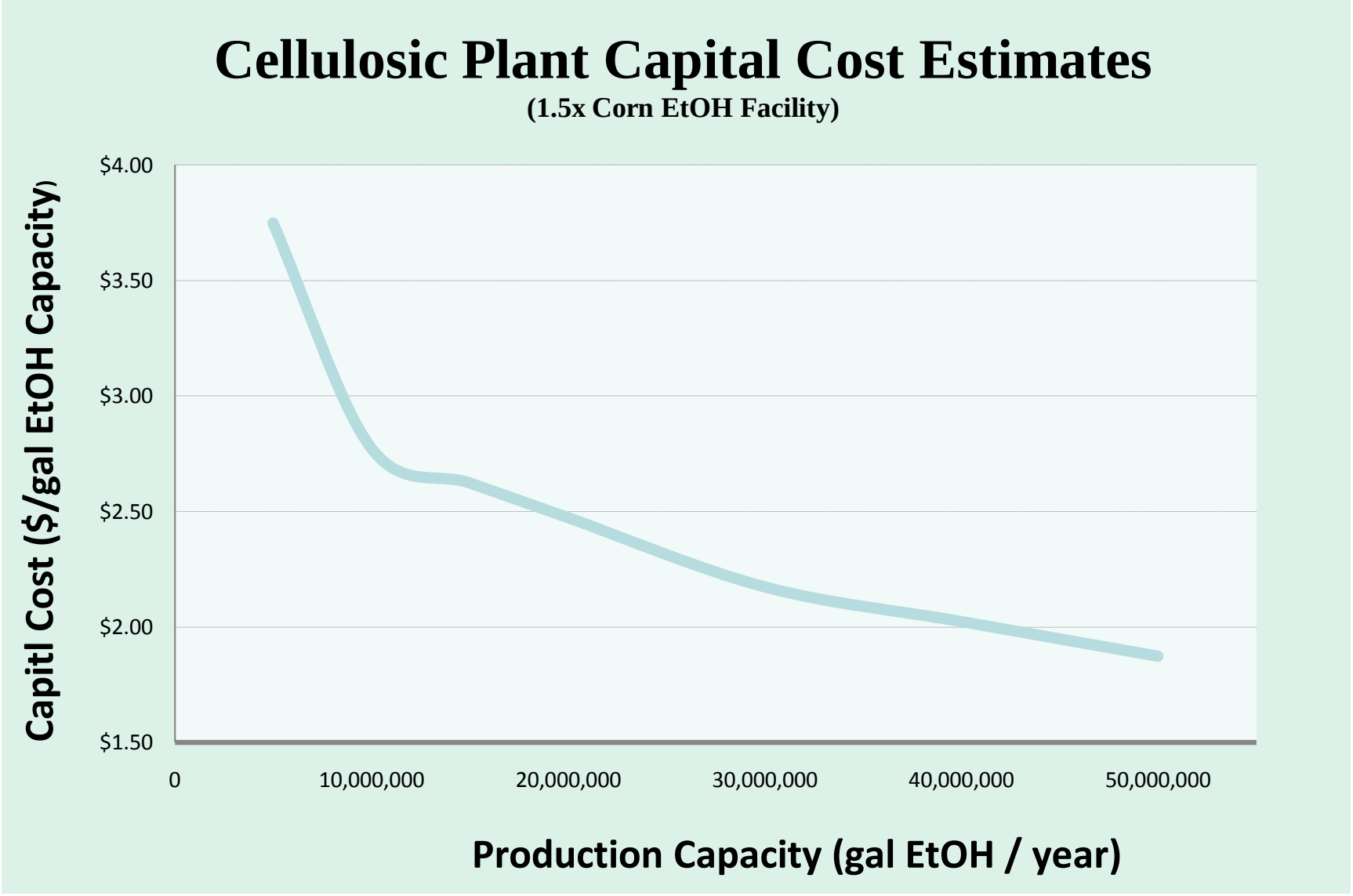
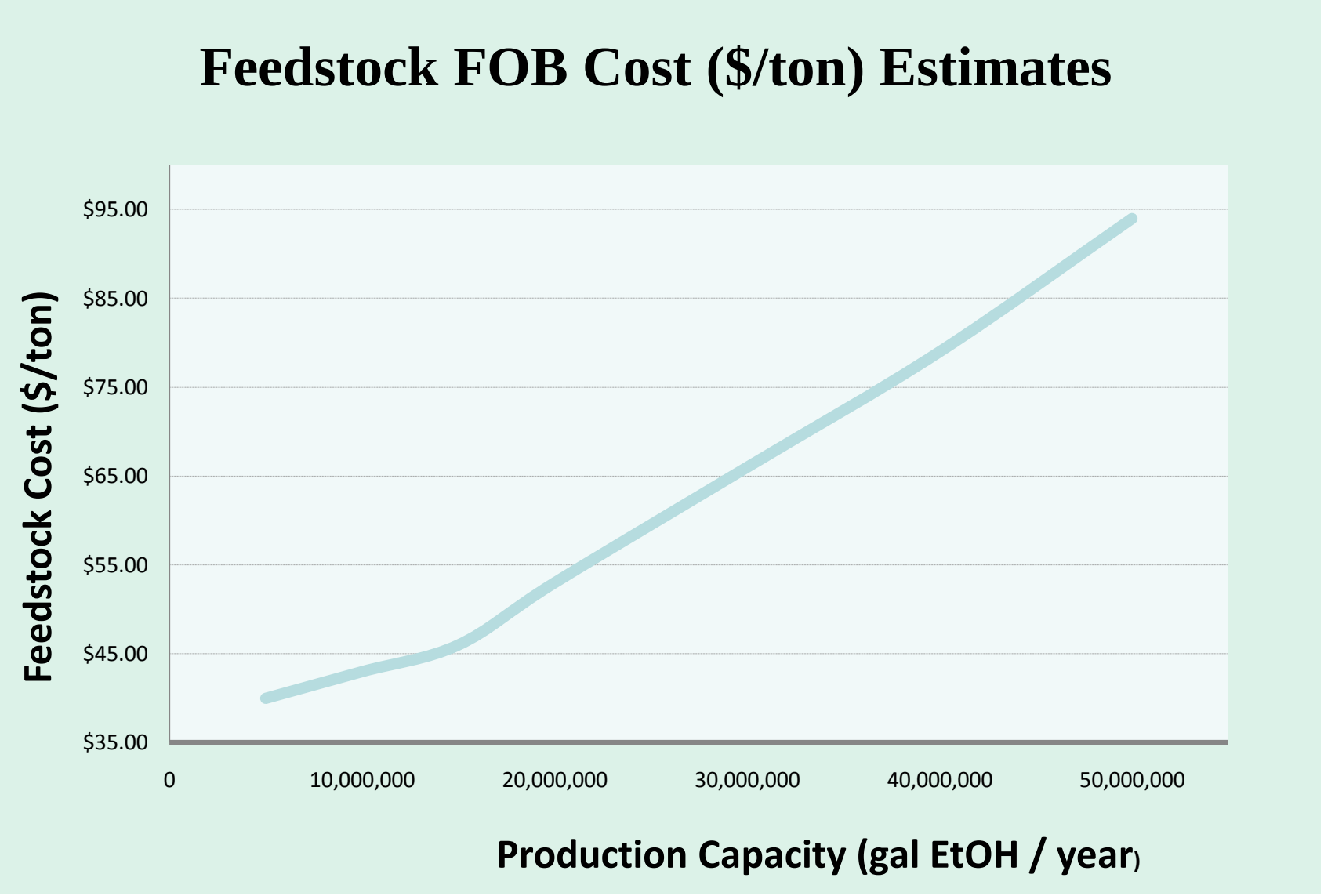
3 Methodology

Under different assumptions, compare and optimize annual cellulosic plant capacity using **corn stover** as feedstock using a techno-economic process and spatial modeling.

Process Model- Uses feedstock composition, laboratory yield parameters, and capital / labor / operating cost inputs to return economic returns to facility

- EtOH Yield per Ton of Stover = f(stover comp., yield assumptions)
- Capital Cost of Facility = f(capacity, technology assumptions)
- Operating Cost = f(capacity, labor, yields, feedstock, inputs)


Cellulosic Plant Capital Cost Estimates
(1.5x Corn EtOH Facility)


Feedstock FOB Cost ($/ton) Estimates

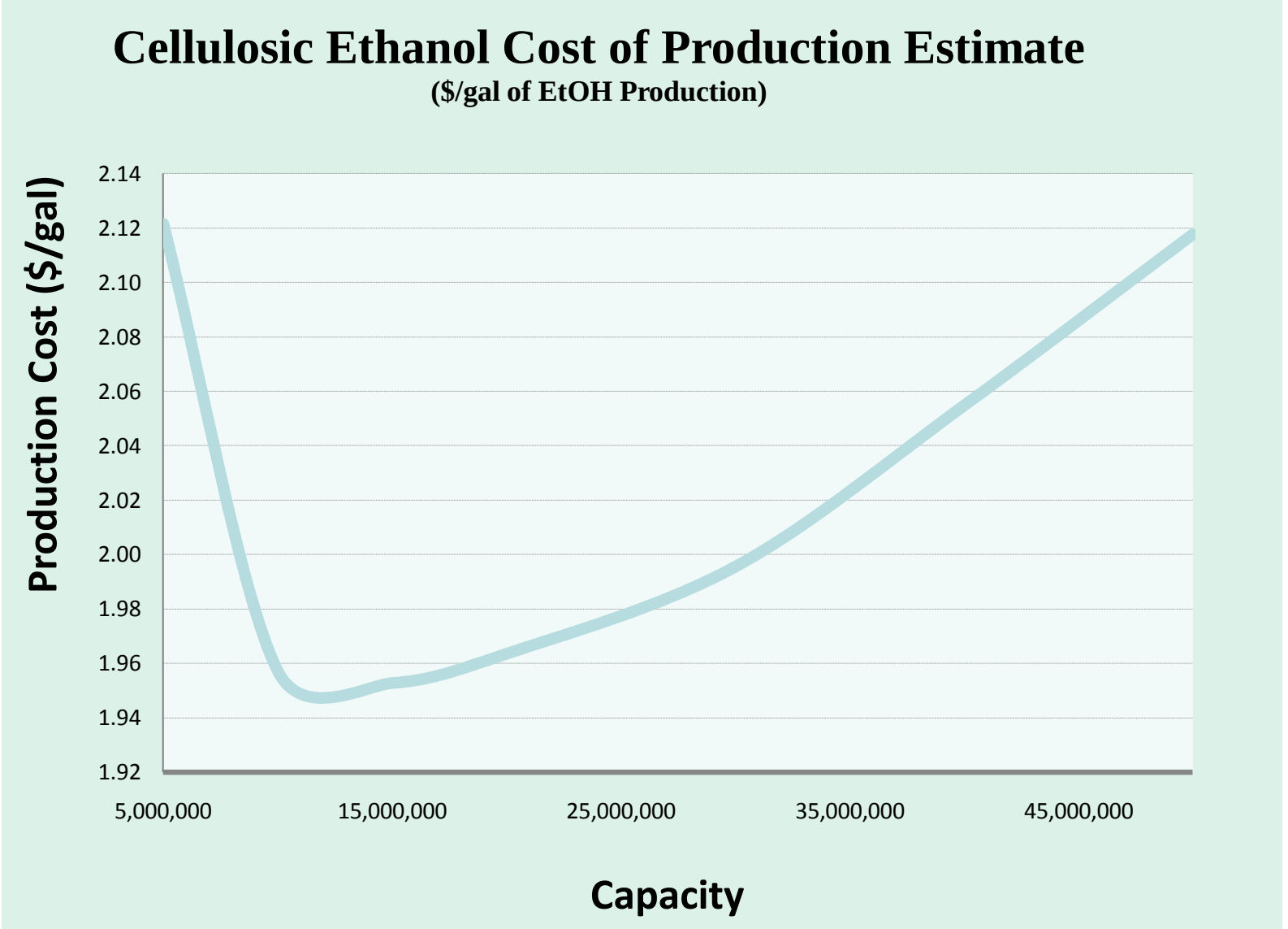
Spatial Feedstock Model- Uses farm level yields, production data, and plant capacity information to estimate the number of acres, distance, and transport cost of stover feedstock:

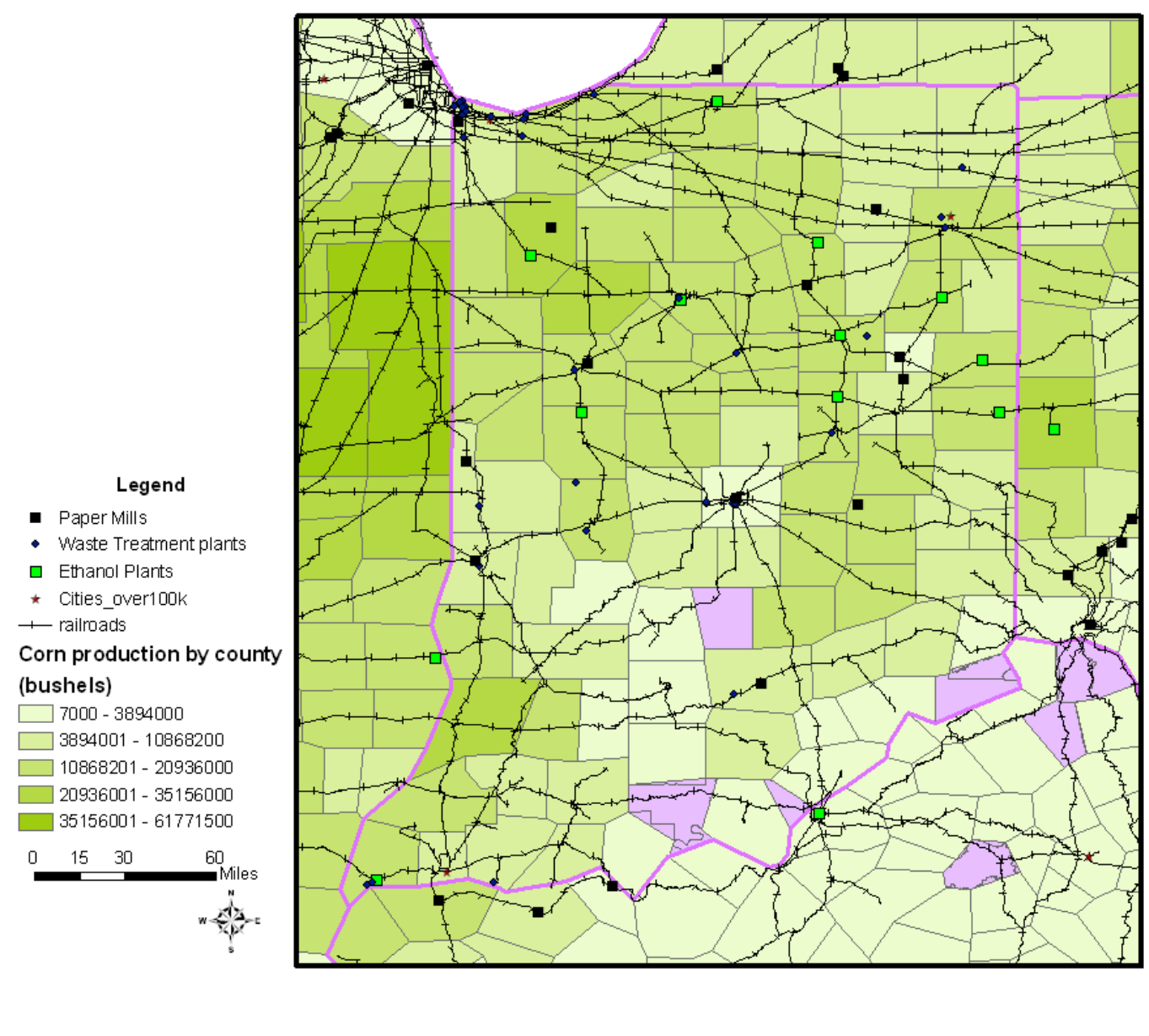
- corn production by county for 2005 (USDA data)
- total corn stover production per acre = f(corn production)
- % of corn stover removable = f($, production, $ N/P/K)

Plant Assumptions		Stover Feedstock				Annualized Costs					
Capacity (mgy)	Capital Cost ($)	Feedstock (tons/year)	Land Req. (acres)	Radius (miles)	FOB Feedstock Cost ($/ton)	Labor ($/year)	Energy / Enzymes ($/year)	Feedstock (FOB)	Capital	Total Cost	**Cost of Prod. ($/gal)**
5,000,000	18,750,000	71,429	14,286	10	40	1,000,000	4,500,000	2,857,143	2,250,000	10,607,143	**2.12**
10,000,000	27,750,000	142,857	28,571	20	43	1,100,000	9,000,000	6,142,857	3,330,000	19,572,857	**1.96**
15,000,000	39,375,000	214,286	42,857	30	46	1,210,000	13,500,000	9,857,143	4,725,000	29,292,143	**1.95**
20,000,000	49,500,000	285,714	57,143	40	53	1,331,000	18,000,000	15,142,857	5,940,000	40,413,857	**2.02**
30,000,000	65,250,000	428,571	85,714	60	66	1,464,100	27,000,000	28,285,714	7,830,000	64,579,814	**2.15**
40,000,000	81,000,000	571,429	114,286	80	79	1,610,510	36,000,000	45,142,857	9,720,000	92,473,367	**2.31**
50,000,000	93,750,000	714,286	142,857	100	94	1,771,561	45,000,000	67,142,857	11,250,000	125,164,418	**2.50**

4 Results

Under the modeled feedstock and process cost assumptions it is found that the optimal plant size is in the 10 – 15 mgy production capacity:


Cellulosic Ethanol Cost of Production Estimate
($/gal of EtOH Production)



5 Potential Consequences

Natural resources depletion
- Conversion of forested or CRP land to 'agricultural land' (Bennett 2000, Fargione, Searchinger)
- Inordinate consumption of water (Spangenberg 2007)
- increased soil erosion (De Oliviera *et al*., 2005)

Increased pollution
- Increased use of fertilizers and pesticides (Hill *et al*., 2006)
- increased aldehydes and nitrates in air (Gaffney *et al*., 1997: Williams 2004)
- increased truck traffic on rural roads (Tyner , 2007)

Other
- incentive to cultivate energy crops rater than food crops (Berndes *et al*., 2001)
- farmers stop corn-soybean rotation
- corn yield fluctuations due to weather patterns (Southworth *et al*., 2000)
- Need to first address energy expenditures through conservation (Bennett 2000, Spangenberg 2007)

6 Areas of future research

- **Change inputs** to model : switchgrass, poplar trees, MSW, etc.
- **Vary model assumptions** → sensitivity analysis
- **Refine spatial component** of model to better reflect actual land use and transportation systems (rail and roads)