VIABILITY ASSESSMENT OF REGIONAL BIOMASS PRE-PROCESSING CENTER BASED BIO-ETHANOL VALUE CHAINS

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ABSTRACT

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Petroleum accounts for 94% of all liquid fuels and 36% of the total of all energy consumed in the United States. Petroleum dependence is problematic because global petroleum reserves are estimated to last only for 40 to 60 years at current consumption rates; global supplies are often located in politically unstable or unfriendly regions; and fossil fuels have negative environmental footprints. Domestic policies have aimed at promoting alternative, renewable liquid fuels, specifically bio-fuels derived from organic matter. Cellulosic bio-ethanol is one promising alternative fuel that has featured prominently in federal bio-fuel mandates under the Energy Independence and Security Act, 2007.

However, the cellulosic bio-ethanol industry faces several technical, physical and industrial organization challenges. This dissertation examines the concept of a network of regional biomass pre-treatment centers (RBPC) that form an extended biomass supply chain feeding into a simplified biorefinery as a way to overcome these challenges. The analyses conducted address the structural and transactional issues facing bio-ethanol value chain establishment; the technical and financial feasibility of a stand alone pre-treatment center (RBPC); the impact of distributed pre-treatment on biomass transport costs; a comparative systems cost evaluation of the performance of the RBPC

chain versus a fully integrated biorefinery ("IBR"), followed by application of the analytical framework to three case study regions.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

KEY TO ABBREVIATIONS

AFEX	Ammonia Fiber Expansion
BR	Bio-refinery
BTU	British Thermal Unit
CAFO	Concentrated Animal Feed Operation
CBP	Consolidate Bio-processing
DCFROR	Discounted Cash Flow Rate of Return
DDG	Dried Distiller’s Grains
DFC	Distance Fixed Cost
DOE	US Department of Energy
DSS	Decision Support System
DVC	Distance Variable Cost
EBA	Equity Based Alliance
EPA	Environmental Protection Agency
EtOH	Ethanol
GHG	Greenhouse Gas
GTL	Gas-to-Liquids
IBR	Integrated Bio-Refinery
IRR	Internal Rate of Return
INL	Idaho National Laboratory
LCB	Ligno-cellulosic biomass

LCBE	Ligno-cellulosic biomass to energy
LCE	Ligno-cellulosic ethanol
LNG	Liquified Natural Gas
LRAC	Long Run Average Cost
MBOE	Million Barrels of Oil Equivalent
MBTE	Methyl Tertiary-Butyl Ether
MES	Minimum Efficient Scale
MESP	Minimum Ethanol Selling Price
MMgal	Million Gallons
NAFTA	North American Free Trade Agreement
NREL	National Renewable Energy Laboratory
PTB	Pre-treated biomass
RBPC	Regional Biomass Processing Center
RBPD	Regional Biomass Processing Depot
RES	Renewable Electricity Standard
RFS	Renewable Fuels Standard
RPS	Renewable Portfolio Standard
SG	Switchgrass
SSCF	Simultaneous Saccharification and Co-fermentation
SSF	Simultaneous Saccharification and Fermentation
TPD	Tons (dry) per day
USDA	United States Department of Agriculture

CHAPTER 1

OVERVIEW AND SUMMARY

1.1 Background

The United States has an 'oil addiction', and in a broader sense, a fossil fuel addiction. 83% of total domestic energy consumption comes from fossil fuels. More strikingly, 94 % of vehicular energy consumption comes from petroleum sources. Fossil fuels are a natural resource that is not renewable. It takes millions of years and naturally occurring conditions of pressure and heat, to produce these. Fossil fuels will run out, in less than 50 years according to some estimates[1]

Alternative, preferably renewable, primary energy sources must be discovered and / or created. This is not a new issue. It has been on the national agenda for at least 40 years, with very little progress to show. While only 28% of our total energy consumption is in the transportation sector, it seems to get the most media attention. This is due primarily to the perception that most petroleum is imported from nations that are viewed as hostile or unstable, and the visible impact of 25% change in prices at the corner gas station. As the supply of oil continues to diminish, the prices at the pump will continue their upward trend. Fossil fuels will no longer be cheap on a per energy unit basis. The energy industry must have a fuel supply ready to fill the supply gap, and it must be commercially ready to complement the fossil fuel infrastructure. If the US is to wean itself off its oil addiction, there must be alternative, readily available, renewable resources ready to fill the void.

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[1] Wallace-wells, 2011

In the liquid fuels sector, ethanol is the most widely consumed non-petroleum fuel in the United States, mostly as an additive to gasoline. Ethanol is an alcohol fuel that can be utilized in internal combustion engines. It is derived from starches is plants. The vast majority (99%) of ethanol comes from corn, which is problematic in the long run. Corn is a food (and feed) staple. It cannot feed the world and fuel the world. Other bio-fuels must be developed.

Cellulosic ethanol seems a promising alternative. However, additional processing steps are required prior to ethanol production. Ethanol is produced by fermenting sugars. Corn and other natural products such as sugarcane and beets have plentiful natural sugars that are easily accessible. Cellulosic ethanol is derived from biomass materials that are more recalcitrant in hydrolyzing their sugars. Most plant biomass consists of hemi-cellulose (5 carbon sugar polymers), cellulose (6 carbon sugar polymers) and lignin, roughly 1/3 each by weight. Pre-treatment of the biomass is required to break down the more complex sugars in these materials into fermentable simple sugars.

Estimates show that there is sufficient supply of non-food biomass feedstocks domestically to produce cellulosic ethanol in quantities that could fill a large portion of the gap that will arise as petroleum supplies tighten. Due to this, federal bio-fuel policy has aimed at promoting cellulosic ethanol as a large part of a new liquid fuel portfolio.

In 2005, the Energy Policy Act ("EPACT") aimed at a number of issues that arise from this domestic energy profile: energy security, environmental quality and economic growth. Its policies were designed to reduce dependence on petroleum imports from non-friendly sources, reduce consumption of fossil fuels, improve the environmental impact of energy and create new jobs through domestic economic development. EPACT 2005 included bio-fuel policies aimed at increasing the percentage of non-petroleum transportation fuels through use of agri-bio-fuels, such as cellulosic ethanol. The first federal Renewal Fuels Standard ("RFS1") set hard volume bio-fuels targets, and included the initial cellulosic ethanol target of 250 million gallons by 2013.

The Energy Independence and Security Act of 2007 ("EISA") added additional policies to improve energy security through improved vehicle fuel economy; increased bio-fuels production; and, increased energy efficiency. EISA created RFS2 (Table 1) to replace RFS1; raised the minimum required fuel economy to 35 miles per gallon by the year 2020; added additional funding for grant programs to encourage the development of cellulosic bio-fuels, plug-in hybrid electric vehicles, and other emerging electric technologies. RFS2 (Table 1) was an attempt to stimulate production of advanced bio-fuels through increased overall volume mandates, caps on corn ethanol contribution, and specific cellulosic bio-fuel targets.

The bio-fuel industry is well positioned to meet the volume targets of corn ethanol. Domestic corn ethanol capacity is 14.9 billion gallons per year, with an additional 140 M-gal of capacity under construction.[2] The EISA target is 15.0 billion gallons by 2015 (Table 1). The real challenge is how to rapidly develop cellulosic ethanol, to meet EISA volumetric targets which ramp up by a factor of 10 from 500 M-gal in 2012

[2] www.ethanolrfa.org/pages/statistics#A

to 5.50 billion gallons by 2017, and then triple again to 16.0 billion gallons by 2022 (Table 1).

Table 1: EIAS RFS2 Mandates (Billon gallons)						
Year	Bio-diesel	Non-Cellulosic Advanced	Cellulosic Bio-fuels	Advanced Bio-fuels Total	Conventional Bio-Fuels	Total Renewable Fuels
2006	0	0.00	0.00	0.00	4.0	4.00
2007	0	0.00	0.00	0.00	4.7	4.70
2008	0	0.00	0.00	0.00	9.0	9.00
2009	0.50	0.10	0.00	0.60	10.5	11.10
2010	0.65	0.20	0.10	0.95	12.0	12.95
2011	0.80	0.30	0.25	1.35	12.6	13.95
2012	1.00	0.50	0.50	2.00	13.2	15.20
2013	1.00	0.75	1.00	2.75	13.8	16.55
2014	1.00	1.00	1.75	3.75	14.4	18.15
2015	1.00	1.50	3.00	5.50	15.0	20.50
2016	1.00	2.00	4.25	7.25	15.0	22.25
2017	1.00	2.50	5.50	9.00	15.0	24.00
2018	1.00	3.00	7.00	11.00	15.0	26.00
2019	1.00	3.50	8.50	13.00	15.0	28.00
2020	1.00	3.50	10.50	15.00	15.0	30.00
2021	1.00	3.50	13.50	18.00	15.0	33.00
2022	1.00	4.00	16.00	21.00	15.0	36.00

The US EIA forecasts that there will be no measurable cellulosic ethanol production until 2013, with very little growth producing less that 0.25% of the federal targets in 2022[3]. The US EPA has ratcheted down targets each of the past three years: from 100 M-gal to 6.5 M-gal in 2010; from 250 M-gals to 6.5 M-gal in 2011; and, from 500 M-gal to 8.65 M-gal in 2012.

[3] US EIA, Annual Energy Outlook 2012, Liquid Fuels Supply and Disposition, Reference case

The cellulosic bio-ethanol industry faces several technical, physical and industrial organization challenges. This thesis explores the concept of a network of regional biomass pre-treatment centers (RBPC) that form an extended biomass supply chain feeding into a simplified biorefinery as a way to overcome these challenges. The analyses conducted address the structural and transactional issues facing bio-ethanol value chain establishment; the technical and financial feasibility of a stand alone RBPC; the impact of distributive pre-treatment on biomass transport costs; a comparative systems cost evaluation of the performance of the RBPC chain versus that of a fully integrated biorefinery ("IBR"); and a case study application of the analytical framework. The key features of the issues facing the industry and the analyses are summarized next.

1.2 Issues facing cellulosic ethanol

Biomass Supply

According to the U.S. Billion Ton Update, there is between 59 and 162 million dry tons per year of un-used agricultural biomass residues and waste, and another 79 to 97 million dry tons of un-used woody biomass available in 2012[4]. Yet, the paucity of available biomass supply is a commonly discussed hurdle to ramping up the cellulosic ethanol industry. The issue regarding feedstock availability is less one of potential available volumes, but rather one of dispersion, price of supply and inability to contract for sufficient volumes. Therefore, it's not really a supply question, but rather a question

4 Update to billion ton vision (2011) baseline for 2012. Low figures are at $40 per ton / high figures at $60 per ton.

of how to get it from where it is to where we need it, efficiently and cost effectively. In other words - it's a logistics problem.

Logistics

The primary problem reported by the USDA committee in its 2010 report was the 'overwhelming' logistic challenges associated with getting the biomass from farm to refinery (harvesting, transporting and storing). These logistic challenges exist across all the value chain activities. On-the-farm challenges include harvesting methods for maximizing biomass yields while addressing environmental concerns, collection choices (i.e. grinding vs. baling; square bales vs. round bales) to storage choices (uncovered, ensiled, covered, etc.). Transportation industry needs i to handle the volumes of biomass that will be required to support the aggressive bio-fuels mandates and future demand. Currently there is no existing supply chain infrastructure to support an LCB ethanol industry.

Technology

The cellulosic ethanol industry is still in its infancy, still late in the development phase; and, not moving very quickly towards commercialization and growth. Industries in this phase of their development also have many competing technologies, pathways and firms. Many pre-treatment and conversion technologies have been proven on a bench scale, but very few have reached a commercial phase. Until these technologies are proven, and can be produced on a commercial scale, it will be difficult to drive down process costs. In view of inherent riskiness of unproven technology, coupled with the high cost processes and recent financial market crisis, and it has not been very easy to access capital for jumpstarting the industry.

Transactional Issues

Beyond these physical logistic issues, there are substantial non-physical logistic issues due to the nature of the envisioned market structure. These transactional issues arise from the necessary transaction between two very different, very distinct, and very nervous industries – agriculture (the biomass suppliers) and the refining industry.

There are a number of transactional characteristics that can lead to a standoff situation in the liquid bio-ethanol industry. These characteristics include high degrees of asset specificity on both sides of this transaction; the lack of a uniform standard or commodity product; the necessity for a large number of bilateral contracts negotiated under uncertainty and informational asymmetries; and, a history of holdup situations in agriculture's dealings with industry. .

1.3 Value Chain Creation and Vertical Co-ordination Choices

The critical component will be development of the logistics infrastructure, or the vertical supply chain, to ensure a secure and reliable stream of feedstock to biorefineries at the appropriate time and at competitive prices. Developing a consistent, economically viable feedstock supply system requires addressing and optimizing diverse physical issues (harvesting, storage, preprocessing, and transportation), as well as addressing the transactional issues. Value chain activities must be vertically coordinated in order to economically produce cellulosic ethanol, while still providing proper incentives for the agents to participate. Stakeholders must determine which channel configuration would best be suited for taking advantages of scale economies and profit maximization incentives, while inducing large numbers of farmers and rural agricultural interests to participate.

Researchers have posited that in order to achieve conversion process economies, fully integrated centralized biorefineries are necessary. This fully integrated biorefinery is envisioned to encompass all the processing technology from the raw feedstock receipt through the finished bio-fuel and related co-products, at times capable of producing some of its own process inputs (i.e. electricity and steam).

However, such biorefineries also entail increased costs of biomass transportation and storage, high transaction costs of contracting with a large number of farmers for biomass supply, and monopsony market power vested with refineries. Furthermore, unless biomass suppliers participate in adding value to their products, they are unlikely to benefit much from greatly increased cellulosic bio-fuels production. This value chain configuration can seemingly address the physical issues within the vertical co-ordination, however does not directly address the transactional issues.

There may be solutions to overcome this standoff within the integrated biorefinery market structure; or, a radically different value chain may be required. Potential solutions within the IBR structure include commoditization of biomass; improvements or innovations in transport methods and technologies; and detailed specification contracting. One alternative channel configuration solution utilizes intermediate facilities as value chain components

1.4 Regional Biomass Processing Centers

In this research a network of regional biomass preprocessing centers (RBPC) that forms an extended biomass supply chain feeding into a simplified biorefinery is introduced as a potential way to address the physical and transactional issues facing the cellulosic ethanol industry. A value chain configuration that utilizes intermediate facilities such as the RBPC allows for: pre-processing activities to be moved down the supply chain which can have multiple material handling benefits (size and moisture reduction, densification, consistency of feedstock) that could lead to lower variable transportation costs; inclusion of a larger total catchment area which should correlate to greater volumes of ethanol; smaller facilities with lower barriers to entry, such as less capital investment required per facility (which could help overcome the capital constraint) that could also lead to local and / or shared ownership; reduction in the per gallon capital costs at the refinery, and greater returns on investment for the refiner. From a transactional perspective, intermediate facilities overcome the standoff situation at the transaction interface (chicken and egg problem); eliminate potential holdup situations; introduce shared risk; and, reduce the volume of transactions for each facility owner. The Ammonia Fiber Expansion RBPC considered here produces an intermediate product with higher valued alternative market channels that could help overcome food vs. fuel issue by providing feed and fuel, while subsidizing the liquid bio-fuel production activity.

Critics of a distributed pre-processing / pre-treatment approach for the biomass to ethanol value chain argue that the fully integrated bio-refinery has too many energy and technology synergies for pre-treatment to be de-coupled from the IBR without creating many technical and economic problems. In addition, longer distances must be traversed by the biomass due to 'back-tracking'. There is double-handling of the biomass; it must be loaded and un-loaded twice because there are two facilities instead of one. Plus, while individual facilities may be less capital intensive, overall a distributed system will actually impose higher total system capital costs.

1.5 This Research

The dissertation opens with a thorough examination transactional issues. What are the key transactional barriers in bio-ethanol value chain development? How will a distributed system help address them? Chapter 3 examines these issues, possible solutions and provides theoretical justification for intermediate facilities.

There are benefits to employing intermediate facilities as value chain intervention mechanisms. This dissertation examines one promising intermediate facility, the Regional Biomass Processing Center, and corresponding value chain configuration to determine if it is feasible; could be at least as efficient as the IBR system in terms of transportation costs and total system cost; and, produce wholesale cellulosic ethanol at a competitive MESP (i.e. competitive with corn ethanol and rack gasoline).

This dissertation examines key research questions regarding the RBPC.

1. Is a RBPC technically feasible to de-couple it from the integrated bio-refinery? If so, is it financially feasible as a stand alone facility? (Chapter 4)
2. Transport costs are a critical component to value chain efficiency. Can a distributed RBPC system be at least as transport cost efficient as an integrated

system? If so, what are the critical variables that determine equivalency? (Chapter 5)

3. What are comparative total system costs of an RBPC vs. IBR system? Under what conditions might the RBPC be more efficient? Which value chain option would an investment agent choose? (Chapter 6)

4. In real world case studies, how do both systems perform vis-à-vis each other and projected wholesale ethanol prices?

The analyses address criticisms levied against a distributed value chain configuration, and demonstrate that RBPCs employing Ammonia Fiber Expansion pre-treatment could indeed be valuable intermediate facilities providing a realistic, viable option to overcoming the implementation issues facing cellulosic ethanol.

1.6 Techno-Financial Analysis of RBPC

One criticism is that pre-treatment technology cannot be de-coupled from a fully integrated biorefinery because a standalone RBPC is neither technically nor from a commercially viable. To address this issue, a technical and financial feasibility of a simple, representative RBPC that uses ammonia fiber expansion (AFEX™) pretreatment process that produces ruminant feed along with biorefinery feedstock is performed. The analysis utilizes a discounted cash flow rate of return investment analysis to determine the financial feasibility, while a detailed engineering analysis assesses the technical feasibility.

The scope of the analysis is limited to the feasibility of the RBPC as a stand alone facility. The effects of stripping out the pre-treatment processes out of the biorefinery in terms of equipment re-configuration, material and energy flow changes, processing costs, capital costs and economies of scale are considered in the comparative systems analyses.

The techno-financial analyses demonstrate that RBPCs can technically be de-coupled from the rest of ethanol production process, as well as operate financially successfully with gross margins (i.e. difference in prices of input feedstock and output pretreated biomass) of as low as $3.32/ton. Gross margins would have to be as high as $31.71/ton in the worst scenario of smallest size RBPC coupled with no animal feed sales.

1.7 Biomass Transport Costs

The analysis compares distance traveled and the transportation costs associated with moving one dry ton of biomass from farm gate to the biorefinery under proposed alternative value chains (IBR and RBPC). A transport cost model that captures the effects of intra-chain biomass densification and tortuosity in roads is developed.

The analyses shows that under minimum distance assumptions, and no densification gains, the average distance traveled from farm to RBPC to biorefinery is always larger than the average distance from a farm directly to an IBR. In addition RBPC structure results in double handling costs.. Hence any transport cost savings from the RBPC system must come from locational and / or geographic conditions where the farm to facility collection routes are significantly tortuous (increased distances under IBR);

and densification of the biomass during pre-treatment (cost savings due to fewer truckloads).

Transport cost functions are specified using values from literature. By varying tortuosity and rural-ness, solutions exist where the transport costs between the two systems are equivalent. In the solution sets, the level of rural-ness is important, as is the ratio of fixed cost (i.e. depot charges) to variable costs - the lower this ratio, the higher the likelihood of a reasonable and realistic solution. The analysis also suggests that disadvantage of double depot charges can be compensated by densification gains.

The model also enables estimation of a 'cutoff radius' for any given regional profile. In catchment areas larger than those corresponding to the cutoff radius, RBPCs will be more transport cost efficient than an IBR. As the rural-ness of an area increases, an RBPC system is more transportation cost effective than an IBR system at smaller and smaller catchment areas. At any rural-ness factor value, greater densification at the pre-treatment center drives the cutoff radius inward (i.e. creates a transport cost equivalency at smaller catchment area).

Transport cost equivalence, however, does not guarantee total system cost equivalence. Once feedstock cost and transport costs are equalized, the difference in costs between the two systems would be driven by pre-treatment and conversion facility costs. Under a distributed system, there will be less capital costs and some operating cost savings at the bio-refinery (vis-à-vis an IBR); but there will be higher capital and operating costs (per ton / gallon) at the RBPCs.

The transport cost analysis also demonstrates that a RBPC based system could be more transport cost effective when the catchment radius becomes larger. Expanding the catchment area ultimately produces more ethanol and allows for the construction of larger ethanol refineries which re-capture some of the economies of scale lost when pre-treatment was stripped from the "integrated" bio-refinery[5]. However, there is no guarantee that that RBPC structure with the larger catchment area is a lower cost option compared to an IBR structure with a smaller catchment area either in terms of total biomass cost (feedstock + transport cost) or the minimum ethanol sales price ("MESP").

1.8 Comparative Value Chain Analysis

To evaluate these total system costs, next I develop a model to compare different vertical value chain configurations for ligno-cellulosic biomass delivery to a bio-refiner (i.e. ethanol producer). The model is a spreadsheet-based Decision Support System (DSS) for a biomass supply chain from farm-gate to wholesale ethanol production. The DSS could be modeled with 'plug and play' activity modules and sub-modules. The centralizing framework is an Investment Analysis Model that generates user-defined performance metrics to assist in evaluating different value chain configurations.

Both value chains, one utilizing an IBR and the other employing a network of RBPCs with a stripped down bio-refinery, are modeled. Assumptions are outlined and the value chain activities are populated. Activities and costs are modeled; functional forms are specified; and, variables are parameterized. Biomass production variables are

[5] Carolan, et. al., 2007

set as sensitivity variables. Biomass production is modeled in a simple, yet analytically pertinent manner. Transportation costs are modeled as specified earlier. Conversion facilities are fully and dynamically modeled with ASPEN® modeling software and Microsoft Excel®. The Investment Analysis is a Discounted Cash Flow Rate of Return ('DCFROR') model. The chosen system performance metrics ethanol volume, financial evaluation measures (NPV, ROE and IRR), and Minimum Ethanol Selling Price ("MESP") are discussed.

MESP is the price that makes the Net Present Value equal to zero. It is equal to the long run average cost of production (LRAC). All cost variables are endogenous and dependent upon size of the catchment area. The MESP = LRAC equilibrium condition is solved at different catchment area radii under specified regional characteristics, technical configuration and co-product market availability to determine the

- optimal IBR size and corresponding MESP;
- optimal RBPC size and corresponding MESP;
- and, the radius of indifference and corresponding MESP.

The problem is initially framed as a single investment agent evaluating the different supply chain configurations. The return is calculated as the return to the agent, not as a return to each individual value chain activity. There are assumed to be two types of agents - a profit-maximizing, vertically integrated, regional monopsonist; and, a profit-maximizing, vertically integrated agent facing competition. The two different agents may make different choices on value chain implementation. The LRAC functions of the value chain options are analyzed to determine which option each agent would choose.

Shocks are then introduced to the cost variables in order to determine ceteris paribus effects on the long run average cost curves, i.e. how do changes to regional, technical and ruminant feed market characteristics shift the curves, and conditions under which the these changes are enough to alter the choices for the different agents.

The system analysis demonstrates that under any set of regional, technical and ruminant feed characteristics, there is always a point of indifference where the long run average cost for the two configurations are the same. In larger catchment areas, RBPC will be less costly. However, the existence of an equivalency point does not translate into RBPC being the emergent choice due to the higher inherent cost structure of the system.

Under the base case scenario, the IBR emerges as the preferred choice for any profit maximizing agent, whether a monopsonist or in competition. The minimum MESP at the optimally sized IBR is lower than the minimum MESP for the RBPC system. A profit maximizing agent will choose the minimum long run average cost structure, and even put up multiple identical smaller facilities rather than choose the higher cost structure of the RBPC.

There are regional and technical factors which shift both the cost functions in the same direction. If these are favorable to the RBPC system (i.e. increased ‘rural-ness’ or lower DVC/DFC ratio), then the gap between minimum MESPs is closed as these move upward. None of these factors alone create a scenario where the RBPC is likely to emerge as the preferred choice.

Two factors that could alter the profit maximizing choice from IBR towards RBPC structure, are additional densification at the RBPC, and the existence of a higher valued alternative market for the intermediate value chain product, which in this case is ruminant feed. Increasing densification via pelletization is not a feasible option in a truck-truck transport system due to limits on truck volume and weight capacities... In order to capture the economic benefits of increasing bulk density, a truck-train multi-modal transport system needs to be employed. Further, due to the additional costs of pelletization, just changing transport modes to a truck-train system is not sufficient to alter the dominance of the IBR structure; other RBPC favorable conditions must be present. Sufficient animal feed subsidies can alter the decision. In the base case, the truck-truck RBPC emerges as the optimal choice for profit maximizing agents if there is a ruminant feed market that purchases at least 17% of the RBPC output of pre-treated biomass. The percentage of output diverted to ruminant feed that is required drops to just over 11% for the truck-train RBPC to emerge as dominant for profit maximizing agents.

Combinations of these factors can create conditions under which RBPCs are the lower cost option. Regional factors impact distance traveled by biomass, as they combine to make distances longer or shorter. A low density ratio (which means high levels of densification at the RBPC) closes the gap in MESPs, as does a low DFC/DVC ratio. There are combinations of these factors under which a truck-truck RBPC is favored over an IBR. There are more scenarios under which a truck-rail RBPC is favored over both of the other two choices. Representative multi-effect cases of possible combinations and decision matrices are presented.

Ruminant feed can make the truck-truck RBPC emerge at any set of technology and geographic factors if it is large enough. With base case technology, in a highly rural, low yield region only 3% of PTB needs to be sold as ruminant feed to create MESP equality. Under all base case conditions, 17% AF is required. In a low rural, high yield area with base case technology, MESP equality is achieved with a 20% AF portion.

1.9 Case Study Application

In this section, a comparison of two alternate (IBR and RBPC), realistic value chain configurations for the ligno-cellulosic biomass to ethanol conversion industry in three different specified geographic regions is presented. It is a case study application of the single agent investment analysis DSS to regions in western Michigan, upstate New York and central Pennsylvania.   By specifying each region, the available biomass and potential animal feed markets are essentially fixed, so The performance metric considered is “minimum ethanol selling price” (‘MESP’), which is a proxy for total system long run average cost of production.

The first area under consideration is a nine county region in South-west Michigan. The region was chosen as it is the Michigan home to the Great Lakes Regional Bio-energy Research Center, a multi-party collaboration researching various aspects of ligno-cellulosic availability, impacts and characteristics within the Great Lakes region.

The New York region considered encompasses a seven county region in North-central New York State. The region was chosen because there is a Western New York Energy 55 million gallon per year corn ethanol facility operating in Shelby, in southwestern Orleans County. Many of the factors that made this region promising for corn ethanol, also make it promising for cellulosic ethanol.

The Pennsylvania region considered is a ten county region in central Pennsylvania. The region was chosen because the first commercial-scale ethanol plant in Pennsylvania is located at the Clearfield Technology Park in Clearfield, Pa. There are plans for a cellulosic pilot plant to be co-located at the site as well. This case is similar to the New York case in that the refinery was located based more on output orientation, rather than proximity to inputs.

The case studies reveal a number of important insights.

1) Even low volume regions like those considered, could produce cellulosic ethanol at a long run average cost / MESP higher than, but close to, projected future wholesale ethanol rack prices. (projected wholesale is $1.6790/gal).

2) Conversion costs (pre-treatment MESP contribution + ethanol conversion MESP contribution) are higher under RBPC because loss of economies of scale in engineering, loss of process efficiency gains from integration, loss of economies of scale in overhead (SG&A, insurance, etc), and difference in capital cost requirements.

3) Biomass transport costs are higher for RBPC system because double depot charges cannot be overcome by savings in pre-treated density gains or shorter in-bound LCB distances, although results do indicate that the RBPC system can provide variable transport cost savings vis-à-vis the IBR in more tortuous regions.

4) The animal feed markets in these regions are relatively small as a percentage of biomass processed. It does not subsidize either system, but closes the gap in MESPs.

5) As demonstrated by the comparative analysis, the two MESPs are very close when RBPC favorable shocks are jointly applied.

6) Lower biomass regions have smaller MESPs gaps.

7) The two systems' MESPs are always within 5 - 10% of each other, with one case being only 2% different.

1.10 Contribution to Literature

The theoretical arguments for utilizing intermediate value chain facilities to overcome presented in Chapter 3 are a novel addition to the body of work on distributed facilities in biomass value chains. The remainder of the thesis addresses another critical gap in the current research on the use of distributed intermediate facilities in the biomass to ethanol value chain. It focuses on the economic claims (both for and against) and the costs associated with this system, not the technical and engineering issues. In March 2012, the Biomass Technical Advisory Committee of the Biomass Research and

Development Board[6] issued quarterly reports on progress and recommendations for future research. Two of the Feedstock Subcommittee's stated keys for future research were understanding conditions that allowed feedstocks to be delivered at a reasonable "economic cost, including potential for distributed processing in depots;" and a "more rigorous analysis of key cost factors…. of biomass delivered to biorefinery with and without distributed processing in depot(s)." [7]

Work to date on regional pre-processing facilities (named variously as Regional Biomass Processing Depots, Local Biomass Processing Depots, Regional Biomass Processing Facilities, or Regional Biomass Processing Centers) is limited, and primarily focused on:

1) Overcoming the engineering and technical hurdles to these facilities;

2) Substantiating the technical claims of benefits of employing these facilities; and,

3) Engineering models of technical design and economic feasibility.

Carolan, et. al. (2007) introduced the concept of the Regional Biomass Processing Center, and showed that, technically an AFEX™ RBPC can be de-coupled from an integrated bio-refinery system. The required price-cost-margin for a reasonable return to capital was calculated as a way to highlight the economic feasibility of these

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[6] An interagency collaboration co-chaired by the U.S. Department of Agriculture (USDA) and the U.S. Department of Energy (DOE). The TAC is made up of industry expert volunteers.

[7] USDA and USDOE, 2012

facilities[8]. Bals and Dale (2012) expanded the range of possible de-coupled RBPD configurations to include not only AFEX™ on corn stover or switchgrass, but also pyrolysis to bio-oil and AFEX™ on high protein double crops. The models include engineering economic factors so that profitability measures can be generated as a way of comparing the different configurations to each other. The spreadsheet based models are intended to be part of larger system analyses.

For Eranki et. al.(2011), RBPDs primary purpose is to collect, densify, and store raw biomass, while producing valuable co-products. Various technical issues are addressed to demonstrate that the RBPD can indeed "process and pre-treat low-density and often unstable biomass into stable, dense intermediate products compatible with current established commodity logistics system"; homogenize feedstocks; and, overcome technical biorefinery supply concerns such as "steady supply, uniform feedstock properties, and stable feedstock costs", which help biomass systems more fully achieve some desirable feedstock and supply chain characteristics.[9] Alternate potential configurations for RBPDs are discussed.

To date, many of the technical and engineering issues are being addressed. There is sound, economic reasoning to justify the need for an intra-chain innovation to overcome the transactional issues. However, none of the economic benefits claimed are substantiated or quantified (thus the TAC reports emphasis on costs and

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8 This article is Chapter 4 of this dissertation. It was previously published in Journal of Agriculture and Food Industrial Organization

9 Eranki, et. al., 2011

economics). In order to keep relying on these, the claims must be analyzed – to substantiate or disclaim.

Proponents claim that because the RBPD system reduces the practical collection radius and provides densification, it can automatically lower transportation costs[10,11]. The distance raw biomass travels from the farm to RBPC is shorter than the distance from farm to IBR. However, much of the pre-treated biomass must 'back-track' over the same ground it's already covered, and it is loaded and unloaded twice. The cost savings may not come from just a shorter first distance, nor may densification overcome the double handling. A full economic examination of the biomass transport cost structure will shed light on *if*, *how* and *where* these cost savings may arise. Chapter 5 examines this claim in detail, from an economic and mathematical point of view.

Another common claim is that by de-coupling the pre-treatment from the IBR, the effective catchment area for a given bio-fuel refiner will increase.[12] The increase in catchment area will produce greater volumes of ethanol through greater regional coverage; and will generate a couple of economic benefits to the refining agent, specifically less required capital (total and per biomass unit processed) at its facility and greater returns on that capital.[13] While the refiner's capital is expected to decrease, the total *system* capital (total and per biomass unit) is expected to increase, creating a

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[10] Eranki, et.al. (2011)

[11] Bals and Dale, 2012

[12] Eranki, et.al., 2011; Carolan, et.al., 2007

[13] Eranki, et.al., 2011; Carolan, et.al., 2007

negative incentive for the RBPD system.[14] No evidence is provided for the capital cost claims (pro or con), nor is any proof provided that the RBPD will actually expand the geographic scope of any bio-fuel refining operation. Chapter 6 challenges these claims from an economic perspective.

Additionally, the DSS presented in Chapter 6 is a key new tool in the evaluation of competing biomass to fuel value chain configurations. It allows the user to rigorously analyze the impact on system performance and cost from variations in key value chain factors, such as intermediate value chain co-products that may have alternate markets. The existence of these is crucial in the effectiveness of this mechanism for overcoming the standoff situation (see above). It has also been proven a key piece in the feasibility of AFEX™ RBPCs (Carolan, et. al., 2007), and touted as another benefit of RBPDs (Eranki, et. al, 2011; Bals and Dale, 2012). With the DSS, an in-depth analysis of how this feed market will impact the long-run cost structures of the systems.

The usefulness of the DSS goes beyond just analyzing factor effects and generating long run cost curves. It provides a tool for predicting agents' decisions and a framework for looking at policy impacts. The DSS structure is flexible so that it can incorporate new findings within activities, different technical alternatives, and even policy impacts. Additional impact assessments could be combined with this DSS to assess environmental impacts (LCAs, etc) or economic impacts (i.e. IMPLAN). Egbendewe-

[14] Eranki, et.al., 2011; Bals and Dale, 2012

Mondzozo, et. al (2011) combined activity models[15] and cost functions with environmental impact and land use switching models to examine the relative environmental impacts of these two systems in a limited geographic region in south-west Michigan[16]. The model does generate a measure of profitability for each the two systems under different ethanol pricing scenarios. Both the Egbendewe-Mondzozo, et. al (2011) model and the DSS presented here are 'cradle to gate' system analyses that employ spreadsheet models and optimization exercises. The aim of the DSS presented here is to generate user defined performance metrics to evaluate not only which system performs better, but what an agent making a bio-fuel investment decision would likely do. Egbendewe-Mondzozo, et. al (2011) looks at environmental impacts first, with profitability as a secondary consideration, finding that the RBPD actually environmentally out-perform IBRs in the specific region. Chapter 7 is a case study application, considering three regions in three different states. It is an application of the DSS framework presented in Chapter 6.

1.11 Organization of the rest of the document

The rest of the document is organized as follows. Chapter 2 provides an historical and institutional background on fossil fuels and alternative liquid fuel consumption and federal policies in the US. Chapter 3 is a structural analysis of a biomass to bio-ethanol value chain, focusing primarily on the biomass transaction, covering economic theories

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[15] He uses Bals and Dale (2012) techno-economic models

[16] Both Carolan & Egbendewe-Mondzozo were working in conjunction with the Great Lakes Bioenergy Research Center and Michigan State University, and therefore used the same geographic region for case study.

regarding vertical co-ordination, structural analysis and transaction economics. Chapter 4 is the techno-financial evaluation of the RBPC as a stand alone facility. Chapter 5 examines the equivalency of costs within the transportation activity. Chapter 6 introduces the DSS and looks at characteristics that can produce equivalency of MESP across the entire biomass to wholesale ethanol value chain. Chapter 7 is the case study application of the DSS framework within three specific geographic regions to evaluate the efficiency of both value chains within these regions. Chapter 8 provides some conclusions, and discussion of implications and limitations of this research.

CHAPTER 2

AMERICA’S FOSSIL FUEL ADDICTION

'We are rapidly approaching a tipping point in the energy story of this country. Three forces are coming together - our growing dependence on an increasingly volatile world market; our commitment to make serious cuts in carbon emissions; and our obligation as a society to ensure that energy remains affordable at a time of huge pressure on household and business incomes. It is going to be extremely difficult to reconcile these three forces as we build the energy market of the future.'
Sam Laidlaw, CEO of Britain's Centrica, July 2011.[17]

"We cannot keep going from shock to trance on the issue of energy security, rushing to propose action when gas prices rise, then hitting the snooze button when they fall again. The United States of America cannot afford to bet our long-term prosperity and security on a resource that will eventually run out. Not anymore. Not when the cost to our economy, our country, and our planet is so high. Not when your generation needs us to get this right. It is time to do what we can to secure our energy future."
President Barack Obama, March 2011[18]

These two statements echo the same themes regarding the energy profile of developed nations worldwide. While the first is about the United Kingdom, it applies directly to the domestic United States situation. This is not a new problem. These are not new themes. As a nation, the United States has a long history of wanting to solve its addiction to fossil fuels. Recent events have made it a high profile topic once again.

Domestic dependence on fossil fuels is at the heart of the national debate on America's energy future. Petroleum consumption has come under attack because of, the negative environmental profile of fossil fuels; the location of current supply in potentially unstable geo-political regions; the fact that reserves are either dwindling, will be exceedingly expensive to develop, or would destroy pristine natural areas; the rapidly increasing international demand for fossil fuels; and, the lack of viable near-term, inexpensive alternatives.

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[17] Forbes, 2011

[18] Obama, 2011

Underlying this national debate are real market issues, such as supply and price shocks. Gasoline prices react quickly and with great volatility to supply shocks, which creates public outcry when price moves up, but quiet when prices move down. This combination of market and public opinion forces have forced policy makers into responding with a number of policies aimed at reducing both the foreign aspect of supply as well as the dependence on a singular source for liquid fuel. Development of a sustainable domestic alternative liquid fuel portfolio is a must to overcome the petroleum addiction. This chapter summarizes the underlying market issues and the policies enacted, before discussing one sustainable liquid fuel – cellulosic ethanol – that may become an important component of the domestic solution.

2.1 Fossil Fuel Addiction: US Energy Profile

The United States consumes almost 100 QUADRILLION Btus of total energy per year, which is 44 million barrels of oil equivalent ("MDOE") per DAY. This is one quarter of the world's entire energy consumption. From 1990 to 2000, total energy consumption increased every single year, steadily rising 29% from 37.6 MBOE/day in 1990 to 44.8 MBOE/day in 2000. Over the next nine years, energy consumption actually declined overall (44.8 to 43.2) while following a pattern of on again / off again year to year increases and decreases.

Energy in the US comes from four non-renewable primary sources and several primary renewable sources. The vast majority of energy (83%) is derived from just three fossil fuel primary sources – petroleum, natural gas and coal. Often these are converted to secondary sources that are easier to transport and utilize, predominantly electricity[19]. Around 40% of all primary sources are converted to electricity in the United States.

Petroleum

In terms of percentage of total US energy consumption, petroleum has been the most dominant primary source since 1950 (Figure 1), and has hovered around 36% of total energy consumption for the last 20 years (high of 38% in 1990; low of 35% in 2008).

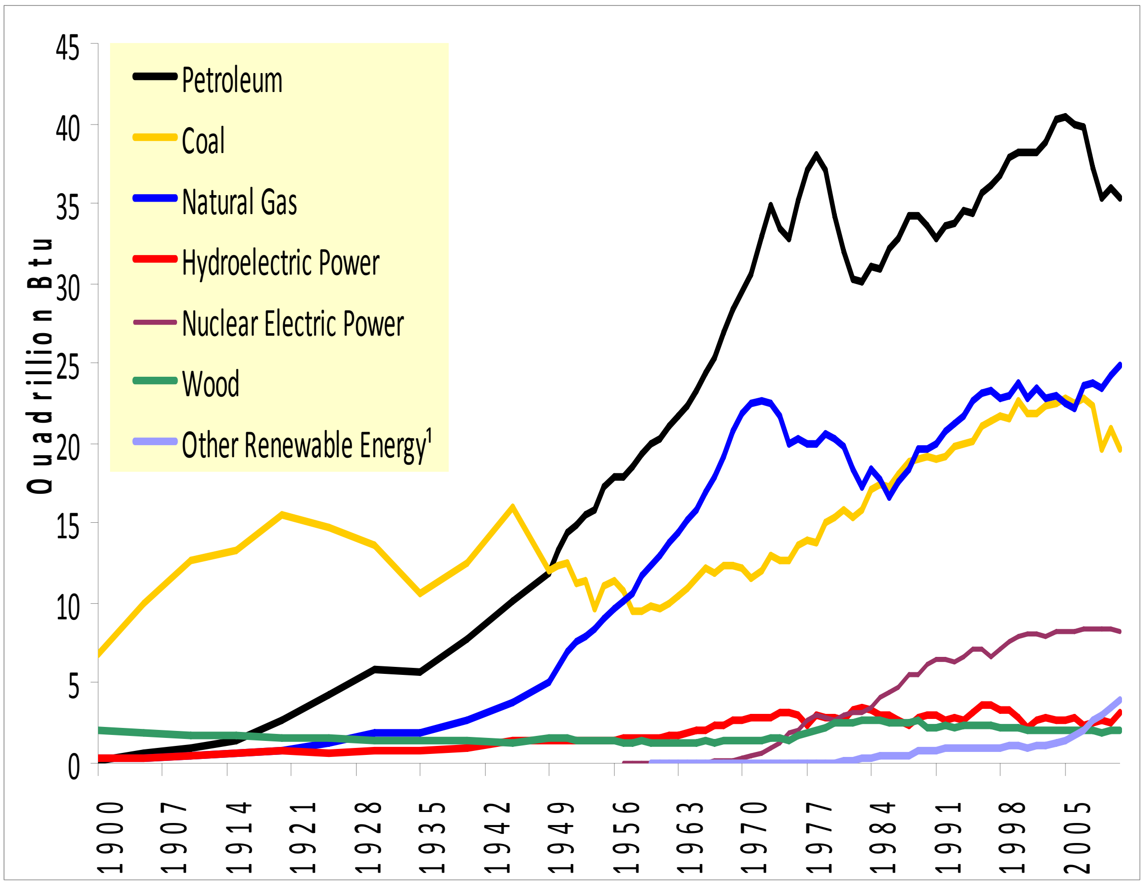

Figure 1 – US Primary Energy Consumption by Source[20]
For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this dissertation.

19 Gasoline & diesel (& other petroleum fuels) are not secondary sources, just *refined* primary source, as opposed to a product created through the *consumption* of a primary source.

20 US EIA, 2009

Approximately 74% of the each barrel of crude oil (raw petroleum) is processed into transportation fuel (gasoline, diesel and jet fuel). The remainder of each barrel is then used in the commercial and industrial sector, in various forms (as an energy source, asphalt, plastic, paint thinners, and dry cleaning solvents). 94% of all transportation fuel is petroleum based.

Petroleum prices

Gasoline pump prices are highly visible and highly volatile. National energy debate often rises or falls in importance depending on the level of these. This the cycle of "shock to trance"[21] stated in President Obama's speech (above). Leading up to the 2008 national elections, gasoline prices at the pump were consistently over $3.00 per gallon, and economy in general was ailing. Energy independence became a large part of the national debate. In 2010, gas prices were down again, even though the economy was still ailing. Jobs and job creation became the primary focus of public discourse. Mandates for renewable energy (RFS & RPS), tax credits and cap & trade were seen as raising the cost of doing business, therefore anti-job creation. In February 2011, the price of a barrel of crude oil peaked above $100 for just a few moments. The $100 per barrel crude price point quickly raises the specter of $4 per gallon gasoline. Crude prices at this level should not have been a total surprise, because in December 2010, NASDAQ published its projections for oil predicting that crude prices would reach this level sooner rather than later. The President responded in March 2011 with his "shock to

[21] Obama, 2011

trance" speech, bringing the energy discussion back to the forefront of national policy debate.

In actuality, the average American consumer spends 4% of every paycheck on gasoline, the same as on home energy (heating and electricity), eating out or entertainment [22]. Residential home energy demand is dominated by two sources natural gas for heating and electricity. Spikes in natural gas and electricity prices, or the future of supply of these sources, do not receive as nearly as much public attention as gasoline price volatility, nor impact public policy debate as strongly.

One reason is liquid transport fuels are not as diversified as residential demand. Liquid transportation fuels are 94% derived from petroleum. Any other sources are blended into with petroleum as an additive or as a substitute. Residential demand has a diversified supply profile (natural gas, coal, nuclear, fuel oil and renewable resources). A price spike in any one primary source will have less of an impact on consumer prices, and can often times be offset by switching to a different source[23].

A second reason is the primary sources for residential demand are almost exclusively domestically produced, while petroleum is not. Natural gas has only recently begun to have a measurable percentage of imports (10%), but 87% of those imports comes from Canada and fall under the auspices of NAFTA. Direct natural gas

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[22] US Dept. of Labor, 2011; "Income before Taxes: Average annual expenditures and characteristics."

[23] For instance, domestic coal production and consumption is being severely curtailed as domestic natural gas production is rapidly increasing due to the so-called 'Shale Gas Revolution.'

consumption accounts for 45% of residential use, and is the primary source for close to 20% of all electrical generation. Natural gas is abundant domestically, now and seemingly in the future. Coal, nuclear and renewables, which are produced domestically, account for the remainder of electrical generation and residential demand. On the other hand, the US imports 51% of its petroleum, of which more than 60% comes from potentially unstable or hostile nations. Figure 2 shows the historical trends in the share of fossil fuel consumption that is produced domestically.

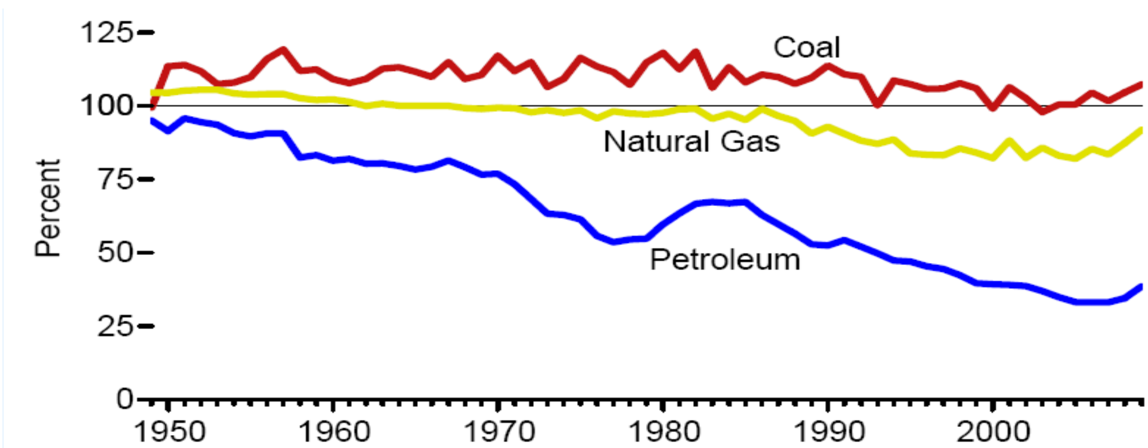

Figure 2 – Production as Share of Consumption for Coal, Natural Gas and Petroleum[24]

Environmental Impact of Fossil Fuels

All fossil fuel production and consumption create negative environmental externalities. Fossil fuels contribute to global warming via emissions of carbon dioxide, which then traps heat in earth's atmosphere. Many claim that burning fossil fuels has caused a 25% increase in atmospheric carbon dioxide (CO2), and been greatly responsible for raising

[24] US EIA, 2009

the earth's temperature. Combustion of fossil fuels (especially coal in electricity generation and petroleum in transportation) releases many other air pollutants, including particulate matter, CO, NOx, SOx and hydro-carbons. In addition to their direct health effects, these pollutants contribute to creation of smog, acid rain, and tropospheric ozone. Exploration, transportation and use of fossil fuels can lead to water issues, land pollution, and catastrophes such as oil spills. Other environmental problems arising from fossil fuel use include water contamination and erosion from strip mining; thermal pollution affecting aquatic life; and, water contamination from natural gas drilling.

These externalities are not only economic and environmental, but can have great impacts on human health and safety. Air pollution is directly harmful to people, as well as the natural environment. Air pollution can cause headaches, irritate the lungs, cause bronchitis and pneumonia, increase stress on heart disease, shortness of breath, lung disease and decrease resistance to respiratory infections. All of the air, water and land impacts can not only hurt wildlife, but crops as well. Fossil fuel use can cause reduced crop yields due to ozone. Acid rain and snow, which pollutes water supply and hydro-environments, can directly and indirectly impact crops. Energy disasters such as the Gulf oil spill have long, lingering impacts on the human beings around them.

Petroleum Supply

If Americans continue to rely on petroleum as the only transportation fuel, the United States must be able to create a production-as-a-percent-of-consumption profile that is similar to its natural gas profile in the near term. This may not be possible. 49% of petroleum that is consumed is already produced domestically. Another 33% comes from Canada and Mexico (under the auspices of NAFTA). Another 7% comes from nations considered 'friendlies' (European and North American sources). Almost 90% of petroleum essentially comes from non-hostile sources.

The Canadian Tar Sands oil reserve is estimated @ 175 billion barrels[25], 2nd only to Saudi Arabia. Estimates of domestic recoverable resources are 130 billion barrels. Another 15 billion or so are in Mexico. While this sounds like a fairly large volume, it would supply the current US consumption (only!) for 20 years. So, friendly-only production of petroleum is not a viable, sustainable option. Nor, for that matter, is reliance on 'foreign oil'.

According to Richard Sears (ex VP of oil exploration @ Shell, and now senior adviser to National Oil Spill Commission)[26], there is somewhere between 30 to 50 years of known supply available. USGS estimates that maybe 650 billion barrels are yet to be discovered[27] worldwide, another 10 years at today's consumption rates. The hotly contested supply in the Arctic would only supply global demand for an additional three years. The bottom line is that in 40 to 60 years, the world will be running very, very low on petroleum. Escalation in global demand will accelerate this.

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[25] www.eia.gov/countries/index.cfm?view_reserves

[26] Wallace-Wells, 2011

[27] Wallace-Wells, 2011

There are solutions for creating non-traditional petroleum, but, they too are based on fossil fuels. A particularly promising technology is called GTL (short for 'gas-to-liquids'). It produces crude and petroleum products from natural gas. Shell will begin producing GTL in large volumes from the deserts of Qatar this year. However, Shell CEO Peter Voser does not foresee this technology being used in a widespread manner in the US. It is may be medium term solution globally, but it is still a non-renewable fossil based energy.

New Energy Sources

Viable, sustainable, environmentally safe alternative sources of energy, especially liquid transportation fuels are needed. Not because of $5 per gallon gasoline, but because the world is going to run out of petroleum. This is not an issue for this generation's grandchildren. It is this generation's issue. Increases in global petroleum demand may be offset with GTL. Domestic petroleum demand may be reduced if hybrid and electric vehicles can penetrate the market. However, with fossil fuel based energy, electricity and liquid fuels will eventually compete over primary sources, increasing the need for greater diversification in energy sources. Without new sources and diversification, there may be a day, in this lifetime, where vehicles that require liquid fuel to run won't have it because there is no supply; or, the cost is so prohibitive that it just can't be accessed.

Liquid fuels must be a large part of any future energy mix. It is unrealistic to assume that a liquid fuel dependent transportation system can be completely discarded any time soon. Liquid fuels are a highly desirable secondary source. They have high energy density; can be relatively easy to transport and store; are used in current combustion engines; and are familiar to consumers.

A portfolio of non-fossil based, reasonably priced, sustainable, environmentally friendly liquid fuels must be developed. If not, this generation faces the Herculean task of overhauling the entire transportation sector and drastically altering its mobile culture.

2.2 Alternative Liquid Fuels

More than a dozen alternative and advanced fuels are in use or under development. A number of these are derived from primary fossil sources - alternative fuels like gas or coal to liquid technology (GTL & CTL), liquid or compressed natural gas ("LNG" & "CNG") and electricity. There are some promising non-fossil, non-liquid fuels (such as hydrogen, biogas and syn-gas), but, as noted previously, any full scale implementation of these would require a very large scale overhaul of consumer mentality and distribution infrastructures. For the foreseeable future, the only real, viable liquid fuels that are not derived from fossil primary sources are "bio-fuels".

Bio-fuels are energy carriers that derive energy from organic materials, essentially converting solar energy via plant or animal conversion paths. There are primary and secondary bio-fuels sources, just as with other energy sources. Primary sources are things like wood combusted for electrical generation. Liquid bio-fuels are secondary energy sources. These can be broken into commercial fuels (grain ethanol and biodiesel) and emerging fuels (alternative source ethanol, bio-butanol, biomass to liquid processes or bio-oil, biomass gas-liquefaction processes). Hydrogen falls under both commercial (fossil based) and emerging.

Liquid bio-fuels

Bio-butanol is a liquid alcohol fuel with lower energy content than gasoline that can be produced by processing domestically grown crops (corn or sugar beets) and other biomass (energy crops and agricultural residues). It can be used in today's gasoline-powered internal combustion engines, either on its own (85% and up qualifies as replacement for petroleum), or as a blended component (up to 11.5%) in gasoline as an oxygenate or on its own merits.

Bio-oil is produced via a bio-mass to liquid pathway, either fast- or flash-pyrolysis, which is very fast, very hot gasification followed by very rapid liquefaction. Bio-oil must be processed further to transportation fuel, but in its initial form can be used in boilers or turbines (like those in electrical generation). Most bio-oil technologies, both fast-pyrolysis and those to upgrade bio-oil to transportation fuel, are still in the pre-commercial or developmental stages.

Bio-diesel is attractive because it can be used in compression-ignition (diesel) engines in its pure form. It is clean burning; can be used as an environmentally enhancing additive; is bio-degradable and non-toxic. As with all bio-fuels, it is derived from organic materials. Domestically, it is produced primarily from soybean oil or recycled vegetable oils. Bio-diesel showed very strong production growth in the early 2000's, expanding from 500,000 gallons in 1999 to almost of 700 million gallons in 2008. Production tailed off to less than 250 million gallons in 2010, but in 2011 biodiesel production hit almost one billion gallons (967 MMgal).[28]

Bio-diesel from algae is starting to make in-roads with policy makers and governmental funding agencies[29]. Micro-algae grow very fast, are naturally rich in oil, and use discharged carbon dioxide from industrial processes (like electrical generation) for food. While algae can also be used to produce hydrogen, ethanol and methane, algal biodiesel is seen as a real, viable substitute for petroleum based diesel fuel. Algae production does not compete with food production and is highly productive, doubling in biomass every day.

Ethanol

Ethanol is an alcohol fuel that can be utilized in internal combustion engines. Most domestic ethanol is produced via the fermentation route from corn. The process is similar to brewing beer, where starches are converted into sugars which are then fermented into the alcohol (ethanol) and then distilled into its final form. There is some synthetic ethanol produced from ethylene (a petroleum refining by-product) which accounts for less than 10% of all domestic production.

While ethanol is the most widely consumed bio-fuel in the United States, it is primarily a fuel additive. It is added to retail gasoline up to 10% (on a volumetric basis).

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[28] www.eia.gov/totalenergy/data/monthly/pdf/sec10_8.pdf

[29] USDA, 2010

This blend is called E10. Most blending decisions are based on price considerations, blender tax credits and local regulations. The 10% cap is due to the fact that most internal combustion engines in domestic cars cannot handle higher than 10% of ethanol without the risk of corrosion and engine failure[30]. Another large percentage of domestic ethanol consumption is as an oxygenate. When methyl tertiary-butyl ether ("MBTE") was banned in the mid to late 1990's, ethanol became the oxygenate substitute of choice. More and more vehicles in the domestic fleet are being fitted with flex-fuel capable engines, which can handle up to E85.

From 1990 to 2010, overall ethanol capacity has increased from 900 million gallons per year to 13.2 billion gallons. Only around 110 million gallons is from sorghum or other cellulosic, the remainder is corn ethanol. There are many factors behind this increase, including subsidies (to corn and ethanol); the growth of the new generation farmers cooperatives and limited liability corporations; the ban on MBTE; technological changes that allow larger, more efficient dry-mill plants; the growth of the markets for DDGs as an animal feed; and volumetric federal mandates.

The Dialectic of Corn Ethanol

This rapid expansion of the corn-ethanol industry is a remarkable symbol of the promise of alternative liquid fuels in an emerging bio-economy, but as a long-term solution, it is fraught with a rather large, inherent contradiction. It is impossible to eat corn and use it for fuel. Plus, there just simply is not enough corn producing land available to actually

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[30] There is considerable debate about this percentage. The EPA has recently issued a ruling that 15% ethanol blend does not harm engines. The auto-makers, however, contend this finding and will not warrant that their engines can handle higher then E10.

put a dent in fossil fuel demand. This limits both the short and long-term potential of corn ethanol. This contradiction has been labeled the 'Food vs. Fuel Debate'. The key points to take from this debate are briefly presented.

Food demand: If a food crop is used to produce fuel, it can no longer be used for food. Soybeans (for bio-diesel) and corn are food crops that the United States exports to other nations which don't (or can't) produce enough domestically. As these crops are diverted to energy use, these export volumes decrease. In the past few years, crop-based energy sources have been blamed for food shortages, rising retail food prices and even food riots. Part of the issue, however, is that the corn used for energy is not directly consumed as a food source. It is used to feed livestock, and used as an ingredient in of processed foods. Dry mill ethanol producers argue that while corn cannot produce food and fuel, it does indeed produce FEED and fuel – DDGs and ethanol. The end result is that a very heated debate exists, not only about the real impact this has on prices and on global food supply; but also how much of this is being driven by policies.

Land limitations: An issue that is in one facet related to the food vs. fuel tug of war is that of land use. Just as a corn cannot be eaten and turned into fuel, the acre of land that produced it cannot produce enough of both food and fuel if only the corn is utilized. According to estimates, even if all corn producing acres were converted entirely to fuel production (which of course would really create food supply pressures), there is just not enough usable land to have corn ethanol make any significant impact on petroleum imports. In 2010, 88.3 million acres of corn were planted, producing 12.66 billion bushels of corn. If all of that were converted to ethanol, it would displace less than 40% of petroleum IMPORTS. And, no food crops would be grown.

Food Prices: The fast expansion of the corn ethanol industry coincided with sharp prices increases in corn prices and even food riots in developing countries. The causal link between these trends has not been proven. However, considering the large role that public discourse has played in attempts at shifting the energy paradigm, any negative perception will hamper the development arc. Any competition is indirect (or hidden), and will be between feed (livestock feed) and fuel, and food additives and fuel, which will have an impact on food prices. Food prices may indeed increase with added demand on an input.

The other category of potential bio-fuels feedstock that has received much attention and publicity is ligno-cellulosic biomass (LCB), because it has shown great promise as a viable and sustainable alternative that seemingly doesn't have the dialectic nature of corn ethanol. LCB is non-food organic material that is either produced specifically for energy production or is a by-product of other production activities. These materials are high in carbohydrate content, which can be converted to sugars and fermented to produce ethanol. Common types of LCB include corn stover, switchgrass, wheat grass, poplar, timber residues, paper residues and even municipal solid waste.

Cellulosic ethanol requires additional processing steps prior to ethanol production. Ethanol is produced by fermenting sugars. Corn and other natural products such as sugarcane and beets have plentiful natural sugars that are easily accessible.

Cellulosic ethanol is derived from biomass materials that are more recalcitrant in hydrolyzing their sugars. Most plant biomass consists of hemi-cellulose (5 carbon sugar polymers), cellulose (6 carbon sugar polymers) and lignin, roughly 1/3 each by weight. Pre-treatment of the biomass is required to break down the more complex sugars in these materials into fermentable simple sugars.

Environmental profile of alternative liquid fuels

By displacing petroleum with liquid bio-fuels, the greenhouse gas emissions from liquid fuel consumption should improve dramatically. While GHG reduction is not the only environmental criteria to consider (i.e. water quality and availability), it is a major contributor to improving air quality and minimizing the impact of energy on global warming.

Figure 3 is from the EPA. It shows estimates of the percent change in lifecycle greenhouse gas emissions (CO2, NOx & CH4), relative to the petroleum fuel that is displaced, on an energy equivalent or BTU basis. For instance, for every BTU of gasoline replaced by corn ethanol, the total lifecycle greenhouse gas emissions that would have been produced from that BTU of gasoline would be reduced by 21.8 percent.[31] Bio-based energy sources, especially cellulosic ethanol, have a much greater impact on improving GHG emissions when used as replacement for petroleum than any of the primary or secondary fossil based fuels.

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[31] U.S. EPA, 2007. Note: This study did not include indirect land use effects. When corrected for these effects (Feb. 2010), EPA found that GHG reduction (relative to gasoline) from corn ethanol is 20%, sugarcane ethanol is 50% and cellulosic bio-fuels are 60%

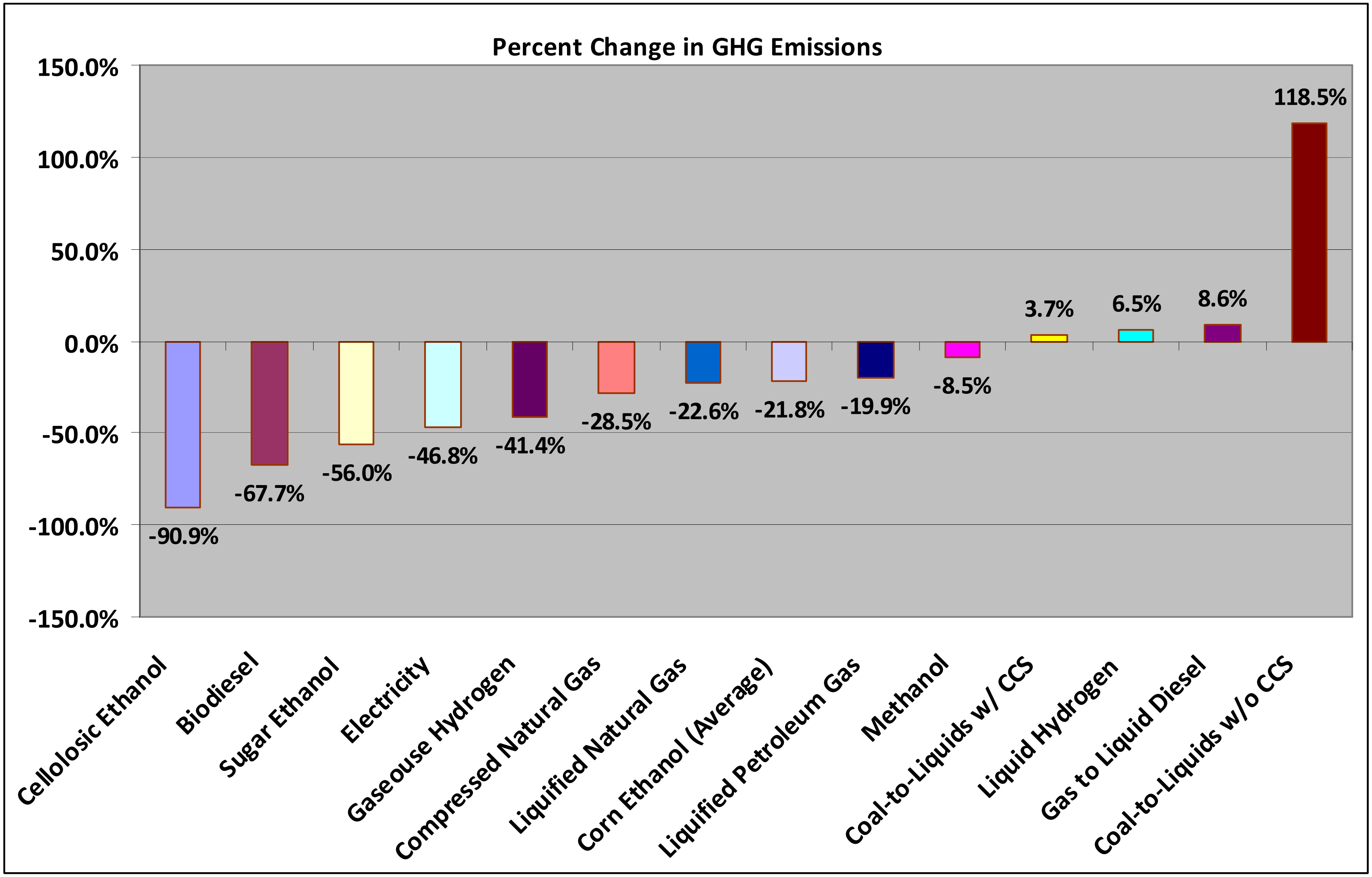

Figure 3 – Percent Change in GHG Emissions with Alternative Liquid Fuels

Advanced liquid fuels are not commercially competitive with fossil sources. Government policies have been the driving force behind bio-fuels research, commercialization efforts and production.

2.3 Fossil Fuel Addiction: Political Action

The United States federal government has a history of enacting legislation to address the national petroleum addiction and encourage alternative energy sources. These legislative efforts date back to 1970 and the Clean Air Act; which, when amended in 1990 became a major driver for a lot of emissions policies and is at the heart of a current controversy regarding whether or not the EPA has the power to enforce certain policies. The last 25 years has seen a more concerted legislative effort to address energy security and domestic alternative energy development, starting with the Energy Policy Act of 1992.

Energy Policy Act of 1992

Passage of EPACT (Energy Policy Act of 1992) came on the heels of the Persian Gulf War, which resulted in a loss of a Middle Eastern oil supplier and seemingly created gasoline price spikes in 1990 and 1991. It was an omni-bus energy bill that addressed many aspects of domestic energy profile – renewable electricity, renewable fuels, energy efficiency and even the nuclear industry. EPACT was enacted specifically to reduce foreign oil dependence, increase national energy security and improve air quality utilizing a mix of voluntary actions, regulatory mechanisms and tax incentives.

As an example of the mixed voluntary and regulatory framework, EPACT set a national goal of displacing 30% of the petroleum in liquid fuels for light-duty motor vehicles with non-petroleum-derived replacement fuels by 2010, with a 50% from domestic sources. Acceptable non-petroleum derived alternative and advanced fuels were specifically named: methanol, ethanol, and other alcohols; blends of 85% or more of alcohol with gasoline (E85); natural gas and liquid fuels domestically produced from natural gas; liquefied petroleum gas; hydrogen; electricity; biodiesel (B100); coal-derived liquid fuels; fuels, other than alcohol, derived from biological materials; and P-Series fuels. EPACT outlined programs that were designed to force federal fleets into using alternative fuels, without mandating use (i.e. a bio-diesel 'credit'). Likewise, EPACT relied on production incentives (REPI) and production tax credits (PTCs) to induce renewable electricity, in lieu of a national mandate, or RPS ("Renewable Portfolio Standard").

Energy Policy Act (2005)

The Energy Policy Act of 2005, "to ensure jobs for our future with secure, affordable, and reliable energy;" was signed by President Bush on August 8, 2005. "Spurred by rising energy prices and growing dependence on foreign oil, this new energy law was shaped by competing concerns about energy security, environmental quality, and economic growth,"[32] it includes provisions for all the major energy sectors, primary and secondary sources. There are policies aimed at improving the electric grid; reducing end use demand; providing incentives for renewable electricity development; and,

[32] Sissine, 2007

policies aimed at maintaining nuclear power as a component of domestic energy mix. EPACT 2005 introduced a national Renewable Fuels Standard (RFS) that mandated the use of ethanol and biodiesel in the transportation sector. It includes a section entitled "Domestic Fossil Fuel Security" covering exploration and production on federal lands, but excludes the Arctic National Wildlife Refuge. There are tax incentives for energy efficiency and conservation, for renewable energy, for domestic oil and gas, for coal, for nuclear and for other electricity generation.

While the 1992 version relied more on indirect policies aimed at incentivizing and inducing voluntary action, EPACT 2005 introduced hard mandates for alternative energy sources. It reinforced and amended regulations from 1992 (like vehicle gasoline performance testing procedures and federal fleet programs); outlined grant funding and loan guarantee programs for demonstration and pre-commercial alternative energy projects; and built upon the existing tax incentive programs for renewable fuels (credit for renewable fuel stations, ethanol blenders and small bio-fuel producers).

EPACT 2005 established the first hard mandate on the amount of domestic fuel that must come from alternative sources. In 1992, the 30% replacement fuel policy was just a goal, hopefully attained through voluntary actions. This became, in 2005, the national Renewable Fuel Standard ("RFS1"). The percentage ramped up to a hard volume of 7.5 billion gallons of renewable fuels by 2012, with succeeding years being a percentage of national transportation fuel consumption. RFS1 also injected cellulosic biomass derived fuel into the public discourse, stating that by 2013, 250 million gallons should be from these sources. To further the development of cellulosic fuels, grant programs were created to fund cellulosic biorefinery demonstration projects through the Department of Energy.[33]

Energy Independence and Security Act (2007)

In 2007, in response to continuing concerns about domestic consumption of foreign oil, President Bush signed into law the Energy Independence & Security Act (EISA). EISA was specifically enacted "to move the United States toward greater energy independence and security, to increase the production of clean renewable fuels, to protect consumers, to increase the efficiency of products, buildings, and vehicles, to promote research on and deploy greenhouse gas capture and storage options, and to improve the energy performance of the Federal Government, and for other purposes."

The primary provisions of EISA are aimed at providing energy security through improved vehicle fuel economy; increased bio-fuels production; and, increased energy savings in various applications and institutions. EISA created RFS2 to replace RFS1; raised the minimum required fuel economy to 35 miles per gallon by the year 2020; added additional funding for grant programs to encourage the development of cellulosic bio-fuels, plug-in hybrid electric vehicles, and other emerging electric technologies.

RFS1 required 7.5 billion gallons of renewable fuel to be blended into gasoline by 2012. RFS2 expanded on RFS1 by including bio-diesel mandates; increasing short term gallon mandates (i.e. for 2008, RFS1 required 5.4 billion; RFS2 upped that to 9.0 billion) and long-term mandates (36 billion gallons by 2022); put a cap on corn-based ethanol

[33] Six projects were funded $385 million by DOE in February 2007. None are fully commercial to date. Most missed their contract milestones. (see below)

(to promote next generation bio-fuels); and tapped the EPA to test and ensure that each category of acceptable advanced fuels actually emits less greenhouse gases than the petroleum that it is replacing. Figure 4 presents both RFS1 mandates ("Previous RFS") and RFS2 mandates[34].

Year	RFS1	Bio-fuel Mandate	Advanced Bio-fuels (not corn starch)Total	Corn Starch Ethanol Cap
2006	4.0	4.00	0.00	4.00
2007	4.7	4.70	0.00	4.70
2008	5.4	9.00	0.00	9.00
2009	6.1	11.10	0.60	10.50
2010	6.8	12.95	0.95	12.00
2011	7.4	13.95	1.35	12.60
2012	7.5	15.20	2.00	13.20
2013	7.6	16.55	2.75	13.80
2014	7.7	18.15	3.75	14.40
2015	7.9	20.50	5.50	15.00
2016	8.0	22.25	7.25	15.00
2017	8.1	24.00	9.00	15.00
2018	8.2	26.00	11.00	15.00
2019	8.3	28.00	13.00	15.00
2020	8.4	30.00	15.00	15.00
2021	8.5	33.00	18.00	15.00
2022	8.6	36.00	21.00	15.00

Figure 4 – RFS1 & RFS 2 Mandates

Energy Policy during Obama Campaign and Administration (2008 to 2011)

In 2008, then candidate Obama issued his "Plan to Make America a Global Energy Leader"[35], which states:

[34] Sissine, 2007

[35] Obama, 2008

"Our nation is confronted by two major energy challenges – global climate change and our dependence on foreign oil – both of which stem from our current dependence on fossil fuels for energy. Every single hour we spend $41 million on foreign oil.

"Every president since Richard Nixon has spoken to the nation about how our oil addiction is jeopardizing our national security. We are held hostage to the spot oil market – forced to watch our fortunes rise and fall with the changing price of every barrel. And we are transferring wealth to oil-producing regimes, enriching countries with economic and national security interests adverse to our own. And we know that our oil dependency is jeopardizing our planet as well as releasing toxic pollutants that harm local communities."

The key component to Obama's Plan was a national carbon Cap and Trade program to reduce US greenhouse gas emissions 80% by 2050. The proceeds of these national auctions would fund clean energy sources and uses, including: funding research and development on next generation bio-fuels (specifically cellulosic ethanol); and, expanding locally owned bio-fuel refineries. The plan called for increasing RFS2 with non-petroleum, non-corn ethanol replacement fuels being 60 billions gallons of domestic liquid fuels by 2030.

In September, 2008, Speaker of the House, Nancy Pelosi pushed through the Comprehensive American Energy Security and Consumer Protection Act, which called for treating the RPS (electricity) in a similar manner as the RFS (i.e. creating a 15% national RPS, Renewable Energy Credit trading; extending Production Tax Credits; increasing energy efficiency measures, etc.) This bill added some controversial policies related to domestic petroleum supplies, such as off-shore exploration restricitions, drilling bans and elimination of tax breaks for oil companies. In response to this, Republicans authored and submitted the New Energy Reform Act. There were minor differences on non-petroleum replacement fuels and clean energy issues. The major points of contention were off-shore and Artic drilling. An attempt at tweaking the EPACT 2005, titled the Clean Energy Act failed to pass twice (2009 & 2010).

The American Clean Energy and Security Act (ACES), also known as the Waxman / Markey act, passed the house, but has been in limbo since June 2009. It includes a national RES, a carbon cap and trade policy, and renewable funding. Also in limbo is the Clean Energy Jobs & American Power Act (Kerry/ Lieberman), which was introduced in 2010, and purports "To secure the energy future of the United States, to provide incentives for the domestic production of clean energy technology, to achieve meaningful pollution reductions, to create jobs, and other purposes."

Energy policy did not garner much support in 2010. Gas prices were down again, even though the economy was still ailing. Jobs and job creation became the primary focus of public discourse. Mandates for renewable energy (RFS & RPS), tax credits and cap & trade were seen as raising the cost of doing business, therefore anti-job creation. The EPA responded by lowering mandated bio-fuel targets. The USDA and DOE began pulling dollars from bio-fuel research and re-allocating it.

In February 2011, the price of a barrel of crude oil peaked above $100 for just a few moments. This was the first time this level had been breached in over two years. It was a result of uprisings in oil producing nations Egypt, Libya and Bahrain. While members of OPEC had announced that they would up production to meet the shortfalls, the markets still reacted negatively due to fears of $4 per gallon gasoline. The fact that crude hit this level should not have been a total surprise, because in December 2010, NASDAQ published its projections for oil. It predicted that crude prices would reach this level sooner rather than later. The political unrest in these countries only hastened the pace of the price change, and brought additional scrutiny to crude oil production.

In March, the president, in the wake of the Mid-East uprisings, BP oil spills and Japanese nuclear disasters again re-introduced the need for national energy policy into public discourse, calling for renewed vigor in commercializing domestic non-petroleum-derived energy sources. In this speech, the gridlock on federal action on this issue was noted, and even used as a microcosmic example of the inability of the US government to move on issues involving partisan viewpoints. President Obama announced the publication of his administration's new energy plan - Blueprint for a Secure Energy Future, a re-issuance of his campaign energy plan.

All this discussion has led to no new energy policy. The only action was the $80 billion for clean energy and energy efficiency included in the American Recovery and Reinvestment Act.

Federal Agency Support

The USDA provided a portfolio of policies, including tax credits, loan guarantees and research funding, in the 2008 Farm Bill. These were specifically to entice agriculture into producing 'sustainable' energy crops, and away from 'unsustainable' corn ethanol. Further support to farmers came via the USDA's Biomass Crop Assistance Program, which provided various financial support mechanisms for energy crop establishment, per ton subsidies to offset logistic costs, and cash incentives for biomass production. The Agricultural Department also created the Biorefinery Assistance Program to assist conversion firms in obtaining loans for bio-refineries.[36] Payments have been made to eligible biomass producers under the Advanced Bio-fuels Payment Program which provides funds for utilization of local biomass for bio-fuels (specifically excluding corn starch). Sixty-eight feasibility studies have been funded through the Rural Energy for America Program.

The Department of Energy's Office of Energy Efficiency and Renewable Energy's Biomass Program provides financial assistance (grants, loans, loan guarantees) to researchers and firms working on biomass feedstock and conversion technologies. While the program has been funding research since the 1980s, its primary focus since the Energy Policy Act of 2005, has been to ensure that cellulosic ethanol is cost competitive by 2012[37]. The Biomass Program's research, development, demonstration, and deployment (RDD&D) efforts are organized around five key technical and three cross-cutting elements. The first two technical program elements – feedstock supply and conversion – primarily focus on research and development (R&D). The next two technical areas - integrated biorefineries and distribution infrastructure – primarily focus on demonstration and deployment. The fifth technical area, bio-power, includes R&D activities to develop improved technologies facilitating the use of biomass as a feedstock for power generation. The cross-cutting elements – sustainability, strategic

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[36] As of January 2011, $405 million in loan guarantees had been issued to 3 facilities, with a combined annual capacity of 73 million gallons per year and 6 MW of electricity. In March 2011, it was announced that an additional $643 million is available

[37] http://www1.eere.energy.gov/biomass/about.html

analysis, and market expansion – focus on addressing barriers that could impede adoption of biomass technologies.[38]

Since 2007, some of the funding has gone to feedstock logistics[39], but most has gone to biorefineries and R & D (Figure 5). A large portion of SBIR/STTR for biomass has been to firms developing Integrated Biorefineries, assisting projects that range from pilot to commercial in scale. There are currently 27 facilities in various stages of development that have received this assistance[40]. There are others that qualified for loans, yet never met milestones.

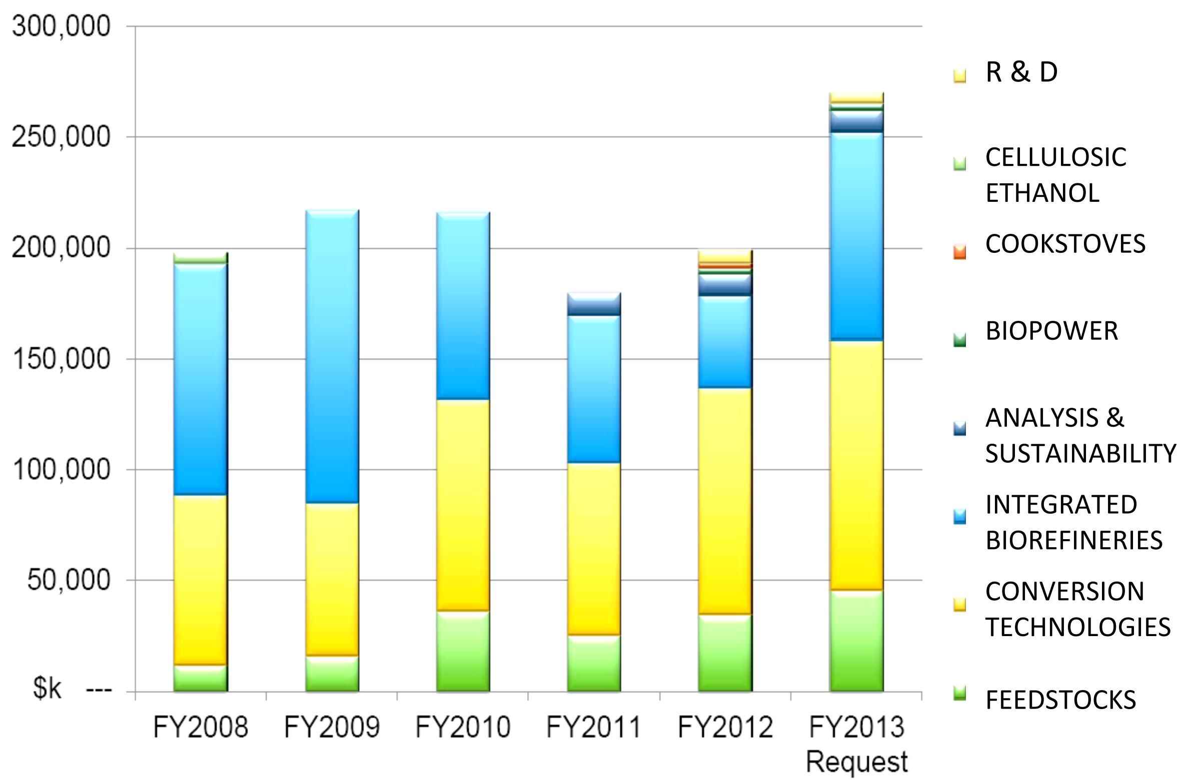

Figure 5 – Biomass Program Appropriations by Technology Platform

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[38] http://www1.eere.energy.gov/biomass/research_development.html

[39] For example, in August 2009 the OBP Feedstock Platform received $21 Million

[40] For a current map & list, visit http://www1.eere.energy.gov/biomass/integrated_biorefineries.html

There are joint USDA and DOE programs, such as the Biomass Research and Development Initiative, with $30 million available to support R & D in advanced bio-fuels and other bio-based products (including energy). These funds, which have a greenhouse gas emissions reduction requirement,[41] were created in response to President Obama's energy initiative to reduce oil imports by 1/3 by 2025.

2.4 Cellulosic Ethanol: Promise and Reality

Petroleum is running out. Corn ethanol has an inherent flaw. An enormous overhaul of the liquid fuels transportation infrastructure is not a solution. Alternative liquid fuels that can be used in internal combustion engines must be developed. They must be sustainable with minimal environmental impact. Cellulosic ethanol has the potential to be a large part of the domestic liquid fuels mix, as a market and policy solution. It can be derived from sustainable non-agricultural feedstock and land. It can be utilized in flex-fuel internal combustion engines. The technology to extract fuel from various sorts of biomass types is just about commercial. It is a large component of the Renewable Fuel mandates. All this has yet to translate into any real production. There are significant hurdles to overcome before the promise can become reality.

State of the Industry

Cellulosic bio-fuels, primarily ethanol, feature prominently in both RFS1 and RFS2. These are the 'advanced' or 'non-corn starch' fuels that are to make up the difference between the overall federal mandated volume and the corn ethanol cap of 15 billion

[41] For further details on all the federal policies and funding opportunities for ethanol go to http://www.afdc.energy.gov/afdc/ethanol/incentives_laws_federal.html

gallons. In 2010 RFS2 mandated that 950 million gallons of the 13 billion total renewable fuels requirement must be from advanced bio-fuels. In February 2010, the EPA ratcheted the cellulosic ethanol target down to a mere 6.6 million gallons because many of the cellulosic companies it contacted (specifically those 30 that had received federal support) had delayed or canceled their projects. Even at these much lower levels, the mandates were not met. In November 2010, the Energy Information Administration projected less than 3.94 million gallons of cellulosic bio-fuels would be produced in 2011[42], far below the 250 million gallons that refiners were mandated to use.

In late 2010, a USDA advisory committee issued its report on the pace of development of the domestic bio-fuels industry. This committee found that, "After two decades of research without a sustainable technical breakthrough to make cellulosic ethanol competitive, it appears that it is time to re-evaluate the research."[43] After funding close to 30 projects, only DuPont Cellulosic in Vonore, TN (250,000 GPY, 2009) and BP Bio-fuels in Jennings, LA (1.4 MPGY, 2007) are producing cellulosic ethanol in any measurable volume. Each of these firms is constructing a second larger scale facility scheduled to begin operations in 2014 or 2015– DuPont's 28 MGPY corn stover facility in Nevada, IA and BP Bio-fuels' 36 MGPY energy cane facility in Highland County, FL[44].

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42 Brasher, 2010. Note: 2.8 million gallons of that estimate were to be from Fiberight's Iowa plant, and even then, Fiberight wasn't sure that they could meet their loan guarantees.

43 USDA, 2010

44 On October 25,2012 BP announced that they are canceling this project

Another 64 MGPY of cellulosic capacity is expected to come online by end of 2013[45]. An important question is, what has happened (or possibly more precisely, what *hasn't* happened) since 2007 in the cellulosic industry to make the EISA mandates un-reachable?

Overly Optimistic Policy Making

These mandates were made from a position of severely bounded rationality fogged by optimism and public posturing. They were just too aggressive. The domestic 'oil addiction' needed quick cures, and the promise of liquid fuels pumping out of the heartland from agricultural leftovers and grasses was just too good to dismiss. However, in hindsight, the technologies just weren't as close to commercial readiness as believed. Policy makers and proponents believed that the industry life cycle was out of the development phase and ready for commercialization or even rapid growth. This was not the case. Jeff Broin of POET, LLC, in response to the EPA's ratcheting down of mandated volumes said, "I think some adjustments right now are prudent. When the renewable fuel standard was created it was a stab in the dark about how fast these facilities would come on line."[46]

Biomass Supply

According to estimates, there should be more than sufficient volume (200 million tons by 2012) across the various feedstock sources (agricultural residues, municipal solid waste, woody bio-mass, and ultimately dedicated energy crops) to meet the RFS2

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[45] INEOS, Vero Beach, FL (8 MG); Fiberight, Blairstown, IA (footnote 30, 6 MGPY); Abengoa, Hugoton, KS (25 MGPY); POET, Emmetsburg, IA (25 MGPY)

[46] Brasher, 2010.

mandates[47]. Yet, the paucity of available biomass supply is a commonly discussed hurdle to ramping up the cellulosic ethanol industry. The issue regarding feedstock availability is less one of quantity, or rather potential quantity, than of dispersion, price of supply and inability to contract for sufficient volumes. It's not really a supply question, but a question of how to get it from where it is to where we need it, efficiently and cost effectively. In other words, it's a logistics problem.

Logistics

The primary problem reported by the USDA committee in its 2010 report was the 'overwhelming' logistic challenges associated with getting the biomass from farm to refinery (harvesting, transporting and storing). This problem was so daunting, that the committee recommended abandoning the idea of developing a large scale biomass to liquid fuels industry, instead using biomass for electrical generation and putting research efforts into algal fuels. "It's just overwhelming, the logistics", said a member of the advisory committee. "We think there is maybe more potential in algae right now than cellulosics."[48]

Logistic challenges exist across all the value chain activities. On-the-farm challenges include harvesting methods for maximizing biomass yields without jeopardizing environmental concerns to collection choices (i.e. grinding vs. baling; square bales vs. round bales) to storage choices (uncovered, ensiled, covered, etc.). Transportation industry is not positioned to handle the volumes of biomass that will be

[47] US DOE, 2003
[48] USDA, 2010

required to support the aggressive bio-fuels mandates and future demand. There is no existing supply chain infrastructure to support an LCB ethanol industry. It must be developed, as noted by two prominent industry sources.

“A thriving domestic bio-fuels industry will require not only biomass growers and processing facilities, but also the infrastructure to connect the two.”

- Richard Hess, Idaho National Laboratory.

The logistical challenges are "legitimate issues that need to be solved and the USDA ought to be about the business of getting them solved."

- Brent Erickson, Biotechnology Industry Organization

Technology

The cellulosic ethanol industry is still in its infancy; and, not moving very quickly towards commercialization and growth. Many of the pre-treatment technologies required to overcome the more recalcitrant sugars, have been proven on a bench scale, but very few have been pushed past into the roll-out phase. Until these technologies are proven, and can be produced on a commercial scale, it will be difficult to drive down process costs. Unproven technology is inherently risky. Couple that with high cost processes and recent financial market developments, and it has not been very easy to get capital backing. Industries in this phase of their development have many competing technologies, pathways and firms. As support was limited, the DOE attempted to filter through these and fund those firms and technologies that they thought had the best chance of being commercially ready sooner rather than later. The firms chosen for funding have been no more successful than the rest of the industry. This slow pace of development has allowed other biomass to energy technologies to catch up and capture the attention of the public and policy makers (biomass to electricity and algal ethanol, for example), diverting potential support (monetarily and politically) elsewhere.

Cellulosic Firms' Perspective

Given all these developments, it is not surprising that the cellulosic firms attempting to jump start the industry, while agreeing that contracting for and moving cheap biomass are problems; insist that their biggest obstacle isn't the logistics or the technical problems of making the ethanol but rather a lack of capital. They blame the recession and tight credit markets for the many cellulosic projects shut down or delayed. They also lament lack of governmental support and overly restrictive government loan guarantees on the support that they do get. Matt Carr of the Biotechnology Industry Organization claims, "Until we see a flow of financing, some combination of public and private investment flowing to construction of commercial facilities, we're going to be stuck in this position of very small amounts of cellulosic bio-fuels being available."

Logistic issues, the lack of sufficient cheap contract-able biomass, and difficulty obtaining capital can be attributed to the fact that most, if not all, of the firms and policy makers are acting under the assumption that the future of the cellulosic ethanol value chain will revolve around very large processing centers, termed 'Integrated Biorefineries' ("IBRs"). These 'substantial hurdles' should not have come as a surprise to any stakeholder, as they are requisite to sustain the IBR value chain as envisioned.

2.5 *Value Chain Envisioned: Fully Integrated Biorefineries*

The current dominant paradigm envisions a system of fully integrated biorefineries fed directly by feedstock suppliers. The centerpieces would be large fully integrated biorefineries (IBR) capable of converting biomass feedstocks such as grains, grasses, wood, residues and municipal solid wastes into fuels, fibers, chemicals and animal feeds. Figure 6 represents the general concept of this value chain[49].

The left hand side represents the biomass producers, harvesting activities, collection agents, inbound transportation infrastructure and feedstock handling which will supply the raw materials and process inputs (like steam, ammonia, etc.) to the integrated biorefinery.

The right hand side shows the post-production activities that will handle the co-product distribution and sales. Output supply chain activities will likely include storage, transportation, distribution, and creation of new retail outlets (i.e. bio-fuel capable filling stations.)

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49 Centrec Consulting, 2006

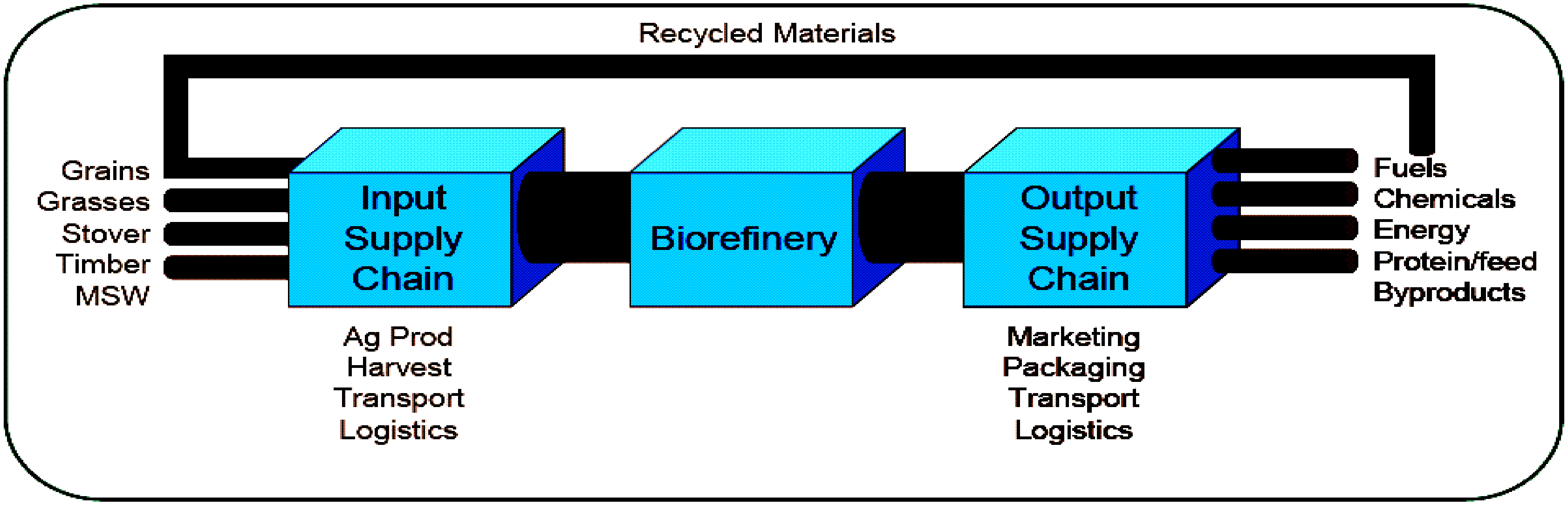

Figure 6- Biorefinery Value Chain

NREL defines the fully integrated bio-refinery as a "facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. The biorefinery concept is analogous to today's petroleum refineries, which produce multiple fuels and products from petroleum. Industrial biorefineries have been identified as the most promising route to the creation of a new domestic bio-based industry."[50] These facilities will succeed because the high-value, low volume co-products provide a number of financial, operational and process supports to the primary product (ethanol in this case). The revenues from the co-products subsidize the primary product, utilize more of each of the heterogeneous feedstocks and provide process synergies (and, thus savings). The co-products are less costly to produce due to the spreading of the fixed costs across both the high volume primary product and the low volume co-products[51]. The cellulosic biorefinery is envisioned to encompass all the processing technology from the raw feedstock through the finished bio-fuel and the related co-products, as well as producing some of its own process inputs such as electricity and steam. It is assumed that the firms willing and capable of constructing, owning and operating these facilities will be the large petroleum and / or chemical firms. These firms have many competitive reasons to get involved, including first mover advantages, business synergies (in regards to production, delivery and business knowledge), diversification and the ability to retain market share of the fuel industry.

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[50] Lynd, et. al, 2005

[51] Lynd, et. al, 2005

Issues with IBR Paradigm

The issues projected as hurdles for this system[52] are the issues specifically cited as the problems causing the current stagnant state of the cellulosic ethanol industry. In order to realize scale economies and get sufficient affordable biomass, the IBR would have to be located in fertile and easily accessible land. This is problematic. Most land that fits this profile is already productive agricultural land. Converting it to dedicated energy crops would inflame the food versus fuel debate, be costly and require long term contracts with high liquidated damages to cover re-conversion costs. IBRs are forced to use other biomass resources, which are dispersed and may have harvesting and collection issues. Since the biomass is dispersed, the IBR must increase its catchment area in order to secure even the lower volumes required for the undersized facility. This situation drives up costs for biomass, cost for transportation and process costs (i.e. losing scale economies and process synergies). It also excludes potentially cheaper, relatively available biomass sources from other marginal non-agriculturally utilized lands.

Beyond these geographic and technology constraints, there are logistical contractual constraints. The larger catchment area and dispersed biomass necessitates a greater number of contracts with a larger number of biomass owners. The pure volume of contracts to manage is overwhelming, and by itself can kill a potential project[53].

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52 See Aden et. al, 2002 for a discussion and analysis of transport costs associated with dispersed biomass supply and the ability of an IBR to reach minimum efficient scale

53 Just as with wind farms. Too many supply contracts have killed many wind projects.

These facilities are very capital intensive due to their size; and, the equipment required to create the co-products and capture the process synergies necessary for the integrated bio-refinery to operate efficiently. High cost facilities with unproven technology; no track record of reducing processing costs; and, difficulties securing long term supply contracts are going to have trouble raising capital, or be required to meet onerous loan guarantee conditions.

Transactional Issues with IBR

In addition to these physical logistic issues, there are substantial non-physical issues due to the nature of the envisioned market structure. These are best termed 'Transactional Issues', and arise because of the necessary transaction between two very different, very distinct, and very nervous industries – agriculture (the biomass suppliers) and the refiners. There is an inter-industry boundary point along the value chain, which is a real, physical boundary from a technology and engineering standpoint because at that point, the biomass is being drastically altered into a different physical form from a raw agricultural material into an input for an industrial conversion process. It is also transactional boundary; the point at which 'delivered feedstock' pricing is set.

There are a number of transactional characteristics at this boundary that contribute to the standoff situation facing the domestic bio-ethanol industry. These characteristics include high degrees of asset specificity on both sides of this transaction; the lack of a commoditize-able product; the necessity for a large number of bilateral contracts negotiated under uncertainty and informational asymmetries; and, a history of holdup situations in agriculture's dealings with industry.

This raises the following questions. What solutions exist to overcome this standoff? Can it be done within the IBR paradigm, or is a radically different value chain required? There are potential solutions within the IBR structure – commoditization of biomass; improvements or innovations in transport methods and technologies; industrial agricultural solutions to biomass availability (i.e. increased yields, conversion of existing cropland, mass adoption over large areas of consistent harvesting practices, etc.); and detailed specification contracting. The likelihood of any of these solutions coming to fruition in the near term in a manner that provides cellulosic ethanol at a competitive price is minimal at best.

What about an alternate value chain structure? Are there other solutions to overcoming the recalcitrant feedstock interface boundary that overcomes the physical and transactional hurdles, while still providing cost-competitive ethanol without eroding food supply and rural economies? Utilizing intermediate preprocessing facilities is one such option, with additional attractive benefits such as providing feed and fuel, smaller stand-alone facilities with lower capital costs (which *might* overcome the capital constraint), lower barriers to entry which could entice local ownership and / or marginal land inclusion.

CHAPTER 3

STRUCTURAL ISSUES WITH THE CELLULOSIC BIO-ETHANOL INDUSTRY

The cellulosic biomass to ethanol industry faces a number of physical and transactional issues that must be overcome for large scale implementation. Chapter 2 outlines these issues, and the market and institutional forces pushing for cellulosic ethanol. This chapter analyzes the components and nature of this value chain to suggest governance solutions to the transactional issues. It describes value chain and activities, and highlights the importance of managing the transaction between biomass suppliers and bio-processors.

This chapter analyzes the nature and characteristics of this critical portion of the cellulosic ethanol supply chain (i.e. the transaction between biomass producer and first handler) through a transaction cost economics framework to:

- identify relevant characteristics of the goods and transaction that impact the form of exchange;
- examine critical characteristics of the various agents to the exchange to identify and explicate the sources of transaction costs and contract hazards;
- Discuss how transaction costs contribute to the current standoff situation in the LCBE industry; and,
- Suggest possible governance structures that may emerge.

3.1 The LCBE ('Ligno-Cellulosic Biomass to Ethanol') value chain

To meet national mandates, advanced bio-fuels must be produced from ligno-cellulosic biomass ("LCB"). Common types of LCB are corn stover, switchgrass, wheat grass, poplar, timber residues, paper residues and even municipal solid waste. These feedstocks are high in carbohydrate content, which can be converted to sugars, which are then fermented to produce ethanol. Large scale realization of a LCB industry entails creating an entirely new value chain with alternative abundant, reliable and diverse feedstocks; new collection, transportation and storage infrastructure; utilization of emerging conversion technologies; facilities that can produce a variety of products; and ultimately, highly developed wholesale & retail distribution chains. The major activities along this value chain, up through bio-ethanol conversion are shown here in Figure 7.

LCB Production	Harvest & Collection	LCB Storage	LCB Transport	LCB Storage	Pre-processing	Pre-treatment	Conversion	End use value chain

Figure 7 - Ligno-cellulosic ethanol value chain

The purple activities are the value chain components that fall under the control of the bio-processing and refining industry. The main pathways for converting biomass into fuels involve thermo-chemical and bio-chemical processes. Thermo-chemical processes are considered most promising for the production of Fischer-Tropsch diesels and hydrogen, while bio-chemical processing has been viewed as the most promising for ethanol production.[54] A pre-treatment step before ethanol conversion is required to facilitate the access of the enzymes to the cellulosic biomass substrates. Many pre-treatment technologies are being investigated, including Acidic pre-treatments

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[54] There are also hybrid thermo-chemical / bio-chemical processes such as bio-oil or syn-gas fermentation

(concentrated & dilute acid, steam explosion, liquid hot water) and alkaline pre-treatments (AFEX™, Ammonia Recycle Percolation, Soaking in Aqueous Ammonia, etc). A more detailed discussion of pre-treatment and ethanol conversion pathways is in Chapter 4. Specific pre-treatment and conversion pathways will be firm dependent and are not relevant to this analysis.

The end use value chain is storage, wholesale distribution and retail handling of the bio-ethanol. This analysis is concerned with the biomass to ethanol value chain, not the ethanol value chain.

The green activities are the feedstock industry segments. Below is a short description of each of these feedstock industry activities.

3.2 Feedstock Industry Activities

LCB Production

In 2003, biomass provided in excess of 200 million dry tons annually to the nation's energy supply, primarily from wood residues. Meeting EISA 2007 targets requires creating new sources of biomass, re-thinking utilization of existing waste materials, and potentially diverting biomass from other current utilizations. Agricultural resources will be created from agricultural residues and dedicated energy crops. Agricultural residues are concentrated mostly in the Midwest and Great Plains and represent the largest available feedstock resource. Dedicated perennial biomass crops will be produced specifically for conversion to bio-fuels. Types include warm-season grasses (such as those used for forage and conservation purposes) and short-rotation tree crops (such as those used commercially for fiber and other bio-energy applications). Agricultural biomass potential is estimated to be 800 million dry tons[55]. Forest and industrial wood residues include logging residues, forest thinnings, bark, mill residues, and spent pulping liquors. Estimated total wood biomass to bio-fuel feedstock potential is 370 million dry tons[56]. Other less abundant sources include municipal solid waste, animal manures, urban wood residues (utility tree trimmings, construction waste, grass clippings and newspaper), and industrial residues.

Harvesting and Collection

The primary goal of this value chain activity is to harvest, collect, and remove the biomass from the field in a sustainable, cost-effective manner. Harvesting and collection methods and technologies have significant impacts on storage, transportation, and preprocessing. Harvest and collection technologies have been developed and optimized for grain harvest, not to optimize residue collection for utilization. While dedicated energy grasses could be harvested with current technology, new sustainable biomass harvest technologies may need to be developed and implemented to supply sufficient crop residue biomass. The goal of sustainable harvest technology is to maximize the amount of residue that can be removed while adhering to sustainability guidelines. Possible technologies include selective harvesting, single pass harvesters and alternative bulk collection systems.

[55] US DOE, 2003

[56] US DOE, 2003

Biomass Storage

As the biomass leaves the production facility, either as a crop or a residue, it is necessary to store the raw material on-site until it is to be picked up for delivery to the bio-processor. Current practice and infrastructure revolve around bales or bundles. New approaches include dry bulk storage options either adapting the existing system for on-site grinding and storage (granulization), pelletization and / or adapting systems that exist for handling other dry bulk feedstock. Wet bulk storage options, such as ensiling, are also under examination, as are hybrid (wet – dry) systems.

LCB Transport

Biomass may be transported by truck on existing roads or by trains and barges on existing rail networks and waterways, with existing technologies. The bulk of research and development in biomass transport has focused on ways to optimize the use of different technologies to minimize transport cost. These studies have examined specific alternate modes of transport - truck transport, rail transport, pipeline transport, barge transport, multi-modal systems – combined with alternate raw biomass formats – round bales of differing sizes, square bales of differing sizes, woody biomass bundles of varying configuration, grinds, pellets, and slurries.

Preprocessing:

> "Biomass, when harvested, is characterized by its low density; varying and often high moisture content; and varying size, shape, density, and chemical makeup of its differing parts. Biomass may also be contaminated with dirt and other undesirable foreign materials that adversely affect the bio-refining quality. Preprocessing treatments are designed to improve biomass handling, transport,

> and storability. Preprocessing can also add value by making biomass more fit for final conversion to fuels, power, and chemicals." [57]

Pre-processing could be considered an activity of the feedstock industry, or fall under the auspices of the bio-processor. The oversight depends on where in the value chain this activity takes place and to what extent the biomass is altered. Simple grinding may take place during harvesting and fall well within the knowledge base of feedstock producers. Options for value chain placement of preprocessing can range from as early in the chain as harvesting, to as late in the chain as pre-treatment.

3.3 The Biomass Transaction

A transaction is defined as an exchange of a good or service across a technologically separable interface,[58] and is the fundamental point of analysis for transaction cost economics. For the cellulosic ethanol industry, the transaction under consideration is the exchange of ligno-cellulosic biomass from the producer of the biomass to the bio-processor.

The exchange involves interaction between the two industries in the value chain, agriculture and refining. Every activity up through the transaction point is undertaken by the feedstock industry, and all activities post-transaction are under the auspices of the bio-processor. The transaction interface may be as high up the supply chain as the refinery gate and as far down as the farm gate, as in the case of Iogen considered by Altman, et. al. (2007).

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[57] US DOE, 2003
[58] Wiiliamson, 1996

Agents to the transaction

The agents to this transaction are the LCB producer (of which there are two types) and the bio-processor. These agents are assumed to have bounded rationality and a penchant for opportunism. Bounded rationality is the idea that perfect rationality by an actor is constrained due to conditions, such as limited time and available information. Opportunism is defined as being self-interested, with guile[59].

Grower types are differentiated according to the type of biomass product they exchange. For this analysis, ligno-cellulosic biomass comes in essentially two types – agricultural residues and dedicated energy crops[60]. While essentially substitutes, they do have crucial differences in terms of how they are created. Suppliers of these different types of biomass will have different characteristics that impact the transaction and the emergent governance structure.

Agricultural Residues vs. Dedicated Energy Crops

Agricultural residues are waste products of other economic or human activities. Examples of agricultural residues are timber waste, municipal solid waste, corn stover or other crop residues. They are currently created, and are either ignored, disposed of (often times at a cost, which is sometimes substantial as in the case of municipal solid waste), or put to use in a marginally productive manner (i.e. corn stover). These are promising as sources of LCB, especially as they do not involve investment in new or

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[59] Williamson, 1996

[60] Woody biomass could be examined similarly – i.e. dedicated forests vs. residues.

specific assets, do not require converting current economic activities into alternative ones, and may be less expensive to purchase. This is the case analyzed by Altman, et. al (2007), in which the bio-refiner (Iogen) has contracted with agricultural residue providers at different prices for different time periods.

Dedicated energy crops (DEC) are those biomass materials that are grown specifically for use as an input into energy production, in this case bio-ethanol. Examples are switchgrass, miscanthus and energy cane. These crops must be intentionally seeded, cultivated and harvested. They will need to be grown on either crop land currently in production, in which case the grower will need to convert it from its current use, or on lands that have no other commercial purpose due to a miscellany of reasons, including conservation or quality of land. Many of these crops, like switchgrass, require a multi-year timeframe for establishment of a harvest-able stand. During the establishment period, the land owner will be garnering no income. In addition, once the stand is established, there will be no other market for the crop (hence 'Dedicated' energy crop). Dedicated energy crops must be harvested and collected within a given seasonal window, just as any other agricultural product. If this product is not immediately consumed as an input by the bio-processor, it must be stored until needed.

3.4 Transaction Costs

Transaction costs are caused because exchanges are not frictionless. The sources of transaction costs in the biomass transaction are examined.

Complementarity

Complementarity, like teamwork in agency theory, means that coordinated effort will bring about greater output than the sum of the individual efforts. The sum of the individual efforts if the two agents are not highly coordinated is zero in this case. There will be no value as neither party will undertake the transaction, and the marginal product of each will be zero.

Bio-processors need biomass in sufficient volumes; that match key characteristics for their specific conversion pathway; that is available when needed; and, that can be delivered at an acceptable price. Feedstock suppliers need to sell to the bio-processors, as there is no other market for their product. This arrangement creates a situation with high complementarity across the transaction interface, which means that after the transaction, the two activities provide a good whose value is much higher than if the transaction doesn't occur (in this case, that marginal product is zero) [61]. These conditions necessitate high levels of system co-ordination. By internalizing these costs, contracting or leveraging human capital through teamwork, the two agents may be able to eliminate frictions, operate more efficiently and reduce transaction costs. This set of criteria poses a large number of risks for a bio-processor, and the cost of a co-ordination error will be high.

Asset Specificity: Bio-processor

Siting for the bio-processor is vital to its ability to leverage scale economies, secure sufficient feedstock supply, and satisfy environmental permitting concerns. Advantages

[61] Peterson, et.al., 2001

can be realized through: reducing input costs by locating close to supply terminals and existing infrastructure (i.e. for ammonia, steam, water, electricity, etc.); reducing product transportation costs by locating close to rail or highway access; reducing animal feed marketing and distribution costs by locating in areas of high ruminant demand; and by locating close to biomass supply. The facility must be located in a geographic region that has sufficient agricultural residues and available crop land for dedicated energy crops to supply it with feedstock. Environmental and other permitting requirements must be met. Therefore, these facilities are fairly site specific assets.

These conversion facilities are highly specific, dedicated assets. The pieces themselves will have alternative uses, the facility as constructed can only be used to process LCB and convert its carbohydrate content into an accessible state. The conversion process and technology is very specific. There is no other current use for pre-treatment technologies and bio-ethanol conversion pathways. Each of these is patented and under exclusive control of its inventor, which adds concerns over leakages (the appropriation or dissipation in the value of specialized knowledge by transaction counterparties[62]) in addition to being highly transaction specific knowledge. Bio-processors face high capital costs, which represent irreversible investment in transaction specific assets.

Asset Specificity: Dedicated Energy Crop Grower

While the cost of entry for a dedicated energy crop grower is not necessarily high in terms of capital outlay (it is the same equipment as many farmers currently use), it is

[62] Williamson, 1996

extremely high in economic cost. Most energy crops are perennials; however a stand usually takes two to three years to be established. In that time, the grower can earn no income. If the grower must convert currently production crop land, he will incur the loss of those rents as well. Compound this with the high cost of exit if the transaction fails due to defection, ethanol market bust or external institutional changes. The grower incurs additional costs to re-establish his previous crop as well as attempt to re-establish contracts with partners that he has abandoned recently. Couple this with the fact that there is no other viable outlet for these crops, and you have highly transaction specific assets, with a relatively high level of quasi-rents (see below), which creates a high risk of expropriation by an opportunistic trading partner.

Asset Specificity: Agricultural Residue

Agricultural residue providers will not require any transaction specific assets, any conversion costs, or any irreversible investments in order to participate. They may have to incur some additional costs for collection and / or transportation, depending on how the distribution networks unfold, however the price they receive will, at a minimum, cover these costs.

Asymmetric Private Information / opportunism:

The bio-processor is in possession of valuable knowledge and private information that it could use to its advantage both ex ante (during negotiation) and ex post. In this transaction, only the bio-processor has a true knowledge of how the conversion process works. This is patented legally protected intellectual property that is highly valuable.

The bio-processor has no incentive to reveal this knowledge to any grower, especially as it may have grave concerns regarding the damage that leakages may do to its strategic position vis-à-vis competitors, as well as the damage to its ex ante bargaining position that revelation may cause. The bio-processor presumably also possesses knowledge of its upstream partners and the petro-chemical industry in general. This networking and industry knowledge provide additional ex-ante bargaining power.

The feedstock provider holds valuable private information in agricultural business, his land's real productive capability and his reservation value. These can give him ex ante leverage, and could create the possibility for ex post opportunism in a similar manner that the bio-processor's private information could be utilized.

Uncertainty

One component to this transaction that will cause both ex ante and ex post transaction costs is the high level of uncertainty being faced by both parties. Much of this is due to the uncertainty in the external institutional environment. The mandates have not to date been strictly enforced, and a change in national leadership may bring about a change in energy policy that eliminates mandates entirely. The market environment adds uncertainty. Corn ethanol production escalated too quickly and the boom turned into a bust. The oxygenate market is over-saturated, and flex-fuel vehicle sales have slowed. Alternative liquid non-fossil based fuels are emerging (see Chapter 2). Capital markets have showed little faith in cellulosic technologies (see Chapter 2). There are threats of ex post defection by both parties that may or may not be credible. Neither party really has an ability to ex ante improve its bargaining position through investment (i.e. create 'standby' assets). Finally, there is the understanding by both parties that potential for holdups exist, and there is a history of holdups in the agricultural sector. This puts a cloud of mistrust over the whole negotiation process, and creates frictions.

Appropriable Quasi-rents

Quasi-rents are the difference in value between the high value specific use of an asset and its' alternative lower value use. For dedicated energy crop producers, this is the difference in value between the net feedstock price and the alternative use, which is essentially zero. For the agricultural residues providers, this would be the difference between selling the net feedstock price and doing nothing (their current situation). For the bio-processor this is the difference in value between operating as a cellulosic ethanol bio-refinery and the salvage value (if any) of the facility.

The existence of these quasi-rents is not in itself a potential market power problem. Problems arise if either party to the transaction is able to capture these, or the quasi-rents are 'appropriable'. A key determinant of how much of these quasi-rents are appropriable is the degree of asset specificity in the transaction; the higher the asset specificity, the greater percentage of quasi-rents that could be appropriated. If there is no other market (or even use) for the product of an asset other than that for which it is being used, all of the quasi-rent value is appropriable.

The existence of appropriable quasi-rents doesn't necessarily mean that one party or the other will unscrupulously capture these during the course of the transactions, only a highly 'opportunistic' and self-serving firm will act in this manner[63]. Presumably, only an actor that believes it can get away with it without negative repercussions, either to reputation or to future profits.

The capacity to appropriate must also exist. If there is no way for these to actually be captured, then these rents remain with each party. For efficiency and performance, however, it would be beneficial that these quasi-rents either disappear, or become internalized. If not, they become added costs to the ultimate product, which in this case means that the wholesale ethanol price would be higher than otherwise, to the extreme that cellulosic ethanol industry never emerges.

There exists appropriable value for the bio-processor to capture because of the following characteristics of the biomass producers and market structure:

- There are no other uses or buyers for this material;
- The assets are highly specific to this transaction (i.e. "dedicated" energy crops);
- There are very high barriers to entry for bio-processors,
- The material is bulky and difficult to transport; and,
- The crops are seasonal, but may be storage-able.

[63] Williamson, 1996

The quasi-rents from dedicated energy crop producers are fully appropriable. In the case of the agricultural residues, the quasi-rents are also fully appropriable; however, the value of these quasi-rents is not as substantial as those of the DEC since there is no specific additional capital or human capital required.

There exist appropriable quasi-rents for the biomass producers to capture from the bio-processor due to these factors:

- An bio-processor faces HUGE initial capital outlays / fixed costs;
- There is limited alternative input supply;
- The product may have limited store-ability, but is seasonal;
- Agricultural residues sources have no barriers to exit;
- The composition and quality of input can be highly variable.

The quasi-rents from the bio-processors are fully appropriable because facilities cannot be used to produce any other product.

3.5 Potential Holdups

Potential holdup scenarios (i.e. market power residing with the bio-processor or with biomass producers) exist because there are appropriable quasi-rents on both sides of the exchange.

Bio-processors could capture market power and quasi-rents in a number of ways. They could operate under a differential pricing policy where they pay the dedicated energy crops a lower price than they pay the agricultural residues suppliers. They could squeeze suppliers by paying the equivalent of next lowest source, which could be the closest excluded producer that might be willing to come in at, or below, production cost just to carve out some market share. It is possible that the bio-processor will pay equivalent to the reservation value of an alternate source, which could severely impact a dedicated producer as the alternate source may be additional agricultural residues feedstock with a reservation wage just barely in excess of transportation cost. The bio-processor could simply threaten to vertically integrate (i.e. buy out a reticent producers competition) in order to internalize costs, in which case the price would be equivalent to the cost of integration. If the payoff by switching trading partners was deemed sufficient, it could simply threaten to (or actually) ex-post defect. Finally, bio-processors could horde inventories during harvesting periods, which would force producers to hold onto their product or halt production, incurring storage costs and impacting cash flow.

They are able to do successfully accomplish this because they are the only purchaser and there are very high barriers to entry for any competition, as well as barriers to exit for dedicated producers. There is not even a threat of entry by a competing bio-processor. If that threat even existed, the bio-processor would be reticent to undertake these activities to capture the appropriable quasi-rents because of the potential impact to its future profits. If another processor was able to start up quickly and easily, this new firm would be able to squeeze the incumbent out because it would not operate in an anti-competitive nature, and the damage done to the incumbent firm's reputation would likely be irreparable. As no threat exists, the suppliers are essentially 'hostages' to the refiner.

The bio-processor also faces the possibility of being held up by the growers through collusion and the threat of defection. By strategically withholding supply, the suppliers put the bio-processor at tremendous peril. Because the fixed costs are so high, the facility must run at close to capacity in order to recover these costs if it is to produce a competitively priced product. Since the facility cannot survive producing co-products alone (the product slate diversity is intended to drive down the primary product price, not sustain the firm in down times), and there is no alternate use for these facilities, it must be able to produce ethanol or fail. The value of these appropriable quasi-rents is not as substantial as those available to an opportunistic bio-processor because there is certainly the threat of entry by competing biomass producers, either from farther away or by conversion of other crop lands or agricultural residues. Therefore, the value that the producers can extract is less than what the bio-processor could extract.

Defection is a realistic threat from agricultural residue producers, as it is simple to revert back to their current mode of dealing with residues. Defection by any single agricultural residue supplier will not impact the bio-processor; however as the refiner will likely require at least some agricultural residues feedstock to operate at full capacity, collective action by all agricultural residue suppliers could indeed holdup the refiner. If collective action can stop the bio-processor in the short run, this could be a crippling blow and would impact future profits. The threat of repetition of this tactic could provide leverage for the producers to ratchet up the value of these quasi-rents.

This may be mitigated by the fact that the relationship between the DEC growers and refiner will presumably be one of mutual reliance vested with credible commitments and irreversible investments by both parties, which pushes the agricultural residues into a supplemental supplier role. The threat of defection by DEC growers is an empty threat as they have no alternative use for their dedicated assets.

3.6 Standoff Situation

A potential outcome if the actors cannot agree ex ante on an appropriate governance structure is that no investment will occur. This is an inefficient outcome that will severely impact the performance of the industry. There are several characteristics on both sides of the transaction interface, which lead to a stalemate situation (i.e. no investment at all). These characteristics, including the potential for holdups, appropriable quasi-rents, high complementarity, and dedicated assets are discussed above. Research shows empirically that holdups and the potential for them lead to distrust and foregoing value added investment.[64] Peterson, et. al.. (2001) point to high complementarity across the exchange interface as an indication that there is potential for very costly coordination errors, which could lead to inaction. Since both parties are rational actors aware of these characteristics, neither one would choose to participate in a system that would result in an outcome of asymmetric market power and potential abuses.

There are three other issues that contribute to a standoff situation outcome. First, the bio-producer and the dedicated feedstock producer are facing a 'chicken and egg' situation. Both would like to participate, but neither is willing to commit capital resources until they have some reliable, relatively low risk assurance that there will be

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[64] Besanko, et.al., 2007

the requisite market for biomass, or some sort of assurance from the other party that it will simultaneously invest. Do the producers convert to dedicated energy crops (which will take a minimum of two years to be fully available) in the belief that the bio-processing facility will come on line? What happens if they don't? On the flip side, does the bio-processor pick a site, go through all the planning and engineering, obtain permits, begin construction, etc. without a supply of feedstock locked up and immediately available? This is exacerbated by the dedicated nature of raw biomass discussed earlier, that there is no real, viable alternative market for biomass in its raw form. With no alternative buyer, many potential dedicated feedstock producers would be hesitant to commit resources.

There is also conversion path dependence between the bio-processor and feedstocks it requires. This creates a kind of mutual dependence on each other. This is typically an uncomfortable, and untenable situation, and would likely lead to non-investment as opposed to the riskier option of 'taking the leap of faith'.

Due to the potential for holdups, high complementarity, dedicated assets, a need for credible commitments from both parties, and mutual dependence, a standoff situation of no investment occurs.

3.7 Possible Governance Structures for Overcoming the Standoff

Option 1: Biomass Commoditization

One method of overcoming the transaction interface impasse is to have the market go through a transformation, from a market of bi-lateral contracting for specific, unique goods transacted by a only a few agents to a market of many agents transacting for quantities of a homogenous good of relatively consistent quality. In other words, make biomass into a commodity similar to other bulk agricultural (or industrial) commodities (i.e. grain, corn, electricity, ammonia, etc.). If possible, this would have numerous advantages:

- Create some uniformity in biomass characteristics;
- Allow biomass to be handled in bulk, like other agricultural commodities;
- Format biomass to be transported much larger distances, allowing producers and bio-processors to be free of geographic proximity for trade;
- Allow parties to entertain faceless transacting / eliminate need for pair-wise identification;
- Allow biomass to be traded with commodity contracts by dispersed parties and agents;
- Create a public price discovery mechanism;
- Alternative sales channels for feedstock producers beyond the local bio-processor;
- Consistent input makes it easier for bio-processor to maintain operational and process parameters optimally;
- Could allow for utilization of multiple feedstocks in a 'blend'; and,
- Increases the scale of the biomass market.

This is the method that agents in international markets for woody biomass have developed with industrial wood pellets. Wood pellets are now traded on the

Amsterdam Energy Exchange, and domestically[65]. In order to be traded as a commodity, wood pellets must meet very detailed specifications (as would, presumably biomass). The contract for industrial wood pellets traded on the Amsterdam Energy Exchange is shown in Figure 8.

Measurement criteria and thin markets pose challenges to commoditization. If biomass is to be commoditized; it may need to be graded on some sort of convertible carbohydrate content criteria[66]. If this doesn't happen, each biomass resource will need to be handled independently, which could lead to thin markets. If each biomass must be treated separately as it creates multiple markets, instead of a single one.

This may lead to thinly traded markets which have a tendency towards highly volatile prices, low volumes and small numbers of participants. This scenario could push agents away from the market and back to bi-lateral contracting.

Option 2: Vertical Integration

Another option would be to entirely internalize the transaction, eliminating the transactional hurdles by becoming one firm. This could happen by the feedstock industry taking over all the activities up the value chain from the feedstock boundary interface (the physical interface), including all the end product storage, sales, marketing and distribution. There have been attempts (some successful, others not) by agricultural firms (co-operatives often) to do this, including in the corn ethanol industry.

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[65] An example of domestic market is WoodPelletPrice.com

[66] A stated R & D thrust in the Roadmap for Agricultural Biomass Supply is to "Develop valuation parameters for biorefinery feedstocks as a commodity or based on fermentable carbohydrates"

INDUSTRIAL WOOD PELLETS	
Description	Industrial Wood Pellets (bulk), Rotterdam Diameter: 4<D<10 mm Length: <50 mm Raw Density >1.12 kg/dm3 Moisture: <10 wt% Ash: < 1.5 wt% Net Caloric Value: basis 17,0 MJ/kg as received (cp) Sulphur: <0.08 wt% Nitrogen: <0.30 wt% Chlorine: <0.03 wt% Additives: < 2 wt% Fines: <3 wt% At the request of the Buyer, the Seller will prove that the industrial wood pellets have been manufactured in a sustainable way and will provide the Buyer with all necessary documents in this regard, such as labels, certificates, etc.
Delivery	Cost Insurance Freight (CIF) Rotterdam Standard cargo size parcels with forward delivery between 1 and 6 weeks from the date of price assessment
Delivery Point	Rotterdam
Contract series	Front to three (3) months ahead Front to three (3) quarters ahead Front year
Contract size	1,000 metric tons
Pricing	In EUR per metric ton (€/MT), excluding taxes
Minimum tick	Twenty-five euro cents (€0.25/MT)per metric ton
Expiration	Last Thursday of each calendar month (in case the last Thursday of the calendar month is not a Business Day, the next following Business Day)
Introduction	Introduction of new contract series at expiry of old contract
Reference Prices	Fixing every Thursday (in case the Thursday is not a Business Day, the next following Business Day) between approximately 14:00 - 16:00 hrs (CET)
Terms and conditions of contracts	Generally accepted Master Agreement for the trade of Industrial Wood Pellets (bulk)
Payment terms	98% of invoice amount within 48 hours after bill of loading, balance adjusted for actual net caloric value to be settled 48 hours after discharge

Figure 8 – Wood Pellet Contract, Amsterdam Energy Exchange

The more likely scenario to unfold would be integration in the opposite direction with the bio-processor backward integrating to take over the raw material supply chain. This is the case in Brazil, where 70% of the ethanol industry is structured such that the bio-processor (sugar mill) owns, operates and manages the entire sugarcane value chain from production, to scheduling harvesting and collection activities, to storage and transport, through conversion and beyond. The sugar to ethanol value chain is a successful, operating example of biomass to bio-fuels value chain. If non-integrated, it would face the same co-ordination / transactional issues as the domestic biomass chain, as this excerpt outlines.

> "In the cane sugar industry, co-ordination between growers and millers focuses on the organisation and process of the mill supply. Decisions made by millers regarding mill capacity, the location of mill and transloading centres, and delivery allocations, will impact on the choices made by growers regarding mechanisation and harvest management. In turn, decisions made by growers regarding variety selection, harvest capacity and work organisation, will impact on milling efficiency. Poor cane quality will reduce crushing capacity, while irregular deliveries will disrupt the continuity of mill supply. Intermediate operators involved in cane flow management, such as harvest contractors and hauliers, will also affect the supply process. Total sugar production at mill area level thus depends on the efficient functioning of these technical interfaces, as well as on each stakeholder's management processes. " [67]

The market environment in Brazil favors a vertically integrated structure. Factors contributing to this include the institutional framework, the historical path of the industry, the density of the biomass, the industry wide efforts on collaboration, geographic characteristics, and demographics of end use demand. Many of these

[67] Gaucher, et. al. 2003, 2003

factors do not exist in the United States, which will make it difficult to employ this strategy.

There are domestic attempts of backward vertical integration. Some woody biomass conversion firms and sugarcane ethanol conversion firms are attempting it on a smaller scale[68]. BP Bio-fuels owns and operates three sugarcane ethanol mills in Brazil, and attempted to bring this structure into the domestic market. Their vertically integrated energy cane to bio-ethanol project in Highland, Florida was to open commercially in 2014. The project has been cancelled[69]. This strategy may prove to become a competitive advantage for these small scale firms, especially if they can leverage any supply and demand profiles or value chains that mirror some of the characteristics of the Brazilian experience. However, vertical integration on a large scale is not likely to occur. There are too many additional problems that a bio-processor would face dealing with a scope of supply and management of that magnitude. Problems include lack of feedstock assembly knowledge; a paucity of large regions with high biomass concentration; too many suppliers to integrate with; and, free market / anti-trust restrictions.

Option 3: Contracts

The commodity market for biomass from agricultural residues and dedicated energy crops does not exist now, nor is it likely in the near term. Thus, the most likely manner

[68] BP Bio-fuels in Highland, FL for example (see Chapter 2)

[69] BP press release, 10-15-2012

of price discovery will not be an open market with full public disclosure of prices; but, rather through private treaty and bilateral contracts.

An exchange will be transacted via bilateral contracting (as opposed to via market exchange) if it has undergone the 'fundamental transformation'.[70] The fundamental transformation occurs when the transaction moves from the realm of large numbers of participants to small numbers, or when ex ante large number of participants doesn't necessarily guarantee ex post large numbers participation. This can occur when there are relatively small numbers of agents available with which to transact, or when the parties to the first transaction gain some sort of competitive advantage over other agents (i.e. realize first mover advantages and economies of reputation). When these conditions occur, bilateral contracting that favors "pair wise identification" prevails over the perfect competition condition of "faceless contracting."[71] The biomass market has a small number of agents available ex ante (limited growers and bio-processors) and large first mover advantages (more so for the bio-processor that beats out competitors, but also for the growers). Thus, it is reasonable to assume that some form bilateral contracting should emerge as the favored mode of transacting.

There is a whole spectrum of contracting options, from simple supply contracts through complex joint venture agreements. The specific form of governance structure employed would likely vary according to the type of biomass supplier (dedicated crop or agricultural residues), as each faces different ex ante situations and decisions.

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[70] Williamson, 1996

[71] Williamson, 1996

Agricultural residues & bio-processor:

The Iogen contract structure examined by Altman, et. al. (2007) is an example of this transaction type. It is a specification contract with options for varying length. The grower can choose different prices for his LCB based on different lengths. The longer they agree to supply the refiner, the more fixed the price. Presumably the more risk-averse grower will lock in at a fixed price for a longer period of time, while the less risk averse may choose to take a shorter term variable price contract. Altman, et. al. (2007) points to the necessity for Iogen to lock up guaranteed supply due to the high asset specificity of the bio-processor, consistent with the theoretical analysis herein. This suggests that the bio-processor, facing high asset specificity and other transactional issues, would push for a governance form that has tighter vertical coordination mechanisms and more internalization of transaction costs.

Characteristics that are indicative of specification contracting are limited information sharing; coordination that can be handled during ex ante negotiation; efficiency that can be attained through the sum of the agents' individual self-interest pursuit more easily than through teamwork (i.e. low complementarity); and, low asset specificity for one of the parties (the agricultural residue provider).[72] All of these exist in the biomass transaction under consideration, and have been discussed previously.

Dedicated Energy Growers and bio-processor

[72] Peterson, et.al., 2001

In this case, there are high levels of asset specificity on both sides of the transaction, large irreversible investments that must be made, the potential for costly coordination errors, mutual distrust due to historical holdups, and potential expropriation or defection through ex post opportunism by either party. Ex ante, this contract environment is fraught with hazards. It would take serious credible commitments by both parties to make this transaction come to fruition.

Credible commitments are reciprocal acts designed to safeguard a relationship, which are used to support alliances, promote exchange and enhance coordination (i.e. increase transaction efficiency). These often take the form of mutual economic hostages which can act ex ante as screening mechanisms and ex post as bonds. When high levels of potential for expropriation exists, it is common to see parties follow the "ugly princess" strategy (i.e. give up something that they are more willing to risk). [73] In a case like this where high asset specificity exists on both sides and there are irreversible, specialized investments then credible commitments may enjoinder mutual investment, sharing of coordination efforts, and joint decision making. The emergence of a 'mutual reliance relation' should ameliorate any expropriation concerns, and avoid the 'ugly princess' strategy which may lead to incentives for defection[74].

Any contract must solve the chicken and egg issue. It will dictate which side commits first and, what happens if one party ex-poste defects. It is likely that during the

[73] Williamson, 1996

[74] Williamson, 1996

planning and permitting phases the two sides would enter into contract negotiations in order to hammer out these terms, defining 'credible commitments' for each party, and liquidated damages if one or the other defaults.

Bi-lateral contracting can solve the transactional issues outlined previously, however, there are additional issues that arise out of the ex ante negotiating required for this governance structure. There are issues with informational asymmetries and the cost associated with the volume of contracts.

On the one hand, agricultural producers are more familiar with this type of system structure and assembly problem. They understand issues like seasonality, storage, timing of harvest, transport and collection equipment, and possibly even collective action. They are well versed in the problems associated with processors holding too much power. This combination of factors may provide leverage and bargaining power for the agricultural agents.

On the other hand, bio-processors will be more familiar with their technology, the ethanol industry and large integrated industrial facilities. They have all the knowledge and commercial contacts for the end product sales, without which their product and the biomass are worthless. They have capital, cross-subsidization (ability to withstand losses), and conglomerate diversification. They may hold the leverage and bargaining power in contract negotiations.

The final contractual aspect that may ultimately favor of the biomass producers is the cost of contracting. Even a smaller sized conversion facility (5,000 tons per day), would require biomass from 350,000 to 700,000 acres of farm land. This will require the biomass producer to contract with maybe 1,000 different small to medium sized parties. Each of these will entail detailed discussions, contract negotiations, monitoring, different incentives depending on the growers' individual fears and needs, etc. This adds a tremendous amount of contracting costs to each relatively small exchange, not to mention likelihood towards escalation as the terms of each successive agreement leak out[75]. A bio-processor might certainly welcome a collective marketing agent that negotiates a full set of contracts for its members in order to decrease these transaction costs, however it then gives up any leverage it might have in price setting, and potentially gives the producers market power (as noted earlier). Reliance on numerous bilateral contracts will drive up ex ante costs, which may ultimately drive up production costs and wholesale prices. The likely consequence of this market characteristic is not that producers gain leverage, but rather that a bio-processor will limit its feedstock suppliers, therefore excluding smaller and marginal producers that are not worth the incremental cost.

To date, neither party at the transaction interface has been willing to enter into the types of contracts being proffered. There are just too many unknowns, too many risks, too little price discovery and a long history of distrust and holdups to overcome.

[75] This issue alone causes many wind farm projects to fail

Ultimately, however, contracts will play an important (not necessarily exclusive) role in overcoming these transaction hurdles.

Option 4: Intermediate Facilities

Theory suggests a governance structure that incorporates greater intensity of mutual control, shared investments and internalization of transaction costs through some formal organization when faced with the type of transactions examined[76]. The form of vertical integration suggested by Peterson et. al (2001) is an Equity Based Alliance (EBA). Key features of the governance are that it entails formal organization (and thus large ex ante negotiation and design), high level of coordination across the transaction interface and mutual investment of 'at risk' capital (i.e. mutual hostages). While this sounds very much like a vertically integrated firm, it differs importantly in that the two parties to an EBA structure maintain separate identities, and therefore some independently owned assets over which each party retains independent decision making powers. Ultimately, each party has the ability to walk away from the transaction, but at the cost of forfeiting their hostage, which is not an 'ugly princess'. For the case under consideration, it is incumbent that the bio-processor and dedicated energy crop growers maintain control over their assets and processes (land and practices for the grower, technology and network for the bio-processor), as neither side has the expertise or wherewithal to undertake the other's activities (i.e. vertically integrate). However, joint ownership and decision making over the transaction activities in an Equity Based Alliance will internalize the transaction costs, ameliorate expropriation concerns, heighten

[76] Peterson, et.al., 2001

coordination, limit the possibilities for defection, provide ex post bonding, provide ex ante screening of reliable partners, mutually share the risk of uncertainty, and overcome the contracting hazards discussed earlier.

The EBA (or joint venture) concept gives rise to an appealing option for overcoming the transaction interface impasse, the introduction of an intermediate facility located at the pre-processing and / or pre-treatment activity interface. Intermediate facilities are not a new concept for industrial biomass to bio-energy production, as Robert Hungate noted in 1950.

> ''An *industrial cellulose fermentation might be profitable* if the *cost* of collection of raw materials could be *minimized through the use of numerous small plants*, if the small plants could be *cheaply constructed*, if the operation could be made automatic to decrease necessary personnel, and if the concentration of cellulose fermented could be increased by continuous removal of fermentation products."

Nor are they an un-common value chain intervention. Warehouse systems are often investigated as intermediaries in emerging economies when an agricultural product displays characteristics such as seasonality, dispersed production, variability in size and quality, smaller production units, the potential for market power abuses, and limited access to financial resources (such as bridge loans until harvest, or production improvement). Oftentimes these warehouses will be co-operatives that lend money, act as a storage facility for the raw material, process the good into intermediate (or final) goods, sort the inputs according to quality standards, and even provide educational resources. In the United States, grain elevators have been used for generations in a similar capacity.

From a transactional perspective, an intermediate facility in the biomass value chain could help to overcome the hurdles facing the feedstock boundary interface. By incorporating pre-processing, it can help overcome the physical logistic issues created by biomass characteristics. Intermediate facilities can reduce size with grinding; reduce moisture by drying; improve storage characteristics like stability and degradation; improve flow-ability of the material; and, improve bulk density with densification technology like pelletization. These physical improvements will translate to economic benefits in handling and transportation as higher density, uniform material is more efficient to deal with than bulky heterogeneous material.

An intermediate facility provides additional logistic and economic benefits. It can act a storage buffer and centralizing facility possibly providing a single trading partner for bio-processors. Uniformity in materials coupled with a common quantifiable and easily measurable characteristic can lead to commoditized biomass, which could help to fundamentally transform the biomass market into one that promotes faceless contracting. Shared ownership internalizes the transaction interface; shares risk; eases the necessity for credible commitments because it is the mutual hostage (i.e. both parties put up some sort of equity at risk); and, lessens the chance of ex post defection or opportunism. Additionally, if the intermediate facility creates an intermediate product with alternative market, it eases holdup potential by eliminating appropriable rents and could cross-subsidizes bio-energy.

It does however create new challenges and potential hurdles. Feedstock must be loaded and unloaded twice, once as it comes into the intermediate facility, and once again as it leaves to the bio-processor. The total distance traveled per ton of biomass may be longer; however, this greatly depends on the bulk density of the outbound biomass. The total capital investment in processing facilities is greater.

Total capital employed become less problematic when looking at optimizing the entire value chain, not just individual components. If, as a system, one with intermediate facilities can produce more energy, utilize more biomass, be environmentally more sustainable and do it at a lower wholesale price of product, then the additional capital investment may be more than defensible.

3.8 Conclusion

Large scale implementation of cellulosic ethanol has yet to emerge. Issues outlined in Chapter 2 included non-binding mandates, overly aggressive policy making, daunting logistics, lack of capital, and slow developing technology. This chapter has outlined the structural issues that have lead to the lack of investment.

Vertical co-ordination across the feedstock boundary interface is critical to success and future of the cellulosic ethanol industry. For this to occur, participation of both the feedstock and conversion industries is a must have. Each party brings different knowledge, experience and technologies to the tables, all which are necessary for success.

There are potential solutions within the IBR structure – commoditization of biomass; improvements or innovations in transport methods and technologies; industrial agricultural solutions to biomass availability (i.e. increased yields, conversion of existing cropland, mass adoption over large areas of consistent harvesting practices, etc.); and detailed specification contracting. To date, these solutions have had limited success.

Idaho National Laboratory is examining commoditizing biomass through its Uniform-Format Solid Feedstock Supply System,[77] but, there is no commodity market for biomass. BP Bio-fuels attempted backward vertically integrating into energy cane production and collection in its failed Highland, FL bio-refinery. POET is leveraging its existing corn supply chain to get access to agricultural residues. Both of these facilities are limited in scope because neither approach will provide enough biomass for the firm to reach efficient scale. The failure of bi-lateral contracting to secure sufficient biomass ultimately killed off most of the 30 government funded projects. It has been un-successful due to all of the issues stated above –volume of contracts, need for and lack to date of credible commitments, asymmetric information, history of holdups, high asset specificity, etc. The transactional impasse at the has not been resolved, neither physically nor transaction-ally.

The analysis of alternative solutions points to the introduction intermediate facilities as a possible alternative to overcoming the standoff. Intermediate facilities could help overcome the physical interface issues, as well as the transactional interface impasse by creating a mechanism for overcoming the chicken and egg problem through joint credible commitments and mutual hostages; and, by avoiding the specter of holdup situations by providing ex-ante bargaining power to feedstock suppliers and eliminating some potential for ex-poste defection of parties (if it is jointly owned).

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[77] Hess, et. al. , 2009

Intermediate preprocessing facilities may provide additional attractive benefits such as producing both feed and fuel; smaller stand-alone facilities with lower capital costs (which *might* overcome the capital constraint); and, lower barriers to entry which could entice local ownership and / or marginal land inclusion. It solves the feedstock interface impasse.

The rest of this dissertation examines whether or not a system with distributed intermediate facilities is feasible technically and economically, and whether it can compete in efficiency with an IBR system.

CHAPTER 4

TECHNO-FINANCIAL ANALYSIS OF REGIONAL BIOMASS PROCESSING CENTERS[78]

[78] Chapter in its current form was previously published in the *Journal for Agricultural and Food Industrial Organization*, December 2007

Bio-fuels for transportation have recently become topics of intense policy debate and action, due to a combination of (1) rapidly increasing global demand for fossil fuels and dwindling reserves, (2) sharply rising energy prices, (3) dependence on imports of crude oil from nations hostile to the U.S. or with unstable political environment, (4) concerns over global warming impacts of fossil fuels (5) high farm program costs and (6) efforts to promote sustainable rural development. Recent policy actions to promote bio-fuels include establishment of a “Renewable Fuels Standard” (RFS) of 7.5 billion gallons of renewable transportation fuels for 2012, under the Energy Policy Act of 2005. President Bush in his State of the Union Address on January 23, 2007, called for an enhanced alternative fuel use target of 35 billion gallons by 2017.

While ethanol from corn is expected to account for most of the US bio-fuels production in the short run, ethanol from ligno-cellulosic biomass is considered to be more promising from a sustainability perspective because of much larger quantities potentially available, significantly lower life cycle greenhouse gas emissions compared to grain ethanol (Sheehan et al., 2004; MacLean and Lave, 2003; Wu et al., 2006), widespread domestic feedstock availability, the potential to ameliorate the perceived conflict over food vs. fuel use of grains, and improve rural incomes by better utilization of marginal lands. Significant research and development effort has gone into technologies for conversion of ligno-cellulosic biomass into liquid transportation fuels, especially ethanol. More recent policy interventions are aimed at commercial production of cellulosic ethanol. For example, in February 2007, DOE announced that it will invest up to $385 million for six biorefinery projects over the next four years to help bring cellulosic ethanol to market (USDOE, 2007). The total investment in these facilities including industry cost share is more than $1.2 billion. Other investments in cellulosic bio-fuels bring the total to well over $4 billion.

A critical component of successful commercialization of cellulosic ethanol industry is a secure and reliable feedstock supply system. Ample feedstock should be available to biorefineries at the appropriate time and at competitive prices, while assuring reasonable, steady profits to the biomass suppliers. Developing a consistent, economically viable feedstock supply system requires addressing and optimizing diverse harvesting, storage, preprocessing, and transportation scenarios (USDOE, 2003). Research indicates that in order to achieve conversion process economies, large biorefineries capable of handling 5,000-10,000 tons of biomass per day are necessary. However, such large biorefineries also entail increased costs of biomass transportation and storage, high transaction costs of contracting with a large number of farmers for biomass supply, and monopsony market power vested with refineries. Furthermore, unless biomass suppliers participate in adding value to their products, they are unlikely to benefit much from greatly increased cellulosic bio-fuels production.

We propose a network of regional biomass preprocessing centers (RBPC) that form an extended biomass supply chain feeding into a biorefinery, as a way to address these issues. The RBPC, in its mature form, is conceptualized as a flexible processing facility capable of pre-treating and converting biomass into appropriate feedstocks for a variety of final products such as fuels, chemicals, electricity, animal feeds. We evaluate the technical and financial feasibility of a simple RBPC that uses ammonia fiber expansion (AFEX™) pretreatment process and produces animal feed along with biorefinery feedstock.

We find that the RBPC supply chain concept appears technically and financially feasible and RBPCs can operate financially successfully with gross margins (i.e. difference in prices of input feedstock and output pretreated biomass) of as low as $3.32/ton in the best case. RBPCs have several advantages over the traditional centralized, integrated biorefinery model from the point of view of both biomass producers and biorefineries. Because of lower feedstock and by-product transportation costs and cross-subsidization from other value added products, the proposed system is likely to result in lower minimum ethanol selling prices.

The rest of the paper is organized as follows. In the next section we provide a brief overview of ligno-cellulosic ethanol conversion process. In section 2 we summarize the research findings on economies of scale in biomass refining that conclude that optimal biomass refineries are likely to be large facilities. In section 3, we summarize the supply chain and organization issues arising from such large size biorefineries, followed by a discussion in section 4 on the proposed regional biomass preprocessing system. The advantages of distributed preprocessing over central preprocessing are discussed in section 5. Section 6 describes the technical set-up of a RBPC, which is followed by financial feasibility analysis. The last section presents the limitations of current analyses and discusses the implications of our findings.

4.1 Ligno-cellulosic biomass ethanol conversion process

Common ligno-cellulosic biomass feedstocks include dedicated energy crops such as switchgrass, miscanthus, and hybrid poplars, agricultural residues such as corn stover, forest and forest product residues, and cellulosic fractions of municipal solid waste. All biomass consists of three major components: cellulose, a polymer of glucose; hemicellulose, a polymer of five and six carbon sugars, mostly xylose; and lignin, a high molecular weight phenylpropane polymer. Each of these components contributes approximately one third by weight of plant biomass.

Two main pathways for converting biomass into fuels involve thermochemical and biochemical processes. Thermo-chemical processes are considered most promising for the production of Fischer-Tropsch diesels and hydrogen, while biochemical processing has been viewed as the most promising for ethanol production. Production of ethanol through biochemical processing consists of five main steps as shown in Figure 9: (a) feedstock collection and transport (b) pretreatment of feedstock (c) hydrolysis, aimed at depolymerizing cellulose and hemicellulose into their component sugars (saccharification); (d) fermentation to convert sugars into ethanol and (e) ethanol recovery.

The main technical challenges in biochemical conversion of ligno-cellulosic feedstocks to ethanol are hydrolysis of recalcitrant cellulose, fermentation of pentose sugars from hemicellulose, and system integration to achieve competitive production costs. Enzymatic hydrolysis with cellulase enzymes is considered the most promising method for cellulose hydrolysis; however, the enzyme costs are still high. The main purpose of feedstock pretreatment is to improve accessibility of cellulose to enzymatic action and thereby reduce enzyme costs. A number of pretreatment alternatives are being considered which are discussed in more detail in section 5. Fermentation of hexose sugars using yeasts is a well established commercial process, but developing (through genetic modification) suitable micro-organisms for pentose sugar fermentation at a commercial scale has been a challenge. Genetically modified thermophilic bacteria and yeast are considered most promising because of their high conversion efficiency, relative high temperature and high solid concentration tolerance. Current processes hydrolyze about 63% of the cellulose into hexose sugars and convert 76% of pentose sugars into ethanol. The goal is to improve both efficiencies to above 95% (Lynd, 2004), thereby increasing the total yield of ethanol from biomass to about 110 gal/MT from the current 60 gal/MT.

Significant efforts are underway to improve the process economics and reduce capital costs by combining several of the process steps. In separate hydrolysis and fermentation (SHF), hydrolysis and fermentation of hexose and pentose sugars are carried out in separate vessels. Simultaneous saccharification and fermentation (SSF) systems can hydrolyze and ferment hexose sugars in the same vessel. Development of effective microorganisms will eventually permit simultaneous saccharification and co-fermentation (SSCF) of both hexose and pentose sugars. Finally, new processes are being designed to combine cellulase enzyme production, enzymatic hydrolysis and fermentation into a single unit operation called consolidated bio-processing (CBP). Review of literature and pilot plant testing suggest that SHF and SSF are relatively close to commercialization, that SSCF may become possible in the near term, while CBP is the furthest from commercialization. U.S. Department of Energy (USDOE) has recently funded six demonstration projects for commercial production of ethanol from cellulosic biomass (USDOE, 2007).

While the above process description focuses on a single product, namely ethanol, future biorefineries are likely to produce a range of co-products along with fuel ethanol, e.g. electricity, animal feed, fibers, organic chemicals such as succinic acid and bio-based polymers. Lynd et al. (2005), in their strategic analysis of biorefineries list the advantages of integrated multi-product biorefineries. First, integrated biorefineries enable maximizing the value generated from heterogeneous feedstock, making use of component fractions. Second, revenues from high-value co-products reduce the selling price of the primary product. Third, the economies of scale provided by a full-size biorefinery lowers the processing costs of low-volume, high-value co-products, because common process elements are involved in producing fermentable carbohydrates, regardless of whether one or more products are produced, and co-production can provide process integration benefits (e.g. meeting process energy requirements with electricity and steam co-generated from process residues). We, however, focus our analysis on fuel ethanol production.

The optimum size of a biorefinery involves tradeoffs between economies of scale with larger plants and increased costs of feedstock transportation. Generally in process industries, the capital cost for equipment increases as a function of throughput according to the power law equation, with an exponent of around 0.6. At the same time, larger plant sizes also mean larger transportation distances for collecting bulky biomass.

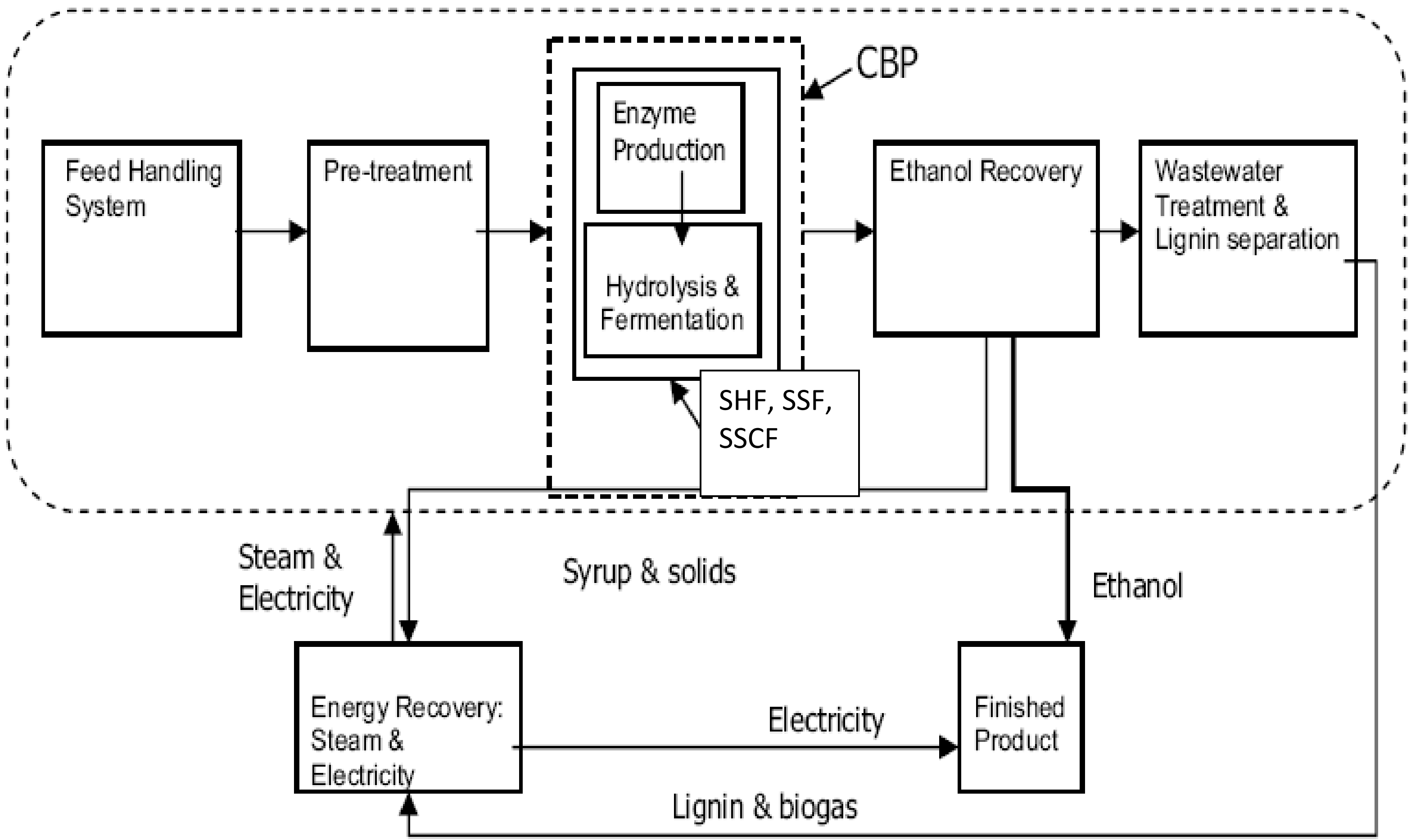

Figure 9: Process Model for Biochemical Conversion of Lignocellulose to Ethanol with Energy Recovery for Steam and Electricity Production (Spatari, 2007)

4.2 Economies of scale and optimal plant size in biorefineries

National Renewable Energy Laboratory (NREL) has carried out detailed process modeling of ligno-cellulosic biomass conversion facilities using co-current dilute acid pre-hydrolysis followed by enzymatic saccharification and co-fermentation (SSCF) (Aden et al., 2002). The process design also includes feedstock (corn stover) handling and storage, wastewater treatment, lignin combustion, storage, and all other required utilities. The NREL process model uses scaling exponent of around 0.7, based on vendor quotes, and estimates the cost or the minimum selling price of ethanol as a function of plant size. The estimated non feedstock costs, i.e. processing and capital costs are shown in Figure 10. As can be seen, the non-feedstock costs for plant sizes below 2,000 TPD increase rapidly, indicating that the minimum economic plant size is likely to be around 2,000 TPD capacity. Increasing the plant size from 2,000 TPD to 10000 TPD reduces the non-feedstock costs by $0.19/gallon or by about 25%.

The collection distance is a function of the quantity of biomass that can be collected per acre, the fraction of farmland from which biomass can be collected and fraction of farmland dedicated to crops. The NREL study conservatively assumes a yield of 2 MT of corn stover per acre, 75% corn acreage, and 10% of acres are available for collection, and nominal feedstock cost of $30/ton to calculate the delivered feedstock costs of biomass at the plant for various plant sizes (Aden et al., 2002). These are also shown in Figure 10, along with total of feedstock and processing costs/gallon of ethanol. As can be seen the optimal plant size appears to be in the 6000-8000TPD range. Sensitivity analysis indicates that if 25% of corn acreage becomes available for corn-stover collection, the optimum plant size increases to 10000 TPD. Similarly any increase in per acre productivity or reduction in ton-mile transportation costs will also increase the optimal plant size.

Kaylen et al. (2000) develop a mathematical programming model to analyze the economic feasibility of producing ethanol from various ligno-cellulosic biomass materials, namely agricultural residues, energy crops, wood processing and logging residues in Missouri. They specifically analyze the tradeoffs between scale economies and transportation costs, and find that estimated NPV of the plant is maximized at a capacity of 4360 TPD, under the conservative assumption that only 10% of available biomass is used in the plant.

Any increase in LCB availability or reduction in unit transportation costs would further increase the optimal plant size. Tembo et al. (2003) in their investment appraisal of bio-ethanol industry assume a facility with a capacity of 100 million gallons per year or 3800 dry tons of biomass per day as being optimal.

Hamelinck et al. (2005), in their detailed techno-economic performance analyses of ligno-cellulosic ethanol plants in the short-middle and long term technology scenarios, assume plant sizes of 2000TPD, 5000TPD and 10000TPD for their short, middle and long term analyses respectively. These are based on their assessments of emerging technologies and required system integration. Lynd et al. (2005) in their strategic analyses of biorefineries, model biorefineries with capacities to handle 2200 dry tons per day, and 10000 dry tons per day as representative plants with near term technology and advanced technology, respectively.

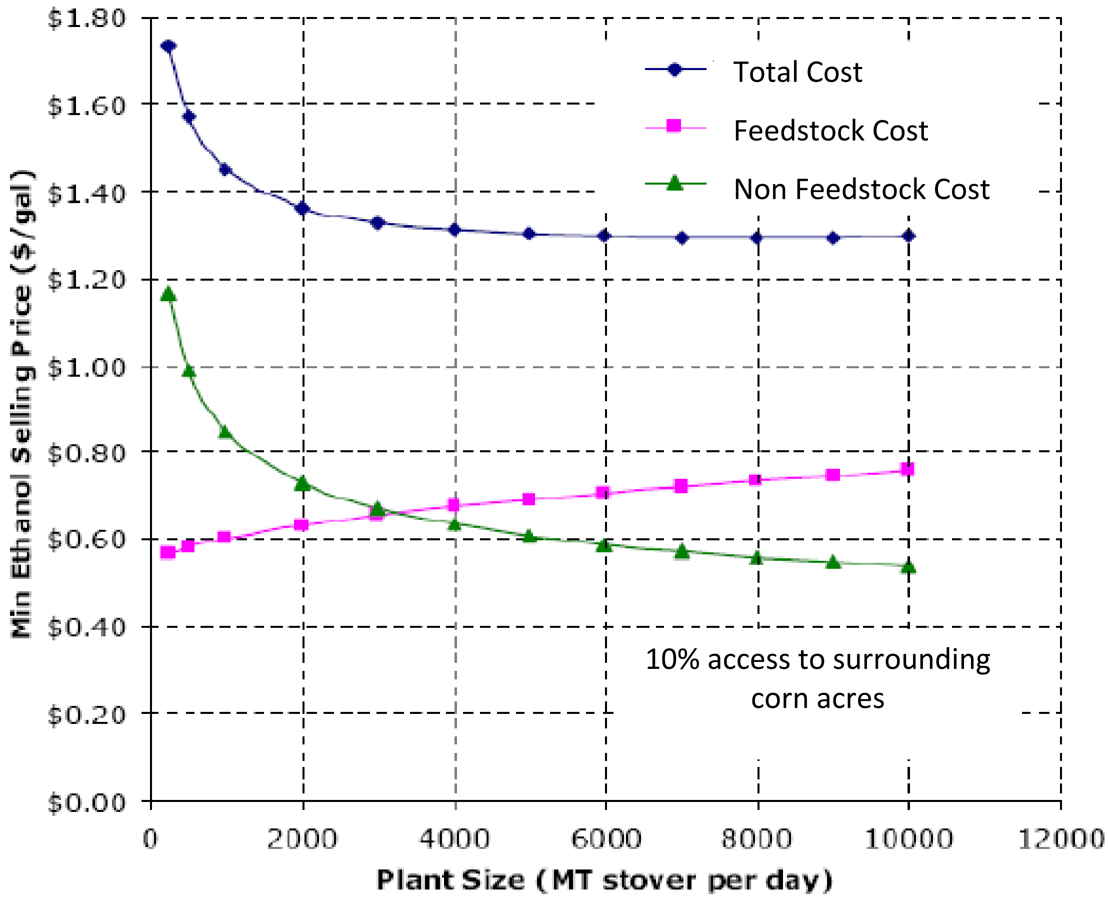

Figure 10: Ethanol Cost as a Function of Plant Size Assuming 10% Availability (Source: Aden et al., 2002)

These studies and discussions with industry experts suggest that future biorefineries are likely to be large facilities with capacities in the range of 5000-10000 TPD of biomass, if not larger. This scale is comparable in size to the largest U.S. corn wet mills. Archer Daniels Midland's Decatur, IL plant, for example, processes an estimated 15,500 dry tons of corn per day.

4.3 Supply chain and organizational issues

Such large biomass refineries face significant challenges in establishing appropriate supply chains. A biorefinery consuming 5000-10000 TPD of corn-stover per day would need to collect the annual output from 0.875-1.75 million acres of corn land assuming an availability of 2 tons of corn stover/acre. The collection area may not significantly lower in the case of dedicated energy crop based biorefineries because the higher expected annual biomass output of 5-7 tons/acre will be offset by the likely fragmented and spread out nature of energy crop acreage compared to corn acreage. Prior to investing in a biorefinery, arrangements have to be made to assure a reliable flow of feedstock. The logistics of feedstock production, harvest, storage, transport, and delivery will be challenging, due to the bulky nature of biomass, large geographical variations in biomass quality, especially if multiple feedstocks are procured, limited harvest windows requiring storage to ensure steady supply, conflicting demands on labor and machines at harvest, product degradation in storage, and combustibility. Compared to corn ethanol industry, which had well developed supply chains when corn-ethanol technology was being commercialized, cellulosic ethanol faces a much more difficult challenge.

Apart from the above mentioned technical and logistical problems, establishing biomass supply chains also requires attention to several organizational questions. Given the earlier discussion on scale economies in biorefineries, it is likely that the biorefinery industry will be characterized by regionally dominant, large capacity biorefineries collecting biomass from a large number of farmers in the surrounding area. Under this scenario, a single buyer will likely monopolize localized markets. From the producer's perspective, there will be a large number of essentially undifferentiated sellers, especially if the biorefineries develop the capability to quickly quantify carbohydrate content in biomass and base their payment accordingly. The product is bulky, seasonal and difficult to transport. Although the effects of long term storage on biomass quality are not fully understood, research indicates that mid-range storage (90 – 120 days) under reasonable conditions degrades product quality minimally. Entry and exit barriers are high for dedicated energy crop producers, as significant costs are involved in converting crop land from its existing use, as well as for reconverting if the market for cellulosic biomass doesn't develop. Therefore, the biorefiners might be able to exert anti-competitive market power. However, for farmers supplying residues such as corn stover, there are few upfront capital requirements if existing harvesting and collection equipment can be used and hence barriers to entry and exit are relatively low.

There are also factors that could lead to the alternative conclusion, that biorefineries may not be able to exercise undue market power. The barriers to entry and exit are huge, as the capital requirements for biorefineries are enormous, as are the costs of abandoning one. Once set up, the biorefinery needs to operate at high capacity utilization because of large fixed costs. Conversion of the facility as a whole to alternate uses is infeasible, although the components can be salvaged and employed elsewhere for a multi-plant firm. The threat of collective action by the sellers may keep the processor from being able to exert monopsony power as the producers can collectively threaten the financial viability of the biorefinery by storing or refusing to sell at all. In this case, the potential for asymmetric market power reverses, and lies in the hands of the suppliers.

This bilateral dependence between biomass suppliers and the biorefinery where trading parties are open to the potential of opportunism and ‘hold-up’ problem arises from asset specificity, i.e. investments in transaction specific assets. Both potential market power scenarios (i.e. market power residing with the biorefinery or with biomass producers) arise because there are appropriable quasi-rents on both sides of the exchange; quasi-rent being the difference in value between the high value specific use of an asset and its alternative lower value use. For dedicated energy crop producers, quasi-rent is the difference in value between the net feedstock price and the alternative use, which is essentially zero. For the by-product biomass producers, this would be the difference between selling the net feedstock price and doing nothing (the current situation). For the biorefinery quasi-rent is the value of operating as a cellulosic ethanol biorefinery and the salvage value (if any) of the facility. The existence of appropriable quasi-rents doesn’t necessarily mean that one party or the other will unscrupulously capture these during the course of the transactions. According to Williamson, only a highly ‘opportunistic’ and self-serving firm, that believes that it can get away with it without negative repercussions, either to reputation or to future profits will act in this manner (Williamson, 1975). However, because of the potential for opportunistic behavior, both parties will be reticent to participate in this market.

Energy crop production and investments in conversion facilities are hence likely to suffer from the classic “chicken and egg” problem; farmers are unlikely to grow biomass in large enough quantities unless there is an assured market and acceptable prices, and investors are unlikely to invest in conversion facilities until adequate feedstock supplies at reasonable prices are assured. Under the circumstances, the biomass supply transactions are likely to be based more on long term, very detailed, 'more complete' contracts than spot markets. Further, due to economies of scale, and widely distributed feedstock production, biorefineries need to contract with a fairly large number of farmers leading more transaction costs. Supply cooperatives may be attractive since they allow a single contract between the co-operative and the biorefinery instead of with each individual producer. Alternatively, harvesting, collection and transportation can be handled by independent consolidators, with whom biorefineries can contract.

The questions remain as how best to economically co-ordinate these activities and provide proper incentives for the agents to participate and which channel configuration would be best suited for, creating value, reducing transaction costs, exploiting scale economies, and balancing market power issues. These organizational issues in biomass supply chain strategy will be central to successful industry development.

4.4 Regional biomass processing centers

We propose a network of regional biomass processing centers (RBPC) to address many of these issues. The RBPC, in its mature form, is conceptualized as a flexible processing facility capable of pre-treating and converting various types of biomass into appropriate feedstocks for a variety of final products such as fuels, chemicals, electricity, animal feeds etc. as shown in Figure 11. It is envisioned that a number of such RBPC will form an extended biomass supply infrastructure feeding into large biomass ethanol refineries and other processing facilities.

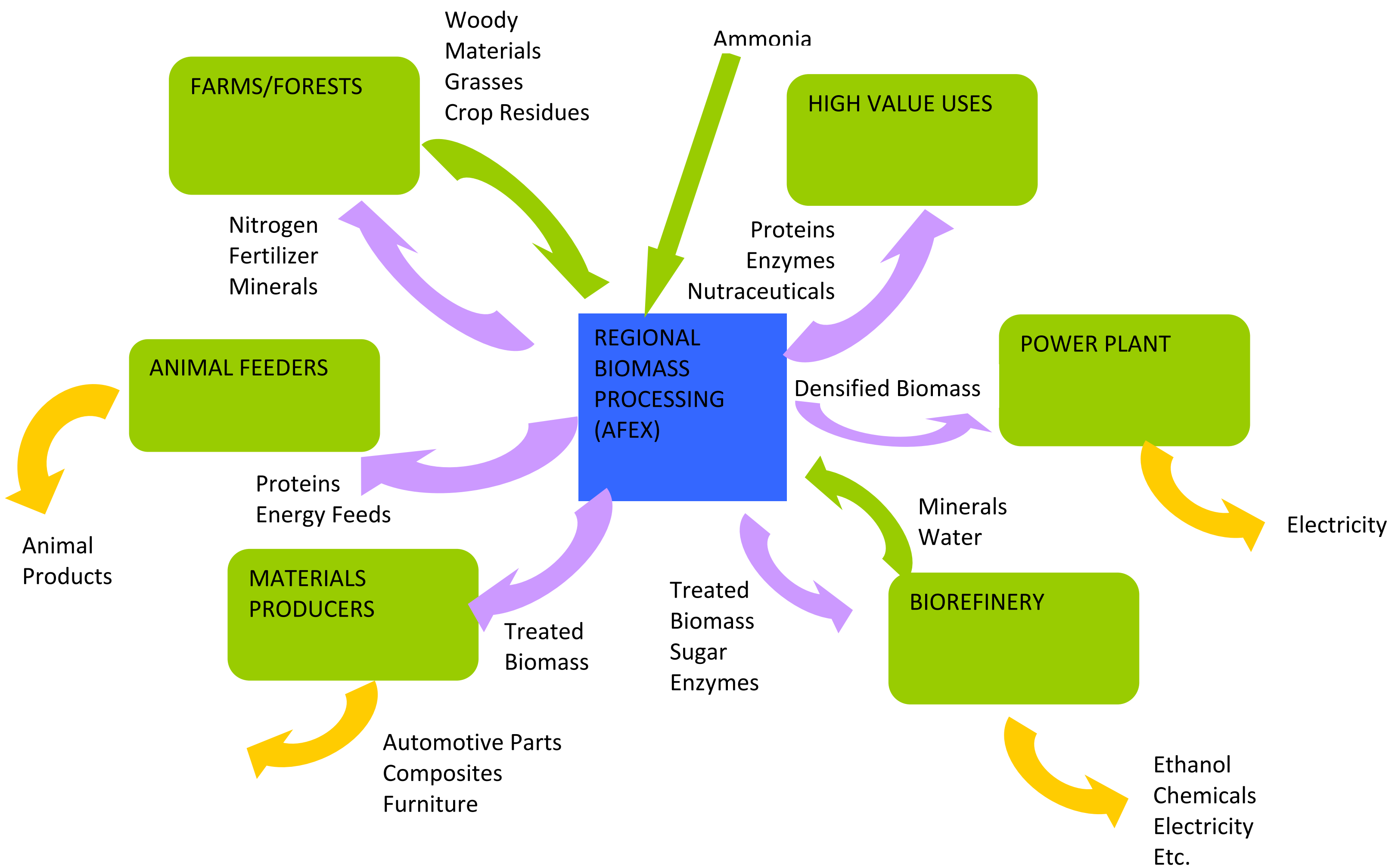

Figure 11: The Concept of Regional Biomass Processing Center (RBPC)

Biomass, when harvested, is characterized by its low density; varying quality in terms of moisture content, size, shape, density, and chemical makeup and contamination with dirt and other undesirable foreign materials. Preprocessing is designed to improve biomass handling, transport, storage-ability, and potentially add value by making biomass more fit for final conversion to fuels, power, and chemicals.

Preprocessing includes: cleaning, separating and sorting, chopping, grinding, mixing/blending, moisture control and potentially densifying. In most of existing literature, biorefineries have been typically designed to accept baled biomass and carry out all the preprocessing onsite at the biorefinery, followed by further processing stages of pretreatment, hydrolysis, fermentation, ethanol recovery. (e.g. Wooley et al., 1999; Aden et al., 2002; Hamelinck, et. al., 2005). We propose to strip both preprocessing and pretreatment steps out of the biorefinery and carry these out at RBPCs. A number of RBPCs will then supply pre-treated biomass to the biorefinery for further processing.

While some prior research has looked at potential small scale on-farm preprocessing of biomass, mainly physical state alteration by chopping and grinding to improve transportability, we propose more advanced preprocessing, which will involve both physical transformation and chemical pre-treatment, in relatively large, intermediate, geographically distributed facilities.

The proposed RBPC is designed to accept baled biomass in trucks, from producers in the surrounding geographic region. These bales are unloaded, unwrapped and biomass is then shredded to appropriate size for further pretreatment. The goal in pretreatment is to make cellulose and hemi-cellulose more accessible to the enzymes that convert the carbohydrate polymers into fermentable sugars. A number of pre-treatment process options are currently being explored (Wyman et al., 2005). Eggeman and Elander (2005) carry out comprehensive process and economic analysis of five biomass pretreatment technologies, namely dilute acid, hot water, ammonia fiber expansion (AFEX™), ammonia recycle percolation (ARP), and lime processes, embedded in a full bio-ethanol facility. They compare process parameters, capital costs, operating costs, minimum ethanol selling prices (MESP) for a bio-ethanol facility employing alternative pretreatment technologies. They find that the direct capital costs are similar for all the pretreatment technologies. Dilute acid process resulted in the lowest MESP closely followed by AFEX™. The other three processes resulted in much higher MESP. Recently, Newton-Sendich et al. (2007) have updated these estimates with recent developments in the AFEX™ process which result in lower ammonia application rates, lower ammonia concentrations in the ammonia recycle stream and less capital intensive ammonia recovery. When these improvements are combined with consolidated bio-processing, they estimate that MESP with advanced AFEX™ declines from $1.41/gal reported by Eggeman and Elander (2005), to as low as $0.81/gal.

We choose the AFEX™ pretreatment process for the RBPC model based on these results. AFEX™ is essentially pretreatment with hot (around 100º C) concentrated aqueous ammonia. The mixture is maintained under pressure for a few minutes. Rapid pressure release from the reaction vessel completes the pretreatment process. Under these conditions, ammonia reacts with lignin and causes depolymerization of lignin, cleavage of lignin-carbohydrate linkages, and hydrolyzes hemi-cellulose. Since lignin is one of the key factors affecting the enzymatic hydrolysis (Dunlap et al., 1976; Mooney et al., 1998; and Lee and Yu, 1995), removal of lignin lowers enzyme requirements. Liquid ammonia also causes cellulose swelling and a phase change in the crystal structure from cellulose I to cellulose III. Thus ammonia affects both micro-and macro-accessibility of cellulose to cellulase enzymes. The moderate temperatures and pH values in AFEX™ process minimize formation of sugar degradation products while giving high monomeric sugar yields. AFEX™ pretreatment gives close to theoretical glucose yields at relatively low enzyme loadings (<5 FPU per gram of biomass or 20 FPU/g cellulose) (Dale, 1986; Dale and Moreira, 1982; Holtzapple et al., 1991; Dale et al., 1996; Moniruzzaman et al., 1997; Foster et al., 2001). Increases in glucan conversion by about six fold and xylan conversion by almost 23 fold with AFEX™ pretreatment, compared no-pretreatment have been reported (Teymouri et al., 2005).

Apart from technical performance and economic competitiveness, the AFEX™ process has other advantages compared to other pre-treatment processes. First, unlike other pre-treatment processes which result in wet pretreated biomass, AFEX™ treated biomass remains relatively dry and inert, and hence it is more easily storable and transportable. In comparison, acid pretreated biomass needs neutralization. Moreover, chopping and grinding prior to AFEX™ treatment increases the bulk density of the biomass from 4-6 lb/ft^3 to 8-12lb/ft^3 which helps reduce transportation costs to the biorefinery. AFEX™ treated biomass can also be pelletized to further improve bulk density and handling properties, and initial trials at Michigan State University suggest that the density and other properties of pellets of AFEX™ treated biomass are better than pellets of untreated biomass (Marshall, 2007). Pelletized biomass flows like cereal grains and can use the existing well-developed handling infrastructure for grains. Hence AFEX™ pretreatment has advantages in supply chain logistics.

Second, AFEX™ treatment significantly improves the animal feed value of biomass, for the same reasons that make it a better feedstock for the biorefinery; i.e. the pretreatment improves the digestibility of biomass by ruminant animals both by breaking the lignin seal and disrupting the crystalline structure of cellulose. Table 2 compares the feed properties of AFEX™ treated corn-stover and switchgrass with other common feeds. As can be seen, AFEX™ treated corn stover[79] has a crude protein level of 10% of dry matter (similar to 15% moisture shelled corn), and a net energy (NEL) of 0.86 Mcal / lb (similar to whey or barley). AFEX™ treated switchgrass has a crude protein level of 12% of dry matter (similar to soyhulls), and a net energy (NEL) of 0.87 Mcal / lb (similar to barley and wheat gluten). Unlike the products from the other pretreatment processes, AFEX™ treated biomass can hence potentially be sold as a feed supplement for ruminant animals without any additional drying or processing. Further, controlled amounts of ammonia can be left in the AFEX™ pretreated biomass which can further add to its nutrient value.

Third, the option value of being able to sell AFEX™ pretreated biomass as an intermediate animal feed product increases the bargaining power of the pretreatment facility *vis a vis* the biorefinery, and can counteract the monopsony power of the

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[79] The data on AFEX treated corn-stover and switchgrass are from Dale (2007a), while data for other feeds are from the animal feed value worksheets from North Dakota State University (Schroeder, 1997).

biorefinery. However, this bargaining power can be exploited by biomass producers only if they have an ownership stake in the pre-treatment facility. As detailed later, the estimated capital costs of pre-treatment facilities are relatively small compared to fully integrated biorefineries, and hence the probability of producer owned (through co-operatives or partnerships) pretreatment facilities is higher.

Table 2: Nutrient Analysis of Animal Feeds

Animal Feed	**Crude Protein (% DM)**	**Net Energy (NEL)(Mcal/lb)**	**Dry Matter (%)**
Oat mill coproduct	3.9	0.34	92
Potatoes, raw	8.9	0.85	91
Corn, shelled -high-moisture	9.5	0.90	74.4
Beet pulp	9.7	0.81	91
AFEX™ treated corn stover	***10***	***0.86***	***85***
Corn, shelled (15.5%)	10	0.90	88
Sorghum or milo	10.4	0.84	89
Wheat	11.3	0.89	89
AFEX™ treated switchgrass	***12***	***0.87***	***85***
Soyhulls	12.1	0.80	90
Barley	12.8	0.87	89
Oats	13	0.80	89
Whey, dried	13	0.85	93

Fourth, the ability to convert biomass into animal feed at the RBPC instead of at the main biorefinery can also potentially reduce costs associated with transporting animal feed product back to the farms. However, these transport cost savings depend on the geographical distribution of animal feeding operations and biomass producers relative to the RBPCs and the biorefinery.

4.5 Other potential benefits from distributed biomass pretreatment

Apart from the above benefits specific to AFEX™ pretreatment in a RBPC, the concept of distributed preprocessing, regardless of the pre-treatment process chosen, has other potential advantages over centralized preprocessing at the biorefinery.

Distributed preprocessing can potentially reduce overall supply chain costs. Because chopping and grinding carried out prior to pretreatment nearly doubles the bulk density of biomass, a two stage collection system where the raw baled biomass from a smaller collection area is first transported to the RBPC, pretreated into more uniform and denser feedstock, and then transported to the central biorefinery may be less costly. However, actual cost savings are a function of the additional costs of handling the feedstock twice, and spatial distribution of the biomass sources relative to the biorefinery and the transportation infrastructure. RBPCs can also be designed to serve as appropriately designed, intermediate storage facilities that can reduce spoilage and deterioration of biomass compared to open on-farm storage. Further, RBPC locations can be chosen to ensure all weather access, so that the biorefinery can draw uniformly from the inventory at the RBPCs even during winter months. Because of high fixed costs, high capacity utilization is critical for financial success of a biorefinery, and on-field storage can be problematic in areas with poor access during some seasons. Distributed preprocessing can also reduce local environmental impacts of biorefineries, e.g. traffic congestion and associated air quality effects, and odor from stored biomass. Distributed preprocessing facilities can also be designed to receive different local feedstocks and mix them appropriately to deliver uniform quality feedstock in terms of composition, size, density, moisture etc. to the biorefinery. In fact, research has shown that growing a mixture of grasses instead of a single variety of grass may increase the biomass energy yield per acre by as much as 238% (Tilman et al., 2006). In view of these advantages, Colusa Biomass Energy Corporation for its upcoming rice-straw to ethanol biorefinery in California, is setting up a two stage collection process with three satellite storage facilities (without any preprocessing), each with a collection radius of about 17 miles (Kotrba, 2007).

The feedstock handling and pretreatment technologies are characterized by near constant returns to scale unlike the subsequent ethanol production steps which are characterized by high returns to scale. Stripping out the constant returns to scale processing steps from the main refinery and organizing them as RBPC can hence further improve economies of scale in the main biorefinery. At the same time, employing the RBPC approach enables building even larger capacity biorefineries with the same capital investment, to better exploit these economies of scale. The overall MESP can hence potentially be lower.

RBPCs in their mature form are visualized as facilities that can accept different biomass such as agricultural and forest residues, and woody and herbaceous energy crops, carry out appropriate preprocessing and produce feedstocks for a number of other products such as electric power, chemicals, proteins, and fibers for composites and other applications. The additional feedstock and product mix flexibility can potentially reduce the cost of the biorefinery feedstock through cross-product subsidization.

Distributed preprocessing facilities acting as intermediaries can potentially reduce the transaction costs of contracting in establishing the supply chain for the biorefinery, as the biorefinery needs to contract with a limited number of RBPCs instead of a much large number of farmers. The effect on the total systemic contracting costs is uncertain. The smaller number of contracts per entity in this two stage contracting process may facilitate better monitoring and lower costs; however, may simultaneously increase the total number of contracts. The additional complexity of animal feed sales by the RBPC may also increase transaction costs.

If some of the RBPCs supplying to a biorefinery are owned by farmers or independent entrepreneurs, it will reduce the monopsony power of the biorefinery. The product-mix flexibility of mature RBPCs can also improve the relative bargaining power of farmers, making them more willing to invest in dedicated energy crop production. At the same time, competition among a number of such independently owned RBPCs can also help alleviate biorefinery's concerns over collective market power of the farmers.

Since the RBPCs have the ability to treat biomass and sell as animal feed independent of the presence of biorefinery, it may be possible to gradually build the supply chain for the biorefinery where the RBPCs expand over time from animal feed production to biorefinery feedstock production to potentially other high value feedstock production. RBPCs can hence help ameliorate the 'chicken and egg' problem between biorefiners and biomass producers and encourage investments in biomass production and conversion.

4.6 Regional biomass preprocessing facility set up

While mature RBPCs are projected expected to be capable of producing feedstocks for a number of products, for our current initial feasibility analysis, we consider a simple RBPC that produces AFEX™ treated biomass that can either be used as an animal feed or as a feedstock for a biorefinery.

Figure 12 shows the set up of the RBPC as conceptualized. The facility consists of two main processing areas: feedstock handling, and AFEX™ treatment. The feedstock handling component is similar to the setup proposed by NREL in its assessment of future fully integrated biorefineries (Lynd et al., 2005). The facility is designed to accept baled biomass in trucks, which are unloaded, unwrapped and then shredded to appropriate size for further pretreatment. The facility includes forklifts, storage slabs, conveyors and shredders as shown. The facility is also designed as intermediate feedstock storage facility and capital costs include adequate onsite, open storage capacity.

The design of the AFEX™ processing area is based on the model proposed by Newton-Sendich et al. (2007), where AFEX™ treatment is followed by ammonia recovery using distillation with quench condensation (Figure 13). The cost of ammonia and especially, the extent of ammonia recovery are major drivers of AFEX™ pretreatment costs (Holtzapple et al., 1992). In the proposed process setup 97% of the ammonia is recovered and reused.

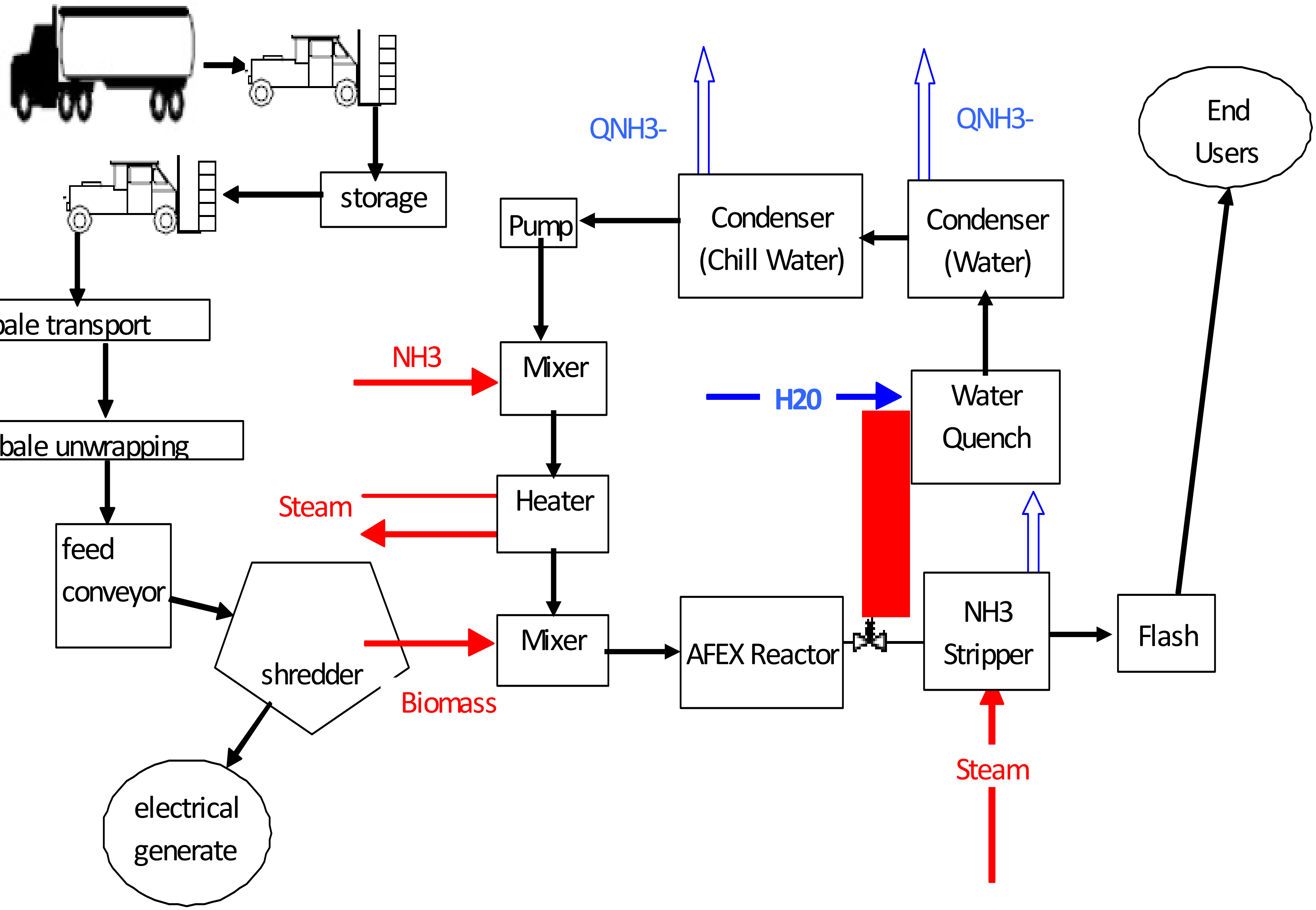

Figure 12: Setup of Regional Biomass Preprocessing Facility

The major equipments at this stage include a first generation AFEX™ system using an extruder to carry out the reaction, NH3 stripping column, and condensers. Recent developments indicate that expensive extruders can be substituted with simpler, less expensive reactors (Dale, 2007b). In our initial analysis we conservatively assume an extrusions AFEX™ reactor but also analyze the implications of the improved, lower cost AFEX™ reactor technology.

We consider a biorefinery with a capacity of 10000 TPD which receives pre-treated biomass from a number of RBPCs. We model five different RBPCs with processing capacities of 4444, 2666, 1333, 888 and 666 TPD, which correspond to distributed supply chains where 3, 5, 10, 15 or 20 RBPCs, respectively, supply pretreated biomass to this biorefinery. In determining these RBPC capacities, we assume that 25% of the pre-treated biomass from these RBPCs will be sold as animal feed. We derive the sizes/capacities of various equipment, operating parameters, and process input requirements (i.e. heat, electricity, ammonia, water, etc) using engineering estimates and an ASPEN simulation model of an integrated biorefinery initially developed by NREL and subsequently used by several researchers. (Aden et al., 2002; Eggeman and Elander, 2005; Newton-Sendich et al., 2007), by essentially separating out the feedstock handling and pre-treatment operations from the biorefinery and making appropriate changes to material balances, and energy flows.

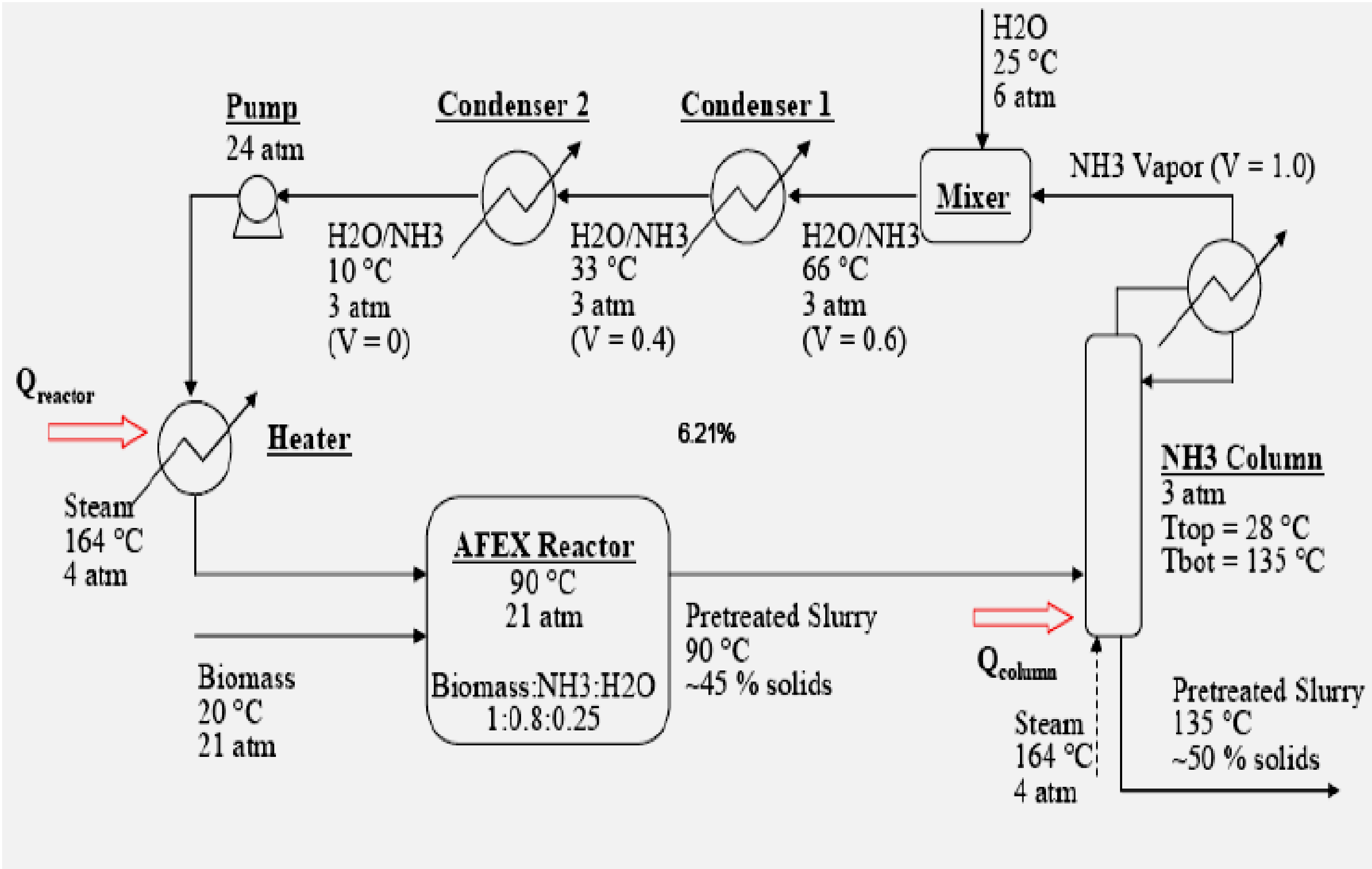

Figure 13: AFEX Pretreatment and Ammonia Recovery

The estimated capital costs of different capacity RBPCs are shown in Table 3. The capital costs range from $9.07 million for a RBPC with 666 TPD capacity to $36.80 million for 4,444 TPD capacity. Pretreatment facilities for AFEX™ and ammonia recovery account for roughly 50% of the capital costs. Feedstock storage facilities account for $0.34-2.28 million. The table also shows that RBPCs exhibit increasing returns to scale.

Table 3: Capital Costs of RBPC of Various Capacities ($ 1000)

Processing Area	**Facility Size TPD**				
	4,444	**2,666**	**1,333**	**888**	**666**
Feedstock Handling	8,436	5,854	3,613	2,740	2,258
Pretreatment	19,210	13,029	7,704	5,666	4,560
Other	9,151	6,250	3,746	2,782	2,257
Total	36,796	25,133	15,063	11,189	9,074
Total cost $ / ton capacity	8.28	9.43	11.30	12.60	13.63

4.7 Financial analysis

We build detailed annual cash flow models for RBPCs of these capacities. The cash flow model includes revenues, capital costs, operating costs and taxes. We estimate the capital costs, operating parameters such as capacity factor, downtime, backup requirements, etc., and process input costs using the ASPEN simulation model. The procedures used for estimating the prices of the primary input parameters (feedstock, steam, ammonia and electricity), and the output products are discussed below. We use standard engineering/business heuristics for estimating other variable costs, SG&A (Selling, General and Administration) expenses, and annual cost escalation factors.

The key assumptions used in the analysis are summarized in Table 4. We assume no external financing, and use after tax return on investment (ROI) as the primary performance measure. Income tax rate of 39% is assumed. We assume a project life of twelve years, where initial capital expenditure occurs in the first two years (1/3 first year) and the plant operates for 10 years. All capital is straight line depreciated over the ten year period. We assume that a minimum of 12% ROI is required, and use 12% as a discount factor for net present value calculations.

Table 4: Summary of Key Assumptions

Assumptions common to all scenarios (all prices in $2007)	
Feedstock	Switchgrass @ 20% moisture
Capital Expenditure - 2 yrs prior to startup	1/3 of total
Capital Expenditure - 1 yr prior to startup	2/3 of total
Depreciation	10 year straightline
Ammonia Loading	0.3 Kg NH3 / kg dry biomass
Ammonia Recycle Rate	97%
Income tax rate	39.0%
Feedstock	$30 per dry ton
Ammonia	$530 per ton
Steam	$9.596 per 1,000 lbs
Electricity	$0.062 per kWh
Number of Bio-refineries	1.0
Bio-refinery Capacity	10,000 dry tons per day
Assumptions that vary across scenarios	
Distributed pre-treatment facilities	
Number of facilities	3,5,10,15 or 20
Capacity of facilities	varies according to number
Capacity factor (online %)	
Fully utilized capacity	95.0%
Operates 6 months a year	50.0%
Animal feed scenarios	
$98.47 per ton and animal feed is 25% of sales volume	
$73.05 per ton and animal feed is 25% of sales volume	
No animal feed sales	

Input parameters

The key variable of interest is the minimum price that a biorefinery would need to pay for the AFEX™ treated biomass, to the RBPC in order for the RBPF to achieve a 12% ROI (or equivalently, zero NPV with a discount rate of 12%). We solve the model to calculate this minimum price under different scenarios and compare them.

<u>Biomass input:</u> Although the RBPF is conceptualized as being capable of handling a range of biomass, we limit the current analysis to corn stover and switchgrass as feedstocks because corn stover and switchgrass appear to be the sources of biomass that show the greatest potential for early implementation. Although these two feedstocks have slightly different composition, technical configurations and economic simulation results are very similar. Therefore, we present the results for switchgrass only. We assume a delivered feedstock cost of $30/ton in line with the Department of Energy targets for feedstock price (USDOE, 2005). While this price might appear unrealistically low, based on current estimates of delivered costs of biomass feedstocks, improvements in yields and technologies for harvesting and transportation are expected to bring down costs. This price level may also be attainable in areas with low land rents or CRP lands where supply costs are mainly driven by harvesting and collection costs (i.e. forage crops as opposed to dedicated energy crops). In any case, the financial feasibility of the RBPC is driven mostly by its margin over feedstock costs.

<u>Steam:</u> Steam used for process heat is the second largest operating cost factor in a RBPC. We assume that the RBPC has access to an external source of steam and do not include steam generation in our facility model. We assume a base year delivered price

of steam at $9.596 per 1,000 lbs, based on actual delivered prices of a steam supplier (WE Energies, 2007). These steam prices are projected to escalate at the rate of 1.5% annually in the financial analyses. However, considering the potential for remote locations for some of these pretreatment centers, it may be necessary to assess the option of including a steam co-generation as part of the technical configuration of each facility. Adding steam generation will increase the initial capital investment, but not likely to affect the overall financial results notably, because the steam cost we consider is full delivered average cost covering variable and capital costs.

Ammonia: As noted before, ammonia is the chemical agent that breaks down lignin-carbohydrate linkages, hydrolyzes hemicellulose and depolymerizes lignin. These effects enhance micro- and macro- accessibility of the cellulose and reduce enzyme requirements. In this configuration a RBPC, 97% of the ammonia is recovered and recycled within the system. Therefore, only 3% of the total volume of ammonia required for this system needs to be injected regularly. Ammonia that remains in the final product, serves as a nitrogen source downstream for fermentation or as a value added component when it is utilized as ruminant animal feed. We use ammonia price of $530/ton based on the mean real price of anhydrous ammonia derived from the data series "Farm Prices for Anhydrous Ammonia" covering the period 1970-2006 from USDA - ERS, adjusted by the Agricultural Producer Price Index for Industrial Chemicals from the Bureau of Labor and Statistics. We assume price escalation of 2.42% per annum based on the projected PPI for industrial chemicals.

Electricity: Electricity accounts for roughly 2% of the operating costs of RBPCs. The assumed first year price of electricity of $0.062 per kWh, is average of the 2006 & 2007 retail price to industrial consumers in Michigan (USDOEEIA, 2007).

Output parameters

The only two markets included in this initial analysis are the livestock feed and pretreated biorefinery feedstock. There are other potential markets, including ground biomass as fuel for electricity generation, and high value products with additional processing, but these are not modeled. We estimate the price of AFEX™ treated biomass as an animal feed using feed evaluation charts published by North Dakota State University (Schroeder, 1997). Basically these charts convert the percentage of dry matter, net energy and crude protein of feeds into corn and soybean equivalent composition. We estimate the projected feed prices of AFEX™ treated biomass by applying these relative compositions and the price of corn and soybeans. Our estimated price for AFEX™ treated biomass as animal feed for the year 2007 is $98.47/ton. As mentioned before, the price of AFEX™ treated biomass as a biorefinery feedstock is then calculated by the financial model as the minimum selling price that enables the biorefinery to earn an ROI of 12%. To be conservative, we assume that these output prices remain constant over the planning period even though the costs are escalating.

4.8 Results

The results of the financial analysis are summarized in Tables 4-9. Table 5 shows the estimated RBPF processing costs/ton of biomass input, which range from $13.82-$21.09/ton. More details on the processing costs are shown in Table 6. Assuming yield of 90 gallons of ethanol per ton of biomass at the biorefinery, the first year feedstock handling and pretreatment cost at the RBPC account for \$0.15-\$0.23/gallon of ethanol produced. The processing costs/ton decrease by 52% when the capacity of the RBPC increases from 666TPD to 4444TPD (i.e. by 667%), which suggest increasing returns to scale. The lower processing costs with increased size are mainly on account of lower electricity and labor costs, in addition to lower capital costs.

Table 7 shows the minimum selling price of AFEX™ treated biomass that the RBPC can charge the biorefinery that allows the RBPC to earn a return on investment of 12%. We analyze three different scenarios; first where the RBPC sells 25% of the pretreated biomass as animal feed at the price of \$98.47/ton; second where the RBPC sells 25% of the pretreated biomass as animal feed at the price of \$73.05/ton; and third where the RBPC sells all the biomass received as feedstock to the biorefinery. The results are shown in columns 2-5 of Table 6. At these price levels, the sale of pretreated biomass as animal feed cross-subsidizes biorefinery feedstock sales and lowers its minimum price. For example, for the 4444 TPD capacity RBPC, the minimum selling price of treated biomass declines from \$52.24/ton when all pretreated biomass is sold as biorefinery feedstock, to \$36.84/ton (i.e. reduction of 30%) when 25% of treated feedstock is sold at \$98.47/ton animal feed as shown in Table 6. The extent of cross-subsidization in the best case is such that the net pre-treatment costs are only \$6.84/ton biomass or \$0.076/gal of ethanol. In other words, this cross-subsidization can reduce the MESP at the biorefinery by as much as \$0.17/gal. Even if the animal feed price declines to \$73.05/ton, the minimum biorefinery feedstock price is lower at

$45.31/ton compared to $52.24/ton in the case with no animal feed sales. However, as the size of RBPC reduces, the extent of cross-subsidization reduces because of increased processing costs/ton. The degree of cross subsidization clearly depends on the feedstock price relative to the animal feed value. Table 8 shows the sensitivity of the minimum selling price of pretreated biomass to changes in feedstock prices, and it is evident that cross subsidization declines when feedstock costs increase. Obviously any increase in the fraction of pretreated biomass sold as animal feed at these prices, will further increase the level of cross subsidization, and if feasible, the RBPC is better off with selling all of the pretreated biomass as animal feed. Our assumption however is that the local demand for animal feed is limited relative to the capacity of the RBPC, and in general, the quantity demanded as feedstock for ethanol/fuel production far exceeds the quantity demanded as animal feed. We choose 25% animal feed sales mainly as an indicative scenario.

Table 5: RBPC Processing Costs per ton Biomass Input (95% Online)

# RBPCs	Capacity TPD	Capital Cost per ton	Operating Cost per ton	Sales, General and Administration Cost per ton
3	4,444	$2.39	$10.83	$0.60
5	2,666	$2.72	$11.37	$0.81
10	1,333	$3.26	$12.55	$1.32
15	888	$3.63	$13.72	$1.80
20	666	$3.93	$14.88	$2.28

Table 6: RBPC Operating Costs ($/ton)

RBPC Capacity TPD **Operating Cost Item**	**4,444**	**2,666**	**1,333**	**888**	**666**
Electricity	$1.13	$1.42	$2.17	$2.91	$3.65
Ammonia	$6.08	$6.08	$6.08	$6.08	$6.08
Steam	$2.80	$2.80	$2.80	$2.80	$2.80
Water	$0.01	$0.01	$0.01	$0.01	$0.01
Maintenance & Repairs	$0.50	$0.57	$0.68	$0.76	$0.82
Labor	$0.20	$0.34	$0.68	$1.02	$1.36
Misc. Operating Expenses	$0.11	$0.11	$0.12	$0.14	$0.15
Total Operating Expenses:	$10.83	$11.34	$12.54	$13.72	$14.88

Table 7: Minimum Selling Price of AFEX™ Treated Biomass to Biorefinery ($/ton) (95% online)

Animal feed scenario RBPF capacity TPD	**25% @ $98.47/ton**	**25% @ $73.05/ton**	**No Feed Sales**
4,444	$36.84	$45.31	$52.24
2,666	$38.87	$47.34	$53.77
1,333	$42.90	$51.37	$56.79
888	$46.32	$54.79	$59.36
666	$49.45	$57.92	$61.71

Table 8: Sensitivity of Minimum Selling Price of AFEX™ Treated Biomass to Changes in Feedstock Price ($/ton) (95% Online)

Feedstock price	**$45/ton**		**$55/ton**		**$65/ton**	
% sold as animal feed (@98.47/ton)Í RBPF capacityĻ	**25%**	**0%**	**25%**	**0%**	**25%**	**0%**
4,444	60.21	69.77	75.79	81.64	91.37	93.15
2,666	62.24	71.30	77.82	82.98	93.41	94.67
1,333	66.27	74.32	81.85	86.00	97.43	97.69
888	69.69	76.88	85.27	88.57	100.86	100.26
666	72.82	79.23	88.40	90.92	103.99	102.61

Table 9 shows the sensitivity of the results to lower capacity utilization, i.e. if the RBPC were to operate at 50% on-line. As can be seen the minimum selling price of AFEX™ treated biomass increases by 11% to 30% depending upon the RBPC size and animal feed price. Because ammonia accounts for a considerable portion of the processing costs, the performance of the RBPC is sensitive to ammonia recovery rates. For example, reduction in ammonia recovery from the assumed 97% to 90% will increase the minimum selling price of pretreated biomass (with no animal feed sales) by 19.8% to 23.4% for RBPCs of capacity 666 TPD and 4444 TPD respectively.

Recent developments indicate that expensive extrusions reactor for AFEX™ can be substituted with simpler, less expensive reactors (Dale, 2007b). We analyze the case where this new technology is adopted. The estimated new capital costs of the RBPCs as well as per ton costs are shown in column 2 of Table 10. The results of financial analyses in terms of minimum selling price of pre-treated biomass are shown in columns 3-5. The minimum selling price reduces by $2.71 to $5.28/ton as a result of this improved technology.

Table 9: Minimum Selling Price of AFEX™ Treated Biomass to Biorefinery ($/ton) (50% Online)

Animal Feed Scenario RBPF Capacity TPD	25% @ $98.47/ton	25% @ $73.05/ton	No Feed Sales
4,444	$44.89	$53.36	$58.28
2,666	$48.11	$56.58	$60.70
1,333	$54.16	$62.63	$65.24
888	$59.06	$67.54	$68.92
666	$63.41	$71.89	$72.18

Table 10: Minimum Selling Price of AFEX™ Treated Biomass to Biorefinery No FIBEX Reactor ($/ton) (95% Online)

RBPF capacity TPD	Animal Feed Scenario Capital Cost $ 1000 ($/ton)	25% @ $98.47/ton	25% @ $73.05/ton	No Feed Sales
4,444	21,651 (1.41)	$33.22	$41.69	$49.53
2,666	15,070 (1.63)	$34.87	$43.34	$50.76
1,333	9,283 (2.01)	$38.30	$46.77	$53.34
888	7,012 (2.28)	$41.33	$49.81	$55.62
666	5,757 (2.49)	$44.17	$52.64	$57.74

In summary, the analyses indicate that RBPCs can be financially successful with gross margins (i.e. difference in prices of input feedstock and output pretreated biomass) as low as $3.32/ton in the best case. ross margins have to be as high as $31.71/ton in the worst scenario of smallest size RBPC coupled with no animal feed sales.

4.9 Discussion

The above analyses are subject to several caveats and limitations. First, the animal feed value of AFEX™ treated biomass is based on laboratory analyses of nutrient value. Animal feeding trials are being planned. The presented best-case results depend critically on the actual field performance and acceptability of AFEX™ treated biomass as animal feed. However, we also present the worst case where none of the AFEX™ treated biomass is sold as animal feed. Our analysis assumes that AFEX™ treated biomass can be stored without any loss in quality and is transportable in conventional vehicles. We do not consider the potential fire hazard associated with storing and transporting pre-treated biomass.

The optimized processing parameters (e.g. shredding energy, ammonia loading, AFEX™ treatment temperature and pressure) and feed/market value of AFEX™ treated biomass and hence its market value may differ across different biomass feedstocks. We treat these differences as minor and do not explicitly model them in our analyses.

The effects of stripping out the pre-treatment processes out of the biorefinery in terms of equipment re-configuration, material and energy flow changes, processing costs, capital costs and economies of scale need to be considered in analyzing the overall techno-economic feasibility of the proposed system. We propose qualitatively that these changes are likely to be favorable, because the biorefinery can be larger with the same capital investment and more efficient due higher economies of scale. However, we do not assess these effects quantitatively. The scope of the current analysis is limited only to the feasibility of the RBPC as a stand alone facility. Similarly, cost savings from the proposed RBPC system compared to a central biorefinery system, specifically savings in biomass transport costs and animal feed product transport costs depend on the geographical distribution of animal feeding operations and biomass producers relative to the RBPCs and the biorefinery. We only point out these potential savings without quantifying them. Location specific analyses are necessary to estimate these costs.

Subject to the above limitations, the RBPC supply chain concept appears technically and financially feasible. It has several potential advantages over the traditional centralized, integrated biorefinery model, both from the point of view of biomass producers as well as biorefineries. The proposed system is likely to result in lower minimum ethanol selling prices because of lower feedstock and by-product transportation costs, higher returns to scale, better capacity utilization and cross-subsidization from other value added products. It can also ameliorate potential market power and hold-up problems due to high investments in transaction specific assets by both parties. Lesser number of contracts between RBPCs and biorefineries can potentially reduce transaction costs for the biorefinery. While a number of ownership structures for the RBPCs are possible, namely vertical integration with biorefineries, ownership by independent operators, farmer supply co-operatives, and RBPCs as independent or farmer owned franchises, some form of farmer ownership will help counteract the market power of biorefineries. If the policy goal is to enable rural producers to get a higher share of the value addition from the emerging bio-fuel industry, promoting farmer owned feedstock supply co-operatives can help.

Future research should aim at location specific feasibility analyses of such distributed biomass preprocessing, more quantitative analyses of the value chain costs and cost savings, techno-economic analyses of more complex RBPCs which supply pre-processed feedstocks for a variety of industries, and rigorous comparative analysis of various contracting arrangements. Research is also needed to address the other limitations of the current study discussed above.

CHAPTER 5

BIOMASS TRANSPORT COSTS

Chapter 4 showed that an Ammonia Fiber Expansion ("AFEX™") Regional Biomass Processing Center ("RBPC") can be technically de-coupled from an integrated bio-refinery ("IBR"), and can operate as a stand alone facility. This chapter addresses the argument that transport costs are inherently higher in a distributed system. The argument is that distances traversed by the biomass must be longer due to 'back-tracking'. In addition, there are extra costs from double loading the biomass.

Distance traveled and transportation costs associated with moving one dry ton of biomass from farm gate to the biorefinery under each of the proposed value chains (IBR and RBPC) are compared. Biomass transport cost literature is reviewed, and a representative form for a transport cost model function consistent with this literature, but with additional variables, is introduced. These additional variables capture the effects of intra-chain biomass densification and non-linearity in transportation infrastructure.

The distances traveled under each value chain specification (a single IBR vs. seven RBPCs) are mathematically compared to determine if the distance under a RBPC must always be larger. The system with less distance traveled won't necessarily be the lower transport cost system. For the RBPC, there are still the additional costs associated with the loading the material a second time. Savings would have to be realized in this activity through densification of the raw biomass at the RBPC, which might mitigate depot costs through fewer loads handled.

Examining the transport costs per ton of biomass processed into ethanol between the two feasible options highlights the important cost drivers that can create transport equivalence. These factors include tortuosity of the region; the 'rural-ness' of the region; the ratio of fixed costs to variable cost in a firms transport costs; and, the amount of biomass densification at the RBPCs.

5.1 Biomass Transport Literature

As the study of moving biomass feedstocks from producer to processor has unfolded, the models used have evolved in complexity. However, virtually all of the models take the same basic form of:

$$TC\ (i,j) = DFC + DVC*Dist(i,j)$$

DFC, short for 'Distance Fixed Cost', is the fixed component per unit of transported biomass, which includes various combinations of the following components: loading, unloading, other terminal costs, transaction costs (i.e. exchange related expenses), equipment costs, depreciation, licenses, stacking, grinding, and equipment sizing (i.e. truck capacity). DVC, short for 'Distance Variable Cost', incorporates various combinations of labor, fuel, repairs, tire, maintenance, lubrication, trailer costs, and equipment cleaning. The term Dist (i,j) is the distance from point i to point j, measured sometimes in kilometers and other times in miles.

Cundiff and Harris (1995) looked only at loading costs ($47 / hour @ 1 hour / load) for a 13.2 metric tonne capacity truck, which generates a DFC per tonne of $3.58. The variable component (DVC) calculation was based on a fixed distance traveled a fixed number of times daily at a fixed truckload cost. This generates a DVC of $0.02 per dry tonne/ km, or a estimated form of the total transport cost function of TC(I,j) = 3.58 + 0.02*Dist(I\i,j).

Kumar and Sokhansanj (2006), using IBSAL (Integrated Biomass Supply Analysis and Logistics), a computer simulation based on EXTEND Simulation software, examined five on-farm collection techniques (square or round bales, on farm grinding, silage or loafing) and combined these with different transport options to calculate estimates of DFC and DVC for each of three combination scenarios. The resulting transport cost functions are:

$$TC(i,j) = 12.38 + 0.1111*Dist(i,j);$$

$$TC(i,j) = 9.84 + 0.1733*Dist(i,j);$$

$$TC(i,j) = 5.66 + 0.2580*Dist(i,j).$$

All DFCs are in dollars per tonne, DVC is in $/dry tonne/km and distance is in km. The first equation is the pertinent one for this analysis as it is based on the system under examination here (i.e. bales on the ground at 'curbside' of the farm picked up by a loader).

Kumar et al (2004) examined the relative costs of transporting biomass via truck, rail and pipeline. The potential advantages of piping biomass in a liquid state are that pipelines can gain economies of scale (as opposed to truck and rail which have more or less constant DFC components) and the fermentation process can possibly be initiated during transit. The resulting estimates for the total transport cost for each mode of transport are:

Via truck: $$TC(i,j) = 4.98 + 0.1114*Dist(i,j);$$

Via rail: $$TC(i,j) = 14.50 + 0.0209*Dist(i,j);$$

Via pipe: $TC(i,j) = 1.47 + 0.1023*Dist(i,j)$.

While the pipeline option seems most efficient, Kumar et al conclude that because of the volume of biomass required to fully utilize a pipeline (the assumption under which these functions are estimated) and gain the scale economies, pipelines are only be the most cost effective option at a minimum of 75 km (46.6 miles) and a minimum of 2 million dry tones per year of biomass.

Kumar et al (2005) analyze a multi-modal system in which trucks are utilized for short haul distances, and then transferred to rail car for longer distances. Terminal charges are calculated and built in, and the resulting multi-modal transport cost function is generated. The authors conclude that this system is efficient only in systems that require hauling over large distances, greater than 250 km.

Other studies have also estimated transport costs for differing regions and specific research projects, such as studies of Biomass Agricultural Products in Harlan, Iowa, which were used as the basis for the transportation models used by National Renewable Energy Laboratory (NREL) (Aden, et. al. 2002) in their process and economic analysis for cellulosic biomass to ethanol facilities. The resulting function was, again, linear with a DCF component and DVC component.

Graham, et.al. (2000) used a transport model embedded in the BIOCOST database model from USDA which is in the form

$$TC(i, j) = KF + KD*Dist(i, j) + KT*Time(i, j)$$

KF is fixed costs of loading and unloading only (regional labor costs), KD is the distance-dependent variable (i.e. DVC) and KT is a time-dependent cost. The last term is an addition to the model framework that the others had been utilizing. Time (i, j) is the driving time for a truck to move from location i to location j. Parameter KT measures time-dependent costs (dollars per hour per dry tonne) related to labor as well as truck and trailer time costs (depreciation, insurance, interest, and fees). Graham, et. al. (2000) do not report estimates of parameters. Zhan, et.al. (2005) use the same data sets and functional form and report parameter estimates of KD, KT, and KF of $3.48 per km per tonne, $0.06 per hour per tonne, and $4.38 per tonne respectively.

Washington State University, in cooperation with the Washington Department of Transportation as part of the Strategic Freight Transportation Analysis (SFTA) study, produced in December 2007 a comprehensive study of the existing models for bio-fuels transport costs, entitled "*Review of Transportation Costs for Alternative Fuels***"**. All of the above papers are included in this review.

The Idaho National Laboratory ('INL') has also done extensive work on determining various cost components associated with full scale utilization of lingo-cellulosic biomass ("LCB") as a critical bio-fuel input. Part of this analysis has been to estimate relative transportation costs of biomass via different transport modes, including trucks, rail and ships. The transport functions for each of these was in the form of TC (i,j) = DFC + DVC*Dist(i,j) . Table 11 presents values for INL's DFC and DVC.

Functions are for the values in Table 11 are graphed and presented in Figure 14. The minimum distances at which each mode of transport would be most efficient are marked. Note, for any distance between 5 miles and 175 miles, semi-trailer transport is the most cost-effective mode of transportation.

Table 11: DFC & DVC values for Wright, et al (2007)

	Fixed ($/ton)	Variable (cents/ton-mi)
SP Bale Transporter	1.48	62.4
Semi - bulk	1.98	10.5
Semi - bales	4.80	13.6
Rail	17.10	1.7

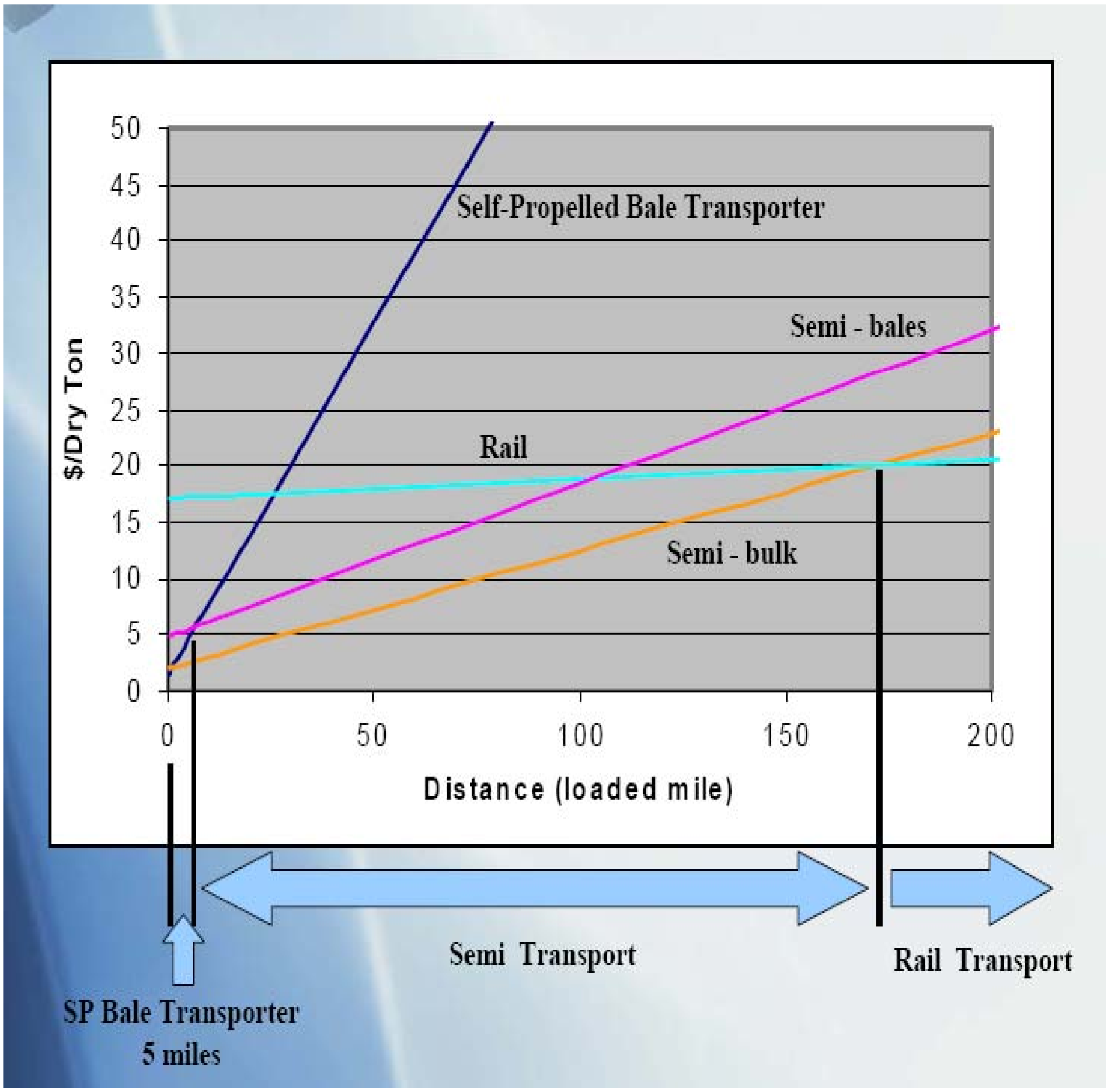

Figure 14 - Distance vs. Transport cost for various modes (Wright, et. al, 2007)

5.2 Model Specification

For each leg of the transportation route, a functional form was specified for the transport costs associated with that leg of the trip. These legs are farm gate to the integrated bio-refinery under the IBR system; farm-gate to RBPC under RBPC system; and RBPC to bio-refinery under the RBPC system.

Farm to IBR

$$In\_trans(f,j) = Q * \{DFC + DVC[R * \tau_H + (1 - R) * \tau_L] * AVG\_DIST(f,j)\}$$

Where:

f = each farm (1 to # farms in the region)

j = refinery j

Q = tons of dry biomass into refinery (i.e. size of refinery in tpd)

DFC = Distance Fixed Cost ($ / dry ton)

DVC = Distance Variable Cost ($ / dry ton / mile)

R = % rural roads

τ_H = High tortuosity (non-linearity of non-highway roads)

τ_L = Low tortuosity (i.e. high quality road like highway or state route)

AVG_DIST (f,j) = average distance from farms to refinery (in miles)

Farm to RBPC

$$In\_trans(f,i) = \sum_{i=1}^{N} q_i * [DFC + DVC * \tau_H * AVG\_DIST(f,i)]$$

Where:

f = each farm

i = $RBPC_i$

N = # RBPCs under consideration in the region

q_i = dry tons of biomass into $RBPC_i$

DFC = Distance Fixed Cost ($ / dry ton)

DVC = Distance Variable Cost ($ / dry ton / mile)

τ_H = High tortuosity (non-linearity of non-highway roads)

AVG_DIST(f,i) = average distance from farms to $RBPC_i$ (in miles)

RBPC to BR

$$In\_trans(i,j) = \sum_{i=1}^{N-1} q_i * \delta * [DFC + DVC * \tau_L * DIST(i,j)]$$

Where:

j = bio-refinery

i = $RBPC_i$

N = # RBPCs under consideration in the region (note: N-1 because one RBPC is located @ the refinery)

q_i = dry tons of biomass *into* $RBPC_i$

δ = density ratio (see below)

DFC = Distance Fixed Cost ($ / dry ton)

DVC = Distance Variable Cost ($ / dry ton / mile)

τ_L = Low tortuosity factor

DIST(i,j) = distance from each $RBPC_i$ to refinery (in miles)

Density Ratio: $\delta = \frac{Density\_of\_Raw\_Biomass}{Density\_of\_Treated\_Biomass}$

DFC (Distance Fixed Cost) is the cost per ton transported. In this specification, it includes loading, equipment costs (trucks, trailers, loaders, etc.), depreciation, licenses, insurance, and other fixed or sunk costs.

DVC (Distance Variable Cost) is variable cost per ton per mile. In this specification, it includes labor, fuel (MPG, price of diesel), repairs, tires, maintenance, lubrication, trailer costs, and equipment cleaning.

Featureless plain & Tortuosity factors

The analysis could be undertaken assuming that the region is a 'featureless plain' that is flat, devoid of obstacles with roads that are straight, unobstructed, paved and of equivalent quality. The featureless plain assumption may be relaxed, by assuming that travel is not "crows' flight" (i.e. not direct and linear), but rather is on winding, hilly and differing types of roads (which impacts time & distance due to quality and speed limits). In other words, roads can be "tortuous". For example, one tortuosity factor from Tiffany, et. al. (2006) is 2.11[80]. A factor of 2.11 means that for each 1 mile "crows' flight" distance it would actually be 2.11 miles when driven. There are limited benchmarks for tortuosity factors in the biomass transport literature, because often times it is calculated using GIS and mathematical algorithms to generate a regionally specific set of factors.

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[80] Tiffany, et. al. (2006)

From farm to RBPC, the roads are lower quality, more winding, hillier and more rural than in the more urban areas, thus the higher tortuosity factor (τ_H). In siting of the RBPC, it is likely that access to highways would be a factor not only for transporting the output, but also for receiving other inputs, such as machinery and ammonia. Therefore, the likelihood that a relatively straight shot from RBPC to BR exists provides a less tortuous route, thus the lower tortuosity factor (τ_L). The farm to IBR factor is a simply a weighted average of the other two (weighted by R).

5.3 *Mathematical Comparison of Transport Cost Functions*

The transport costs associated with moving one dry ton of biomass through to ethanol production under each of two alternative configurations are mathematically compared. This is equivalent with comparing the total transport cost per gallon of ethanol produced as each dry ton of biomass produces a fixed quantity of ethanol (approximately 90 gallons per dry ton of biomass). As noted earlier, the total weight of biomass (in dry tons) is not altered through the pre-treatment process, only the bulk density. Therefore, dry tons from farm into the IBR and dry tons of pre-treated biomass ("PTB") from the RBPC into the stripped down bio-refinery are equivalent measures and allow for consistent and valid comparison.

The transport costs associated with the two different value chain configuration can be compared as: RBPC_Total_Trans_Cost = IBR_Total_Trans_Cost + αQ; which simply states the two total transport costs may differ by some amount, αQ, where α is a markup per ton of biomass. Substituting

RBPC_Total_Trans_Cost = In_Trans (f,i) + In_Trans(i,j)

IBR_Total_Trans_Cost = In_Trans (f,j)

and reducing produces this relationship.

$$Q\alpha = [\delta * DFC * \sum_{i=1}^{N-1} q_i] +$$

$$DVC * \begin{bmatrix} \tau_H \sum_{i=1}^{N} q_i * AVG\_DIST(f,i) - \\ \sum_{i=1}^{N} q_i * \left(R\tau_H + (1-R)\tau_L\right) * AVG\_DIST(f,j) + \delta\tau_L \sum_{i=1}^{N-1} q_i * DIST(i,j) \end{bmatrix}$$

The first term on the right hand side is the second depot charge. The second term is simply the density weighted distance variable cost (DVC) times the difference in tortuosity weighted distance between the two systems. These are the algebraic statements of the two claims against a distributed system: that it will be more costly because of double handling; and, the biomass must travel greater distances. The condition for RBPC transport costs to be less than or equal to those under an IBR is $\alpha \leq 0$.

Under a set of relatively simple assumptions, all RBPCs would be identical. These assumptions are the supply of biomass is homogeneous and uniformly distributed across the region; and, each farm sells its biomass to the nearest facility. The two value chains process the same quantity of biomass and have equal catchment areas; therefore, all q_i's are equal to each other and to Q/N (or alternatively $\sum_{i=1}^{N} q_i = Q$). This is the expression for α.

$$\alpha = \frac{(N-1)}{N} * \delta * DFC + DVC * \begin{bmatrix} \tau_H (AVG\_DIST(f,i) - R * AVG\_DIST(f,j)) \\ + \tau_L \left(\left(\frac{N-1}{N} \right) * \delta * DIST(i,j) - (1-R) * AVG\_DIST(f,j) \right) \end{bmatrix}$$

This expression shows that since the second depot charge must always be positive, any transport cost savings from the RBPC system must come from

1) the right mix of locational and / or geographic conditions which cause farm to facility collection routes to be significantly more tortuous than the routes from the RBPCs to the refinery; and

2) Densification of the biomass during pre-treatment (which equates to less double loading and fewer truckloads from RBPC to refinery).

Average Distance Functions

Functions for each of the distance terms are specified. Biomass is homogenous and uniformly distributed across the supply region. The distance functions can be average distance functions. The two systems are one IBR with a circular catchment area versus a RBPC system of seven hexagonal supply areas (which would emerge under this set of assumptions).

The catchment areas under either value chain choice are equal. As noted, $\sum_{i=1}^{N} q_i$ = Q, where N is the number of RBPCs. Under uniform distribution equal biomass supply creates two equal areas. It is only a matter of how the area is tiled. The area of the hexagonal regions are determined by setting the total catchment area of all seven supply regions area equal to the area of the circular IBR region. All distance functions are thus functions of the IBR radius, r.

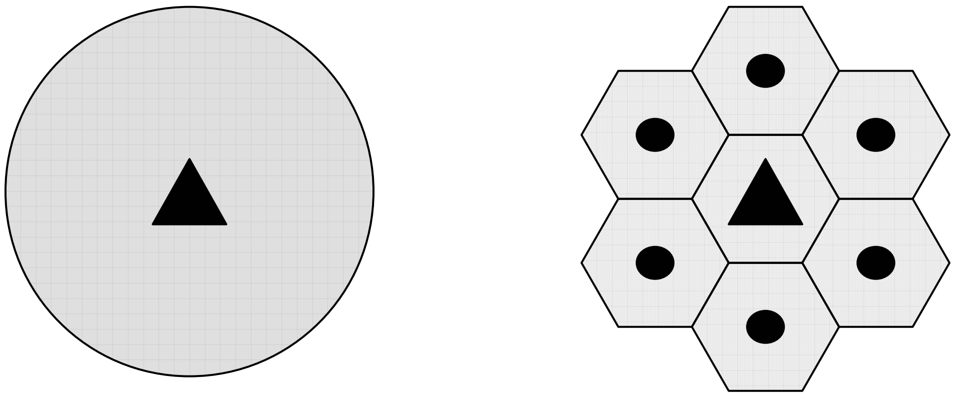

Figure 15: Catchment areas under IBR (left) and RBPC (right)

The distance terms are:

Distance from farm to IBR = average distance from all points in a circle to its center:

AVG_DIST (f,j) = (2/3)*r

Distance from farm to RBPC = average distance from all points in a hexagon to its center:

AVG_DIST (f,i) = .2527r (r is the radius of the circular catchment area)

Distance from RBPC to refinery = twice the distance from the center of a hexagon to the bisection of one its sides:

DIST(i,j) = 2h = 2*.3599r = .7198r (r is the radius of the circular catchment area)

Under these system configurations, without the density ratio (i.e. no densification gains; δ = 1.0) or the winding factors (all tortuosity = 1.0), the distance traveled per dry ton of biomass under the RBPC system would be roughly 30% greater.

Average miles traveled per ton under RBPC = (6/7)*(.2527r + .7198r) + (1/7)*(.2527r)→

0.8697r

vs. 0.6667r (under IBR system) → or 30.5% more miles per dry ton of biomass under RBPC

If all roads were straight and flat, then the RBPC system would have a structural cost dis-advantage. However, no region will have entirely flat and straight roads from every biomass producer to the initial processing facility. Tortuosity factors must be examined to determine if there are conditions which create total distance equivalence or shorter distances in a RBPC system. In the absence of density differences, the necessary condition for this is:

$$\tau_H * AVG\_DIST(f,i) + \left(\frac{6}{7}\right) * \tau_L * DIST(i,j) \leq \left[\tau_H * R + \tau_L * (1-R)\right] * AVG\_DIST(f,j)$$

The left hand side of the equation is the total distance traveled per dry ton of biomass under a seven RBPC value chain and right hand side is the total distance traveled under a single IBR system. This relationship reduces to a relative simple condition.

$$(\tau_H / \tau_L) \leq 1 - \left(\frac{.8033}{1 - 2.6382 * R}\right)$$

This relationship is very revealing. There is no possible combination of tortuosity factors that will equilibrate the two system distances whenever R (% of rural roads in the region) is less than 38%. Any time this factor is greater than 38%; there is a reasonable possibility of a RBPC system having the same, or less, total distance per ton of biomass transported as an IBR system. Table 12 shows the requisite tortuosity ratio (τ_H / τ_L) for the RBPC system to have a distance advantage with differing levels of percent of rural roads.

Table 12: Required Tortuosity vis-à-vis % Rural Roads

% of rural roads	required tortuosity ratio
≤ 38%	no solution
38% ≤ R ≥ 53%	3.0 or higher
53% ≤ R ≥ 68%	between 2.0 & 3.0
68% ≤ R	between 1.49 & 2.0

In a region that is roughly 40 – 50% rural roads; these must be very tortuous compared to non-rural roads, before the distances are equal. As the region becomes more rural, this ratio decreases and the rural roads need to be less tortuous as compared to the non-rural roads. In a region with a high percentage of rural roads (R > 68%), a relatively low tortuosity ratio will create distance equivalence. Figure 16 shows this graphically.

In regions which are sufficiently rural with limited linear highway infrastructure, a RBPC system could hold an advantage over an IBR system in terms of distance traveled per ton of dry biomass. The distance on tortuous roads is less under an RBPC configuration than under an IBR chain. This result holds in the absence of densification gains, which would translate to fewer total miles because of reduced trips carrying PTB.

Less distance traveled, however, does not necessarily translate to lower transport costs. There are additional costs associated with loading the material a second time. Savings will be realized in this activity through densification of the raw biomass at the RBPC. Densification will not eliminate the additional costs, but will mitigate them through fewer loads. The density ratio term captures this affect.

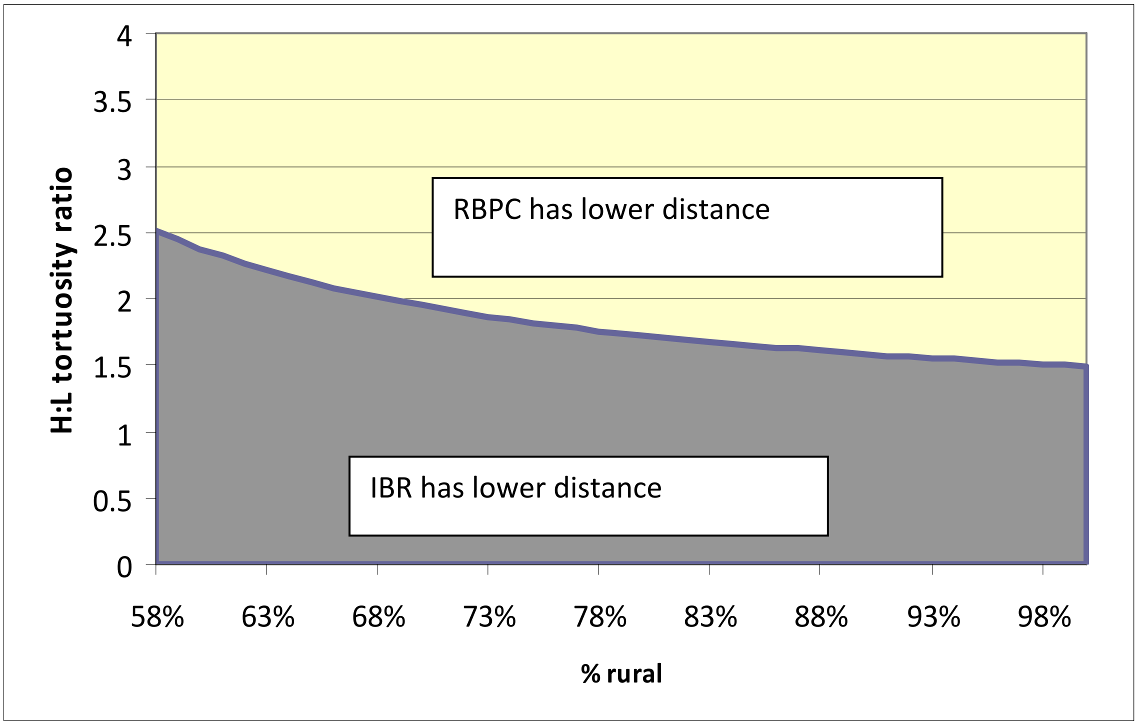

Figure 16: Required Tortuosity vis-à-vis % Rural Roads

With equal transport costs alpha = 0. This is the necessary condition for transport cost equivalence.

$$\delta*(6/7)*(DFC/DVC)=\left[\tau_H(2/3*R-0.2527)+\tau_L(2/3-2/3*R-(6/7)*0.7198*\delta)\right]*r$$

There are many reasonable combinations of DFC, DVC, tortuosity and rural road % that satisfy this condition. Any of these solution sets generate conditions of equal transport costs between the two systems.

5.4 Equivalence Scenarios using existing literature

The radius of collection is fixed at 50 miles. Different transport cost functional specifications are tested (Table 13).

Table 13: Bale based biomass transport models

Reference	DFC/dry tonne	DVC/ tonne/ km	DFC/dry ton	DVC/ ton/ km	DVC/ton/mile	Biomass & Format
Glassner (1998)	6.76	0.1167	6.87	0.1186	0.1908	corn stove bales
Perlack & Turhollow (2002)	5.91	0.0527	6.00	0.0535	0.0862	round bales
Perlack & Turhollow (2002)	5.84	0.0596	5.93	0.0606	0.0975	rectangle bales
Searcy, et. al (2007)	4.39	0.1200	4.46	0.1219	0.1962	stover / SG bales
Kumar & Sokhansaj (2006)	12.38	0.1111	12.58	0.1129	0.1817	stover / SG bales
Jenkins (2000)	4.43	0.1348	4.50	0.1370	0.2204	straw bales
Kumar (2003)	4.76	0.1309	4.84	0.1330	0.2140	straw bales
Marrison & Larson (1995)	3.31	0.1984	3.36	0.2016	0.3244	SG bales
INL (2007)			4.80		0.1360	bales

Table 14 presents solutions to the equal transport cost condition for each of these sets of fixed and variable cost specifications. The source of the specification and the DFC/DVC ratio that corresponds to the specification are listed. The first part of the table shows solutions when only the density ratio is variable. This is done under two different geographic specifications. One is the flat featureless plain with all distance being linear crow's flight distance. The other scenario has factor values that resemble a reasonably rural region, with a tortuosity ratio of 2.11 and rural road percent of 75%.

Table 14: Equal Transport Cost Solutions

	A	B	C	D	E	F	G	H	I
Source	Marrison & Larson (1995)	Jenkins (2000)	Kumar (2003)	Searcy, Flynn (2007)	INL (2007)	Glassner (1998)	P & T rectangle (2002)	Kumar, et. al. (2006)	P & T round (2002)
DFC/DVC ratio	10.36	20.42	22.62	22.73	35.29	36.00	60.86	69.23	69.66
PTB Density w/ fixed rural factors									
Featureless plain	15.35	18.69	19.41	19.45	23.62	24.00	32.00	35.00	35.00
Reasonably rural	9.23	11.24	11.67	11.70	14.20	14.34	19.30	20.96	21.05
Rural factors w/ 10.8 PTB									
$\tau_{High} : \tau_{Low}$	2.068	2.222	2.232	2.232	2.414	2.440	3.000	3.656	3.672
R (% rural) value	62%	75%	78%	78%	90%	90%	90%	90%	90%
Rural factors w/ 12.0 PTB									
$\tau_{High} : \tau_{Low}$	1.900	1.938	1.951	1.952	2.154	2.177	2.996	3.271	3.285
R (% rural) value	57%	75%	78%	78%	90%	90%	90%	90%	90%
Comment	No additional densification required Rural factors are reasonable				Require additional densification and / or high values on rural factors				

Solutions to the equal transport cost condition are presented when the density ratio is fixed, and rural factors are varied. One case utilizes a density ratio of 0.74, which corresponds to a biomass density at farm gate of 8.0 lbs. / cu. ft., and a bulk density of pre-treated biomass of 10.8 lbs. / cu. ft. PTB density of10.8 lbs/cu. ft. is the limit when employing truck transport due to tonnage restrictions on roads and hauling capacity of trucking equipment. The other case assumes a density ratio of 0.67, which corresponds to a biomass density at farm gate of 8.0 lbs. / cu. ft., and a bulk density for PTB of 12.0 lbs. / cu. ft. Density of 12.0 lbs. / cu. ft. is the density that occurs when LCB is AFEX™ pre-treated without any additional densification equipment or processing. A set of tortuosity ratio and percent of rural roads in the region which solves the equal cost condition is shown for each cost specification.

The solutions show that either distance gains under the RBPC (due to increasing rural-ness not a larger radius) or densification can overcome the cost differences that arise from double depot charges. Density ratios ranging from 15 to 35 on a flat, straight infrastructure can create transport cost equality between the two systems. Combinations of tortuosity ratios with relatively high percentage of tortuous roads (75% and greater) can also accomplish this. Specification A has a very low DFC/DVC ratio, and therefore comparatively low depot charges. It can satisfy the equal cost condition at very low levels of rural roads and tortuosity.

When densification gains are combined with reasonable non-linearity and percent of tortuous transport infrastructure, all of these functional specifications can create transport cost equality at 50 mile radius. Some (A – D) do not require any additional densification at the RBPCs. The rest (E – I) must increase bulk density at RBPCs beyond the levels already occurring in the pre-treatment process.

The DFC/DVC ratio measures the relative weight of total transport costs that are depot charges vis-à-vis distance charges. The higher it is, the greater the percentage that is generated by depot charges. This favors the IBR system because of the double depot charges incurred in the RBPC system. Therefore, lower DFC/DVC ratios favor the RBPC. These results bear this out.

The data is presented with the lowest DFC/DVC ratio in the first column and highest in the final column to left (i.e. A is lowest, I is highest). The required density ratio increases from left to right, along with the increasing DFC/DVC ratio. As the DFC/DVC ratio increases, a higher percentage of total transport costs are from loading and un-loading, and greater densification is required to overcome the increasing costs of the double depot charges. The increased densification offsets this through fewer trips and lowering the variable cost per mile on those trips.

The combination of rural factors follows this pattern of increasing as the DFC/DVC ratio increases as well. The more rural and tortuous the region, the longer the distances covered from farm-gate to facilities. This counters the higher depot charges inherent in the cost structure by increasing the total distance traveled, thus lowering the percentage of total transport cost that is fixed and increasing the variable component.

Increased distance and additional densification complement each other. The longer the distances traveled, the less the necessary densification required. Each of these effects increases the percent of total transport costs that are variable, lowering the impact of the second depot charge on total transport costs. Densification further lowers the magnitude of the second depot charge as less second-leg trips are required. When these factors move upward together, the required magnitude of any single factor is less than when only one factor is varied.

These results are independent of biomass productivity (tons / acre / year). The only biomass assumptions here are that the available biomass is uniformly distributed across the region and is fungible.

These solution sets create transport cost equivalence in a catchment area of 7,854 square miles (50 mile IBR circular radius). With the density ratio, tortuosity ratio and rural road % in a solution set, any larger catchment areas would result in transport costs under RBPC being less than the IBR. In other words, beyond 50 miles, with these conditions, the transport cost per ton of biomass from farm-gate to bio-refinery would be less under RBPC than under IBR.

5.5 A More General Case

In a given region, with a given biomass profile, and existing transportation infra-structure, stakeholders must determine which value chain configuration would perform better in terms of price and volume. The farm gate biomass price would be the equal under either system, as would the volume of ethanol produced. If the transportation costs are lower under a RBPC system, then potentially these cost savings could offset any additional capital and loss of scale economies.

It is reasonable to assume that a firm evaluating alternative value chains will have a given transport cost structure and baseline technological configuration for its pre-treatment pathway. The density and DFC / DVC ratios will be fixed. In the equivalence condition,

$$\delta * (6/7) * (DFC/DVC) = \left[\tau_H \left(2/3 * R - 0.2527\right) + \tau_L \left(2/3 - 2/3 * R - (6/7) * 0.7198 * \delta\right)\right] * r$$

, the left hand side is a weighted "technology constant", which is simply the baseline density ratio (known & fixed) multiplied by the DFC/DVC ratio (known and fixed). It is weighted by (N-1)/N, where N is the number of RBPCs. In this case N = 7, with hexagonal supply regions.

Fixing the low tortuosity factor at 1.0 makes the high tortuosity factor just a relative measure, i.e. 'how much more tortuous are the rural roads than the non-rural roads'. The relationship simplifies to:

$$F(R, \tau_{High}) = (9/7)*Tech\_const*(1/r) + 0.9255\ \delta$$

The left hand side is a measure of the 'rural-ness' of the region:

$$F(R, \tau_{High}) = \tau_{High} *(R - 0.3790) - (R-1)$$

It is now possible to determine the 'cutoff radius' beyond which an RBPC system is more transport cost effective than an IBR system, and below which the IBR system is more transport cost effective under a given set of technological factors (density ratio, transport factors). Figure 17 shows the 'cutoff radius' for various rural-ness values when pre-treated biomass has density of 10.8 and 12.0 lbs. / cu. ft.[81]

As the rural-ness of an area increases, an RBPC system is more transportation cost effective than an IBR system at smaller and smaller catchment areas. At any rural-ness factor value, greater densification at the pre-treatment center drives the cutoff radius inward (i.e. creates a transport cost equivalency at smaller catchment area). These rural-ness factors describe regions that are fairly rural. In order to achieve a 1.0 factor, a region must 72% rural

[81] DFC/DVC ratio used is the simple average of the literature specifications; it is a generic case with un-specified region and homogenous biomass.

roads with tortuosity factor of 2.10. At 1.0 rural-ness, the cutoff radius for a system based on density of 12.0 lbs/cu. ft. for pre-treated biomass would be only 70 miles. It may be that further densification could create additional transportation savings and drive the requisite rural-ness and cutoff radius down further.

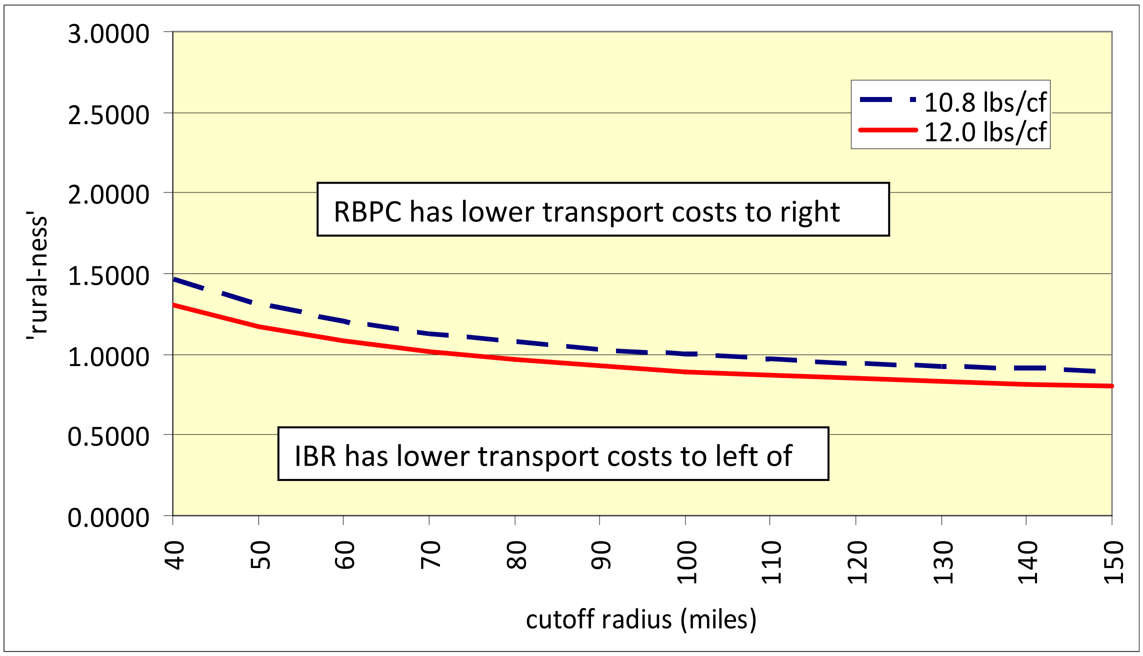

Figure 17: Rural-ness vs. Cut-off Radius

Larger catchment areas favor the RBPC system. The percentage of total transport costs that are distance determined increases as the radius increases due to increased per ton total distances traveled. These longer hauls are on tortuous roads, driving up the transport costs under IBR more than under RBPC.

5.6 Conclusions

Proponents of a fully integrated bio-refinery approach to bio-ethanol supply chain infrastructure argue that transport costs under a distributed system will always be greater due to back-tracking and double depot charges. The mathematical results demonstrate that when the rural-ness of a region, the non-linearity of roads, and the densification of biomass at the pre-treatment facilities are taken into account, transport costs could easily be equivalent between the two systems, and even lower under the RBPC.

It is not automatically true that the RBPC system requires hauling biomass over more miles. There are geographic factors that increase the distance traveled on the first leg of each trip, from farm gate to either RBPC or IBR. Biomass being hauled directly to an IBR must traverse more of these miles. The RBPC has siting advantages. It can locate on a highway, which correlates to a direct route (e.g., 'crows flight' distance) for the trip to the IBR. A higher percentage of rural roads, more tortuous environment and a larger catchment create a situation of less mileage per ton of biomass; and, increase the proportion of total costs which are variable, distance determined costs. These favor the RBPC.

There are technology factors which contribute to transport cost equivalence. Double handling cannot be avoided. There is an additional stop which requires un-loading raw biomass and loading the pre-treated biomass. The additional cost incurred can be offset by increasing the bulk density of the pre-treated biomass. This reduces the number of additional loadings, lessening the impact of the second depot charge, and reduces average total mile per ton of biomass. Lower DFC/DVC ratios, determined by the transport model employed, are RBPC favorable as well. These correspond to lower depot charges directly, and indirectly lead to higher proportion of distance determined costs in the total transport cost.

For a given set of geographic factors, there is always a set of technology factors which satisfy the transport cost equivalence condition. And vice-versa, for any given set of technology factors, there is a set of geographic factors which satisfy this condition.

Transport cost equivalence does not guarantee MESP equivalence. MESP is the Minimum Ethanol Selling Price. It is the minimum wholesale price that a firm requires for each gallon of ethanol it produces to cover the total cost of production. The total costs from farm gate to ethanol production would be the sum of the total costs of each activity along the value chain. A system will be more likely to be implemented if its total costs are minimized. If feedstock cost and transport costs are equivalent, the system cost differences would be driven by pre-treatment and conversion facility costs. Under a distributed system, there will be less capital costs and some operating cost savings at the bio-refinery (vis-à-vis an IBR); but there will be higher capital and operating costs (per ton / gallon) at the RBPCs. The loss of scale and synergy economies inherent in a distributed facility system is not examined in this chapter. Capital costs and operating costs under a distributed pre-treatment system are likely to be higher. While it may be possible to achieve lower transport costs under the RBPC system, it will require more facilities that are likely to be more costly on a per-ton-of-biomass basis, which may drive up the delivered cost of feedstock to the biorefinery. For MESP equivalence, there would need to be a combination of operating and capital cost savings at the stripped down bio-refinery, in addition to the transport cost equivalence (or savings) and feedstock cost equivalence.

The findings in this chapter do not substantiate the claim that a RBPC value chain could help to expand the biomass catchment area in a region beyond that which an IBR could encompass. They demonstrate that in a region with a specific rural-ness and biomass profile, a RBPC system could be more transport cost effective when the catchment radius becomes larger, and there are other RBPC favorable factors present. These findings demonstrate that feedstock arrives at the ethanol facility cheaper under RBPC than IBR when BOTH are at the larger catchment area. Expanding the catchment area ultimately produces more ethanol and allows for the construction of larger ethanol refineries which re-captures some of the economies of scale lost when pre-treatment was stripped from the "integrated" bio-refinery. It also requires bigger RBPCs, which creates additional scale economies.[82] This result does not say that RBPC at the larger catchment area is lower in total biomass cost (feedstock + transport) than an IBR at the smaller catchment area. Nor does it say that MESP is lower with RBPC at larger catchment area than with IBR at smaller catchment area. Chapter 6 addresses total system comparison and provides the MESP analyses.

[82] See Chapter 4 – bigger RBPCs are better

CHAPTER 6

COMPARATIVE VALUE CHAIN ANALYSIS

This chapter presents a model to compare different vertical value chain configurations for ligno-cellulosic biomass delivery to a bio-refiner (i.e. ethanol producer). The model is a spreadsheet-based Decision Support System (DSS) for a biomass supply chain from farm-gate to wholesale ethanol production. The DSS is modeled with 'plug and play' activity modules and sub-modules. The centralizing framework is an Investment Analysis Model that generates user-defined performance metrics to assist in evaluating different value chain configurations.

Two value chains, one utilizing an IBR and the other employing a network of RBPCs with a stripped down bio-refinery, are modeled. Assumptions are outlined and the value chain activities are populated. Activities and costs are modeled; functional forms are specified; and, variables are parameterized. Biomass production variables are user defined sensitivity variables. Biomass production is modeled in a simplistic, yet analytically pertinent manner. Transportation costs are modeled as specified in Chapter 5. Facilities are fully and dynamically modeled with ASPEN and Microsoft Excel®. The Investment Analysis is a Discounted Cash Flow Rate of Return ('DCFROR') model. The chosen performance metrics examined are ethanol volume, financial evaluation measures (NPV, ROE and IRR), and Minimum Ethanol Selling Price ("MESP").

MESP is the price that makes the Net Present Value equal to zero. It is equal to the long run average cost of production ("LRAC"). All cost variables are endogenous and dependent upon size of the catchment area. The MESP = LRAC equilibrium condition is solved at different catchment area radii under specified regional characteristics, technical configuration and co-product market availability to determine the

- optimal IBR size and corresponding MESP;
- optimal RBPC size and corresponding MESP; and,
- the radius of indifference and corresponding MESP.

The problem is framed as a single investment agent evaluating the different chains. One stakeholder is evaluating different value chain arrangements under the assumption that the entire biomass to ethanol chain is vertically coordinated by that actor. The return is calculated as the return to the agent, not as a return to each individual value chain activity. Different types of agents may make different choices on value chain implementation, depending on choice of performance metrics. I then evaluate which value chain is likely to emerge and if which, if any, of the alternative choices dominates the others.

Shocks are introduced to the cost variables in order to determine ceteris paribus effects on the long run average cost curves. For example how do changes to regional, technical and ruminant feed market characteristics shift the curves, do the curves ever shift enough to alter the choices for the different agents? What about multi-variable shocks? Specifically, are there scenarios where RBPC network is clearly superior for all agent types? If so, are the claims of expanded regional coverage (therefore more ethanol) and enhanced financial performance for the refiner (i.e. lower capital & operating costs per gallon, and greater returns) substantiated?

6.1 Analytical Framework

Integrated Biorefinery (IBR) System

NREL defines an IBR as a “facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. The biorefinery concept is analogous to today’s petroleum refineries, which produce multiple fuels and products from petroleum. Industrial biorefineries have been identified as the most promising route to the creation of a new domestic bio-based industry” (Lynd, et al, 2005). These facilities encompass all the processing technology from the raw feedstock through the finished bio-fuel and related co-products, capable of producing some of its own process inputs (i.e. electricity and steam). It is also assumed that the firms willing and capable of constructing, owning and operating these facilities would likely be large petroleum and / or chemical firms. The activities along this value chain would be:

On - farm Activities			Bio-refinery activities					Post - Ethanol activities
LCB Growth	Harvest & Collect	LCB Storage	Input Transport	LCB Storage	Grind	Pre-treat	EtOH Processing	

Regional Biomass Processing Center (RBPC) System

The RBPC strips out the feedstock handling, grinding and pre-treatment from an integrated biorefinery, and arranges these activities into dispersed stand-alone facilities. These facilities utilize the AFEX™ pre-treatment technology as it provides efficient conversion at a very competitive cost; can be de-coupled from the IBR; and, allows control of nitrogen content in the intermediate product. This product is consumable by ruminants, something which other pre-treatment technologies cannot currently support.

A fuller description of this system, which adds activities into the value chain, as well as shifting performance of activities away from the biorefineries into the hands of the regional processing centers, can be found in Carolan, et.al. (2007). The activities along this vertical chain would be:

On - farm Activities			RBPC Activities				Bio-refinery	Post-EtOH
LCB Growth	Harvest & Collect	LCB Storage	Input Transport	LCB Storage	Grind & Pre-treat	PTB Store & Transport	Ethanol	

This configuration adds activities into the value chain, as well as shifting performance of activities away from the biorefineries and into the hands of the regional processing centers.

Post-ethanol production activities are not considered, as the issue under analysis is alternate configurations of the supply chain up through wholesale ethanol production.

Decision Support System

A Decision Support System ("DSS"), is a computer-based system that supports stakeholder decision making, and evaluation of multiple real alternatives, by creating readily understandable outputs from all the disparate information (raw data, heuristic applications, personal knowledge, business and engineering models, etc.) that exists on the different alternatives.

The DSS presented aims at supporting stakeholders for investment analysis decisions on biomass to ethanol value chains in a given area. While investment decisions are central to the operation of the model, stakeholders may wish to determine the performance of different value chain configurations in terms of additional stakeholder defined performance measures (such as volume of ethanol produced).

The spreadsheet-oriented DSS provides a centralized investment analysis framework that operates on 'plug and play' value chain activity modules and sub-modules. Activities can be modeled with additional spreadsheet applications, database models, heuristic modeling, or any other application which flows critical information into the central value chain model. The model receives inputs, processes the information, and produces user-defined outputs that are variables of interest. These metrics provide the information for stakeholder performance evaluation.

Problem Definition

A region has biomass resources. Stakeholders have options with what to do with these biomass resources. There are big picture decisions, such as whether the end use will be energy or an alternate use, such as animal feed. If the end use is to be energy, the bio-energy produced could be electricity, liquid fuel, or syn-gas. If it's to be liquid fuels, then what type? To a certain extent, these decisions are driven by federal mandates, which are pushing certain bio-fuels such as cellulosic ethanol, considered in this case. The conversion pathway must be decided upon, as well as the specific technology employed for that conversion path.

The end use in this analysis is bio-ethanol produced via Consolidated Bio-processing (CBP) with Ammonia Fiber Explosion ("AFEX™") as the pre-treatment technology. Now that the pathway is set, stakeholders must determine the best way to configure the value chain to maximize performance. They must choose among wide ranging options for feedstock logistics to get the biomass from producer to conversion expert, including which modes of transport to employ. Vertical co-ordination mechanisms must be chosen. Make or buy decisions on inputs such as steam must be made.

Investment problems involve measures of capital employed and return on that capital. So stakeholders must answer the following. How much will each option cost? Are certain options always lower cost options? Do other options produce more ethanol, but at a higher cost? Ultimately the decision will come do the value chain that performs best in that region. The performance metrics employed will depend on the nature of the stakeholder. Some stakeholders will look to minimize cost, while others will look to maximize ethanol volume regardless of cost.

The DSS presented is a tool to assist stakeholders in this evaluation. Outputs that it provides include:

1) The minimum wholesale ethanol price that an investor must receive to guarantee a non-negative return on investment for each alternative value chain considered.

2) At a fixed price, the configuration that would maximize profitability for the investor.

3) The conditions, under which the different systems are essentially equivalent from an investment-decision stand-point.

4) The configuration that produces more ethanol, and the corresponding price.

5) The Long Run Average Costs function for each configuration.

The investment decision problem is posed as a single agent problem. One stakeholder is evaluating different value chain arrangements under the assumption that the entire biomass to ethanol chain is under vertical co-ordination control of that actor. Two different types of investment agents evaluating the same region are examined. Under some conditions, one value chain may out-perform the other on all performance metrics, and become the dominant choice of all agent types. In other cases, the different agent types may make different choices on value chain implementation, depending on the performance metrics important to them.

Agent Types

One agent type is a profit-maximizing, vertically integrated, regional monopsonist that has gained control over all the biomass in the region. The agent has ex ante locked up the supply either through ownership of the feedstock production, vertical integration or contracting. A number of corn ethanol facilities are constructed under this type of supply arrangement. Corn co-operatives that desire to capitalize on ethanol production will invite potential ethanol firms to compete for their supply. The winning bidder than becomes the refiner for the entire regional supply. Brazilian sugar ethanol production would be an example of a vertically integrated agent. For this agent type, it is assumed that the vertical integration extends at a minimum from farm-gate through ethanol production, so the agent makes choices on transport modes, pre-treatment technology and conversion pathway. Since profit maximization / cost minimization are the primary incentives for this agent, it will trade off product volume and other considerations in order to generate greater returns to capital employed.

A second agent type is a profit-maximizing agent facing competition from other refining firms. This agent is the same as the first, except it has not been able to ex-ante lock up supply, and therefore must compete with other agents for biomass under market conditions. Feedstock suppliers will reserve their ability to transact with any partner, and not agree ex ante to an exclusive bi-lateral arrangement. This would be the corollary case to the one above where corn ethanol producers enter into a supply region and buy corn on the open market without being invited to enter.

Concept Outline

A flexible modular spreadsheet has been created to enable the technical–financial analysis of different biomass to ethanol value chains. The user must define a configuration by choosing value chain components. These component choices can include macro-choices such as which value chain activities to include; and how to populate these activity modules. Other macro-level choices could be the state of regional infrastructure and the existence of co-product markets. Choices can also be micro-level choices within activity modules and sub-modules, such as technology employed, process flows, and input parameters.

Each activity along the biomass to ethanol value chain is envisioned as a dynamic process with inputs (micro- and macro-parameters) that impact its performance and cost, and outputs (physical ones such as intermediary value chain products and financial ones such as added costs to the ultimate end product). These inputs can be either an output of the previous activity, activity specific inputs or outputs from an external activity. Each activity along the value chain transforms the inputs in some manner, usually as a value added process. Outputs can flow directly to the next activity or leave the value chain via an external avenue, or be consumed intra-activity (i.e. steam). These stand alone processes are modeled, both in physical and monetary units, in a spreadsheet format. These activities are then linked together (again physically as well as monetarily) to simulate the value chain. There are physical and economic macro-level variables that flow through the entire value chain from activity to activity as inputs to one activity and outputs from another.

In this value chain, it is raw biomass moved from activity to activity and transformed ultimately into a liquid fuel. At each activity, the biomass is transformed in some manner and then moved onto the next activity in the chain. A graphical representation of the general conceptual framework is presented in Appendix A.

The investment analysis model will produce user defined outputs. These outputs include commonly applied investment criteria such as Net Present Value, Return on Equity, or Internal Rate of Return; and other variables of interest such as volume of products and co-products, the cost of individual value chain activities, or hurdle rates for prices. The DSS provides the user with the metrics, and the user can then apply their own performance ranking to the alternatives.

Discounted Cash Flow Rate of Return (DCFROR) Models

Dynamic, detailed annual cash flow models were constructed for Integrated biorefineries ("IBRs"), biorefineries stripped of pre-treatment ("BRs") and regional biomass processing centers ("RBPCs"). [83,84] The cash flow models include revenues, capital costs, variable operating costs, fixed operating costs and taxes (Table 15). Models employ Ammonia Fiber Expansion ("AFEX™") as the pre-treatment technology and Consolidated Bio-processing (CBP) as the ethanol conversion pathway. Process input requirements were estimated using ASPEN simulation models and engineering methods. Capital costs; operating parameters such as capacity factor, downtime, backup requirements, etc.; variable costs; SG&A (Selling, General and Administration) expenses; prices of the primary inputs; and, annual cost escalation factors are estimated through use of standard engineering or business heuristics and estimation techniques.

Interest & principal payments are zero as this analysis is not considering corporate financing strategies. All investment is 100% equity. No external financing was considered, and net present value of after tax cash flow is used as the primary performance measure. Income tax rate of 39% is assumed. There is a three year period where capital expenditure occurs prior to project startup. An operating project life of twenty five years is assumed. Facilities are depreciated with double-declining balance method. Steam and electricity co-generation equipment has a 20 year depreciable life. All other equipment at the refineries and RBPCs has a 10 year depreciable life.

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[83] The basis for the IBR model comes from Eggeman, 2008

[84] The dynamic DCFROR model for the RBPC was created by Joseph Carolan, and was the model utilized by Carolan, et. al. (2007) in JAFIO

Table 15: Costs in DCFROR

RBPC	IBR / BR
Variable Operating Costs	**Variable Operating Costs**
Electricity	Electricity - net (post by-product use)
Ammonia	Ammonia
Steam	Water
Water	Labor
Maintenance & Repairs	Process chemicals
Labor	Waste Water Polymer
Miscellaneous Operating Expenses	Cellulase
	Disposal of Gasifier Ash
RBPC	**IBR / BR**
Fixed Operating Costs	**Fixed Operating Costs**
Overhead	Overhead
Maintenance	Maintenance
Misc. Expenses	Insurance
Licenses, Fees& Insurance	Salaried employees
Administration	Taxes (non-income)
Marketing	
Taxes (non-income)	

DSS Modules

The DSS models all value chain activities in varying degrees of complexity and functionality to evaluate the two specific value chain configurations under consideration to determine general regional conditions that might lead to the RBPC out-performing the IBR. The aim is not to estimate the price of wholesale ethanol, but rather to compare two different, theoretical (yet realistic) value chain options to evaluate relative investment performance metrics vis-à-vis the other alternative to assist stakeholders.

Diagrams of the inputs, physical outputs, financial outputs and general model form for each value chain component module included in this comparative analysis DSS are included in Appendix A.

Outputs / performance metrics

Financial Performance Measures

Net Present Value (NPV) is the current value of the discounted future expected after tax cash flows from the project.

$$NPV = \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t}$$

Where, T is the number of expected years of project life;

r is the discount rate employed (12%); and

CF_t is the expected annual after-tax cash flow in year t.

CF_t = Net After Tax $Income_t$ + $Depreciation_t$ – Capital $Expenditure_t$

Net After tax $income_t$ = $EBITDA_t$ – $depreciation_t$ – $taxes_t$

$EBITDA_t$ = $Revenues_t$ – Variable Operating $Costs_t$ – Fixed Operating $Costs_t$

$Revenues_t$ = (gal EtOH) $_t$*MESP + (tons Animal Feed)$_t$ * Animal Feed Price

$$\underline{\text{Variable Operating Costs}}_t = (\text{Variable Op Cost @ BR})_t + \left(\sum_{n=1}^{N} \text{Variable Op Cost @ RBPC}_n\right)_t$$

$$\underline{\text{Fixed Operating Costs}}_t = (\text{Fixed Op Cost @ BR})_t + \left(\sum_{n=1}^{N} \text{Fixed Op Cost @ Each RBPC}_n\right)_t$$

Where N is the number of RBPCs in the system (for IBR, N=0).

<u>IRR , Return on Equity & Return on Investment</u>

The problem is posed initially as a single agent problem. One stakeholder is evaluating different value chain arrangements under the assumption that the entire biomass to ethanol chain will be vertically coordinated / integrated by that actor. There are no intra-firm transfer fees. The return is calculated as the return to the agent, not as a return to each individual value chain activity. ROE is calculated from the after tax cash flows over the entire 28 year period (the three year investment period and the 25 year operating period), even if the cash flows in later years become negative. Note, under a 100% equity scenario, Return on Equity (ROE) is equal to Return on Investment (ROI), and in this analysis these terms may be used inter-changeably. The Internal Rate of Return (IRR) is calculated from the same 28 year after-tax cash flow. If there are no positive to negative fluctuations in the cash flows, the calculated IRR should be equivalent to ROE.

Value Chain Evaluation Metrics

<u>Volume of Ethanol</u>

Displacement of liquid fossil fuels is the ultimate goal of any renewable fuels agenda. Federal policies aimed at stimulating the industry are volumetric mandates. Therefore, it is possible that a higher volume, higher price value chain solution is more favorable than cheaper alternatives. There are potential higher value co-products (such as ruminant feed) that will not only be an attractive market alternative to the investing actor, but may also make or break the success of the value chain because it will subsidize the ethanol production. If these co-product markets reduce ethanol production but drive down MESP, which might value chain configuration might the stakeholders opt for? Ethanol volume is therefore an important metric in any decision matrix.

Minimum Ethanol Selling Price

The MESP is the ***minimum*** price that the investing actor would need to receive in order to guarantee that the entire value chain under consideration has an essentially zero, non-negative NPV at the discount rate; or equivalently, it is the investment realizing an ROI equal to the 12% discount rate. It is the ethanol sales price that makes this statement true.

$$\text{NPV} = \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t} = 0$$

Where NPV is calculated as above.

It is also the price point such that Price = Long run average cost. Any solution where the MESP is below the expected wholesale ethanol rack price could be a viable investment.

6.2 Assumptions

Homogenous Plain

Biomass distribution can be modeled and / or specified. The analytical region here is assumed to be a homogenous plain that is equally fertile every where with evenly distributed resources, which creates a uniform biomass distribution. This allows for,

1) the use of average distances in calculation of transport costs; and,
2) the approximation of the shapes of the supply areas for the spatial monopolists (RBPC or IBR) under consideration.

Farm Level Assumptions (feedstock, productivity, moisture content, feedstock handling)

The types and quantities of usable biomass feedstocks will depend on the precise region under consideration. Each biomass type could have its characteristics (productivity, moisture content, harvest method, degradation during storage, etc.) specified and / or modeled. Possible feedstock types include agricultural residues, dedicated energy crops, woody biomass and municipal solid waste.

At this level of analysis, it is not the exact type of biomass, but how much total biomass in a region could be available. For simplicity, only those feedstocks which can be baled are currently considered - agricultural residues and dedicated energy crops. These feedstocks are assumed to be fungible in all characteristics.

Biomass Productivity (dry ton per harvested acre per year): Feedstock productivity is one of the sensitivity variables, with user defined lower and upper limits. It is assumed to be the same for all biomass and is uniform across the region.

Harvest & Collection: Crops and grain residues are raked into windrows and field dried to approximately 15% moisture content. The biomass is picked up from the windrow and formed into round bales. A towed bale wagon is loaded and towed to the edge of the field / roadside, where the bales are stacked and tarped.

Density (lbs. / cu ft): Biomass density is one of the sensitivity variables, with user defined lower and upper limits. It is assumed to be the same for all biomass and is uniform across the region.

'Infinite Store-ability:' LCB must be harvested and / or collected within a given seasonal window, just as any other agricultural product. If this product is not immediately consumed as an input by the bio-processor, it must be stored until needed. It is assumed that growers could store it infinitely at the farm, out in the open air, tarped, on the ground with no loss to quality. Under this current set of assumptions, no bales will be stored for more than a year.

The LCB fungibility assumptions make it possible to examine all available bale-able biomass in the region as there is no differentiation for the processor in regards to quality or process requirements. Input sources are similar enough and are found in enough quantity that they can essentially be regarded as fungible, either because of similarities in characteristics, or because the processor will blend these two feedstocks prior to grinding (or pre-treatment) in a known ratio to achieve a consistent input.

Any system of harvesting, collection and storage could be modeled and specified for use in the DSS, and indeed much work is being done to determine the optimal shape and size of bales, optimal storage, and the impact of each configuration on the degradation of the biomass. There is no consensus on this currently, therefore the assumptions of infinite storability and round bales are reasonable for this analysis.

"All-in" Feedstock Price

The feedstock price Includes all feedstock producer activities from biomass creation (growing in the case of dedicated energy crops; by-product or waste creation for residues) through to on site storage. The price is paid by the first handler (either the pre-treatment processor or biorefinery) on an as-taken basis. The feedstock is assumed to be stored for no more than one year, in a manner consistent with specifications dictated by the first handler (round bales in this case), and which must be readily accessible to the first handler's transport agents. This is similar to the requirements in Iogen contracts for biomass examined by Altman, et. al. (2007). In the current case, all biomass receives the same price, $40 per dry ton.

Featureless plain & Tortuosity factors

The analysis could be undertaken assuming that the region is a 'featureless plain' that is flat, devoid of obstacles with roads that are straight, unobstructed, paved and of equivalent quality. The featureless plain assumption may also be relaxed, by assuming that travel is not "crows' flight" (i.e. not direct and linear), but rather is on winding, hilly and differing types of roads (which impacts time & distance due to quality and speed limits). In other words, roads can be "tortuous". A tortuosity factor of 2.11 means that for each 1 mile "crows' flight" distance it would be 2.11 miles when driven.

From farm to RBPC, the roads are lower quality, more winding, hillier and more rural than in the more urban areas, thus the High tortuosity factor (τ_H). In siting of the

RBPC, it is likely that access to highways would be a factor not only for transporting the output, but also for receiving other inputs, such as machinery and ammonia. Therefore, the likelihood that a relatively straight shot from RBPC to BR exists leads to a less tortuous route, thus the Low tortuosity factor (τ_L). The farm to IBR factor is a simply a rural percentage weighted average of the other two. For a featureless plain analysis, rural percentage would be 50% and all tortuosity factors would be equal to one (1.0).

Both the High tortuosity factor (τ_H) and Low tortuosity factor (τ_L) are sensitivity variables, with user defined lower and upper limits, as is rural percentage.

Supply Area Assumptions

It is assumed that the geography is uniform and consistent, assumptions that fairly well represent regions that are likely to produce agricultural residues and dedicated energy crops. The biomass is uniformly distributed across the region, and has constant characteristics, which produces a homogenous and fungible commodity.

The consistency of biomass productivity, content and moisture, combined with a known geographic area allow for the use of an average distance, based on geometric principles. This average distance for all points in any polygon to the center point is calculated as:

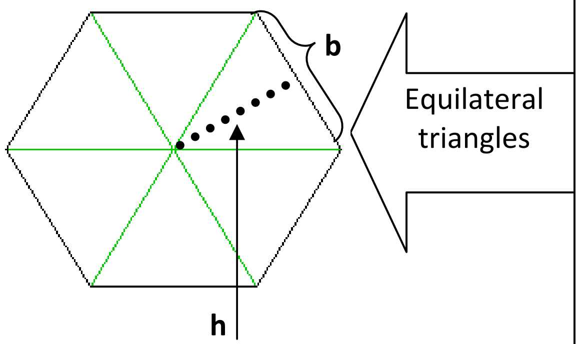
$$\rho_0(N) = \frac{2N\int_0^{\pi/N}\int_0^{\frac{\cos(\pi/N)}{\cos\theta}} r^2 dr d\theta}{\left(2N\int_0^{\pi/N}\int_0^{\frac{\cos(\pi/N)}{\cos\theta}} r dr d\theta\right)^{3/2}}$$

where r = maximal radius of polygon (i.e. the radius of the smallest circle in which the polygon can be inscribed),π= pi (3.1415….) and Θ is the angle of a ray from the center of the polygon to the midpoint of each side.

Supply areas were chosen by the most efficient tiling pattern for the number of contracting facilities. For an IBR case, there is only one purchaser, and only one facility in the region. The catchment area was assumed to be a circle, with the IBR located in the center (i.e. N=1). The average distance from any point to the center of a circle is two-thirds the radius (2/3*r), where radius is the square root of the area divided by pi ($r = \sqrt{(Area / \pi)}$). Under an IBR scenario, with uniform LCB density, the catchment area is best approximated as a circle.

Under the RBPC model, there now becomes competition for inputs. Sellers no longer operate under a monopsonistic regime. Assuming that suppliers will contract with the nearest facility, the above assumptions follow those of Parr and Swales (1999), which will lead to a honeycomb pattern of regular hexagonal supply areas. A hexagonal pattern of coverage by is shown by Morgan and Bolton (2002) to 'beat any other collection of congruent or non-congruent shapes of equal or unequal areas, in finite or infinite domains' in regards to efficiency. Hexagonal tiling should emerge even with inclusion of tortuosity factors as they are uniformly applied across the supply regions when considering farm-gate to facility travel. Therefore, no specific RBPC gains any advantage due to channelization economies.

N= 6: RBPC case – Hexagon[85]



Average Distance to the center =

b*{⅓+¼*ln(3)}, where

b = √{[2/(3√3)]*hexagonal area}
(see footnote 11)

Under hexagonal supply areas, this is the average distance for LCB to get from source to RBPC.
PTB will travel from center of one hexagon to center of adjacent one.

'Infinite Store-ability' of Pre-treated Biomass

Long term stability and quality preservation have been demonstrated on a very small experimental scale with AFEX™ treated switchgrass and corn stover, but has yet to be proven at a commercial scale. Pre-treated biomass (PTB) has been stored in a laboratory setting for over a year without any degradation in quality. The current analysis assumes this storability property holds in less controlled environments. It is assumed to be infinitely store-able without quality loss.

PTB is high in sugar content; and has nitrogen, NEL, and crude protein in levels appropriate for consumption as a ruminant feed (Carolan, et.al., 2007). Therefore, some of this product could be sold into the animal feed market, and the rest is stored until needed by the bio-refinery.

- [85] Mean distance of any point to Apex of a triangle, with sides a, b & c is
  $$\overline{D} = \int_0^1 D(t)\,dt = \frac{c}{6}\left[u\left(1+v^2\right)+\frac{1}{2}\left(1-u^2\right)\left(1-v^2\right)\ln\left(\frac{u-1}{u+1}\right)\right]$$
  where u = (a+b)/c and v = (a-b)/c.
- For equilateral triangle: a=b=c; u=2; v = 0 , therefore Avg. Dist = b*{⅓+¼*ln(3)} ≈ 0.6079864*b

While the total weight of the biomass does not diminish during pre-treatment, the density of the material is increased - density in untreated biomass bales is assumed to be 8 lbs/ft^3 while the density of PTB is 12 lbs/ft^3. This will reduce the DFC portion of the transport cost function as fewer trucks and lower terminal costs (i.e. less loads) are incurred per ton; and the DVC component as more tons per trip reduce the per ton mile variable costs[86].

Fungible inputs

1) <u>AFEX™ technology</u>*:* It is assumed that the pre-treatment facilities all utilize AFEX™ on any type of biomass considered[87], and thus all produce a product that is fungible between facilities, and which can be sold into the animal feed market as well as to bio-refineries.
2) <u>Ethanol production:</u> Conversion constant @ 88.89 gallons per ton LCB.
3) <u>No favoritism</u> – first handlers purchase equally from all possible suppliers. With LCB fungibility in characteristics and productivity, there is no differentiation amongst biomass types or producers.

The LCB input fungibility assumptions make it possible to examine all available biomass in the region as there is no differentiation for the processor in regards to quality or process requirements. Input sources are similar enough and are found in enough quantity that they can essentially be regarded as fungible, either because of similarities

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86 See Chapter 5 for a more robust treatment of density effects on the transport cost functions

87 Those that are certainly NOT capable of pre-treatment with AFEX were not included in the biomass inventory

in characteristics, or because the processor will blend these two feedstocks prior to grinding (or pre-treatment) in a known ratio to achieve a consistent input.

Fungible outputs

1) Ethanol production: There is no quality difference in PTB (due to the fungibility assumptions and homogeneous facilities), so there will be no differentiation or favoritism in terms of collection and / or price.

2) Ruminant feed: There is no quality difference in PTB (due to the fungibility assumptions and homogeneous facilities), so CAFOs purchase from the closest facility, with no favoritism.

These assumptions ameliorate any potential for the RBPC to find itself in an untenable, monopsony situation vis-à-vis the bio-refiners. If the PTB was not storable, not saleable as ruminant feed, and there were vast quality differences between producers, each producer could find itself with very large appropriable quasi-rents. This would impact the governance choices of the RBPC not only upstream (i.e. to bio-refiner) but also downstream (to the grower).

Ruminant Feed Market

AFEX™ treatment significantly improves the animal feed value of biomass, for the same reasons that make it a better feedstock for the biorefinery. AFEX™ treated biomass can potentially be sold as a feed supplement for ruminant animals without any additional drying or processing[88].

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[88] Chapter 4; Carolan, et. al (2007)

It may be possible that some of the ruminant feed will be back-hauled to the biomass grower, the vast majority of the market potential for this type of bulk ruminant feed will be large, Concentrated Animal Feed Operations (CAFOs). A CAFO only ruminant market is employed. The price of the treated biomass was assumed to be $115.34 / ton[89].

Transport process

The LCB is assumed to be stored on the biomass producer's farm, in bales, in an accessible location for collection equipment. The bio-processor is responsible for collection, transportation, grinding capital and costs, and certainly is impacted by any quality loss. As the bio-processor requires, it will send its collection agents out and pick up the bales. The bales will be ground at the bio-processing facility and fed immediately into the production process. This is almost a just in time delivery method for the bio-processor. Under this scenario, (which is the Iogen case considered by Altman, et al, 2007) the farmer is responsible for providing assets for storage, as well as incurring any inventory, carrying and / or loss costs.

All the transport equipment is owned and operated by the biomass processor (either RBPC or IBR), which collects the bales as required. The handling and storage functions at the processing facility are designed to handle enough biomass for continuous operations, based on delivery from 8 AM to 5 PM daily (i.e. 7 days per week). This assumption eliminates paying a return to a third party, as well as allowing the use

89 See Carolan, et. al (2007) for estimation in 2007$. This figure has been adjusted for inflation and market trends.

of an average distance rather than looking at optimal routing functions. It is realistic in the sense that there will likely not be third party biomass collection agents, and a vertical coordination evaluation would likely point to these two activities being vertically coordinated so that the transaction costs would be internalized and the possibility for synchronization errors minimized.

The model for untreated biomass transport will be the applicable functional form.

Farm to IBR:

$$In\_trans(f, j) = Q * \{DFC + DVC[R * \tau_H + (1-R) * \tau_L] * AVG\_DIST(f, j)\}$$

Farm to RBPC:

$$In\_trans(f, i) = \sum_{i=1}^{N} q_i * [DFC + DVC * \tau_H * AVG\_DIST(f, i)]$$

Outbound (PTB) transport specification

$$Out\_trans(i, CAFO) = \sum_{i=1}^{N-1} AF_i * \delta * [DFC + DVC * DIST(i, CAFO)]$$

Activity costs are allocated as:

Facility Specific Depot Costs - unloading and stacking at processing and/or conversion facility, equipment and capital associated with unloading & stacking at facility, other terminal charges – are included in the applicable facility model.

DFC (Distance Fixed Cost) - cost per ton transported – includes loading, equipment costs (trucks, trailers, loaders, etc.), depreciation, licenses, insurance, other fixed or sunk costs, transaction costs.

DVC (Distance Variable Cost) - variable cost per mile – includes labor, fuel (MPG, price of diesel), repairs, tires, maintenance, lubrication, trailer costs, and equipment cleaning.

Homogeneous facilities

All facilities utilize AFEX™ pre-treatment, regardless of the value chain employed[90]. Homogeneity across facilities is essential in order to minimize costly co-ordination errors, to ensure fungibility of inputs and to avoid holdup situations. Whether or not this is accomplished via vertical integration (i.e. one firm owns all the processing facilities) or intense vertical co-ordination (i.e. contracts, franchises, joint venture) is tangential to this discussion. Suffice it to say that the region under consideration can only sustain one firm operating in its biomass space, and that one firm will make sure that its technology is utilized across the entire span of the value chain. For our case, this firm employs AFEX™ and CBP conversion pathways.

This has a couple of implications worth stressing. First, under uniform LCB distribution across the entire region and fungibility assumptions, all RBPC are identical in size, and evenly sized supply areas will emerge in a pattern of complete coverage. Second, the cost structures for all the facilities will be identical. Third, outputs are homogenous across facilities.

Mature Technology

All the underlying engineering models assume mature technology, as if these facilities are operating at that level of technological and industrial efficiency, but are priced as if

[90] Chapter 4 discusses pre-treatment choices in depth. AFEX is the method utilized.

they are being constructed and operated in 2011 dollars. Within this construct, firms (and the industry) have moved through the developmental, introduction and growth stages of the product life cycle to the mature stage. This has a few minor implications. One is that above normal profits are no longer tenable, reflected in a reasonable return to investment measure of 12%. Another implication is that the requisite wholesale ethanol price produced from this framework should be comparable with wholesale ethanol prices in other mature ethanol industries (i.e. corn ethanol). The final implication is that while for modeling purposes input prices and costs are in current dollars, any facility that actually would begin construction in 2011 would not be at a mature stage. Therefore, prices from these models should not be taken as achievable at this point in time. This does not diminish the comparative analysis as both chains under consideration operate under identical conditions.

6.3 Refinery[91]

The cellulosic ethanol processes modeled feature biological conversion and include the following steps: feedstock handling, pretreatment, biological conversion, product recovery, utilities production, and waste treatment. The National Renewable Energy Laboratory's (NREL) 2002 study (Aden, et. al. 2002) served as a starting point, and Laser, et. al. (2007) provides the mature technology design.

The process can be briefly described as ammonia fiber expansion (AFEX™) of the ligno-cellulosic biomass with consolidated bio-processing (CBP), evaporative

[91] Description is adapted from Laser, et. al, 2007

concentration of liquid distillation bottoms, and water recycle prior to wastewater treatment.

The feedstock is delivered to the feed handling area for storage and size reduction. From there, the biomass is conveyed to AFEX™ pretreatment [detailed description in Chapter 4] and conditioning. Consolidated bio-processing (CBP) in which cellulose production, cellulose hydrolysis, hexose fermentation, and pentose fermentation are combined in a single process step, eliminates the need for separate enzyme production. Ethanol recovery is accomplished via distillation in a single column with direct steam injection and an intermediate heat pump with optimal side stream return.

The liquid portion of bottoms from the ethanol distillation is sent directly to wastewater treatment, which consists of anaerobic digestion followed by treatment in an aerated lagoon and a clarification step. Biogas is produced by anaerobic digestion of organic compounds in wastewater treatment. The treated water is considered suitable for recycling and is returned to the process, so there is no water discharge from the process.

The solids from distillation, the concentrated syrup from the evaporator, and biogas from anaerobic digestion are combusted in a fluidized bed combustor to produce steam for process heat. Soluble components in the wet boiler feed are combusted and some water vapor exits through the stack. The process produces excess steam that is converted to electricity for use in the plant; any excess electricity is sold to the local power grid.

Figure 18 shows a simplified schematic of the fully integrated facility[92]. The stripped down bio-refinery does not have the pre-treatment process as that is handled at the AFEX™ RBPC.

Refinery models

There are seven refinery activities modeled - feedstock handling, pre-treatment, biological conversion, product recovery, wastewater treatment, storage, residue processing / co-generation, and utilities.

Under the distributed system, pre-treatment is stripped from the bio-refinery and re-located further down the value chain in the RBPC. This facility is described in detail in Chapter 4. The elimination of this activity from the IBR has both direct and in-direct effects on the refinery model. The intra-IBR pre-treatment component to the DSS is eliminated. Feedstock, now PTB, moves directly from handling and storage to bio-chemical conversion. That is the direct effect. The indirect effect is that process synergies and requirements needed for the AFEX™ process are no longer required. The volume of residues generated from the ethanol production is not impacted, so the co-generation facility is sized as it is in the IBR. This results in additional electricity being available for export. The remainder of the BR facility is identical to the IBR facility. Capital and equipment are sized according to throughput of biomass and internal process flows. Each piece of equipment is sized and specified with a scale factor commiserate with the type of equipment. The size of each facility is determined as described above (i.e. the radius and parameters determines throughput).

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[92] This is a simplified version. For the full process design see pg. 40 Laser, et. al. 2007

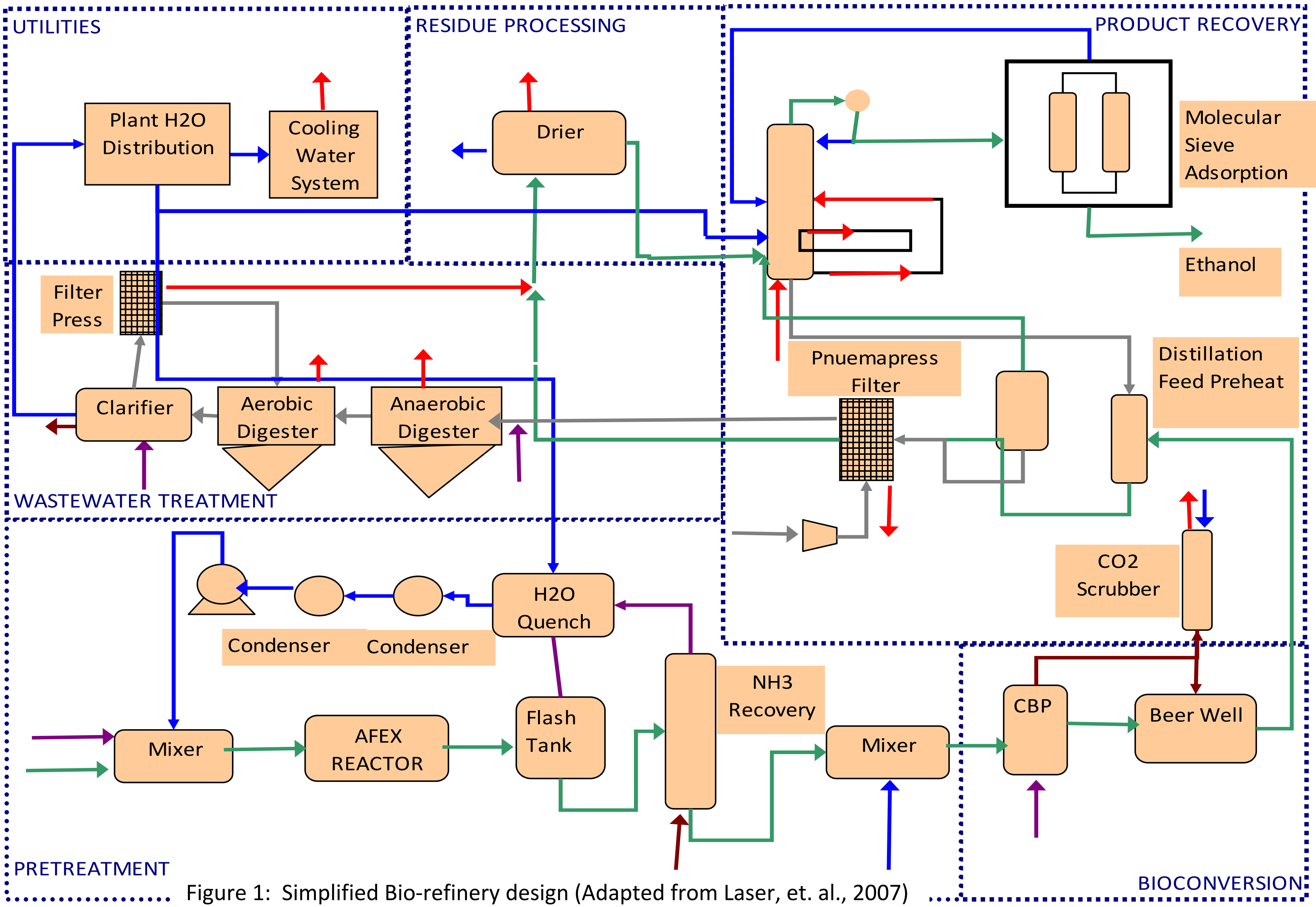


Figure 1: Simplified Bio-refinery design (Adapted from Laser, et. al., 2007)

Table 16 shows the variables, parameters and functions that are specified for every piece of equipment in each of the seven intra-refinery activities in the equipment module.

Table 16: Equipment Specifications in Refinery Models

Variable	Source[93]
Number Required	Engineering design
Number Spares	Engineering design
Equipment Name	Engineering design
Scaling Stream Flow (units per kg biomass)	Engineering estimate
New Stream Flow (units / kg)	Dependent variable - on scale from DSS
Size Ratio	= New stream flow / scaling stream
Base Year Cost ($US / unit)	cost estimate
Base Year	year of cost estimate
Total Cost in base year	= # req'd x cost / unit
Scaling Exponent	Engineering estimate
Installation Factor	Engineering estimate
Total Installed Cost (base)	= (size ratio)^(scaling exponent)x(total cost)x(installation factor)
Installed Cost (2012)	Inflation adjsuted TIC

The facility throughput set by the radius and DSS parameters scales each piece of equipment up or down depending on the relative size vis-à-vis the base. Economies of scale are realized as the facility gets larger through the scaling exponents. Scale factors range from 0.30 to 1.00, being 0.69 on average.

93 Sources for line items vary by line item. Sources include ASPEN modeling, Eggeman (2008), Lynd, et. al (2005), Bals and Dale (2012), Newton-Sendich (2007), et. al. (2007), Aden (2002), Carolan, et.al. (2007)

Capital Expenditure

Capital expenditure requirements are generated by applying industry standard added costs to the total of facility equipment cost estimates. The added costs applied are presented in Table 18. The added cost rate applied to the refineries is approximately 41%. This is similar in magnitude to the petroleum refining industry, which has an average added cost rate of approximately 43.5%[94]

Other capital expenditure, financing and cash flow modeling assumptions are specified. These are shown in table 17 with the specifications utilized in all the analyses. These assumptions and estimates populate other modules within the DSS, flowing ultimately to the facility investment analysis models.

Table 17: Added Costs in Refinery Models

Equipment Costs		
Add: Installed capital costs		
Warehouse	1.50%	of Equipment Costs
Site Development	9.00%	select equipment costs
Total Installed Cost (TIC)		
Add: Indirect Costs		
Field Expenses	20.00%	of TIC
Home Office & Construction Fee	25.00%	of TIC
Project Contingency	3.00%	of TIC
Total Capital Investment (TCI)		
Add: Other Costs (Startup, Permits, etc.)	10.00%	of TCI
Total Project Investment (TPI)		

[94] Eggeman (2008) , from Gary & Handwerk

Table 18: Other capital expenditure, financing and cash flow modeling assumptions

Assumptions	General Plant	Steam Plant
Salvage Value	0	0
Type of Depreciation	DDB	DDB
Depreciation Period (Years)	10	20
Equity	100%	100%
Working Capital (% of TPI)	5.00%	5.00%
Construction Period (Years)	2.5	2.5
% Spent in Year -2	8.0%	8.0%
% Spent in Year -1	60.0%	60.0%
% Spent in Year 0	32.0%	32.0%
Start-up Time (Years)	0.5	0.5
Revenues (% of Normal)	50%	50%
Variable Costs (% of Normal)	75%	75%
Fixed Cost (% of Normal)	100%	100%
Income Tax Rate	39.00%	39.00%

Table 21 demonstrates how capital expenditure scales up as throughput scales up.

Process requirements

Process requirements for the bio-refineries are determined from the equipment model. Each piece of equipment that requires a process input generates a demand for that input. This demand is scaled up or down as the equipment is scaled up or down according to throughput. Each process input's demand is totaled across the facility. For instance, make up water is calculated as the difference between total water demanded by pre-treatment, CO_2 scrubbing, slurry dilution, and cooling less treated wastewater.

Some inputs are purchased as raw materials. Others are generated within the facility. All those that are generated onsite have dedicated sub-modules. Table 19 shows the inputs required; whether they are purchased externally as a raw material or made on-site; and, price estimates utilized in the analyses in this chapter.

Table 19 - Refinery Process inputs & prices

Input	Source	2012 Cost ($/lb)	Price Quote source
Ammonia	Raw Material	0.2589	Carolan, et.al. (2007)
Diammonium Phosphate	Raw Material	0.0754	Eggeman (2008)
Cooling Tower Chems	Raw Material	1.0894	Eggeman (2008)
WasteWater Chems	Raw Material	0.1686	Eggeman (2008)
WasteWater Polymer	Raw Material	2.7235	Eggeman (2008)
Cellulase	Raw Material	0.0590	Eggeman (2008)
Makeup Water	Raw Material	0.0001	Bals and Dale (2012)
Water	Onsite Recycle		
Electricity	Generated Onsite	$30 / MWh[95]	Carolan, et.al. (2012)
Steam	Generated Onsite		

On site electrical generation exceeds on site demand. Generation equipment is sized not to meet internal demand, but to maximize electricity production based on the available by products. The on-site demand in an IBR configuration will be greater than that of a BR configuration as the AFEX™ pre-treatment utilized electricity as an input. Therefore, electricity exported and co-product revenue will be higher for a BR than for an IBR. The reciprocal effect of this, however, is that an RBPC system must purchase electricity at the distributed facilities, at a higher per MWh price than it will receive for the incremental export.

Table 20 demonstrates how the input demands scale up as the refineries scale up. This is under base case assumptions, varying only the catchment radius.

95 note that this is the wholesale clearing price that the facility will receive for export

Table 20 – Input Demand with varying levels of biomass throughput

	Capacity (dry tons per day)			
Input	2,000	5,000	10,000	28,800
Diammonium Phosphate (lbs/hr)	264	660	1,321	3,803
Cooling Tower Chems (lbs/hr)	36	90	180	519
WasteWater Chems (lbs/hr)	360	901	1,802	5,189
WasteWater Polymer (lbs/hr)	360	901	1,802	5,189
Cellulase (tons/hr)	21.1	52.9	105.7	304.4
Makeup Water (tons/hr)	400	1,001	2,002	5,767
Electricity Demand (MW)	25.47	63.68	127.35	366.78

Other operating costs specified include: salaries specified by employee type and number of that type of employee required, which scales up or down according to facility throughput; an overhead markup of 60% of labor costs; maintenance, property taxes and insurance which are a percent of TIC (2% and 1.5% respectively).

6.4 Investment Analysis Model

Ultimately, all model inputs are utilized in the DCFROR, either directly or via a sub-model, or module. The MESP that solves the LRAC condition (NPV=0) is determined and recorded. The next catchment radius is specified and the process is re-run. A summary of cash flow items into the refinery investment model (DCFROR) and their sources within the DSS is presented in Table 21.

Table 22 demonstrates how capital cost, conversion costs and transport costs scale up as the biomass throughput increases.

Table 21: Sources of Input to refinery DCFROR Models

Stripped out bio-refinery + RBPC	
Cap Ex	
Bio-refinery CapEx	equipment to CapEX worksheet
All RBPCs CapEx	equipment to CapEX worksheet
Working Capital (BR)	equipment to CapEX worksheet
Revenues	
Ethanol Sales	EtOH vol x MESP
By-Product Credit	electricity sub-module
Animal Feed	From RBPC model
RBPC Expenses	From RBPC model
Refinery Expenses	Operating cost module
Raw Materials	Raw Materials sub-module
Disposal of Gasifier Ash	Raw Materials sub-module
Operating costs	Op_cost sub-module

Integrated Biorefinery	
Cap Ex	
Fixed Capital Investment	equipment to CapEX worksheet
Working Capital	equipment to CapEX worksheet
Revenues	
Ethanol Sales	EtOH vol x MESP
By-Product Credit	electricity sub-module
Animal Feed	parameters
Refinery Expenses	Operating cost module & parameters
Feedstock cost	parameters
AR transport	parameters
DEC transport	parameters
AF transport	parameters
Raw Materials	Raw Materials sub-module
Disposal of gasifier ash	Raw Materials sub-module
Fixed Operating Costs	Op_cost sub-module

Table 22: Capital, Conversion and Transport Scale Up vis-à-vis Catchment

Catchment Radius:	25 mile	50 mi - 15% AF	50 mi - no AF	75 mile
dry tons per day	10,329	41,314	41,314	92,957
DT / day @ BR		35,117		
MMGal EthOH / year	340.4	1,361.5	1,361.5	3,063.4
MMGal EthOH / year @ BR		1,157.3		
Total CapEx ($M)				
BR	396.3	941.0	1,059.6	1,938.0
RBPC System	744.2	1,828.1	1,946.8	3,483.8
IBR	543.7	1,434.7	1,434.7	2,604.2
Total Conversion ($M/yr)				
BR	186.4	611.4	717.1	1,998.6
RBPC System	269.9	867.6	973.2	2,121.7
IBR	232.9	898.7	898.7	1,593.6
Biomass Transport ($M/yr)				
BR	6.3	23.2	27.3	65.8
RBPC System	33.5	158.0	162.1	428.4
IBR	36.1	206.3	206.3	603.6

Wholesale Ethanol up-stream distribution

An ethanol wholesaler will purchase the bio-ethanol from the refiner, and handle all outbound logistics. As the location for the two bio-refineries is the same, these upstream costs will be identical regardless of channel configuration.

6.5 DSS Parameter and Functional Specification

For each case under consideration, parameters and functions are specified. These are listed in Table 23 with the values specified for the base case analysis.

These values populate functions and parameters across the DSS, including the facility DCFROR models; transport cost models; and, activity costing modules and sub-modules.

They generate important intermediate variables such as biomass yield, rural-ness factor, density ratio and technology constant.

Table 23 – Parameters & Functional Specification in DSS

Macro-assumptions		***Biomass Variables***	
gals/ ton LCB	89.00	Ag Residue %	50.0%
# RBPCs	7	Biomass production (tons/acre/yr)	5
Facilities Online %	100%	% of Agricultural land in region	60.00%
operating hours per year	8,760	Participation of biomass producers	100.00%
expenses escalate @	2.00%	Biomass distribution uniform?	uniform
Feedstock pricing		***Regional Variables***	
DEC price	40.00	Tortuosity: farm to RBPC	1.30
AR price	40.00	Tortuosity: farm to IBR	1.22
Delivery point / price setting point	Farm-gate	Tortuosity: RBPC to BR	1.00
		% rural roads	72%
Animal Feed Variables		***Technology Variables***	
AF format	grinds	inbound DFC ($ / ton, per load / unload)	5.35
AF price ($/ton)	115.637	inbound DVC ($ / ton / mile)	0.1630
AF % @ RBPC	0.0%	density raw biomass (lbs/cu ft)	8.00
AF % @ IBR	0.0%	density treated biomass (lbs/ cu ft)	12.00
% of CAFOs: rural	75%	PTB form	grinds
% of CAFOs: suburban	25%	outbound DFC	3.5667
% of CAFOs: urban	0%	outbound DVC	0.1087

Radius of the circular catchment area is the independent variable for the LRAC analyses. It is varied in value from 20 miles to 200 miles in 10-mile increments. Each change in value drives changes throughout the entire DSS as it changes the scale of the system under consideration. When combined with the parameters defined in Table 22 above, this generates key values such as total biomass utilized, which then determines the scale of each facility in dry tons per day; the total ethanol produced; and the catchment areas of facilities which provides values for the variables in the distance functions.

Average distance functions are specified for the items shown in Table 24. The specifications utilized for the analyses in this chapter were presented above and in Chapter 5.

Table 24: Distance Functions	
AR distance (to RBPC)	rural CAFOs to RBPC: distance
DEC distance (to RBPC)	rural CAFOS to IBR: distance
distance RBPCs to BR (crows flight)	suburban CAFOs to RBPC: distance
distance RBPCs to BR (w/ tortuosity)	suburban CAFOs to IBR: distance
avg distance FG to IBR (crows flight)	urban CAFOs to RBPC / IBR: distance
avg distance FG to IBR w/ tortuosity	

6.6 Results

The MESP equals long run average cost condition (i.e. MESP such that NPV = 0) is solved for different size facilities under a given set of regional characteristics. Facility through-put capacity is determined by the quantity of biomass expected, which is a function of catchment area and biomass yield. Average cost curves for each of the two systems are generated and plotted against catchment area radii and thousand-tons per day of biomass processed.

Base Case (bio-ethanol only)

The DSS parameters for the base case are shown in Table 22 above. Figure 19 shows graphically the Long Run Average Cost curves for both the base case IBR and RBPC.

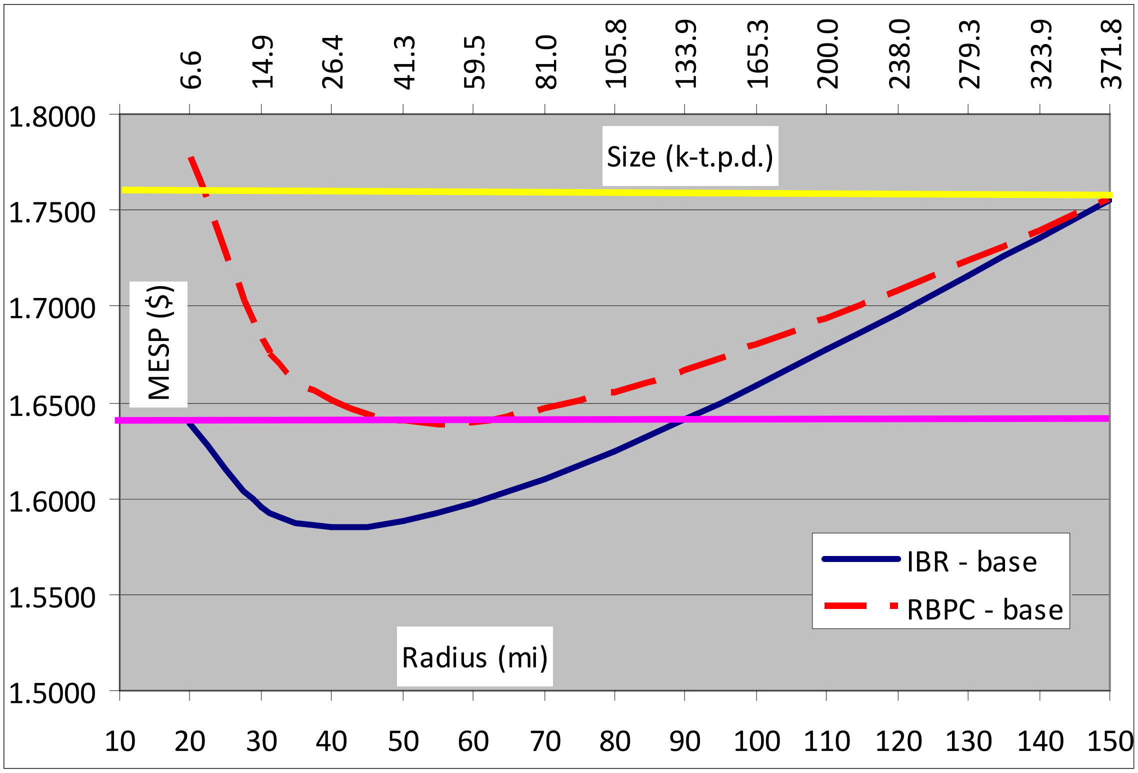


Figure 19 - Base Case Long Run Average Cost Curves

Each @ its Minimum Efficient Scale

	MESP ($/gal)	Radius (mi)	Size (TPD)	EtOH (Mgals)	Capital ($M/gal)	Conversion ($/gal)
IBR	1.5852	41	27,780	915.5	1.178	0.665
RBPC	1.6395	55	49,085	1,617.6	1.089	0.700

Point of Indifference (RBPC & IBR produce at same cost)

	MESP ($/gal)	Radius (mi)	Size (TPD)	EtOH (Mgals)	Capital ($M/gal)	Conversion ($/gal)
IBR	1.7537	149	367,921	12,124.70	0.613	0.645
RBPC	1.7537	149	367,921	12,124.70	0.669	0.668

The single profit-maximizing, vertically integrated, regional monopsonist (i.e. has exclusive control over, or access to, the biomass supply) will always choose the IBR system, as long as the expected wholesale price exceeds $1.5852. To cover the entire region, it would build multiple identical facilities that are all at the minimum efficient scale (minimum of LRAC curve) of approximately 28,000 tons per day, rather than a single larger bio-refinery. Maximum profits would be realized at the point of minimum long run average cost.

As a regional monopolist, the agent has the ability to earn above normal profits. Without competition, it can set the wholesale ethanol price in the region, as long as it is at or below the national rack price. No other cellulosic ethanol producer can operate in the region, so there is no other actor that could force the regional price to the minimum of long run average costs. Under this scenario, the investor will always choose an IBR structure.

Consider the case where the expected wholesale price is $1.6395 (pink line). At this price level, a RBPC system with a collection radius of 55 miles is a realistic option. With the RBPC, the agent would realize normal profits (12% ROI) and could generate additional profit any time price exceeds $1.6395. However, at $1.6395, the agent would still maximize returns with the smaller (28k) IBR: NPV of $540 M (vs. NPV of zero)!

In fact, the single investing agent could put two identical 28k bio-refineries in essentially the same geographic space as the 55 mile radius RBPC at its minimum cost structure. This multi-facility investment strategy costs more in total initial capital ($2.16 B vs. $1.78 B), but will utilize more biomass, produce 11% more ethanol, and generate returns to the investing agent of $1.08 B.

Consider the case where the expected wholesale price exceeds $1.7500; which is the MESP that corresponds to the point of indifference (yellow line). While the RBPC begins to out-perform the IBR at these larger scales, the choice for a profit maximizing agent would remain the minimum cost RBPC (54k) or the minimum cost IBR (28k). The outcome would remain the multiple min-cost IBR strategy.

A profit-maximizing agent facing competition would invest in IBRs at the minimum efficient scale (28k tpd). It may or may not be able to build multiple facilities due to multiple firms operating in the same region. Where competition exists, there will be price pressures for inputs and outputs. The existence of competition eliminates the ability of the actor to realize above normal profits. It becomes a situation where regional price is not necessarily the same as national price. Depending on the volume of regional production as a percentage of national volume, the regional price may or may not impact national price levels. Competition will drive the regional price down to marginal cost. The agent must operate at minimum LRAC, or will be under-cut by regional competitors.

The RBPC could not emerge under this scenario. As there are lower cost structures in the region, the market price level would be below the requisite MESP that makes RBPC a viable option.

6.7 Structural cost differences

Total capital investment is greater for an RBPC at every equivalent size (Figure 20). RBPCs are smaller facilities, and lose scale economies. These synergistic gains are lost when the pre-treatment activity is de-coupled. In a fully integrated bio-refinery electricity and steam are generated on-site utilizing waste products for combustion and water is recovered. At the RBPCs, these utilities must be purchased (Figure 21).

Estimated costs determined by capital costs (labor, property tax, insurance, and others) are also inherently higher for a RBPC system (Figure 21).

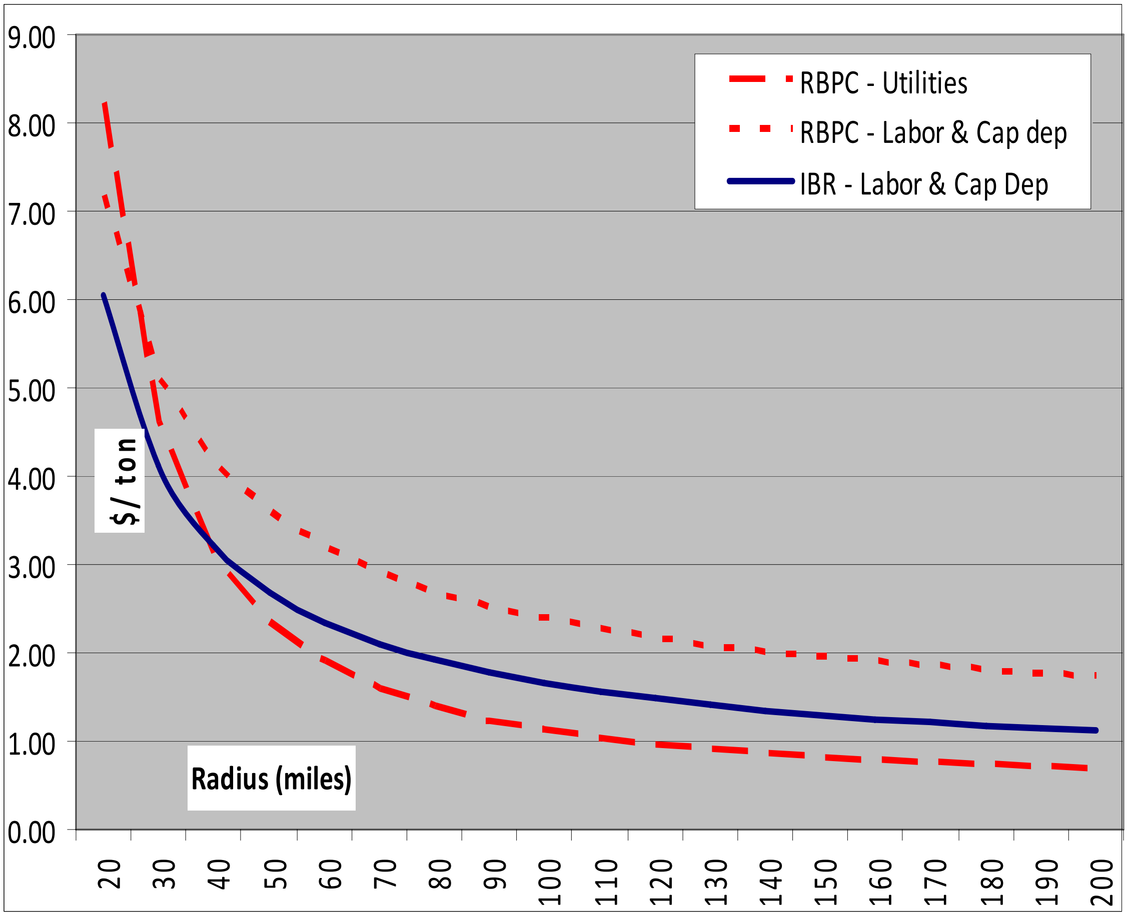


Figure 20: Total Capital Required ($/M-gal)

A RBPC system also must overcome transport costs associated with double depot charges and backtracking. Chapter 5 discusses these issues in depth. If an RBPC system is to produce ethanol at a lower MESP, these inherent structural cost differences must be overcome by transportation cost advantages, favorable regional characteristics and/or additional revenue sources from the intermediate product produced at the RBPC.

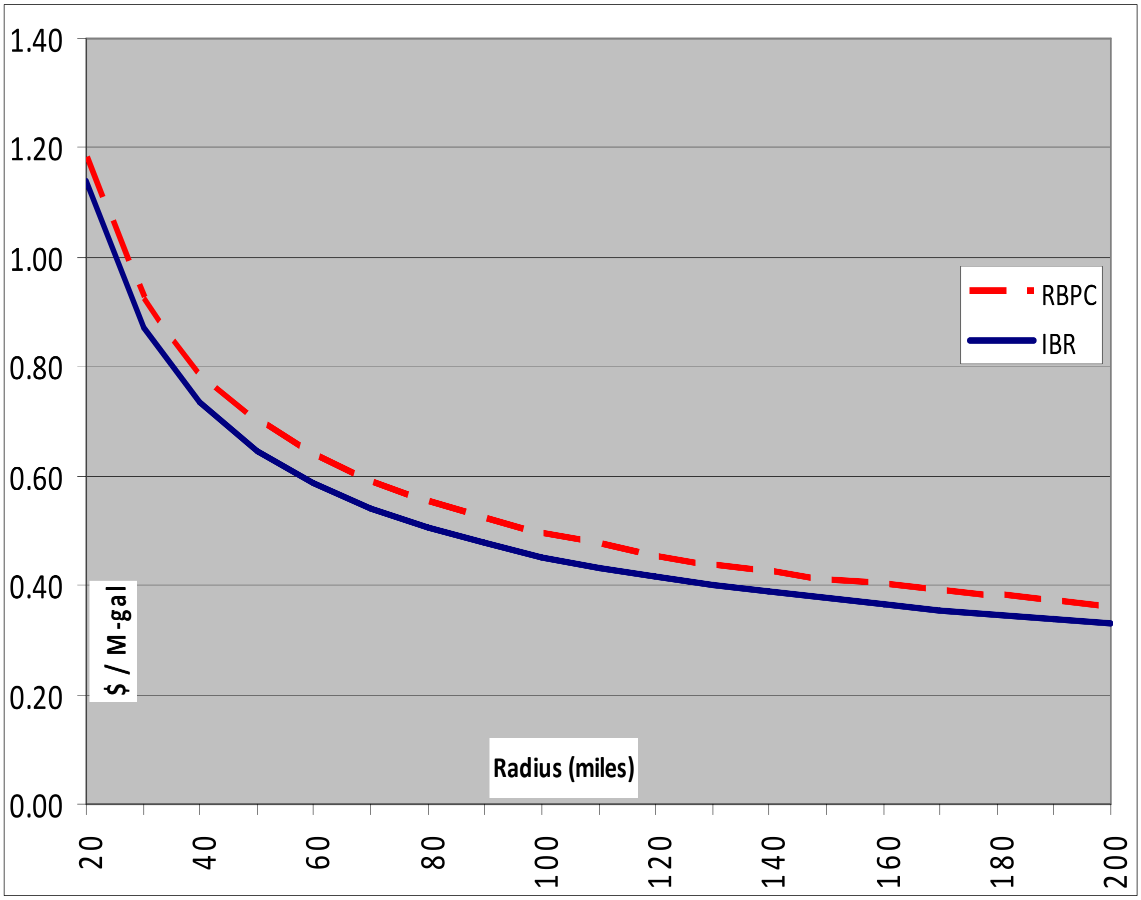


Figure 21: Facility Costs ($ / ton biomass processed)

6.8 Ceteris Paribas shocks

The above analysis raises the following questions. How do the cost curves shift with exogenous shocks to different choice variables? Is any single factor alone so critical as to make the RBPC system emerge as the dominant investment option over the IBR? Is this a regional factor, which would indicate that RBPCs might emerge in specific regions? Or, is it a technology factor, which indicates that the firm itself may have the ability to alter the optimal choice paradigm? Key regional characteristics and technology factors are varied independently of other factors; the effects to the LRAC curves are examined; and, investment agent choices are re-examined.

Regional Factor: Biomass Yield

Biomass yield is a function of biomass productivity (tons per year per acre), percentage of regional land in biomass production, and participation of these lands in the biomass production. Three additional cases with differing biomass yields are considered.

Lower biomass yields will shift the LRAC functions upwards for both systems due to higher transportation costs and smaller facilities in equivalent catchment areas. Higher biomass yields will be a positive shock the cost structures, lowering the MESP at every catchment radius. Neither shift will alter the investment choice outcomes. The IBR is still the dominant choice for the agents. However, lower yields push curves closer together (i.e. RBPC minimum MESP approaches IBR minimum MESP), which lends some credence to argument that depot system increases inclusion of lower productivity, more remote biomass producers. Yields alone cannot create equivalence or a paradigm shift. Figure 22 show the shifts corresponding to the three cases outlined here.

	Base	Energy Cane	Switchgrass	Stover
Biomass production (tons/acre/yr)	5.00	10.00	7.00	2.00
% of Agricultural land in region	60%	75%	75%	75%
Participation of biomass producers	100%	75%	80%	75%
Biomass Yield (tons/acre/yr)	3.000	5.625	4.200	1.125

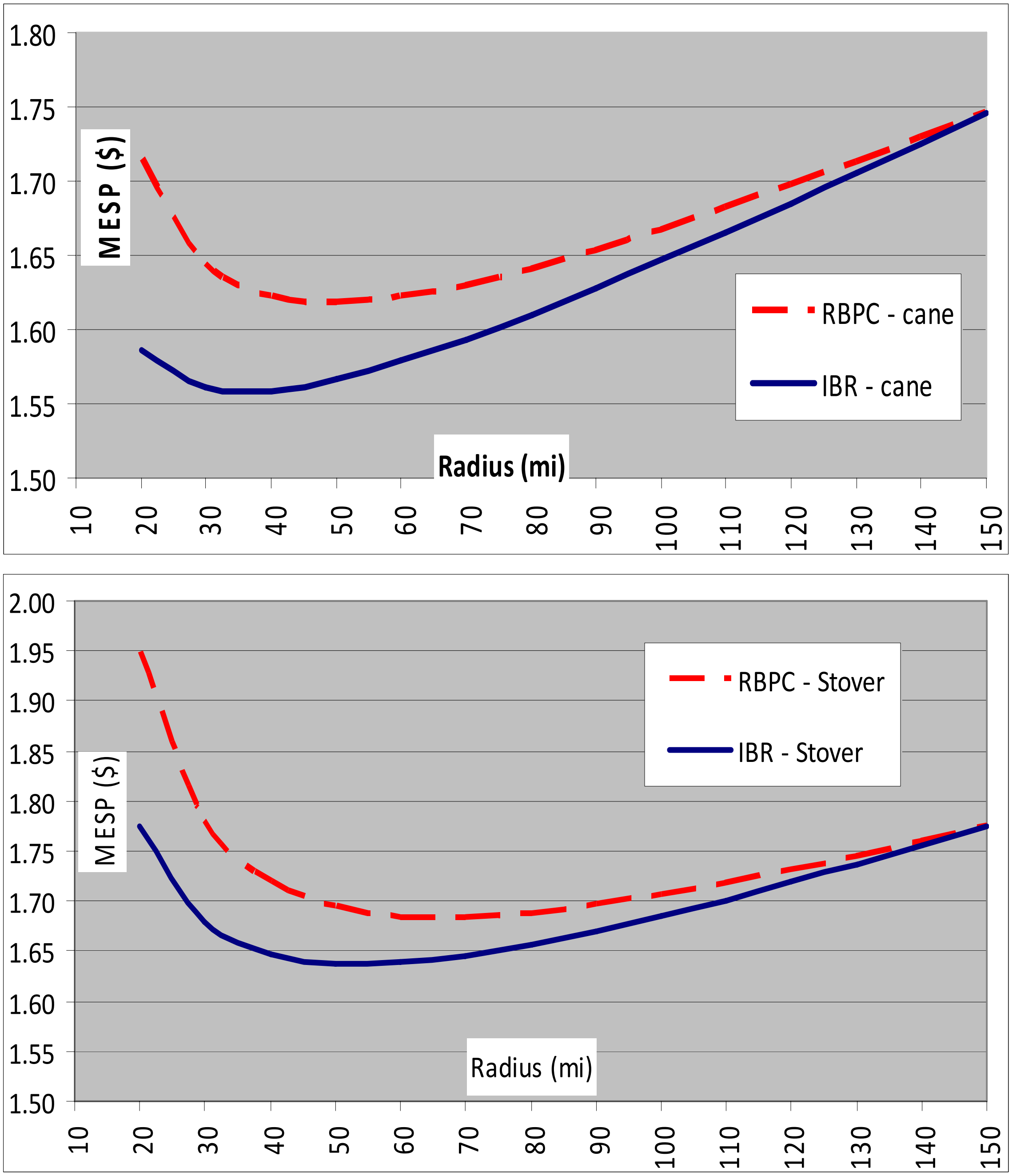
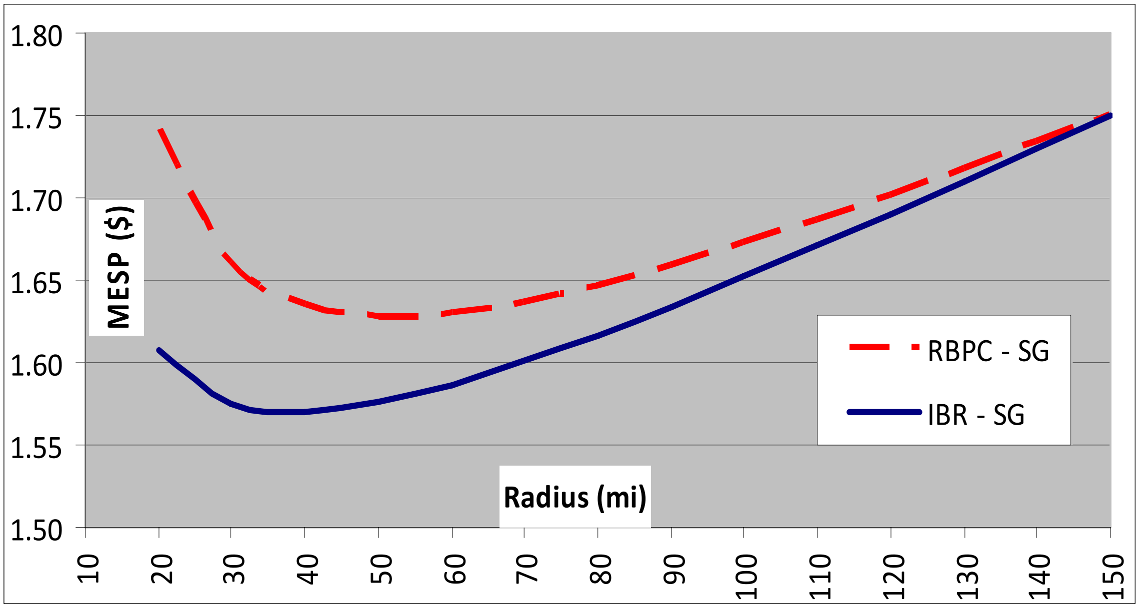


Figure 22: Biomass Yield Effects

Figure 22: (Cont'd)



Regional Factor: Rural-ness

The transportation analysis (Chapter 5) demonstrated that in more rural regions, with winding and rough roads, the distance traveled and cost of transporting a ton of biomass under the two systems could be equal, or even less with a RBPC chain. The 'Rural-ness factor' is defined as

$$F(R, \tau_{High}) = \tau_{High}*(R - 0.3790) - (R-1)$$

where τ_{High} is the tortuosity of rural roads and R = % rural roads in the region.[96,97] The base case rural-ness factor = 0.830. This regional factor is varied over three additional cases – 1.00, 1.25 and 1.50 - to examine the effect on the investment agent decisions,

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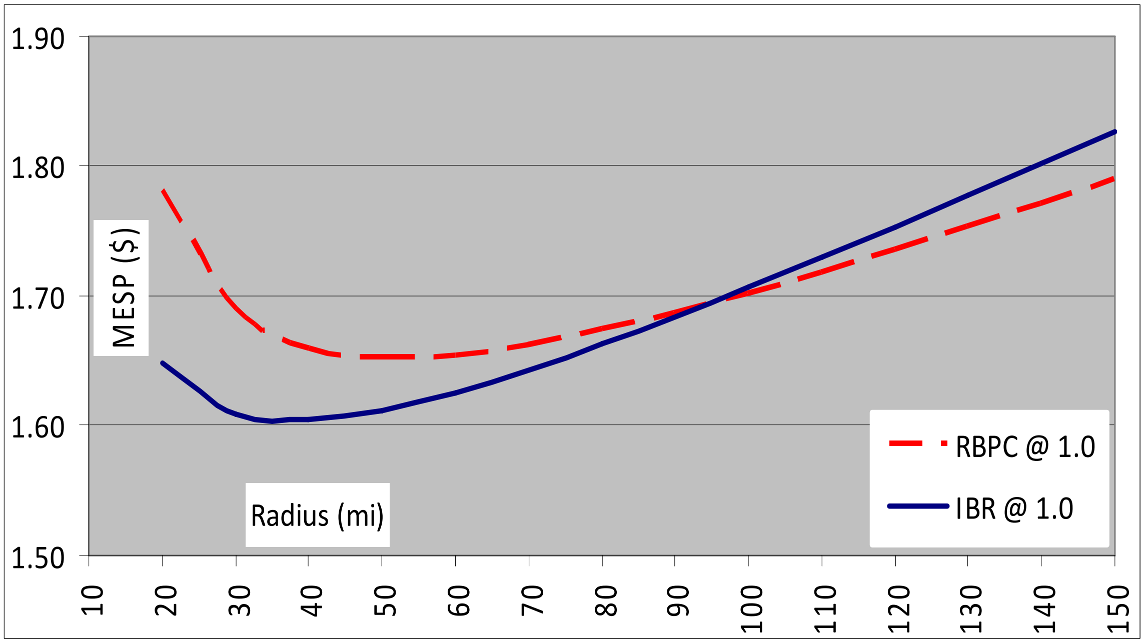
96 τ_{Low} is set @ 1.0 so τ_{High} is a measure of relative tortuosity

97 This exact specification only holds for 7 hexagonal RBPCs vs. one circular IBR. For the more general specification, refer to Chapter 5

MESP, MES and radius of indifference. The impact of a more rural environment on the long run average cost curves for the three cases are shown in figure 23.

Rural-ness factor = 1.0



Rural-ness factor = 1.25

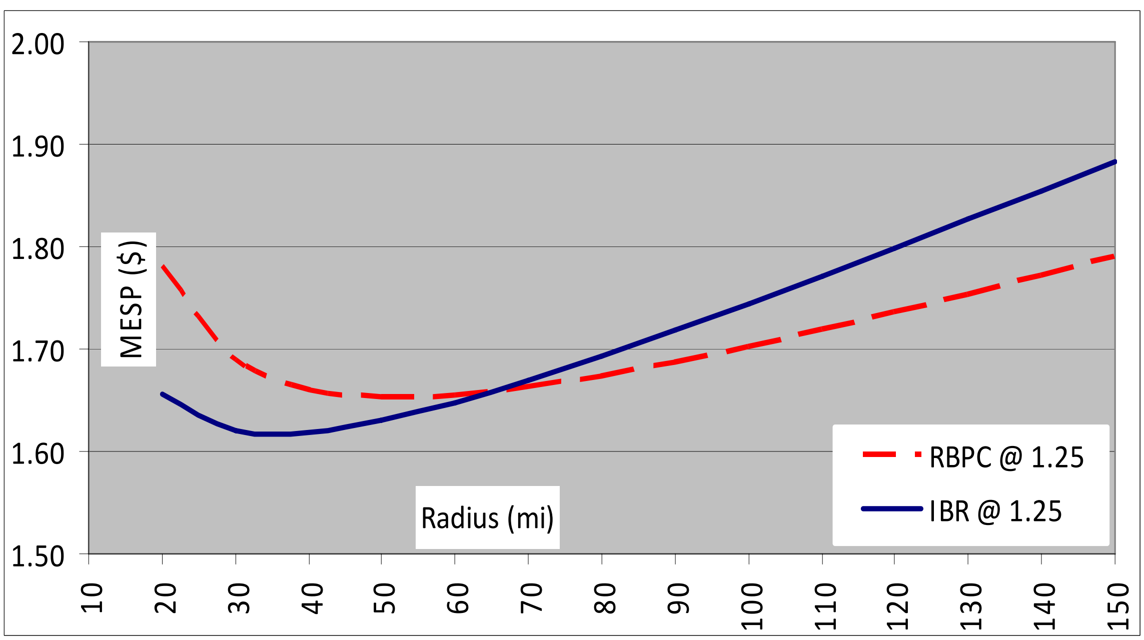
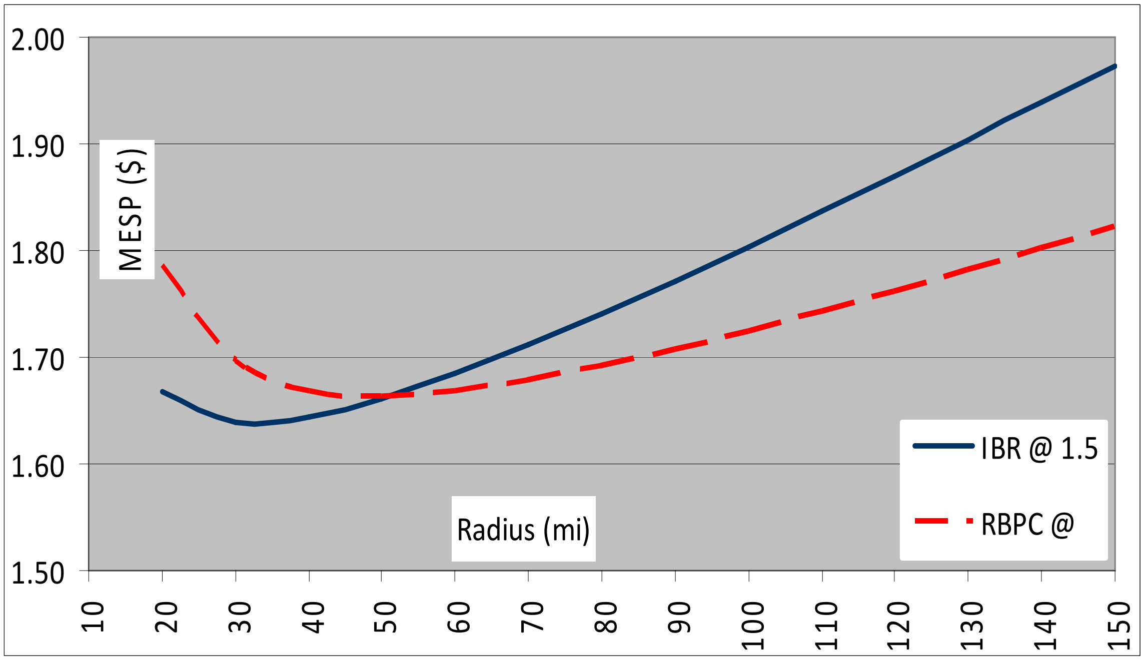


Figure 23: Rural-ness Impacts on MESP

Figure 23 (Cont'd)

Rural-ness factor = 1.50



Increased rural-ness adds costs to either system, creating an upward shift of the LRAC curves. The magnitude of the impact is less for the RBPC than for the IBR, pushing the radius of indifference inward and lessening the gap between minimum MESPs. The RBPC chain would not produce ethanol at a lower cost until the rural-ness factor exceeds 1.92, which would require a τ_{High} value greater than 3.0 in an entirely (100%) rural region.

Profit maximizing actors would continue choose one or multiple smaller IBRs at its MES.

Transportation Cost Structure

Transportation cost structures are likely to be firm specific, and different from other firms' structures. These differences can arise from any combination of bale types, regions, equipment choices, operating procedures, firm cost allocations, etc. As demonstrated in the transportation analysis, the RBPC system can actually prove to be less distance intensive than the IBR system, but will always shoulder double depot charges. Transport cost structures where the fixed cost to variable cost ratio is lower are more favorable to the distributed nature of the RBPC than to the centralized nature of the IBR.

The distance fixed and variable cost estimates (DFC & DVC) from two different biomass cost models are substituted for the base values to assess the effects of this variable on the LRAC of the two systems. Both sets of values are more favorable to the RBPC, with lower depot charges and higher variable costs. The effect of these alternate cost structures are shown in Figures 24 (Marrison and Larsen, 1995) and 25 (Kumar, 2004).

Both sets of alternate transport constants add cost to both systems; and, once again, an upward shift of the LRAC curves is witnessed, corresponding to a higher MESP required before any investment will occur. The arrows show the relative magnitude of the impact to each system at the same radius. The IBR system is impacted more than the RBPC from the higher per mile cost.

Model	DFC	DVC	DFC:DVC
Base case	5.35	0.163	32.82
Kumar (2004)	4.84	0.214	22.62
Marrison & Larsen (1995)	3.36	0.3244	10.36

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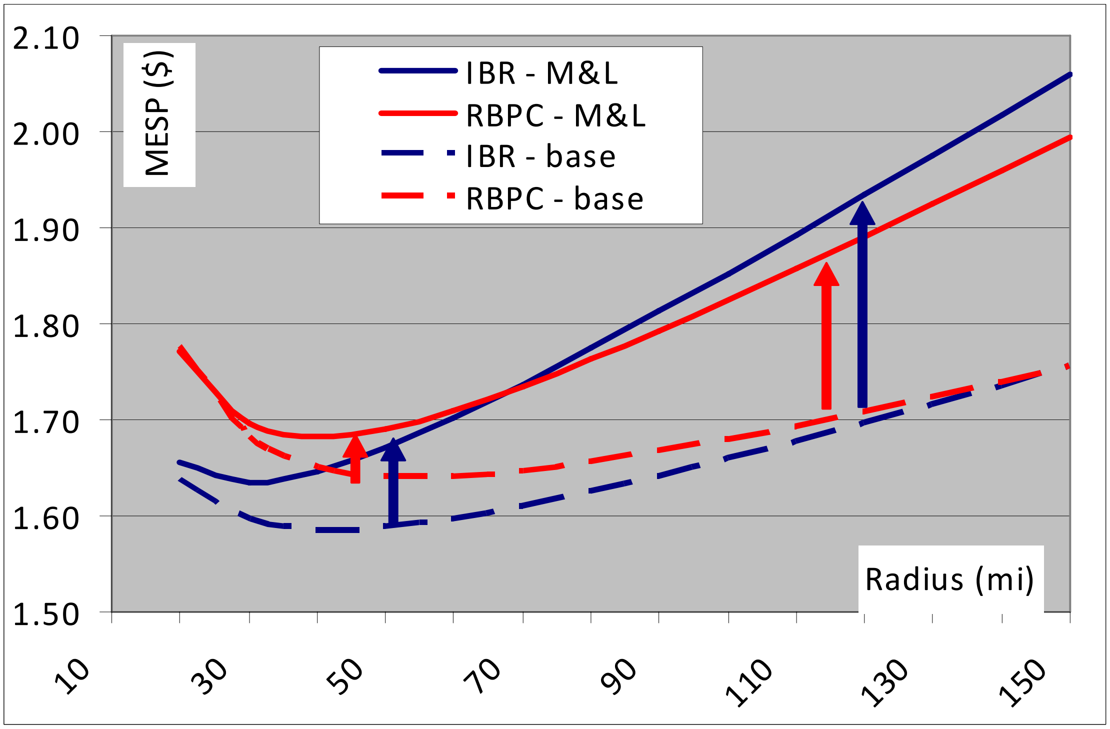

Figure 24: Low DFC/DVC Ratio Case

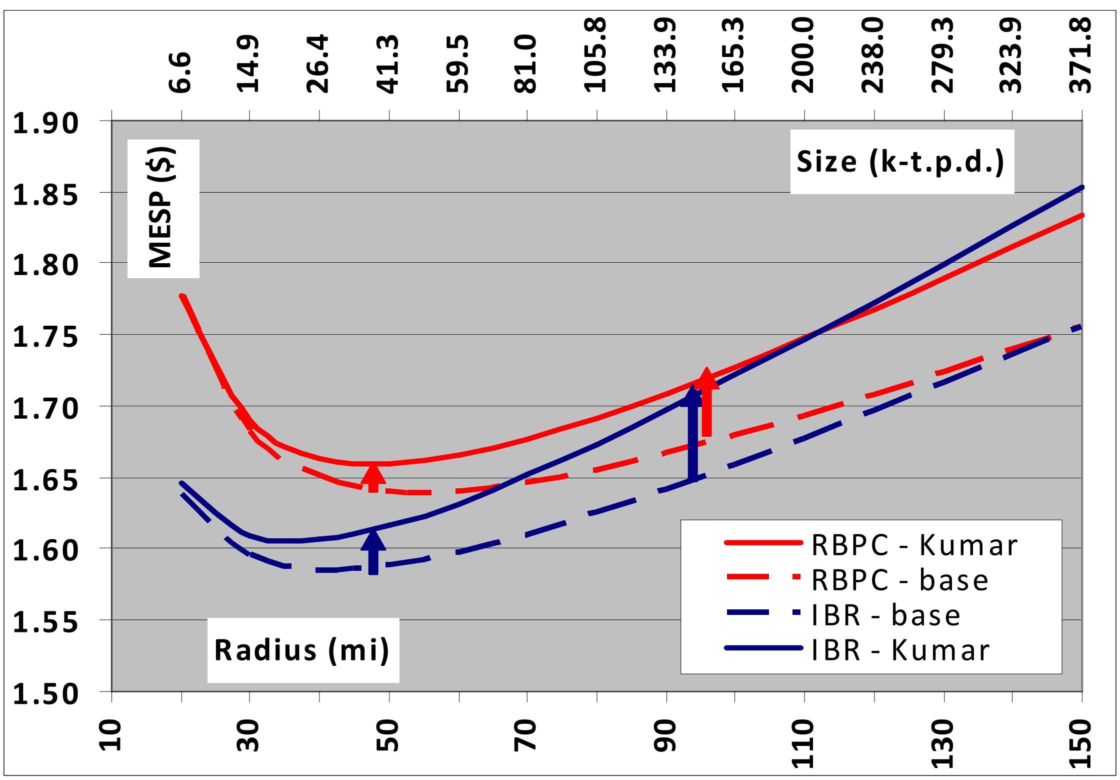

Figure 25: Medium DFC/DVC Ratio Case

In both cases, the higher DVC creates a LRAC for the IBR that becomes much steeper once the minimum efficient scale has been reached, as the marginal cost per gallon becomes increasingly larger due to the necessity to transport the biomass larger and larger distances. This effect is mitigated under the RBPC system. The marginal cost per gallon does not increase as rapidly under the RBPC at longer distances due to the distributed collection and densification effects.

The multi-IBR at minimum efficient scale strategy remains the dominant choice

Densification

Increasing the density of the pre-treated biomass drives down the transportation costs under the RBPC system through less depot charges and fewer trips between the RBPC and the bio-refinery. Increased densification could potentially alter the decisions made by the investment agent because shocks will shift the cost curves of the RBPC downward without impacting the IBR costs. Cases with pre-treated biomass density of 16.0, 24.0 and 27.0 pounds per cubic foot are analyzed. The LRAC curves from these different cases are shown in figure 24.[98] As a comparison, the bulk density of shelled corn is approximately 45.0 Lbs / cu. ft.; of wood pellets approximately 42.0 lbs/ cu. ft.; and, of corn stover pellets approximately 37.5 lbs/ cu ft.

When pre-treated biomass density of 27.0 lbs. / cf. is reached, the dominant outcome of IBR as the preferred choice in most cases is challenged. The RBPC system can produce ethanol at a lower minimum MESP at a larger MES.

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[98] Additional capital and operating costs associated with increased densification were not modeled.

Regional monopsonist agents have control over the entire regional biomass supply, so must consider the type-specific optimal strategy for tiling the region. A multi-IBR investment strategy must be done in a step-wise manner. Each facility is identical at 27.8k capacity. Variations from this design are no longer at MES. To cover a region, the agent must construct units in 27.8k increments. The catchment area corresponding to RBPC at MES is 2 ½ times the area of the catchment area corresponding to the IBR at MES. As agents cannot deploy 2 ½ IBRs at MES, the choice set for regional monopsonists becomes two 27.8k IBRs, three 27.8k IBRs and a single 68.8k RBPC system. Key results for these three options are in Table 25 and LRAC curves are in shown in Figure 26.

The single RBPC strategy out-performs the dual IBR strategy in many performance metrics – more ethanol, lower capital per gallon and greater return upside; but, has slightly higher upfront capital and higher conversion costs. A pure profit maximizing agent will opt for the choice with lower cost structure and potential upside, which is the RBPC.

Table 25: Agent Choices in Low Density Ratio Case

	IBR (x 2)	IBR (x 3)	RBPC
MES Radius	41	41	64.5
k-tons per day	55.6	83.3	68.8
MESP @ MES	1.5852	1.5852	1.5847
Capital ($M)	2,157	3,236	2,262
Capital / gal	1.178	1.178	0.999
Conversion / gal	0.665	0.665	0.691
Ethanol (M-gal/yr)	1,831	2,746	2,266
NPV @ $1.625	$0.80 B	$1.21 B	$1.08 B
NPV @ $1.675	$1.72 B	$2.59 B	$2.28 B

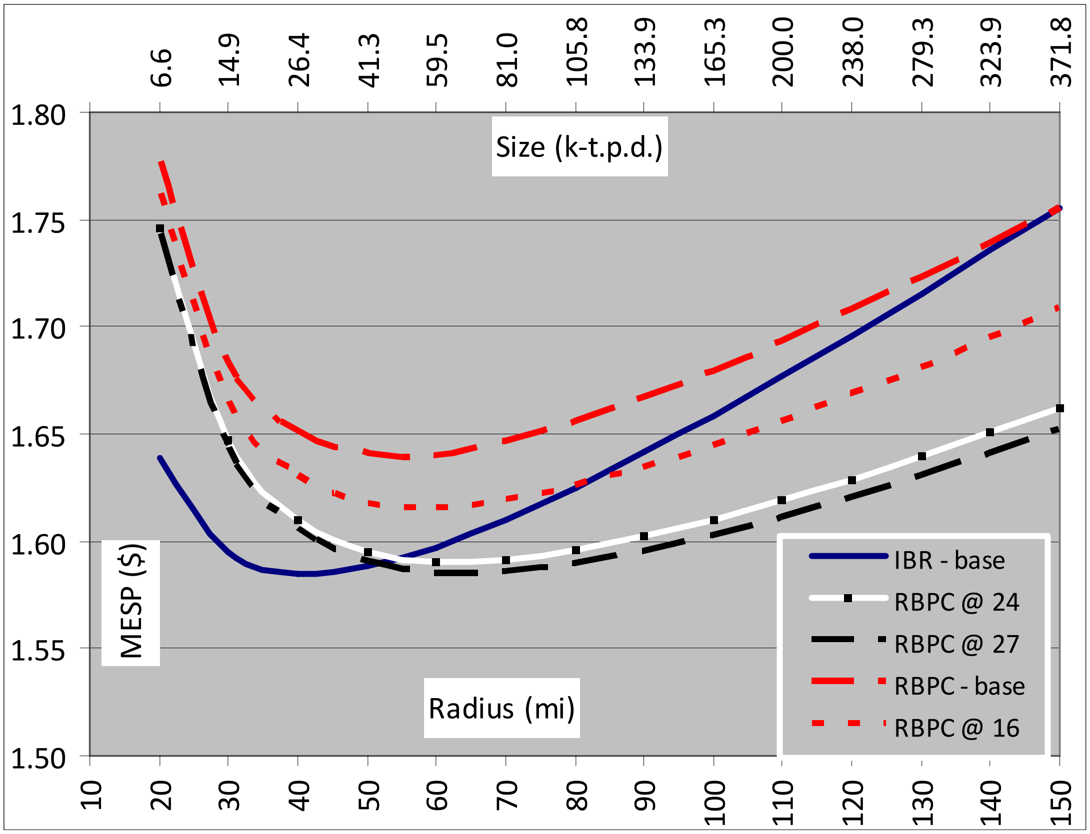

Figure 26: Densification Shocks

The choice becomes less clear cut when considering a three IBR strategy. While the RBPC operates at a lower cost structure, lower total capital and lower capital per gallon; the three IBRs are more efficient on conversion costs, produce more ethanol and provide additional upside. The lower cost structure of the RBPC versus the higher upside potential of the three IBRs necessitates some metric ranking by the agent. The higher conversion cost per gallon at the RBPC dampens potential upside at higher prices. Expected wholesale price becomes a critical factor in the agent's choice, not just the magnitude, but the certainty of the estimate. Every incremental increase in ethanol price will generate more profit for the IBR system than for the RBPC. This measure is the change in profit with change in price (∂∏/∂Price) not, 'marginal profit' which is the change in profit per change in quantity (∂∏/∂Q). If the agent is very confident it will consistently receive a rack price higher than $1.5852, it will be more comfortable putting the higher capital required for the IBR at risk in return for the higher returns. On the other hand, if it lacks confidence in the estimate of future prices, it may opt for the RBPC putting less capital at risk and capitalizing on the lower cost structure.

A profit maximizing agent facing competition might ex-ante try to improve its position by locking up access to all the biomass in the region; thus becoming the regional monopsonist. In this case a RBPC at a larger catchment area is the optimal option for the profit maximizing agent, so there is incentive to try to lock up the regional supply. If an agent is successful in an ex-ante monopsony play, then the decision process becomes that of the regional monopsonist discussed earlier. If no single agent can create a monopsony position, a pattern of smaller IBRs at the MES is likely to emerge, with the biomass producers selling to the nearest refiner. If successful in becoming the regional monopsonist, the RBPC would emerge.

Increased densification can overcome the MESP gap and make the RBPC as efficient as an IBR. A firm employing a transport model that relies on trucks to move the pre-treated biomass cannot, however, realize this advantage. Due to road regulations regarding weight and capacity limits; current truck-trailer technology; and, container volumes, additional densification does not lead to decreased depot stops nor reduced trips. 12.0 lbs./cf. is the maximum density that can be realized when employing truck transport. If the pre-treated biomass can be densified and transported in a manner that does meet regulatory constraints, it will reduce loading, unloading and number of trips. Utilizing train transport with highly densified biomass from the RBPC to the bio-refinery might accomplish this.

Transport by rail

Transporting the pre-treated biomass by rail car is not constrained by weight limits. This allows for a highly densified product to be transported via a transport mode characterized by low variable cost components. There will be fewer depot charges as fewer cars are required, and each car can carry a larger quantity of pre-treated biomass. It is assumed that any RBPC utilizing rail transport will have train access and will consider this when siting its location.[99]

The densification technology utilized is pelletization. Pelletization can increase the bulk density of the pre-treated biomass to 45 lbs. / cu. ft. This comes at a cost, both capital and operational. These additional costs are built into the DSS when rail transport is considered.[100]

If the transport savings realized can be greater than the inherent systemic differences plus the increased cost of densification, than a RBPC employing multi-modal transport could out-perform an IBR. Figures 26 through 28 show that this multi-modal configuration does improve the LRAC structure of the RBPC, but not enough to alter the decisions of the investment agents considered under any of these regional specifications.

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[99] Cost of any required rail spurs have not been built into the DSS

[100] Pelletization capital and operating assumptions are based on discussions with Dr. Bryan Bals, MBI

Figure 27 is the base case; figures 28 and 29 are low biomass yield and high rural-ness cases respectively.

Employing this transport method does create cost structures for the RBPC that nearly meet the lowest MESP of the corresponding IBR. The cost of the additional densification increases the operating and capital cost gap between the two systems, which dampens the positive gains from transport savings.

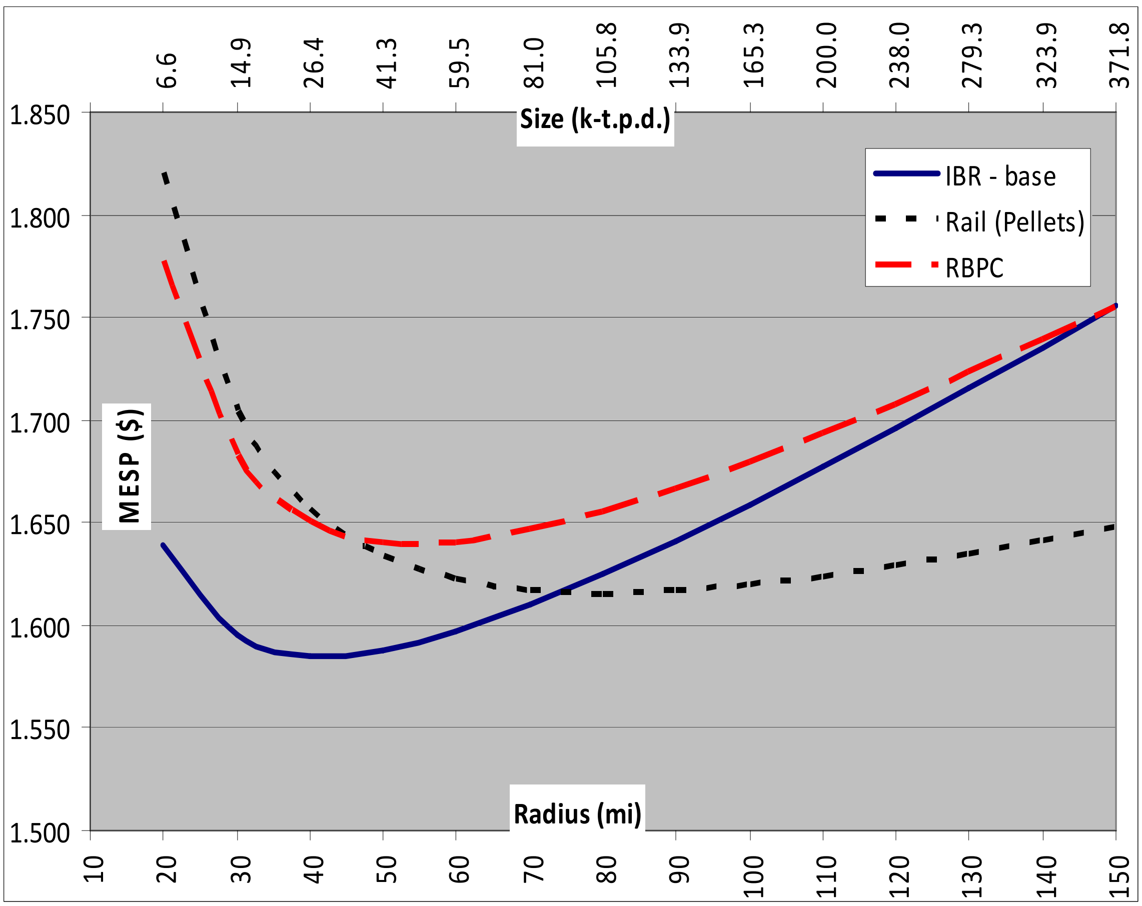

Figure 27: Base Case with Truck-rail RBPC

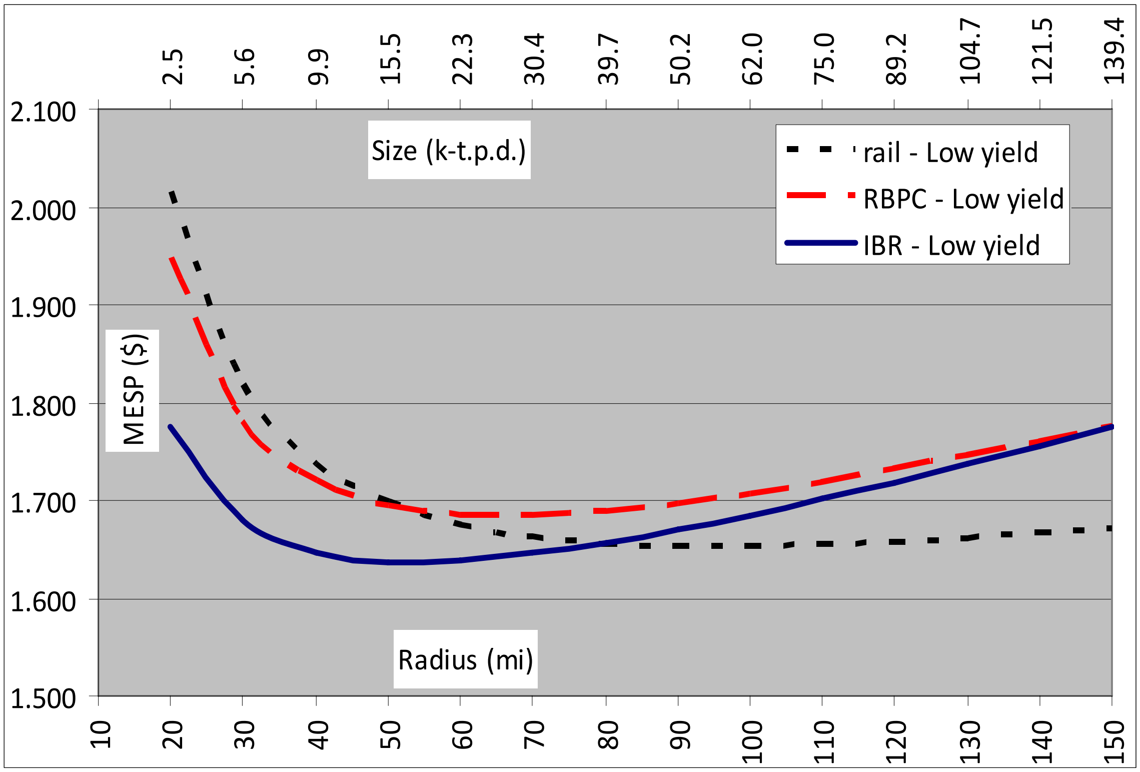

Figure 28: Low Yield with Truck-rail RBPC

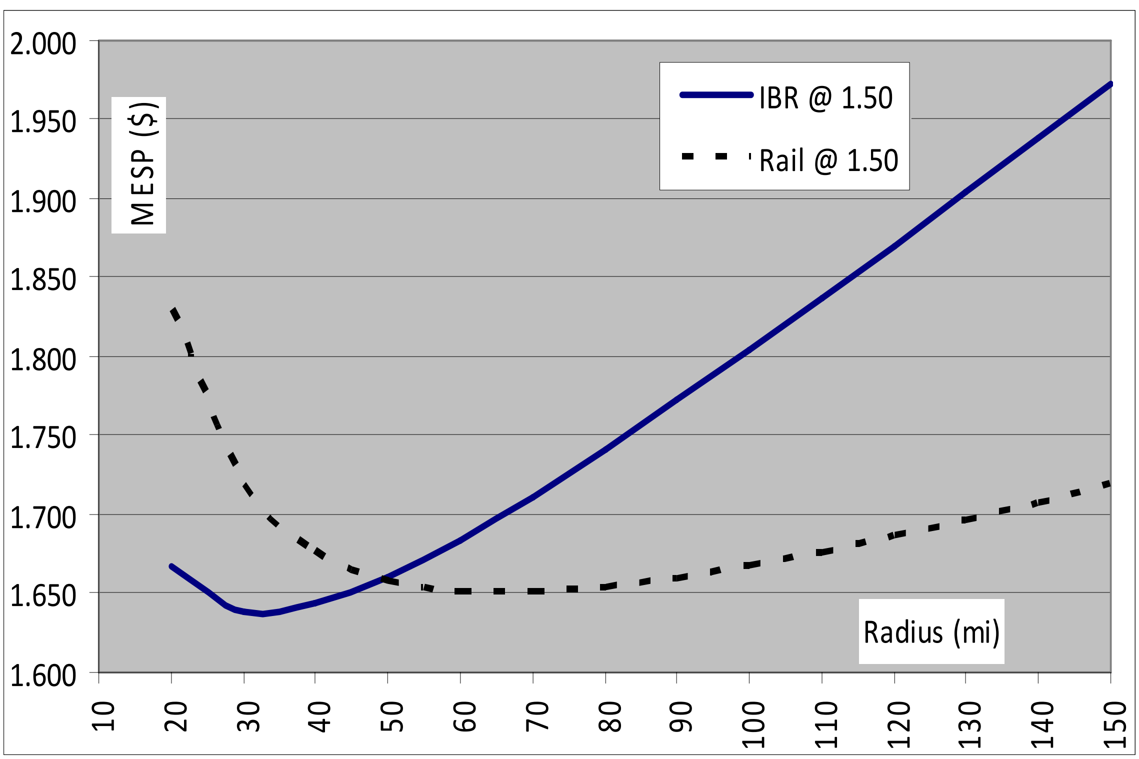

Figure 29: Rural-ness factor of 1.50 with Truck-rail RBPC

Regional Factor: Ruminant Feed Market

The potential to sell a higher valued intermediate product from the regional processing facilities is important in overcoming many of the transactional barriers facing the cellulosic ethanol industry – mutual hostages, avoidance of the holdup problem, etc. In addition, the ability to sell the intermediate product at a price per gallon equivalent that is higher than the ethanol rack price[101] subsidizes bio-ethanol production. Graphically, the effects of having a significant ruminant feed market (16.8% & 25%) are shown in Figure 30. Table 26 summarizes key data for the options facing the investment agent under these two cases.

The independent variable in this case is not the radius of collection, but rather the volume of ethanol produced. If the RBPCs choose to sell into the ruminant feed market, less biomass is converted to bio-fuels. Making the dependent variable ethanol volume forces the stripped down bio-refinery and the integrated biorefinery to be of the same productive scale, allowing for a more 'apples-to-apples' comparison for the profit-maximizing agent.

As with densification, the existence of an alternate marketing channel shifts the RPBC cost functions downward, while not impacting the IBR. When the feed market is large enough, it can alter the decision paradigm, creating a scenario under which the RBPC system would emerge as the dominant choice for certain types of investors.

[101] The ruminant feed 2012 price estimate is $115.637 / ton

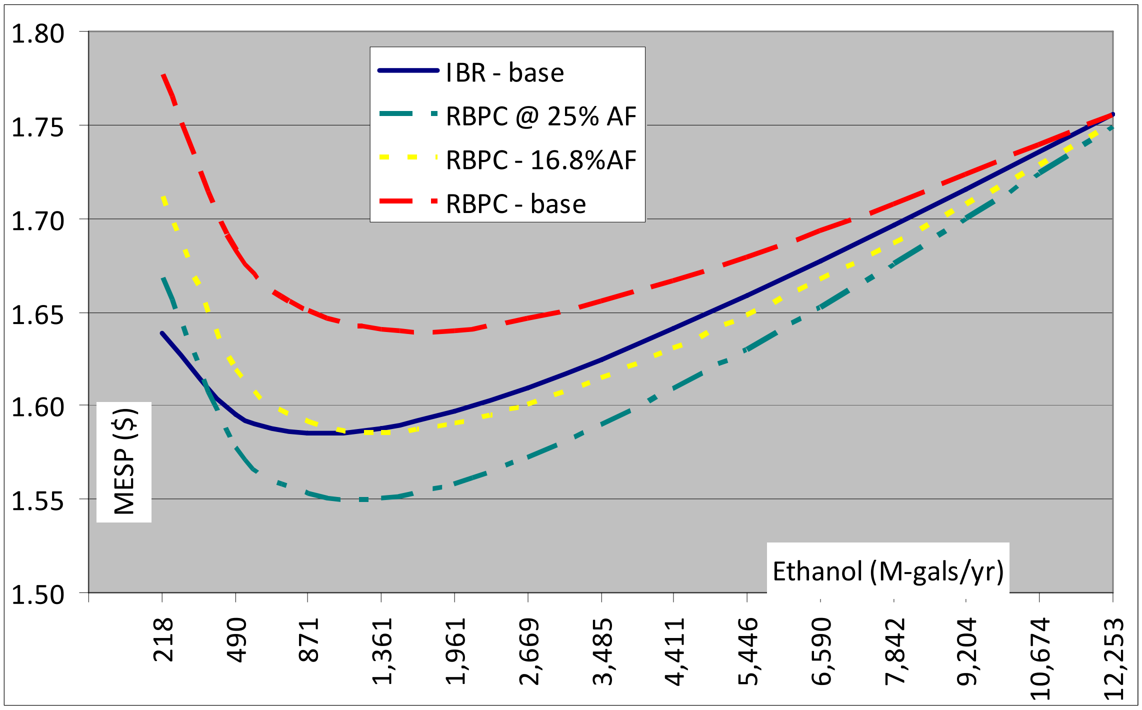

Figure 30: Ruminant Feed Market Impacts

Table 26: Agents' Choice Set in Ruminant Feed Cases

	IBR (x 2)	RBPC w/ 16.8% AF	RBPC w/ 25% AF
MES Radius	41 (each)	54.8	57.7
LCB (M-tons/yr)	20.3	18.1	20.1
MESP @ MES	1.5852	1.5852	1.5499
Capital ($M)	2,157	1,622	1,667
Capital / gal	1.178	1.191	1.225
Conversion / gal	0.665	0.736	0.757
Ethanol (Mmgal/yr)	1,831	1,361	1,361
NPV @ $1.600	$0.310B	$0.245 B	$0.806 B
NPV @ $1.650	$1.273B	$1.015 B	$1.539 B

The profit motivated investment agent faces a choice between two smaller IBRs, each operating at minimum efficient scale of 915.5 million gallons per year; and, a single, larger RBPC system at MES of 1,361 million gallons per year.

The least percent of pre-treated biomass sold as ruminant feed that equilibrates the two minimum MESPs is 16.8%; which corresponds to 433,664 tons of ruminant feed sales per year, enough to feed approximately 95,000 cows[102]. Even under these conditions of equal minimum MESP, the multi-IBR strategy would be the choice for a profit maximizing agent. It uses more biomass, produces more ethanol, has lower capital and conversion costs per gallon, and has greater upside potential with increased MESP.

In cases where ruminant feed sales exceed 17%, the purely profit motivated monopsonist would opt for the RBPC as its LRAC structure out-performs the IBR at every level, even though the subsidy received by RBPC from animal feed is muted at higher ethanol prices (i.e. the price gap between higher & lower valued product decreases).

This paradigm shift is easier to realize with truck-rail transport. At only 11.3 % of pre-treated biomass being sold as higher valued ruminant feed, the RBPC system and IBR system are equilibrated in terms of MESP. Any quantity of feed beyond this level would tip the scales in favor of the RBPC (Figure 31).

[102] This is at 100% of traditional feed replaced with ruminant feed. As a reference, the 17 county Michigan case study region (Chapter 7) has 110,000 cows. So, in that region this quantity could replace 2/3 of annual feed consumption

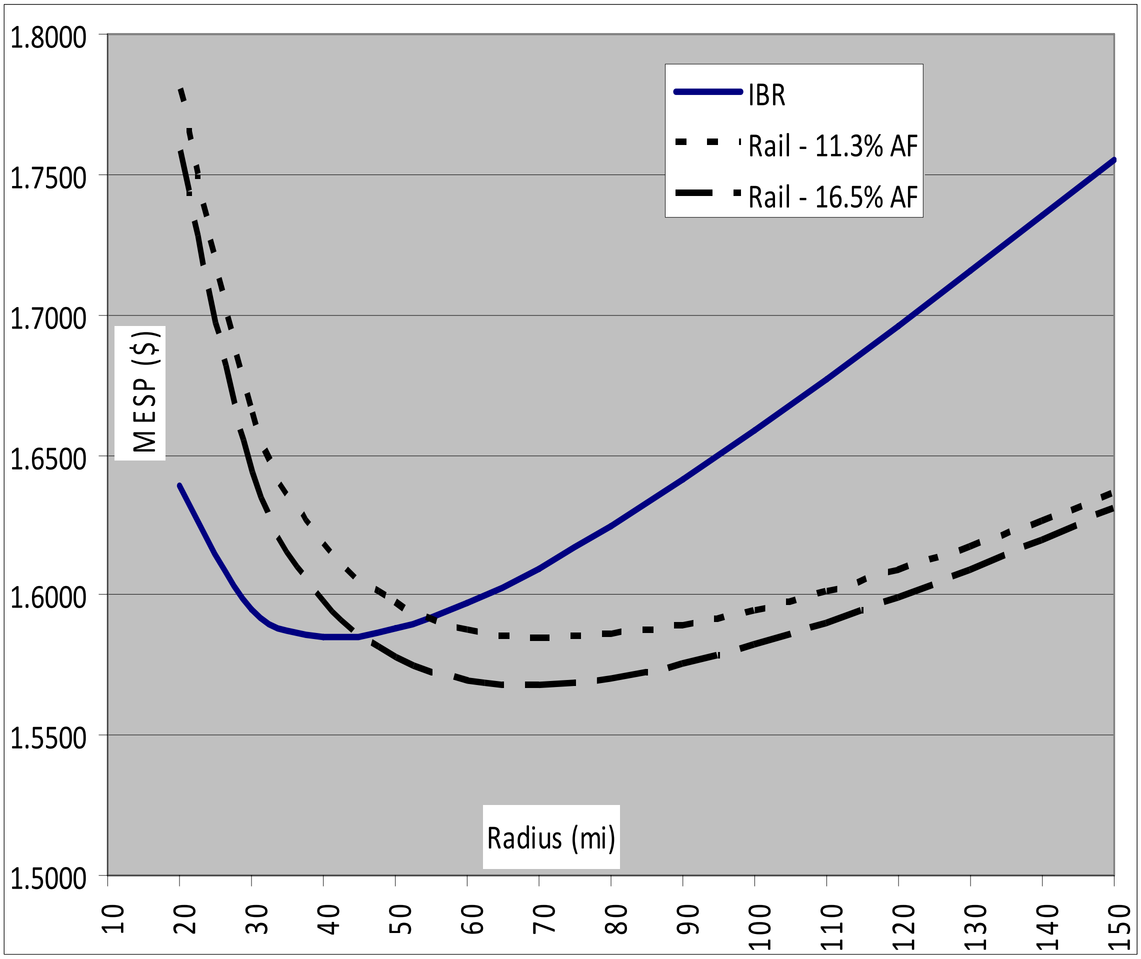

Figure 31: Ruminant Feed Effects with Truck-rail RBPC

6.9 Multiple Factor Effects

Variations from the base case would not, likely, happen in isolation. A technology improvement, such as additional densification, could happen without other factors being different; however, each region will have its own specific set of characteristics that differ from other regions. Each agent will have its specific technology. Transportation variables and modes will vary from the base case. Combinations of factor shocks can create scenarios where the MES of the RBPC is competitive with the multi-IBR strategy, without any individual factor being radically altered.

Regional Characteristics

The region's inherent characteristics, not firm factors such as technology or transport, are varied. The region considered is rural (rural-ness factor = 1.255) with low biomass yields (biomass yield = 0.28). The resulting LRAC curves are shown in figure 32.

This is a relatively biomass poor region which necessitates large catchment areas to realize MES, with low volume minimum scales: 7,591 tons per day for IBR; 12,549 tons per day for RBPC with truck-truck transport; and, 22,310 tons per day for RBPC with truck-train transport. The choice set faced by the investing agents does not include a multi-IBR strategy. The choices are one IBR @ 7.6k tpd, a truck-truck RBPC @ 12.5k tpd, and a truck-train RBPC @ 22.3k tpd. Table 27 shows the key choice metrics.

Agents would opt to employ the truck-train RBPC at its MES. It utilizes more biomass and produces the most ethanol at the lowest cost structure with the greatest upside potential (measured either in absolute terms or ROE).

This case is important. It upholds one argument that proponents of depot systems have promulgated, that RBPCs can increase the size of refineries in marginal lands in a cost effective manner, thereby producing more bio-ethanol. The inherently higher conversion costs and total capital in a de-coupled system are overcome through the combination of savings in transportation costs and, the capital savings per gallon, which are realized scale economies (i.e., either a 4.5 or 8 million gallon de-coupled biorefinery gains scale economies over a fully integrated 2.8 million gallon biorefinery).

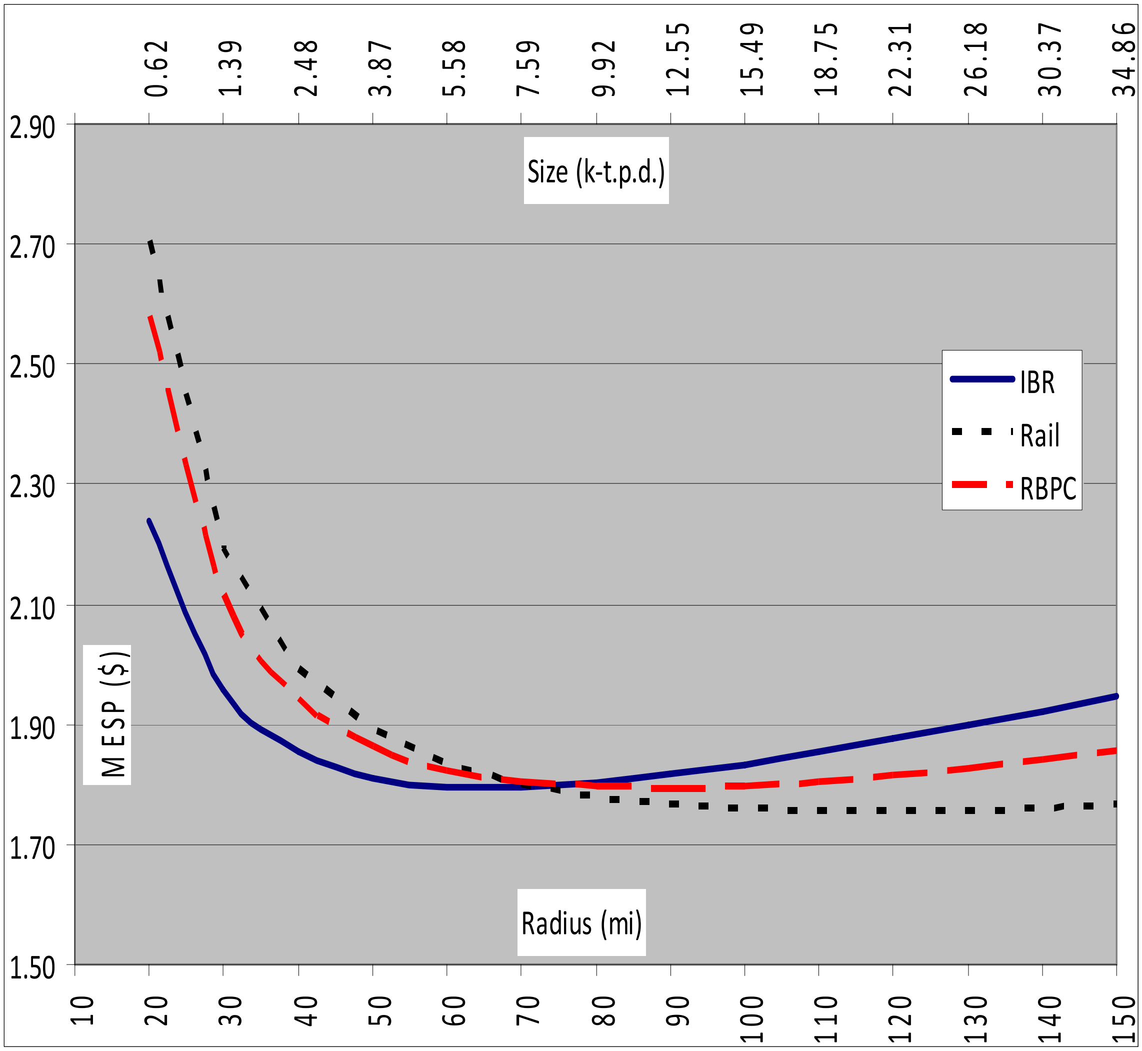

Figure 32: Multi-regional factor effects

Table 27: Agents' Choice Set in Multi-Regional Factor Case

	IBR	RBPC - truck	RBPC - rail
MES Radius	70	90	120
LCB (M-tons/yr)	2.77	4.58	8.14
MESP @ MES	1.7965	1.7930	1.7550
Capital / gal	1.771	1.584	1.717
Conversion / gal	0.693	0.725	0.717
Ethanol (Mmgal/yr)	250.2	413.6	735.2
NPV @ 1.90	255.4	468.4	1,094.2
ROE @ 1.90	26.3%	32.4%	34.3%
NPV @ 2.00	472.0	843.1	1,731.6
ROE @ 2.00	32.6%	39.3%	40.8%

Regional Factors with technology factors

This case examines a region with still rather low biomass yields that are realized not from low biomass productivity (3.0 tons per acre per year), but rather due to the region being relatively non-agricultural with relatively low participation of biomass producers. It is still a relatively rural area, with rural-ness factor of 1.20. The firm has a trucking cost model with low DFC/DVC ratio. There is no ruminant feed market in the region. The RBPC with truck-rail configuration emerges as the dominant choice (Figure 33).

This case demonstrates that for a firm with low depot costs and higher variable cost trucking cost model, the RBPC can compete in somewhat higher yielding (biomass yield = 0.90), rural regions. The benefits to the RBPC of employing a truck-train transport system are obvious. The rural-ness adds distance to the biomass transport which assists the RBPC, as the variable cost component of total transport cost increases, the lower variable costs from higher density offset the other inherently higher RBPC costs.

In low yield, highly rural areas, the truck-rail RBPC emerges as a preferred option. With this RBPC favorable truck cost function, this result can hold for all very rural regions that have biomass yield of 2.340 or lower. Biomass yield of 2.340 can be attained by the combination of factors shown below[103].

[103] The percentages could be reversed as biomass yield is just the product of these three factors

Biomass productivity (tons / acre / yr)	3.00	4.00	5.00	6.00	7.00
% of Agricultural land in region	90.0%	73.0%	64.3%	57.8%	65.9%
Participation of biomass producers	90.0%	83.2%	75.6%	70.1%	52.7%

These are regions with lower biomass yields, although highly agricultural and with high levels of participation; or regions with higher biomass productivity, and less agricultural and participation of biomass producers. This case is presented graphically in Figure 34.

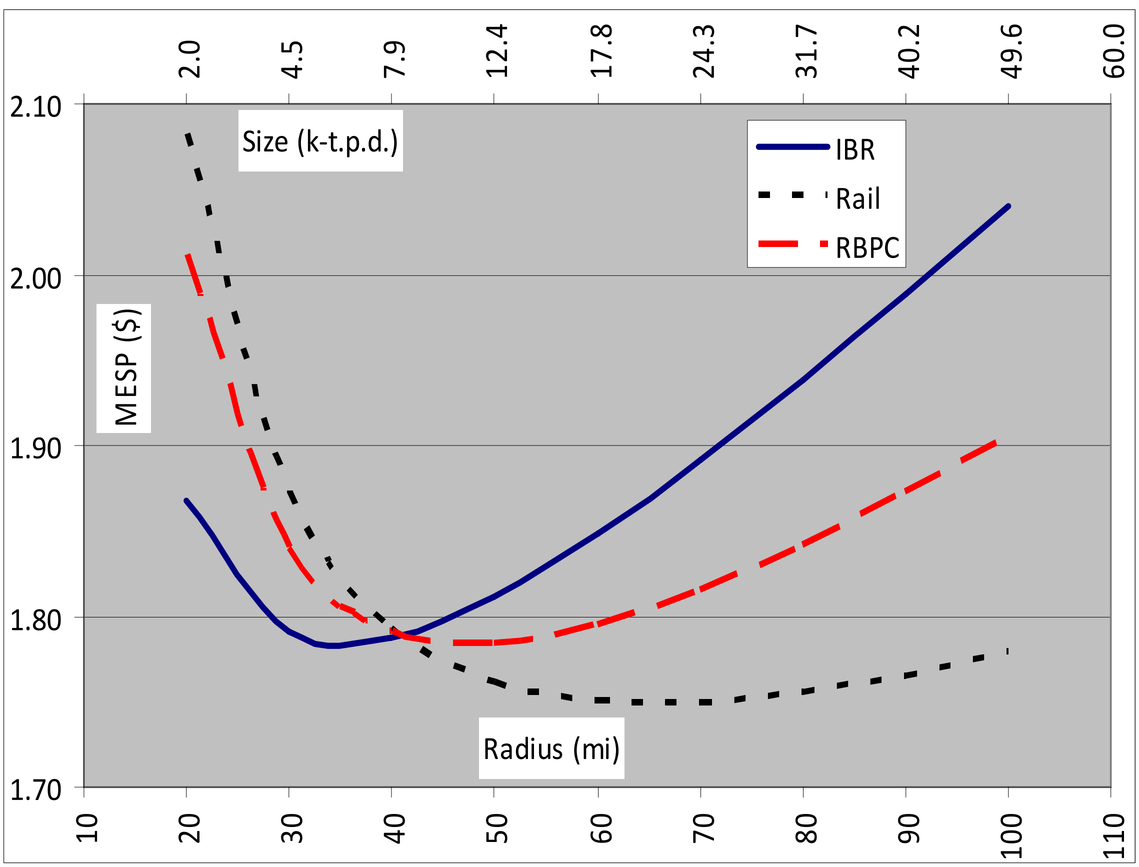

Figure 33: Multi-regional factor with Technology Impacts

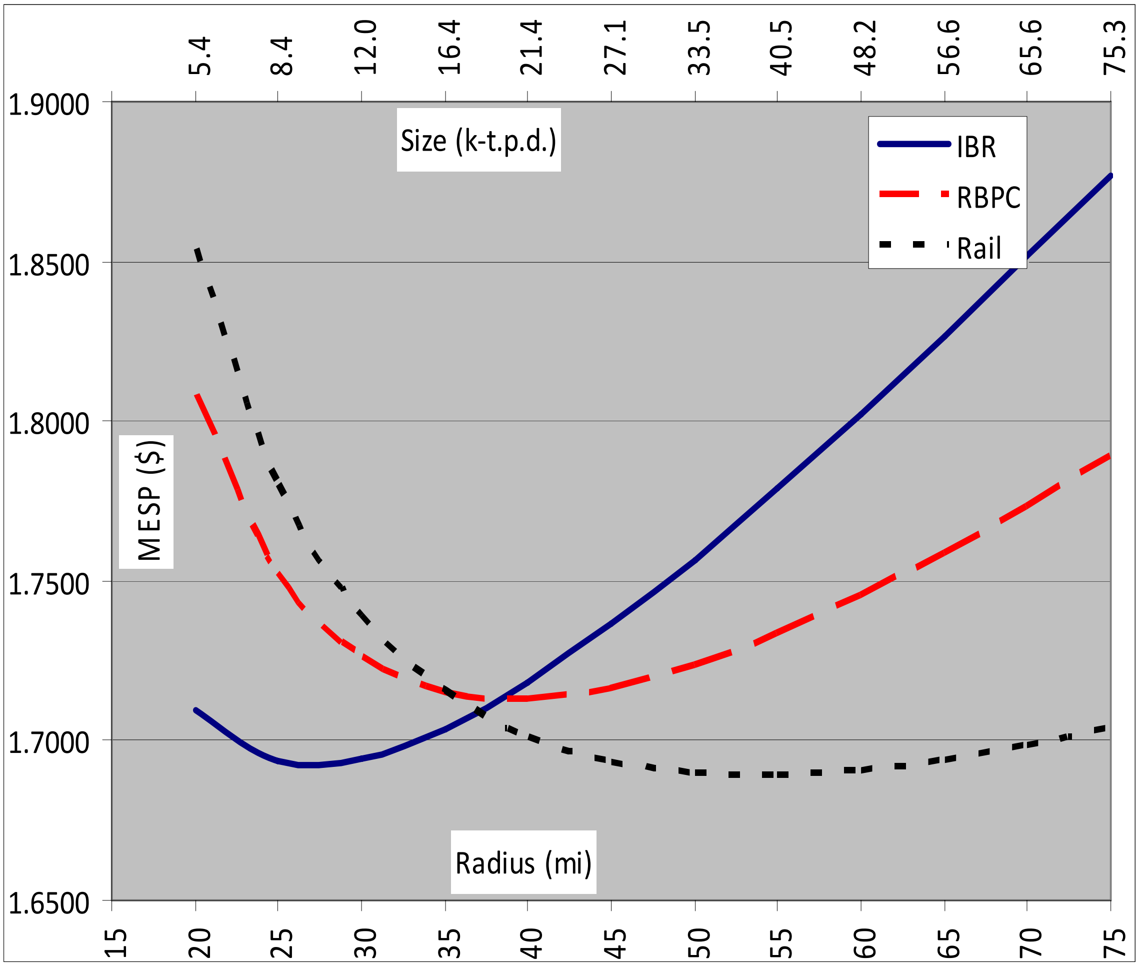

Figure 34: Low yield, high rural case

The profit maximizing agents are faced with a multi-IBR versus truck-rail RBPC choice. The key metrics are shown in Table 28.

The profit maximizing monopsonist will choose the truck-rail RBPC as it has lower LRAC structure, a larger MES, lower capital per gallon, lower total capital, higher NPV, and no worse than equivalent upside potential. A profit maximizing agent facing competition may not be able to lock up the entire biomass supply if it fails in ex-ante negotiating. It may be forced into a single or multi-IBR strategy.

Table 28: Agents' Choice Set in Low Yield, High Rural Case

	multi- IBR (x4)	Rail
MES Radius	28	54
Total Area	9,852	9,161
k-tons per day	42.0	39.0
MESP @ MES	1.6928	1.6887
Capital ($M)	2,196	1,486
Capital / gal	1.588	1.155
Conversion / gal	0.684	0.704
Ethanol (Mmgal/yr)	1,383.4	1,286.3
NPV ($ M) @ $1.700	107.2	168.1
NPV ($ M) @ $1.750	820.0	881.9

6.10 Multiple factors, with Ruminant Feed Market

It has been demonstrated that the existence of a relatively small, local ruminant feed market can shift the decision maker's IBR dominant paradigm to one that favors the RBPC. This is in absence of other shocks. At every combination of rural-ness factor and biomass yield, there exists a level of animal feed market at which the truck-truck RBPC and IBR have equivalent minimum efficient scale costs. At this equilibrating feed level, the truck-rail RBPC out-performs both other options. Table 29 presents a full range of combinations of rural-ness and biomass yield with corresponding equilibrating animal feed market and the rail MESP at the equilibrating level. This is with base case technology. One representative case is shown in Figure 35.

In high biomass yield, non-rural areas, the animal feed market needed to equilibrate the truck-truck RBPC and IBR is close to 20%. The animal feed market that corresponds to truck-rail RBPC and IBR minimum MESP equivalence (not shown in the chart) is, however, only 14%. In very rural, low yield areas, even small local animal feed markets (less than 10%) can create truck-truck RBPC equivalence. Any larger ruminant market will make either RBPC option superior to the IBR.

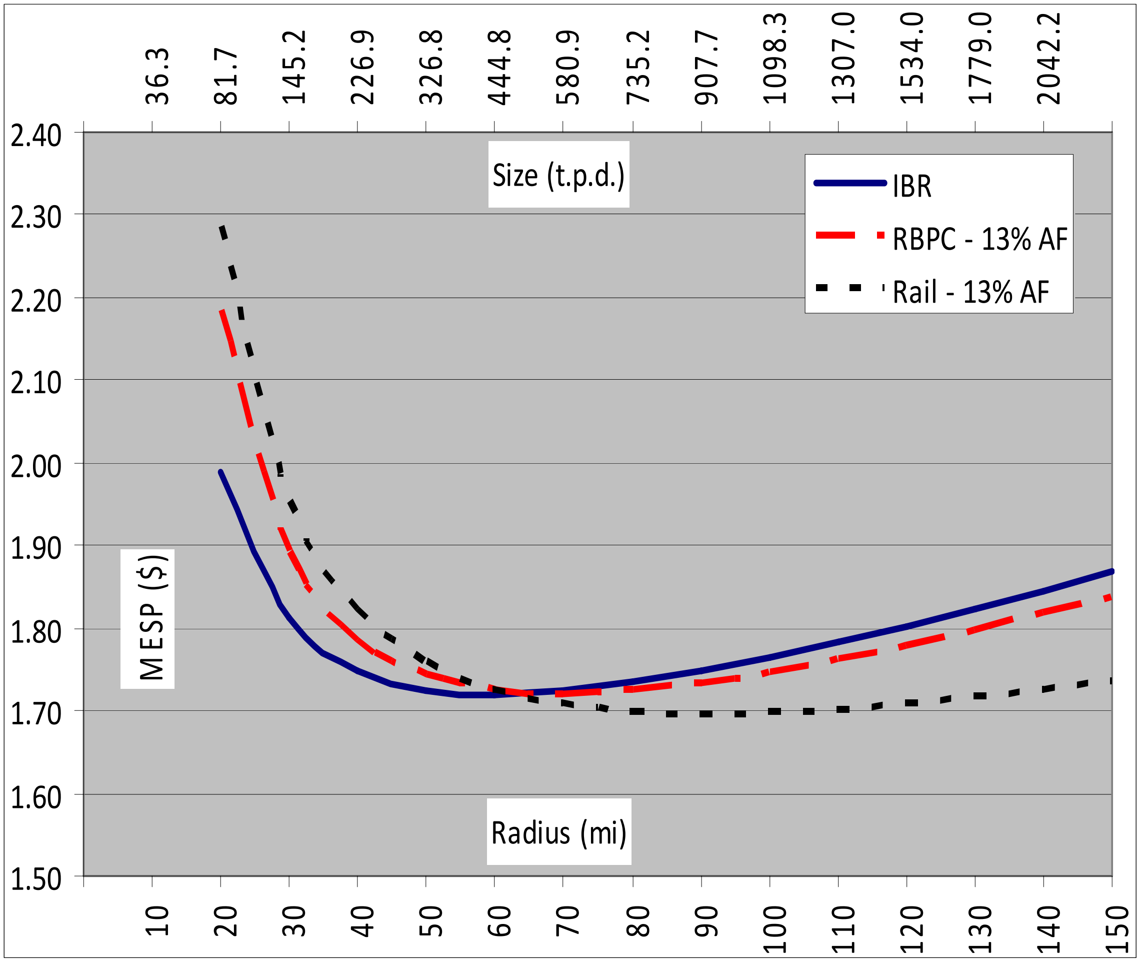

Figure 35 - Representative Ruminant Feed Case with Truck-Train RBPC Emergence

Profit motivated actors (regional monopsonist or facing competition) would choose the truck-rail RBPC at its MES in any case presented. It is the dominant choice under all these scenarios.

Table 29 – Animal Feed Market Equivalence vs. Rural-ness and Yield

			Radius of MES			MESP		Ethanol (M-gal / year)		
Rural-ness	Eff. Yield	AF %	IBR	RBPC	Rail	IBR / RBPC	Rail	IBR	RBPC	Rail
0.67	3.00	18.9%	44.1	53.1	78.0	1.5691	1.5502	1,059	1,245	2,686
	5.00	19.1%	41.9	51.1	71.0	1.5485	1.5316	1,593	1,918	3,703
	7.50	19.3%	38.9	49.1	67.5	1.5340	1.5179	2,060	2,648	5,004
1.00	0.50	13.0%	59.0	73.0	96.5	1.7196	1.6959	316	2,525	735
	1.00	13.8%	51.3	63.2	84.0	1.6684	1.6507	478	625	1,104
	1.50	14.5%	45.0	58.0	78.1	1.6424	1.6273	551	784	1,421
	2.43	15.3%	40.0	54.0	70.6	1.6150	1.6021	706	1,089	1,860
	3.00	15.6%	39.0	51.5	67.0	1.6040	1.5920	828	1,219	2,062
	5.00	16.6%	33.9	46.5	63.5	1.5795	1.5689	1,043	1,636	3,051
	7.50	17.4%	30.1	45.1	60.9	1.5620	1.5522	1,233	2,287	4,170
1.25	0.50	3.4%	57.9	74.9	98.9	1.7414	1.7128	304	492	857
	1.00	7.3%	49.0	63.8	87.1	1.6868	1.6659	436	685	1,276
	1.50	9.1%	43.2	58.8	77.0	1.6587	1.6414	508	856	1,467
	2.43	10.7%	40.5	54.1	71.0	1.6303	1.6157	723	1,153	1,985
	3.00	11.7%	35.0	50.6	68.0	1.6177	1.6042	667	1,231	2,223
	5.00	13.4%	32.0	47.6	63.0	1.5917	1.5800	929	1,782	3,121
	7.50	14.6%	29.0	45.1	58.7	1.5731	1.5623	1,145	2,365	4,007

6.11 Summary

The spreadsheet based decision support system introduced proves to be an effective analytical tool for evaluating the relative performance of alternate value chain configurations. The two bio-ethanol chains considered were sufficiently modeled to produce reasonable and reliable estimates, while generating performance metrics that are useful in comparing the proposed systems vis-à-vis each other. The investment agents under consideration can rely on the DSS output to provide information in an easily accessible format, which will assist them in making their particular investment decision. The choice is based on each agent's particular ranking of the DSS generated performance metrics.

The system analysis demonstrates that under any set of regional, technical and ruminant feed characteristics, there is always a radius of indifference where the long run average cost for the two configurations are the same. In any catchment area larger than the one corresponding to this radius of indifference, the RBPC will be less costly. The existence of an equivalency point does not translate into RBPC being the emergent choice due to the higher inherent cost structure of the system.

Under the base case scenario, the IBR emerges as the preferred choice for any profit maximizing agent, whether a monopsonist or in competition. The minimum MESP at the optimally sized IBR is lower than the minimum MESP for the RBPC system. Any profit maximizing agent will choose the minimum long run average cost structure, and even put up multiple identical smaller facilities rather than choose the higher cost structure of the RBPC.

There are regional and technical factors which shift both the cost functions in the same direction. If these are favorable to the RBPC system (i.e. increased 'rural-ness' or lower DVC/DFC ratio), then the gap between minimum MESPs is closed as these move upward. None of these factors alone can create a scenario where the RBPC is likely to emerge as the preferred choice.

There are two factors that could alter the current paradigm by shifting the profit maximization choice from IBR to RBPC. These shocks favorably shift the LRAC curves of the RBPC without impacting the structure of the IBR. This decreases the radius of indifference and drives the RBPC minimum MESP downward. The factors are additional densification at the RBPC and the existence of a higher valued alternative market for the intermediate value chain product, which in this case is ruminant feed.

Increasing densification is not an option in a truck-truck transport system due to truck capacities and weight limits. In order to capture the economic benefits of increasing bulk density, a truck-train multi-modal transport system must be employed. Due to the additional costs of pelletization, just changing transport modes to a truck-train system cannot alter the IBR dominant paradigm, other RBPC favorable conditions must be present.

Sufficient animal feed subsidies alter the decision. In the base case, the truck-truck RBPC emerges as the optimal choice for profit maximizing agents if there is a ruminant feed market that purchases 17% of the RBPC output of pre-treated biomass. The percentage of output diverted to ruminant feed that is required drops to just over 11% for the truck-train RBPC to emerge as dominant for profit maximizing agents. Table

30 summarizes the factors; when each favors a RBPC by closing the MESP gap; and, if (when), ceteris paribas, that factor could alter the decision.

Table 30: Summary of Single Factor Impacts on RBPC

Factor	Favors RBPC if	Change choice CP?
biomass yield	lower	No
rural-ness	higher	If > 1.92
DFC/DVC ratio	lower	No
densification ratio	lower	If > 27, BUT can't in truck-truck
truck-rail	employed	No
animal feed / truck-truck	higher	big enough (17% in base case)
animal feed / truck-rail	higher	big enough (11% in base case)

Multi-Factor Effects

Combinations of these factors can create conditions under which RBPCs are the lower cost option. The Figures 36 and 37 below are decision matrices. They have regional factors on one side, and technology factors on the other. Regional factors impact distance traveled by biomass, as they combine to make distances longer or shorter. Lower yield and higher rural-ness is higher in terms of distance, and vice-versa. The two technology factors impact the MESP in the same direction. A low density ratio (which means high levels of densification at the RBPC) closes the gap in MESPs, as does a low DFC/DVC ratio.

Locating the regional factors that exist in a region on one side and the technology factors brought to the table by the investment agent on the other, and finding the point in the decision space that corresponds to these factor combinations will show the value chain that would likely emerge for the agent under those conditions. The Figure 36 shows the decision matrix when only a truck-truck RBPC and IBR are considered. The Figure 37 shows the decision matrix when a truck-rail RBPC option is included in the set of feasible options. The representative multi-effect cases in this chapter are examples of possible combinations and the corresponding outcomes, consistent with these decision matrices.

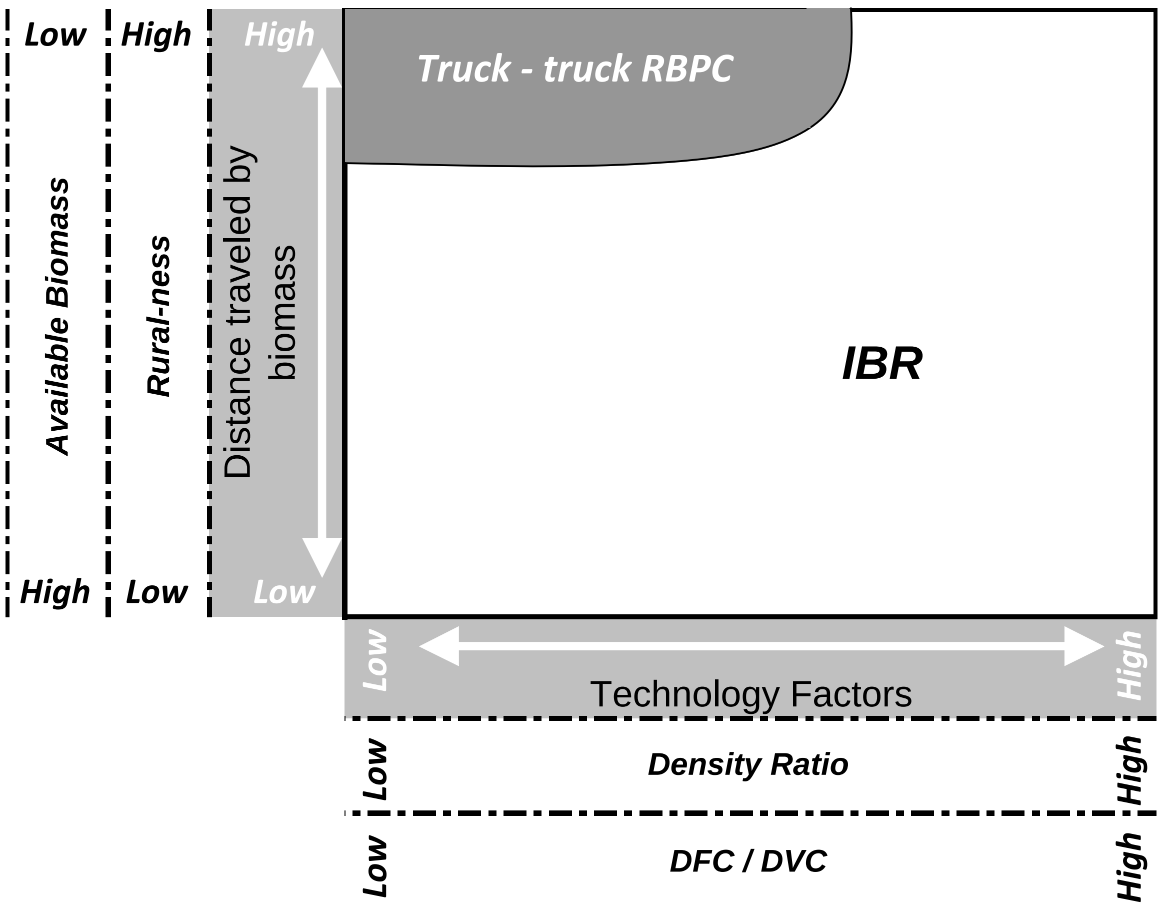

Figure 36: Decision Matrix for Truck-truck RBPC and IBR

Multi-Factor with Ruminant Feed

Ruminant feed can make the truck-truck RBPC emerge at any set of technology and geographic factors if it is large enough. With base case technology, in a highly rural, low yield region only 3% of PTB needs to be sold as ruminant feed to create MESP equality.

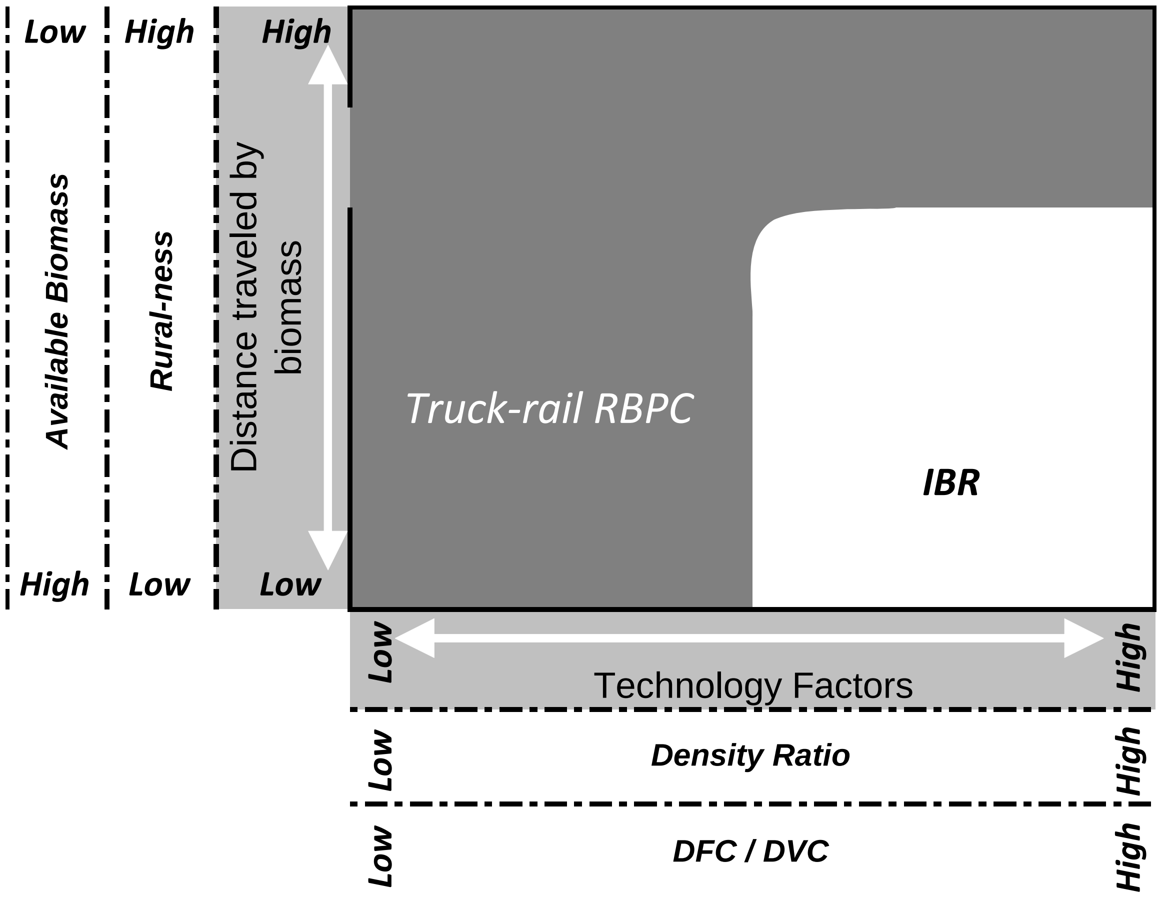

Figure 37: Decision Matrix for Truck-rail RBPC and IBR

Under all base case conditions, 17% AF is required. In a low rural, high yield area with base case technology, MESP equality is achieved with a 20% AF portion. In Figure 38, the vertical line that runs through the base case point represents base case technology at all combinations of rural-ness set and available biomass.

The three points described are shown on the vertical line. As the technology factors decrease (i.e. movements to the left of the vertical line), at any given set of rural and biomass factors, a lower volume of animal feed is required for truck-truck RBPC and IBR MESP equality (arrow labeled "lower AF% required"). As the technology factors increase (i.e. movements to the right of the vertical line), more ruminant feed sales will be required for the MESP equality (arrow labeled "higher AF % required")

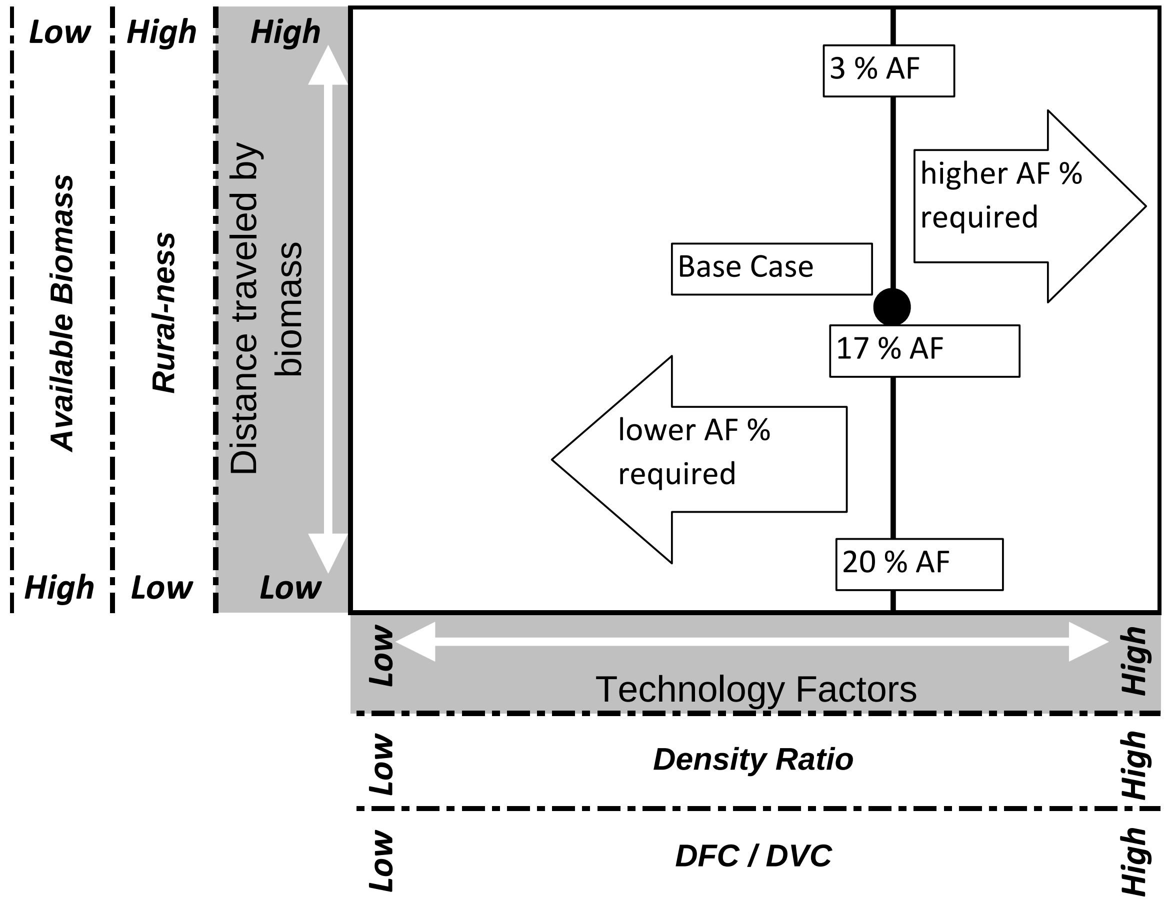

Figure 38: Decision Matrix - Animal Feed Requirements vis-à-vis Base Case

A truck-rail RBPC will always be favored over a truck-truck RBPC, and over an IBR in most cases (Figure 37). In the cases where an IBR is favored, the existence of a ruminant feed market could shift the choice to the truck-rail RBPC. The size of the animal feed market required to create truck-rail RBPC preference will always be smaller than what is required for a truck-truck RBPC to emerge under the same conditions. For example, under the base case conditions, a truck-truck RBPC requires 17% of RBPC output sold as ruminant feed, while a truck-rail requires only 11% of RBPC output into ruminant feed.

CHAPTER 7

DSS APPLICATION: REGIONAL CASE STUDIES

In this chapter I compare two alternative, realistic value chain configurations for the ligno-cellulosic biomass to ethanol conversion industry in three different specific geographic regions (one each in Michigan, New York and Pennsylvania). The two alternatives are an integrated bio-refinery and a system based on AFEX™ regional biomass processing centers. By specifying each region, the available biomass is essentially fixed, so consideration of performance based on volumetric production is not considered. The spreadsheet-based Decision Support System (DSS) introduced in Chapter 6 is adapted for each case. The primary performance metric considered is "minimum ethanol selling price" ('MESP'), which is a proxy for total system cost. Which system performs better?

Integrated Biorefinery (IBR) System: NREL defines an IBR as a "facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. The biorefinery concept is analogous to today's petroleum refineries, which produce multiple fuels and products from petroleum. Industrial biorefineries have been identified as the most promising route to the creation of a new domestic bio-based industry" . These facilities are envisioned to encompass all the processing technology from the raw feedstock through the finished bio-fuel and related co-products, at times capable of producing some of its own process inputs (i.e. electricity and steam). The activities along this value chain would be:

On - farm Activities			Bio-refinery activities					Post - Ethanol activities
LCB Growth	Harvest & Collect	LCB Storage	Input Transport	LCB Storage	Grind	Pre-treat	EtOH Processing	

This analysis is not concerned with post-ethanol activities, as the issue is alternate configurations of the biomass supply chain up to ethanol production.

RBPC System: The RBPC strips out the feedstock handling, grinding and pre-treatment from an integrated biorefinery, and arranges these activities into dispersed stand-alone facilities. These facilities utilize the AFEX™ pre-treatment technology as it provides efficient conversion at a very competitive cost; can be de-coupled from the IBR; and, allows control of nitrogen content in the product. The product from AFEX™ pre-treatment is consumable by ruminants, something which other pre-treatment technologies cannot currently support. The activities along this vertical chain would be:

On - farm Activities			RBPC Activities				Bio-refinery	Post-EtOH
LCB Growth	Harvest & Collect	LCB Storage	Input Transport	LCB Storage	Grind & Pre-treat	PTB Store & Transport	Ethanol	

7.1 Outline of Cases

There are six comparisons in each region, three cases with and three cases without a ruminant feed market. Cases vary by geography (featureless vs. tortuous); biomass distribution (regional vs. county); RBPC catchment shape (hexagonal, rectangular tiling or square); and, the number of RBPCs. Where regional distribution is considered, uniform tiling (either hexagons or squares) of supply areas will emerge. When each county is considered as a catchment area on its own, the number of RBPCs is determined by the number of counties with biomass production. Each county will have its own catchment area shape. The IBR system always employs regional coverage. One RBPC is always co-located with the bio-refinery.

Case	Geography	Biomass Distribution	RBPC catchment
Base	Featureless Plain	Uniform across region	Regional tiling
Tortuous	Tortuous Landscape	Uniform across region	Regional tiling
County by County	Featureless Plain	Uniform across county	County
Grass Only (MI)	Featureless Plain	Uniform across county	County

Biomass utilized varies from region to region, but all available is used in base case. For the Michigan region, there is one additional case, the grass only case. Biomass is always assumed to be uniformly distributed in the region under consideration.

Model Specification & Parameter Valuation

The DSS as specified in Chapter 6 is utilized. Assumptions, parameter values and specification in Chapters 4 and 5 hold for this case study. Exceptions or alternate specifications are noted.

The variable of interest is the wholesale minimum ethanol sales price (MESP) as defined in Chapter 6. The regions are fixed geographically and in regards to biomass production. Volumetric considerations vis-à-vis different value chains is meaningless as either chain will produce the same volume of ethanol.

Biomass estimation

Biomass availability varies from region to region. For the Michigan case, I consider agricultural residues, switchgrass and woody biomass. The New York case assumes that dedicated grasses, stover and willow are utilized. The Pennsylvania case considers switchgrass, hay (not including alfalfa hay), agricultural residues (wheat, oat & barley), and corn stover. For the Michigan region, a grass only case is examined in which woody biomass and some agricultural residues are dropped from the usable biomass inventory.

The New York case biomass estimates come directly from a biomass inventory undertaken by Dr. Peter Woodbury at Cornell University[104].

The Michigan and Pennsylvania cases follow the biomass estimation utilized by Milbrandt (2005)[105]. (See, Milbrandt for list of the parameters such as DM %, K values, ratios, etc). Switchgrass is grown on CRP land, and harvested once per year in mid to late August. The productivity is assumed to be 5.0 dry tons per acre per year. Switchgrass is mowed, raked into windrows; field dried to approximately 15% moisture content; picked up from the windrow and formed into bales. Bales are stacked and tarped at the field edge. It is assumed that these bales can be infinitely stored without degradation, although there will be no bales stored for more than a year. Agricultural residues are calculated using the following formulas (Milbrandt, 2005). For crops reported in pounds (such as beans, peas, peanuts, cotton, canola, rice, sunflower, etc.): Usable residue = 0.35 * (crop production * crop to residue ratio * Dry Matter % / 2205). For crops reported in BU (barley, corn, oats, rye, sorghum, soybeans, wheat, and flaxseed): Usable residue = 0.35 * (crop production * crop to residue ratio * Dry Matter % / K). All usable residues are included in available biomass estimates. Estimates of woody biomass residues are from Milbrandt (2005)[106]. Woody biomass is the total of forest residues, primary mill residues, secondary mill residues and urban wood residues.

Activity Assumptions in brief

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104 Personal correspondence, 2009

105 Milbrandt, 2005

106 Milbrandt provides calculated results, backup data was provided by Dr. Froese, Michigan Tech Univ.

Previous chapters' biomass assumptions hold. Biomass is uniformly distributed across a homogenous plain. It is fungible with regards to AFEX™ technology and ethanol production. There is no favoritism to any specific biomass or biomass producer. It is infinitely storable with no degradation. All biomass receives a farm-gate "all-in" price of $50 per ton.

Technology employed is as specified in chapters 4 and 5. The harvest, collection and storage system is baled biomass stored by road-side for truck collection. The transport system employed is a truck-truck system. All pre-treatment is via AFEX™. Conversion is SSCF. Facilities are homogenous with mature technology.

The pre-treated biomass is homogeneous in regards to flow-ability, store-ability, ethanol production and ruminant feed. It is fungible and infinitely store-able.

Ethanol up-stream distribution is not considered.

Ruminant Feed Market

It is assumed that 25% of all annual grain consumption at each Concentrated Animal Feed Operation CAFO in the region is replaced with AFEX™ treated biomass. The price of the treated biomass was assumed to be $98.47 / ton[107]. The ruminant feed is supplied by the closest facility under either value chain configuration (i.e. RBPCs and IBR produce ruminant feed).

Biomass Transport Model

The transport cost model for untreated biomass (from farm gate to first facility) is

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[107] See Carolan, et. al (2007) for estimation in 2007$. This figure was not adjusted for inflation.

$$TC(i,j) = 4.790 + 0.2462*Dist(i,j).$$ [108]

DFC & DVC activity costs are allocated as specified in Chapter 5. Untreated raw biomass has a bulk density 8.0 (lbs. / cu ft. AFEX™ treated biomass has a bulk density of 10.75 lbs. / cu. ft. This gives rise to a density ratio of 0.744. The corresponding PTB transport cost function is:

$$TC(i,j) = 3.565 + 0.1832*Dist(i,j)$$ [109]

Supply Area Shapes

Biomass supply areas are approximated as standard geographic shapes. An IBR will always have a regional catchment area; circular in Michigan and Pennsylvania and rectangular in New York (see case for rationale). For the RBPC cases, the shape of the supply areas is dependent on the region and the case under consideration (i.e. county by county or region-wide). For county by county, each county's cartographic shape was roughly approximated. For the region-wide case, the supply areas were chosen by the most efficient tiling pattern, either six equal squares or seven equal hexagons.

Distance Estimation

Where possible, distances were approximated using MapQuest. This was most often employed from facility to facility (i.e. CAFO to IBR, RBPC to IBR, etc). In all other instances, a distance function was employed.

The average distance for all points in any polygon to the center point is calculated as described in Chapter 5 (page 188). With a rectangular supply area, the

[108] This is the average of the eight baled truck transport specifications discussed in Chapter 5.
[109] This is the density ratio valued version of the raw biomass function.

average distance to the center was calculated by triangulation, and employing the mean distance of any point to the apex of a triangle, properly weighted (footnote 85 in Chapter 6).

Where a tortuous landscape is presumed, average distance calculations are weighted with relevant tortuosity factors. Cases 1 & 3 are featureless plains, without this weighting. Case 2 has tortuous landscape with High tortuosity factor of 2.11, which is applied to all rural roads. The low tortuosity factor for RBPC to the bio-refinery remains equal to 1.00, as distances from each assumed RBPC location to each bio-refinery location were estimated with MapQuest. Rural roads account for 65% of the transportation infrastructure, which creates a farm to IBR tortuosity of 1.72.

7.2 Michigan

The area under consideration is a nine county region in South-west Michigan (Appendix B). The region is the Michigan home to the Great Lakes Bio-energy Research Center, a multi-party collaboration researching various aspects of lingo-cellulosic biomass, impacts and characteristics within the Great Lakes region.

Galesburg, MI is the assumed location for either bio-refinery. It is close to center of Kalamazoo County and the entire region. It is very close to I-94, a major interstate that stretches from Chicago to Detroit (and beyond), through St. Josephs, Battle Creek, Jackson, Kalamazoo, Gary (IN) and Ann Arbor. It is on a rail line. This infrastructure guarantees access to inputs as well as to upstream distribution of ethanol, which is transported mostly by truck, train, and barge. Ethanol cannot be transported via current system of fuel pipelines because it mixes with water, which may create two problems – either an un-usable fuel and / or corrosion in the pipelines, so the absence or presence of an oil pipeline is a non-factor.

Galesburg is non-urban, relatively rural, with some commercial and industrial tenants, but without any dominating commercial or industrial firm yet close enough to Kalamazoo to have ancillary services (i.e. engineering, construction, legal, skilled labor, transport labor, etc.) readily available. These characteristics indicate that the community would likely host an ethanol conversion facility.

Biomass in the Region

Switchgrass grown on CRP land is the only dedicated energy crop. There is only one harvest per year, in mid to late August. The yield is 5 dry tons per acre per year[110]. Agricultural residues comprise the majority of usable biomass (greater than 50%). These are derived almost exclusively from corn and soybean (Appendix B). Woody biomass is also consumed in slightly smaller quantities. Table 31 summarizes the usable biomass for each county.

Table 31: Michigan Biomass by County (tons per year)

COUNTY	Woody Biomass	Energy Crops	Ag Residues	Total
ALLEGAN	63,989	24,279	127,232	215,500
BARRY	27,312	983	59,403	87,698
BRANCH	14,489	35,709	140,552	190,750
CALHOUN	46,188	111,610	117,527	275,325
CASS	17,797	99,735	113,559	231,091
EATON	27,404	99,735	133,641	260,780
KALAMAZOO	47,744	99,735	79,736	227,214
ST. JOSEPH	24,260	983	147,084	172,327
VAN BUREN	27,758	61,448	61,331	150,537
Region	296,939	534,217	980,065	1,811,222

110 Milbrandt, 2005

Biomass Availability

Under the homogenous plain assumption, biomass is uniformly distributed across either analytical region – the entire nine-county region or each county as a stand-alone region. The choice of analytical region has repercussions for both biomass availability and the shape of the catchment area for each RBPC. The regional and county-wide biomass availability is shown here in Table 32.

Table 32: Michigan Biomass Availability by County

County	Area (sq mile)	Biomass (dry tons)	Available LCB (dry tons / mile)
Allegan	828	215,500	260.3
Barry	556	87,698	157.7
Branch	507	190,750	376.2
Calhoun	709	275,325	388.3
Cass	492	231,091	469.7
Eaton	576	260,780	452.7
Kalamazoo	562	227,214	404.3
St. Joes	504	172,327	341.9
Van Buren	611	150,537	246.4
Region	5345	1,811,222	338.9

Animal Feed Market (CAFOs)

There are fifteen (15) ruminant state-permitted CAFOs (13 dairy, 1 veal and 1 beef). [111] Together these represent a market in excess of 32,000 animals, or an annual grain consumption of approximately 146,000 tons.[112] The assumed ruminant feed demand satisfied by AFEX™ treated biomass is 36,525 tons per year.

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[111] Current list available from Michigan DEQ at http://www.michigan.gov/deq/0,1607,7-135-3313_3682_3713-96774--,00.html

[112] Dairy cow eat around 25 lbs of grain daily. Multiple sources confirmed this, including http://www.dairyfarmingtoday.org/DairyFarmingToday/Learn-More/FAQ/#What%20do%20cows%20eat

Michigan Cases

Case 1 (flat) and Case 2 (tortuous) utilize all available biomass. The biomass is distributed uniformly across the region. The bio-refineries are sized at 4,960 dry tons per day without animal feed, and 4,860 tpd when animal feed is sold. The IBR has a circular catchment area. Case 1 assumes a featureless plain, while Case 2 assumes a tortuous environment.

Hexagonal supply areas for RBPCs were applied. There are seven (7) identical RBPCs at 710 tpd each, one which is co-located with the bio-refinery. The average distance of every point within the hexagon to the center of the hexagon is calculated (see above). Distances for RBPC to the bio-refinery are estimated using MapQuest, from each RBPC to the Galesburg bio-refinery, as are all distances for animal feed distribution from each RBPC to the CAFO address.

Case 3 considers each county as a separate catchment area, with one uniquely sized RBPC in each county. It is a featureless plain. All available biomass is consumed, and is uniformly distributed within each county. Each RBPC consumes only the biomass in its county. Bio-refinery capacities are the same as other cases. Only four counties have animal feed markets, which are serviced by that county's RBPC. The ruminant feed markets (in tons per year) are Allegan County: 15,120; Barry County: 2,079; Kalamazoo County: 14,916; and, St. Joseph County: 4,410.

Counties were assumed to be either rectangular or square. Average distance to the center was calculated (see above). Distance from the center of one county to the bio-refinery is approximated using MapQuest, from county center to Galesburg. Table 33 summarizes RBPC sizes, catchment area shapes and distances.

Table 33: RBPC sizes and catchment areas (Michigan)

County	Biomass (dry tons)	RBPC size (tpd)	County Shape	Area (sq. miles)	Avg. to County Center (mi)	County Center to Galesburg
Allegan	215,500	590	rectangle	828	13.71	33.31
Barry	87,698	240	square	556	9.02	28.53
Branch	190,750	520	square	507	8.61	32.68
Calhoun	275,325	750	rectangle	709	10.74	23.12
Cass	231,091	630	square	492	8.49	32.45
Eaton	260,780	715	square	576	9.18	51.43
Kalamazoo	227,214	620	square	562	9.07	0.00
St. Joseph	172,327	470	square	504	8.59	20.30
Van Buren	150,537	410	square	611	9.46	21.43

Case 4 considers each county as a separate catchment area, with one uniquely sized RBPC in each county. It is a featureless plain. Only grassy biomass (corn, oat, rye and wheat residues; and switchgrass) is utilized. Grass is uniformly distributed within each county. Each RBPC consumes only the biomass from its county. RBPC sizes are shown in Table 34. Bio-refinery capacities are 3,345 dry tons per day (tpd) without animal feed, and 3,245 tpd with animal feed. The animal feed markets are identical to those in Case 3.

Table 34: County Specific RBPCs (Michigan)

County	Biomass (dry tons)	RBPC size (tpd)
ALLEGAN	120,047	330
BARRY	42,179	115
BRANCH	129,129	350
CALHOUN	189,198	520
CASS	181,602	500
EATON	185,362	510
KALAMAZOO	156,509	430
ST. JOSEPH	112,661	310
VAN BUREN	103,580	280

7.3 New York

The New York region is a seven county region in North-central New York State, the Niagara Frontier region and two eastern neighbors. The region is on the southern shore of Lake Ontario, and centered by Orleans County. The other six counties surround Orleans, and make up the potential catchment area for biomass (see Appendix B for map).

The region was chosen because there is a Western New York Energy 55 million gallon per year corn ethanol facility operating in Shelby, in southwestern Orleans County. Many of the factors that made this region promising for corn ethanol, also make it promising for cellulosic ethanol –proximity to road and rail transportation, the area's solid work force, the reception the idea received [from residents], local participation in the project, support from the regions farmers for a local market, and governmental support. New York state provided grant money, tax credits, $3.1 million to build transportation infrastructure to the site, tax breaks (because the site is in an Empire Zone), proposed alternative fueling stations along the NY state Thruway and incentives for consumers to purchase alternative fuels.[113]

Biomass in the Region

Feedstock estimates for this region were produced by a team led by Peter Woodbury of Cornell University[114]. The biomass inventory estimates include willow, corn stover and warm season grasses, but not woody biomass or other agricultural residues. Warm-season grasses are dedicated energy crops, such as switchgrass, grown under an

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113 Tyler, David. "Work at Orleans County site may start in June, be first in N.Y." The Rochester Democrat and Chronicle. Downloaded from Western New York Energy website, wnyenergy.com

114 Personal correspondence, 2009

intensive production system using best management practices and improved genetic material. Short-rotation willow is harvested every 3 years, also under an intensive production system using best management practices. For corn stover estimates, only 25% of stover is harvested from any field, and only half of fields are harvested. Thus these estimates represent 12.5% of the total stover production in the state. The ratio of stover to grain is assumed to be 1:1.

Biomass Availability

Under the homogenous plain assumption, biomass is uniformly distributed across the area under analysis. Regional and county biomass totals are presented in Table 35.

Table 35: New York Biomass by County (tons per year)

Name	Area (sq mile)	Biomass (dry tons)	Available LCB (dry tons / sq. mile)
Erie	1,044	215,343	206.3
Genesee	494	233,962	473.6
Livingston	632	297,799	471.2
Monroe	659	158,469	240.5
Niagara	523	314,650	601.6
Orleans	391	218,330	558.4
Wyoming	593	226,423	381.8
total region	4,336	1,664,976	384.0

Animal Feed Market (CAFOs)

There are one hundred and nineteen (119) permitted animal feed operations. These CAFOs represent a market more than 150,000 ruminant animals, with an approximate annual grain consumption of almost 700,000 tons.[115] The ruminant feed market for AFEX™ treated biomass is assumed to be 171,212 tons per year.

New York Cases

Case 1 (flat) and Case 2 (tortuous) utilize all usable grass, willow and corn stover. The biomass is distributed uniformly across the region. The bio-refineries are sized at 4,570 dry tons per day without animal feed, and 4,100 tpd when animal feed is sold. There are six (6) identical RBPCs at 760 tpd each, one which is co-located with the bio-refinery. Case 1 assumes a featureless plain, while Case 2 assumes a tortuous environment.

The bio-refinery in this case is an output-oriented facility, not input-oriented. It is not centrally or optimally located. It is an existing production facility with many benefits that outweigh optimal supply siting locational considerations. For the regional case, an RBPC system based on hexagonal supply areas is not feasible. A system of RBPCs based on six equal square regions is employed (Figure 39). One RBPC was sited within each region. The IBR has a rectangular catchment area. CAFOs were supplied by the nearest facility.

The average distance of every point within the square to its center is calculated (see above). Distances for RBPC to the bio-refinery are estimated using MapQuest, from each RBPC to the Shelby bio-refinery, as are all distances for animal feed distribution from each RBPC to each CAFO.

Case 3 considers each county as a separate catchment area, with one uniquely sized RBPC in each county. It is a featureless plain. All usable grass, willow and corn

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115 Dairy cow eat around 25 lbs of grain daily. Multiple sources, including http://www.dairyfarmingtoday.org/DairyFarmingToday/Learn-More/FAQ/#What%20do%20cows%20eat

stover is consumed, and is uniformly distributed within each county. Each RBPC consumes only the biomass in its county. Bio-refinery capacities are the same as first two cases.

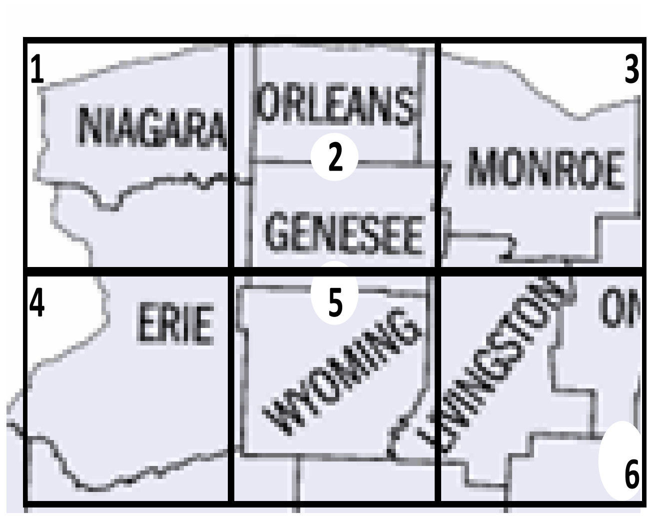

Figure 39: RBPC Catchment Areas (New York)

Counties were assumed to be rectangular. One RBPC was sited within each county. Each CAFO was supplied by the RBPC in its county. Table 36 summarizes each county's animal feed market, RBPC capacity, and distances to Shelby and RBPC.

Table 36: New York Biomass Availability by County

County	annual tons feed	RBPC size (tpd)	Area (sq. miles)	Avg. to Shelby (mi.)	Avg. distance to RBPC (mi.)
Erie	12,630	560	828	24.9	12.5
Genesee	42,342	530	556	17.2	8.6
Livingston	36,069	720	507	47.6	10.4
Monroe	1,460	440	709	39.2	9.8
Niagara	13,454	830	492	18.3	9.2
Orleans	717	600	576	15.5	7.7
Wyoming	64,539	450	562	35.6	9.3

7.4 Pennsylvania

The region is a ten county region in central Pennsylvania. It was chosen because the first commercial-scale ethanol plant in Pennsylvania - Bionol Clearfield, a 110 MMgy corn ethanol plant - is located at the Clearfield Technology Park in Clearfield, Pa. This site, adjacent to the West Branch Susquehanna River and RJ Corman Railroad, was chosen not because of its proximity to corn (75% comes in from PA and eastern Ohio & 25% by rail), but rather because it is a location that "the company considers a gateway to blending terminals in New York".[116] The developers received $22M in grants and loans from the State of Pennsylvania for this location as well. There are plans for a cellulosic pilot plant to be co-located at the site. This case is similar to the New York case in that the refinery was located based more on output orientation, rather than proximity to inputs.

Biomass in the Region

Biomass considered is switchgrass on CRP, hay (not including alfalfa hay), agricultural residues (wheat, oat & barley), and corn stover. Feedstock estimates for this region were generated with the same protocol as employed for Michigan. The data for this analysis was obtained at http://pabiomass.org/ag.html. Under the homogenous plain assumption, biomass is uniformly distributed across the area under analysis. Regional and county data are summarized here. This region is not particularly rich in potential biomass sources (or corn for that matter). It is the least dense of the three regions, by

[116] February 8, 2010 – Ethanol Producer Magazine, online article; can be found @ http://www.ethanolproducer.com/article.jsp?article_id=6331

far, with its richest county (Indiana) being less than ½ of all other counties considered (except Barry County in Michigan).

Table 37: Pennsylvania Biomass by County (tons per year)

Name	Area (sq mile)	Biomass (dry tons)	Available LCB (dry tons / sq. mile)
Blair	527	32,918	62.5
Cambria	693	64,562	93.2
Cameron	399	171	0.4
Centre	1112	88,830	79.9
Clearfield	1154	21,761	18.9
Clinton	898	49,929	55.6
Elk	832	414	0.5
Huntingdon	889	57,389	64.6
Indiana	834	86,455	103.7
Jefferson	657	68,018	103.5
Region	7,995	470,445	58.8

Animal Feed Market (CAFOs)

The potential market for ruminant feed is minimal. Only four counties have any CAFO presence, with two of those having very few (less than 4 each). The only two counties any reasonable feed potential are Huntingdon and Blair (17,500 and 15,300 head respectively). These were the only two considered, and were assumed to be supplied locally (i.e. from the RBPC in that county). Ruminant feed market is 37,422 tons per year.

Pennsylvania Cases

Case 1 (flat) and Case 2 (tortuous) utilize all available biomass. The biomass is distributed uniformly across the region. The bio-refineries are sized at 1,290 dry tons per day without animal feed, and 1,190 tpd when animal feed is sold. The IBR has a circular catchment area. Case 1 assumes a featureless plain, while Case 2 assumes a tortuous environment.

Hexagonal supply areas for RBPCs were applied. There are seven (7) identical RBPCs at 185 tpd each, one which is co-located with the bio-refinery. The average distance of every point within the hexagon to the center of the hexagon was calculated (see above). Distances for RBPC to the bio-refinery were estimated using MapQuest, from the location of RBPC to the Clearfield bio-refinery. CAFO locations were not available; therefore an average distance from the RBPC was calculated.

Case 3 considers each county as a separate catchment area, with one uniquely sized RBPC in each county. It is a featureless plain. All available biomass is consumed, and is uniformly distributed within each county. Each RBPC consumes only the biomass in its county. There will be no activity in Elk or Cameron counties. Neither of these counties have sufficient biomass potential to support any sized RBPC. The IBR operates with a circular catchment area. Bio-refinery capacities remain at 1,290 tpd and 1,190 tpd. The ruminant feed market is limited to two counties Blair County, with market of 17,464 tons per year, and Huntingdon County, at 19,958 tons per year.

Counties were all assumed to be rectangular. Average distance to the county center was calculated (see above). Distance from county center to Clearfield was approximated using MapQuest. Table 37 summarizes RBPC sizes and distances.

Table 38: RBPC sizes and catchment areas (Pennsylvania)

County	Area (sq. miles)	RBPC size (tpd)	Avg. to Clearfield (mi.)	Avg. distance to RBPC (mi.)
Blair	527	90	22.1	11.0
Cambria	693	175	22.1	11.0
Cameron	399	0	8.0	4.0
Centre	1112	250	30.0	15.0
Clearfield	1154	60	13.0	13.0
Clinton	898	135	28.6	14.3

Table 38 (cont'd)				
Elk	832	0	18.9	9.5
Huntingdon	889	160	22.1	11.0
Indiana	834	235	22.1	11.0
Jefferson	657	185	37.8	18.9

7.5 Results

The results of the analyses are shown in Figures 40 through 43. Figure 40 summarizes the volume of ethanol produced, the Minimum Ethanol Selling Price (MESP), and the gasoline equivalent price corresponding to the MESP for ever case considered. Figures 41 through 43 present the contributions by each value chain activity to the MESP for every case.

Region	Process		Case 1 NO Feed Mkt	Case 1 w/ Feed Mkt	Case 2 NO Feed Mkt	Case 2 w/ Feed Mkt	Case 3 NO Feed Mkt	Case 3 w/ Feed Mkt	Case 4 (MI only) NO Feed Mkt	Case 4 (MI only) w/ Feed Mkt
Michigan	IBR	EtOH (Mgal/yr)	160.8	157.7	160.8	157.7	160.8	157.7	108.4	105.2
		MESP ($ / gal)	1.579	1.591	1.635	1.647	1.592	1.603	1.686	1.707
		Gas Eq Price	2.39	2.407	2.473	2.492	2.409	2.426	2.551	2.583
	RBPC	EtOH (Mgal/yr)	160.8	157.7	160.8	157.7	160.8	157.7	108.4	105.2
		MESP ($ / gal)	1.752	1.755	1.797	1.802	1.766	1.769	1.864	1.871
		Gas Eq Price	2.651	2.656	2.719	2.726	2.672	2.676	2.821	2.831
		RBPC greater by	***10.90%***	***10.40%***	***9.90%***	***9.40%***	***10.90%***	***10.30%***	***10.60%***	***9.60%***
New York	IBR	EtOH (Mgal/yr)	147.9	132.7	147.9	132.7	147.9	132.7		
		MESP ($ / gal)	1.605	1.622	1.667	1.691	1.598	1.614		
		Gas Eq Price	2.429	2.455	2.522	2.558	2.419	2.443		
	RBPC	EtOH (Mgal/yr)	147.9	132.7	147.9	132.7	147.9	132.7		
		MESP ($ / gal)	1.73	1.727	1.759	1.76	1.767	1.768		
		Gas Eq Price	2.617	2.613	2.662	2.663	2.673	2.675		
		RBPC greater by	***7.70%***	***6.50%***	***5.50%***	***4.10%***	***10.50%***	***9.50%***		
Pennsylvania	IBR	EtOH (Mgal/yr)	41.8	38.5	41.8	38.5	41.8	38.5		
		MESP ($ / gal)	2.064	2.121	2.134	2.197	2.089	2.149		
		Gas Eq Price	3.124	3.21	3.229	3.325	3.161	3.251		
	RBPC	EtOH (Mgal/yr)	41.8	38.5	41.8	38.5	41.8	38.5		
		MESP ($ / gal)	2.165	2.197	2.204	2.239	2.208	2.249		
		Gas Eq Price	3.276	3.324	3.335	3.388	3.341	3.403		
		RBPC greater by	***4.90%***	***3.60%***	***3.30%***	***1.90%***	***5.70%***	***4.70%***		

Figure 40: MESPs by Region and Case

	IBR			RBPCs		
No Animal Feed	**flat**	**winding**	**cty by cty**	**flat**	**winding**	**cty by cty**
Feedstock	0.563	0.563	0.563	0.563	0.563	0.563
LCB inbound transport	0.130	0.186	0.143	0.083	0.113	0.081
Pre-treatment @ RBPC				0.238	0.238	0.249
PTB transport				0.087	0.102	0.092
IBR process cost	0.886	0.886	0.886	0.781	0.781	0.781
AF sales offset						
AF transport						
total transport	0.130	0.186	0.143	0.170	0.215	0.173
total process cost	0.886	0.886	0.886	1.019	1.019	1.030
feedstock less AF	0.563	0.563	0.563	0.563	0.563	0.563
MESP	1.579	1.635	1.592	1.752	1.797	1.766

	IBR			RBPCs		
With Animal Feed	**flat**	**winding**	**cty by cty**	**flat**	**winding**	**cty by cty**
Feedstock	0.574	0.574	0.574	0.574	0.574	0.574
LCB inbound transport	0.133	0.189	0.146	0.085	0.117	0.083
Pre-treatment @ RBPC				0.245	0.245	0.256
PTB transport				0.088	0.102	0.093
IBR process cost	0.904	0.904	0.904	0.785	0.785	0.785
AF sales offset	-0.023	-0.023	-0.023	-0.023	-0.023	-0.023
AF transport	0.002	0.002	0.002	0.001	0.001	0.001
total transport	0.135	0.192	0.148	0.174	0.221	0.177
total process cost	0.904	0.904	0.904	1.029	1.029	1.041
feedstock less AF	0.552	0.552	0.552	0.552	0.552	0.552
MESP	1.591	1.648	1.604	1.755	1.802	1.770

Figure 41: MESP Contributions by Value Chain Activity - Michigan

	IBR			RBPCs		
No Animal Feed	**flat**	**winding**	**cty by cty**	**flat**	**winding**	**cty by cty**
Feedstock	0.563	0.563	0.563	0.563	0.563	0.563
LCB inbound transport	0.139	0.201	0.132	0.082	0.112	0.081
Pre-treatment @ RBPC				0.196	0.196	0.249
PTB transport				0.094	0.094	0.092
IBR process cost	0.903	0.903	0.903	0.795	0.795	0.781
AF sales offset						
AF transport						
total transport	0.139	0.201	0.132	0.176	0.205	0.167
total process cost	0.903	0.903	0.903	0.991	0.991	1.037
feedstock less AF	0.563	0.563	0.563	0.563	0.563	0.563
MESP	1.605	1.667	1.598	1.730	1.759	1.767
	IBR			***RBPCs***		
With Animal Feed	**flat**	**winding**	**cty by cty**	**flat**	**winding**	**cty by cty**
Feedstock	0.627	0.627	0.627	0.627	0.627	0.627
LCB inbound transport	0.155	0.224	0.147	0.092	0.124	0.090
Pre-treatment @ RBPC				0.219	0.219	0.269
PTB transport				0.094	0.094	0.085
IBR process cost	0.951	0.951	0.951	0.816	0.816	0.816
AF sales offset	-0.127	-0.127	-0.127	-0.127	-0.127	-0.127
AF transport	0.016	0.016	0.016	0.007	0.007	0.007
total transport	0.171	0.239	0.163	0.192	0.225	0.183
total process cost	0.951	0.951	0.951	1.034	1.034	1.085
feedstock less AF	0.500	0.500	0.500	0.500	0.500	0.500
MESP	1.622	1.690	1.614	1.726	1.759	1.768

Figure 42: MESP Contributions by Value Chain Activity – New York

	IBR			RBPCs		
No Animal Feed	**flat**	**winding**	**cty by cty**	**flat**	**winding**	**cty by cty**
Feedstock	0.563	0.563	0.563	0.563	0.563	0.563
LCB inbound transport	0.151	0.220	0.176	0.089	0.128	0.091
Pre-treatment @ RBPC				0.277	0.277	0.280
PTB transport				0.066	0.066	0.103
IBR process cost	1.351	1.351	1.351	1.170	1.170	1.170
AF sales offset						
AF transport						
total transport	0.151	0.220	0.176	0.156	0.194	0.194
total process cost	1.351	1.351	1.351	1.447	1.447	1.451
feedstock less AF	0.563	0.563	0.563	0.563	0.563	0.563
MESP	2.065	2.134	2.090	2.166	2.204	2.208

	IBR			RBPCs		
With Animal Feed	**flat**	**winding**	**cty by cty**	**flat**	**winding**	**cty by cty**
Feedstock	0.611	0.611	0.611	0.611	0.611	0.611
LCB inbound transport	0.164	0.240	0.191	0.097	0.139	0.099
Pre-treatment @ RBPC	0.000	0.000	0.000	0.301	0.301	0.305
PTB transport	0.000	0.000	0.000	0.066	0.066	0.112
IBR process cost	1.429	1.429	1.429	1.210	1.210	1.210
AF sales offset	-0.096	-0.096	-0.096	-0.096	-0.096	-0.096
AF transport	0.013	0.013	0.013	0.007	0.007	0.007
total transport	0.177	0.253	0.204	0.170	0.212	0.218
total process cost	1.429	1.429	1.429	1.511	1.511	1.515
feedstock less AF	0.516	0.516	0.516	0.516	0.516	0.516
MESP	2.122	2.198	2.149	2.197	2.239	2.249

Figure 43: MESP Contributions by Value Chain Activity – Pennsylvania

7.6 Discussion of Results

The regions are fixed area regions, with relatively low biomass densities. Neither system would be able to reach its un-constrained minimum efficient scale. Volume of bio-ethanol produced under both configurations will be identical, so performance ranking based on volumetric measures is meaningless.

The MESPs are mostly higher than EIA projected price wholesale ethanol price of $1.6790, yet not that far. The mature technology assumption generates a LRAC estimates as if this is a mature industry. In an un-constrained and higher yielding region, the MESPs would be closer to the EIA estimate (Chapter 6). A $4.00 per gallon retail gasoline price point corresponds to roughly $3.00 wholesale gasoline, which is about $2.05 per gallon wholesale ethanol. The Pennsylvania region which is the largest with the lowest biomass yield, would struggle to meet this benchmark.

The differences in MESP between the two systems arise from a combination of higher conversion costs and transport costs under the RBPC system than under the IBR system. Conversion costs (pre-treatment MESP contribution + ethanol conversion MESP contribution) are higher under RBPC because loss of economies of scale in engineering, loss of process efficiency gains from integration, loss of economies of scale in overhead (SG&A, insurance, etc), and difference in capital cost requirements. Transport costs are higher because double depot charges cannot be overcome through savings generated by the current level of pre-treated density gains or due to shorter in-bound LCB distances.

The animal feed markets in these regions are relatively small as a percentage of biomass processed - 2% in MI, 8% in PA, and 10% in NY. The volume is not sufficient to substantially subsidize either system. The net revenues cannot overcome the loss of scale economies incurred by down-sizing the ethanol conversion facilities. Processing costs are pushed up because the variable cost structures of the smaller facilities become less efficient the further from MES. The effect of this downsizing is more pronounced on the initial, steeper downward slope (marginal costs) of the LRAC at smaller sizes (i.e. facilities that are small compared to the MES). Although the animal feed market does not subsidize either configuration, it does close the gap between MESPs, re-enforcing the finding that the positive impact of animal feed revenues to an RBPC is greater than impact to the performance of the IBR.

Dropping the uniform biomass distribution assumption seems to favor a centralized system over a distributed system. While some RBPCs gain on scale economies because they are larger than those considered under the uniform case, others incur additional losses in scale economies. These losses have a larger joint impact than the gains, again due to the steepness of the LRAC curves (i.e. the marginal cost impacts noted above). This is likely due to the relatively low biomass productivity across these regions. It may be more instructive to eliminate those very small counties from the RBPC system and compare it to the IBR system with the entire regional biomass supply. Volumetric consideration would again become part of the performance assessment.

Transport costs are increased as the tortuous nature of the regions is considered, regardless of system employed. The gap between MESPs is narrowed, indicating that the RBPC system can provide variable transport cost savings vis-à-vis the IBR in more tortuous regions. These savings cannot overcome the double depot charges.

The closest gap between MESPs occurs when tortuosity factors are combined with ruminant feed sales. As shown in Chapter 6, small RBPC favorable shocks in combination could create MESP equivalence. The conditions for MESP equivalence are not present in large enough quantities in these regions, although the Pennsylvania region does generate fairly close MESPs.

All of these regions have very low biomass productivity and availability. Biomass availability in annual dry tons per acre are approximately 0.1, 0.4, and 0.5 for Pennsylvania, New York and Michigan respectively. These results show that the lower the biomass supply the closer the gap between the MESPs as the lowest gap in MESP corresponds to the lowest effective yield (PA), as does the highest (MI).

These case studies demonstrate that with mature conversion technology bio-ethanol can potentially be produced at a competitive MESP in biomass constrained regions with low biomass potential. It has shown that the cost structure of non-MES RBPCs and IBRs are 5-10% apart. The gap narrows to as little as 2% when the ruminant feed market and non-linearity of roads are considered.

The theoretical analysis in Chapter 6 outlined characteristics that could lead to MESP equivalence and even create conditions where RBPCs emerge as the likely choice for investment agents. These findings are confirmed in these three real world cases:

lower effective yields lessen the gap between MESPs; a more tortuous road infrastructure pushes LRACs closer; and, a ruminant feed market subsidizes the RBPC shifting the LRACs lowering the MESP gap.

CHAPTER 8

CONCLUSION, LIMITATIONS AND FUTURE RESEARCH

In this dissertation, a network of regional biomass preprocessing centers (RBPC) that forms an extended biomass supply chain feeding into a simplified biorefinery is introduced as a way to address the physical and transactional issues facing the cellulosic ethanol industry. A value chain configuration that utilizes intermediate facilities such as the RBPC allows for: pre-processing activities to be moved down the supply chain which can have multiple material handling benefits (size and moisture reduction, densification, consistency of feedstock) that could lead to lower transportation costs; inclusion of a larger total catchment area which should correlate to greater volumes of ethanol; smaller facilities with lower barriers to entry, such as less capital investment required per facility (which could help overcome the capital constraint) that could also lead to local and / or shared ownership; reduction in the per gallon capital costs at the refinery, and greater returns on investment for the refiner. From a transactional perspective, intermediate facilities can overcome the standoff situation at the transaction interface (chicken and egg problem); ameliorate potential holdup situations; introduce shared risk; and, reduce the volume of transactions for each facility owner. The AFEX RBPC considered here produces an intermediate product with higher valued alternative market channels that would help overcome food vs. fuel issue by providing feed and fuel, while subsidizing bio-ethanol production.

Critics of this distributed pre-processing / pre-treatment approach for the biomass to ethanol value chain argue that the fully integrated bio-refinery has too many energy and technology synergies that pre-treatment cannot be de-coupled from the IBR without creating too many problems to be overcome technically and / or economically.

Even if it could be de-coupled, the distributed value chain faces additional problems. Longer distances must be traversed by the biomass due to *perceived* ‘back-tracking’. There is double-handling of the biomass (must be loaded and un-loaded twice) because there are two facilities instead of one. Plus, while individual facilities may be less capital intensive, overall a distributed system will actually impose higher *total* system capital costs. For critics, these all add up to an IBR system always proving the more efficient configuration (i.e. producing ethanol at a lower average cost and therefore marginal wholesale price).

This thesis addresses a critical gap in the current research on the use of distributed intermediate facilities in the biomass to ethanol value chain. There is sound, economic reasoning to justify the need for an intra-chain innovation to overcome the transactional issues. To date, many of the technical and engineering issues are being addressed. However, none of the economic benefits claimed are substantiated or quantified. This thesis analyzed the economic claims (both for and against) and the costs associated with this system, not the technical and engineering issues.

The EISA 2007 targets have been revised significantly downwards, from a 2012 initial target of 500 million gallons to a mere 8.6 million gallons in response to the conditions facing the industry. The analyses provided arguments as to why the cellulosic ethanol industry is struggling to meet the EISA 2007 mandates; why there exists a lack of investment situation; and, possible solutions to overcoming these issues. The DSS as presented is a tool that can assist stakeholders in determining which value chain provides the lowest cost option for overcoming the chicken and egg problem in any given region.

8.1 RBPC is a viable option

The research outlined in Chapter 3 demonstrates that the RBPC supply chain concept appears technically and financially feasible. AFEX based RBPCs can be technically de-coupled from the fully integrated bio-refinery. RBPCs can be financially successful with price-cost margins (i.e. difference in prices of input feedstock and output pretreated biomass) as low as $3.32/ton in the best case, which includes subsidization from animal feed sales.

When the rural-ness of a region, the non-linearity of roads, and the densification of biomass at the pre-treatment facilities are taken into account in transport cost modeling, differences in transport costs could be equivalent between the two value chain alternatives. Loading and un-loading the material twice cannot be avoided, but the additional cost can be overcome by a savings in variable costs, distance savings and a firm cost structure.

The spreadsheet based decision support system introduced in Chapter 5 provides an effective analytical tool for evaluating the relative performance of entire alternate value chain configurations. The two bio-ethanol chains considered are modeled in sufficient detail to produce reasonable and reliable estimates, while generating pertinent performance metrics.

The system analysis demonstrates that under any set of regional, technical and ruminant feed characteristics, there is always a point of indifference where the long run average cost for the two configurations are the same. In catchment areas larger than that corresponding to that equivalence radius, the RBPC will require a lower MESP. The existence of an equivalency point does not translate into RBPC being the emergent choice due to the higher inherent cost structure of the system. There are combinations of regional characteristics, technology factors, transportation modes and ruminant feed that create conditions where a RBPC could be the lower cost option at larger minimum efficient scale creating more ethanol at a lower cost.

Even low volume regions like those considered in the case study could produce cellulosic ethanol at a long run average cost / MESP close to projected future wholesale ethanol rack prices. The conversion costs and transport costs are higher under the RBPC than under an IBR, but the two systems' MESPs are within 5 to 10% in every case.

8.2 Value Chain Choices

The RBPC system is technically and economically viable. It could produce more ethanol at any given level of expected rack bio-ethanol prices (as long as the hurdle MESP is exceeded). Transport cost equivalence could be achieved. The minimum MESP (at the minimum efficient scale) of the RBPC could be equal to, or even below, that of the IBR. All of this does not, however, translate into the RBPC emerging as the choice.

In the base case scenario, the IBR emerges as the preferred choice for profit maximizing agents. There are regional and technical shocks which shift both the cost functions in the same direction. If these shocks are favorable to the RBPC system (i.e. increased 'rural-ness' or lower DVC/DFC ratio), then the gap between minimum MESPs is closed as these move upward. None of these factors alone can create a scenario where the RBPC is likely to emerge as the preferred choice. Two factors could alter the current paradigm by shifting the profit maximization choice from IBR to RBPC: additional densification at the RBPC; and, the existence of a higher valued alternative market for ruminant feed. Due to the additional costs of pelletization, simply choosing a truck-train multi-modal transport system instead of a truck-truck system cannot change the outcome. Sufficient animal feed subsidies can alter the decision, with a truck-truck RBPC being the lower cost option.

A truck-truck RBPC can emerge without an animal feed market if the region is rural enough, has low biomass yields and the firm's transport costs have a high percentage of variable costs vis-à-vis depot charges. A truck-rail RBPC can emerge without animal feed under a much larger range of rural and technology factors. An IBR is a viable choice under many sets of conditions. Animal feed markets can always tip the scales in favor of the RBPC. In more rural, lower yielding regions, less animal feed is needed for this to occur; while in higher yielding regions a larger ruminant market must exist.

8.3 Limitations and Future Research

Transaction Cost Advantages

The transactional advantages of employing an RBPC as an intermediate value chain facility are discussed in detail in Chapter 3. There are other potential transaction cost savings that could arise under a RBPC value chain system.

The RBPC is envisioned as an Equity Based Alliance between the biomass providers and the bio-ethanol refiner. This arrangement creates a co-dependence that can overcome the standoff situation and allay fears of holdup and ex-post defection. The nature of the feedstock providers' representation in the ownership of the RBPC has not been speculated upon. However, it is likely that it might take the form of a co-operative as that is historically an approach taken in dry mill corn ethanol facilities. This arrangement should ease the ex-ante contracting costs for feedstock, and could drive down the acquisition costs for feedstock because of lower reservation rents.There will also be fewer contracts per facility and more homogeneity in the contracting, which will tend to lower ex ante feedstock acquisition costs. On the other side of the ledger, there will be formation costs for the Equity Based Alliance and RBPC that would drive up the negotiating costs.

The nature of the RBPC system could create cost advantages vis-à-vis an IBR system in siting, permitting and regulatory approval. In a RBPC, the pre-treatment sites are relatively small, compared to the IBR. There will be $1/7^{th}$ the volume of inbound truck traffic at each site compared to an IBR. The environmental footprint of an individual RBPC is minimal. The facility itself is a local enterprise, not a foreign one. It will create local jobs and keep the economic impact local. All of these will likely improve the acceptance of the RBPC to the host community. Less opposition and smaller facilities will create lower costs for siting, permitting and approval. The impact at the bio-refinery is less clear cut. There will be less inbound traffic under an RBPC than under an IBR; however the facility may not be smaller in terms of footprint or capacity. It actually may be bigger under an RBPC than it would under an IBR due to the larger size at MES.

The combination of lower reservation rents, less contracting costs, siting advantages and lower regulatory costs can provide substantial transaction cost savings. If the transaction savings under a RBPC value chain are significant, The RBPC could be the preferred choice in many more regions.

While, the values of these are not quantified in the DSS, they can be inferred from the results measured as a difference in the feedstock prices between the two choices. For instance, in the case studies, a difference as little as $3.78 per ton in the Pennsylvania tortuous and ruminant feed case would make the RBPC and IBR cost structures equal. On average, $8 per ton in PA, $11 per ton in NY, and $15 per ton in MI would create conditions under which the RBPC would be more likely to emerge. Additional analyses can be run with differential pricing schemes and reduced capital costs, modeling these transaction cost advantages in order to determine the magnitudes required to see RBPC emergence become the dominant outcome.

This is from a purely profit maximization stand point. The advantages discussed will likely have a larger impact on value chain choices when a triple bottom line approach is employed. Under a triple bottom line approach, the impact to profits, people and environment are all taken into account. With future enhancements to the DSS, these evaluation metrics will be considered. It is likely that when transaction costs are valued and impacts to other triple bottom line measures are considered, the RBPC will emerge as the more favored value chain in all but the regions with high biomass production and density.

Densification technology

This research demonstrated that increasing densification of the biomass during the pre-processing and pre-treatment activities is a key factor in RBPC emerging (vis-à-vis the IBR) in a market environment. Increases in the bulk density of the pre-treated biomass translate into potentially large transport savings, enough that the RBPC LRAC structure becomes more favorable than the IBR in a manner that the RBPC price induced marginal profits exceed the IBR price induced marginal profits. Additional densification requires additional equipment, additional inputs, and greater operating costs. It will require different transportation technology and / or infrastructure, such as rail.

An important step in the distributed bio-ethanol value chain literature would be to model, technically and economically, the different choices for densification and use the DSS presented to compare these[117]. There are many options available for additional densification at the RBPCs, including pelletization, cubing, briquetting, torrefaction, and liquefaction. Cubing and briquetting are similar to pelletization, with products that differ from pellets in size, shape and bulk density. Torrefaction is a thermo-chemical treatment of the biomass which produces a hardened, dried more energy dense product that has a much higher bulk density than raw biomass, similar to pelletization in transport and handling characteristics. Liquefaction is a thermo-chemical process that liquefies biomass. Processes for biomass liquefaction include fast pyrolysis. The product is a liquid bio-oil (See Brown, et.al., 2010) for a full discussion. These options have different process configuration, different equipment and capital needs, different

[117] See Eranki, et. al. (2011) for some possible candidates

handling equipment and procedures, and may require different transport modes between the RBPC and bio-refinery. These could be modeled, technically and economically, and be plugged in as an activity sub-module in the DSS.

Ruminant Feed Analyses

The other factor that favors RBPCs over IBR is a ruminant feed market. It is the AFEX process utilized at the RPBC that creates this important intermediate product. From a transaction perspective, this provides a mechanism to overcome potential holdups by eliminating appropriable quasi-rents. The sales of the animal feed provide critical revenue streams that subsidize the entire system. When large enough, these subsidies can make the RBPC more attractive to profit maximizing firms. The subsidization is enhanced under the RBPC due to the proximity of CAFOs to the geographically dispersed RBPC, as seen in the case studies. The estimation of ruminant feed pricing in this analysis shows that it is likely to be a higher valued product (higher than if it is used as a bio-ethanol input). However, a real economic value should be determined. This will depend on the characteristics of the material and its ability to be consumed by ruminants. Feed trials and pricing analyses should provide the necessary data to generate a true price.

The size of a regional ruminant feed market is important in determining which value chain emerges. The assumptions used in this analysis were very conservative – only 25% of a ruminant's diet would be replaced with pre-treated biomass. It may be the case that a ruminant could replace a much higher portion of its diet with these materials. It may be that CAFOs find this material to be a very good replacement for the current mix of feed, and utilize a much larger quantity of this material than is necessary for an RBPC to emerge vis-à-vis an IBR. These facilities may not limit their market to the region in which they are located, and may possibly market internationally. Under these conditions, the ruminant feed application for these biomass feedstocks will draw supply away from bio-ethanol production, rather than subsidize it. However, it will free up additional corn for conventional ethanol production or human consumption, easing the food versus fuel tension. A more in depth analysis of this market should be undertaken, quantifying the size and potential impacts of these various scenarios.

AFEX RBPCs can exist technically and operate economically as stand-alone facilities when the price-cost margin is sufficient. Selling the pre-treated biomass as ruminant feed rather than as an input into bio-ethanol production commands a higher price. Therefore, it is possible that not only may these facilities divert biomass from ethanol production to ruminant feed applications, but they may actually emerge as ruminant feed producers, not as feedstock suppliers to the bio-ethanol industry. This will have impacts on value chain decisions for bio-ethanol investment agents. If a region's biomass is dedicated to ruminant feed production, bio-ethanol may not emerge in that region. If after ruminant feed production, there is still sufficient feedstock available, it may now be dispersed. This will favor the RBPC. The AFEX process can be scaled up in relatively small increments. The existing ruminant feed operations may scale up to handle the additional throughput created by bio-ethanol demand. The delivered cost of pre-treated biomass to the refinery may actually be less under the ruminant feed first scenario than under a bio-ethanol first RBPC due to lower capital costs and scale economies in operations (it is now a value-added activity as opposed to bio-ethanol dedicated assets). Also, under this alternative scenario, the RBPC will have significant first mover advantages in the value chain decision. Refiners will have to negotiate with the RBPCs, and either integrate them into their chain, or create an entirely separate supply chain. Analyses that investigate the various impacts that this ruminant feed first, bio-ethanol second emergence strategy will have on bio-refinery investment decisions and the volume potential of cellulosic ethanol is needed.

Additional DSS Analyses

There are additional claims of advantages for an RBPC system. For instance, can a RBPC system allow for far flung pockets of biomass supply that cannot feasibly individually be brought together under the umbrella of an IBR to be locally collected and pre-treated in a RBPC and then collectively transported to a refinery?

If the animal feed market doesn't materialize, then the AFEX RBPC loses some of its attractiveness. Economically, how does the depot only approach stand up against an IBR system? Under what conditions would it emerge as a preferred choice for the various investment agents? This system would not create an intermediate high value product, but it could fundamentally change the industry into one based on commoditization of biomass. The techno-economic work being done by INL can be adapted and utilized as a sub-module in the DSS. Insights will be gained from a systems analysis.

Only one pre-treatment (AFEX), and one bio-ethanol pathway (CBP) were considered. There are many other pre-treatment technologies under investigation[118]. It is possible that other can be technically de-coupled from an IBR. These may not provide the ruminant feed, but may be able to generate lower cost structures, improving the attractiveness of distributed systems in bio-ethanol value chains. There are other bio-chemical conversion pathways (i.e., SSCF) to consider, as well as thermo-chemical pathways. There are other bio-energy pathways, such as bio-electricity. The set of value chain choices ultimately includes all combinations of pathways. The AFEX CBP is a realistic and important case, but not the only one. For instance, models presented by Bals and Dale (2012) include engineering economic factors so that profitability measures can be generated as a way of comparing the different configurations to each other. His spreadsheet based models are intended to be part of larger system analyses. These can be integrated into the DSS presented and multiple-pathway LRAC analyses can be done.

Modeling Limitations

As in any modeling effort, activities and functional relationships can be specified in greater detail than the current level of detail. The addition of more modules and sub-modules, and greater specification of other DSS activities and sub-activities could shed additional light on factors that will impact value chain choices. For instance, the impact of feedstock variability across a region in terms of distribution, type, yield and prices of feedstock can be tested. It’s possible to specify equipment, labor and processes in multiple activities included in the DSS framework, such as harvest and collection activity.

[118] see chapter 3

The underlying cost factors that generate DFC and DVC could be specified and be regionally specific. For example, the fuel cost contribution to variable costs may be a critical variable. It was demonstrated that the ratio of fixed cost to variable cost in transport costs is one of the key drivers in determining optimal chain structure. If fuel costs are a large component of variable costs, increases in fuel prices will have significant impacts on the DFC/DVC ratio in a manner that will favor RBPC emergence, especially under a truck-train system. Storage and degradation of biomass are related, and the effects of these on the performance of the different configurations can be modeled and tested.

The feedstock uniformity, fungibility and heterogeneity assumptions are simplifications. Each type of biomass has its own characteristics, including sugar content, pre-treatment conditions, and ethanol yield. In a broad sense, they can be seen as one product, but there may be impacts to value chain choices. For instance, a depot system could handle one biomass source at one location and another at another location, pre-treating each under unique operating conditions and forwarding the PTB onto the bio-refinery in a state where the unique-ness has been overcome.

Decision Support System Enhancements

Bio-fuel mandates are a policy tool aimed at promoting the development of domestic alternative liquid fuels. Increasing the production and consumption of alternative liquid fuels assists in increasing domestic energy independence and security through reducing dependence on imported petroleum; reducing dependence on petroleum in transport;

and, minimizing the impact of rising oil prices and volatility. There are other bio-fuel policy goals, which include: reducing environmental impacts, global warming impacts and carbon footprint of domestic liquid fuel consumption; creating long-term sustainable alternative energy sources; and providing a reliable source of agricultural income which can improve rural economies through job creation and new economic development.

The research/DSS presented here identifies options for minimizing MESP through logistics optimization and ways to address the chicken and egg problem. It can be a tool for stakeholders and policy makers in determining what value chain might emerge in a market environment. As currently modeled, there are not modules for producing performance metrics to determine the impact these choices have on the other policy goals listed above. Modules can be created as add-ons and the DSS can generate these metrics, which will allow for ranking different performance criteria and assessing the impact of tradeoffs among all the objectives. Key additions will include modeling land-use choices, environmental impact assessment, and economic impact analysis.

APPENDICES

Appendix A

DSS Modules
Structure, Flow Charts and Variables

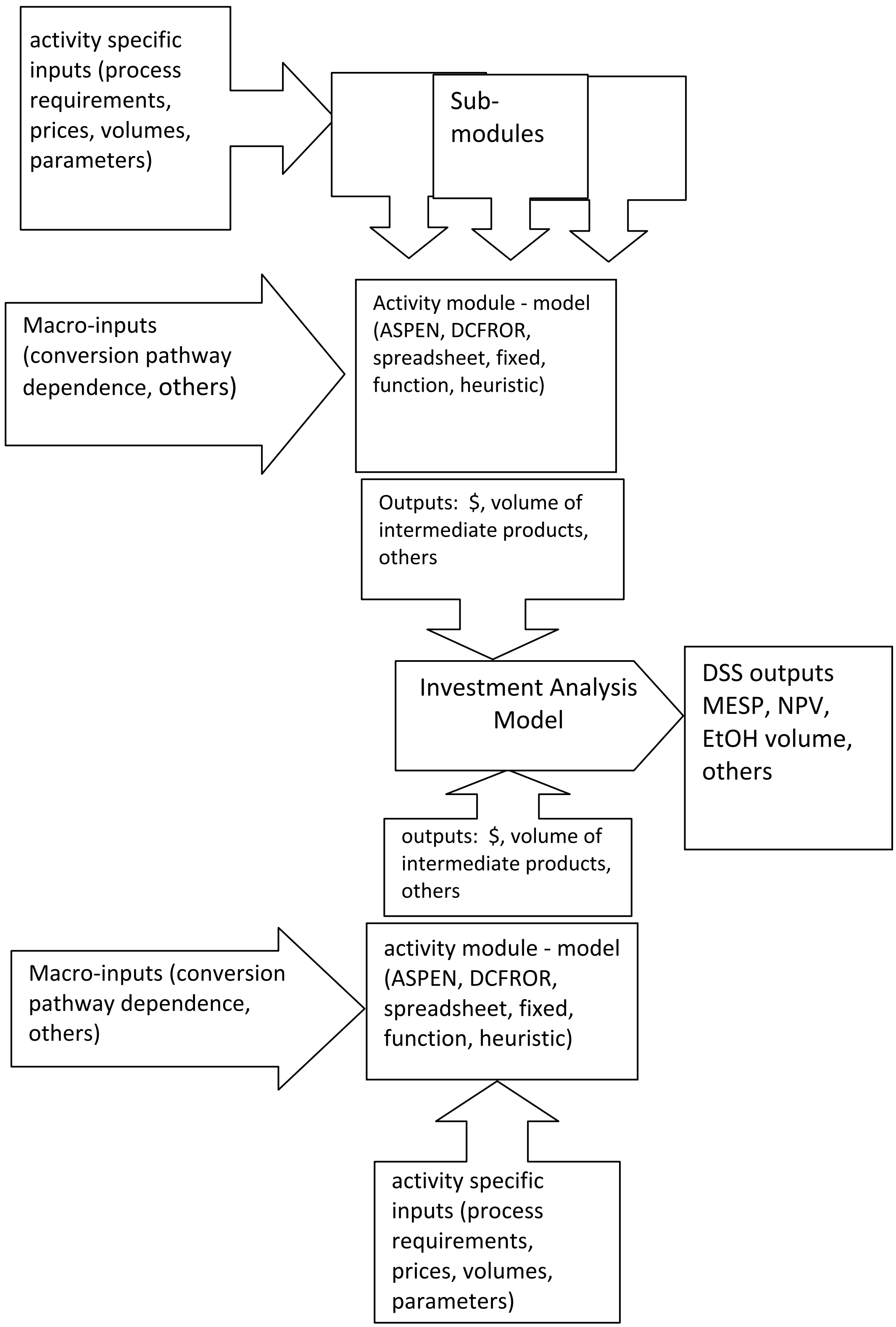

Figure 44: DSS Structure

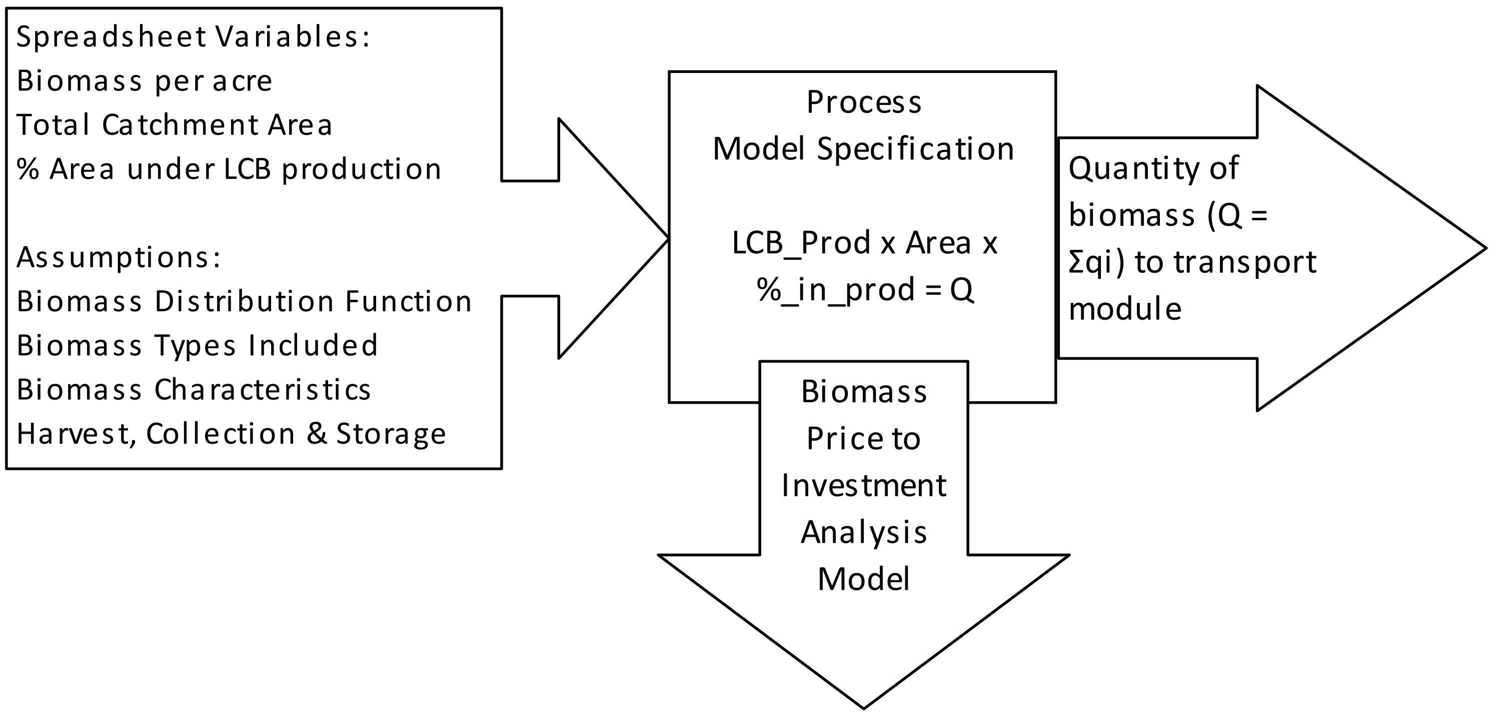

Figure 45: Biomass Production Module

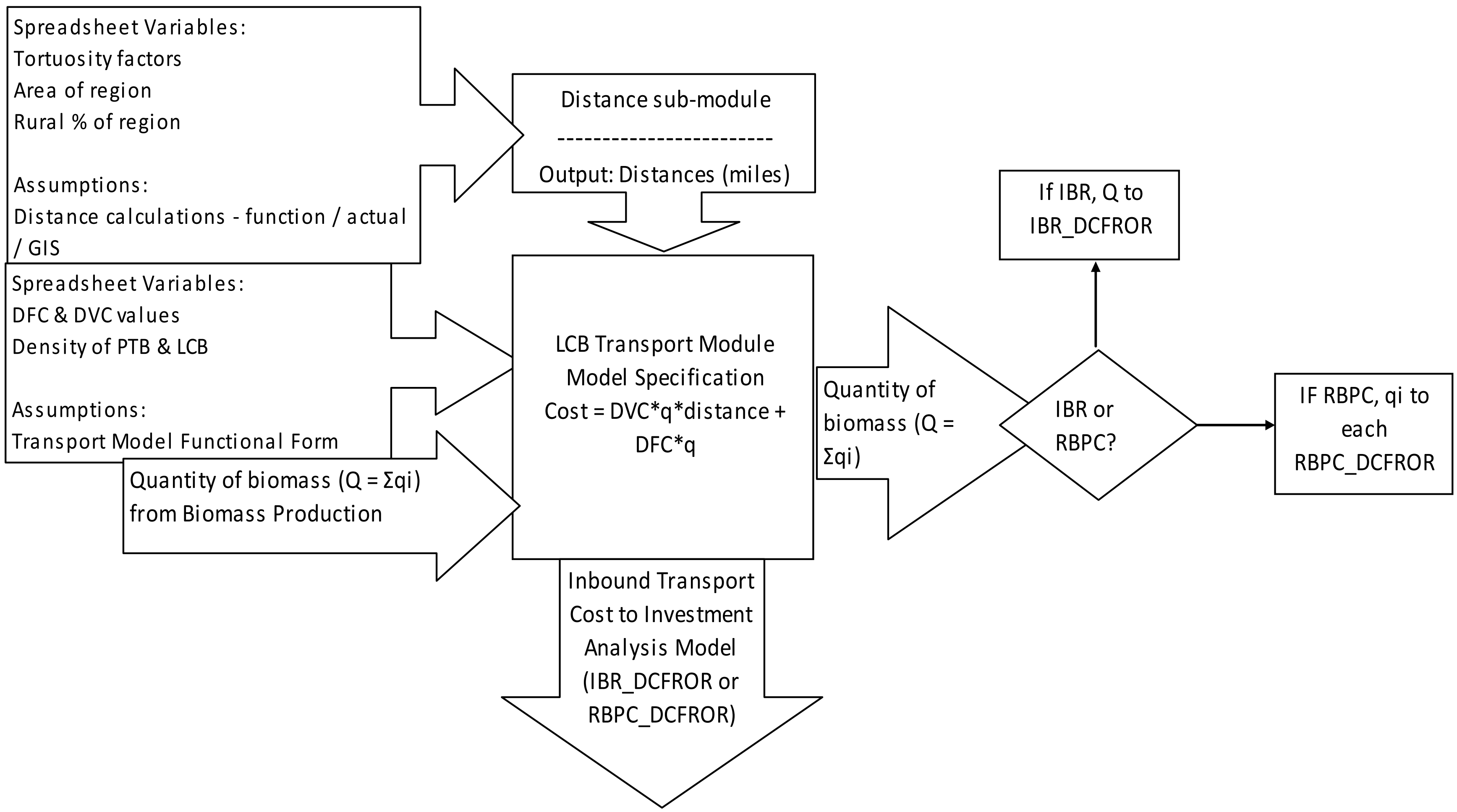

Figure 46: LCB transport module

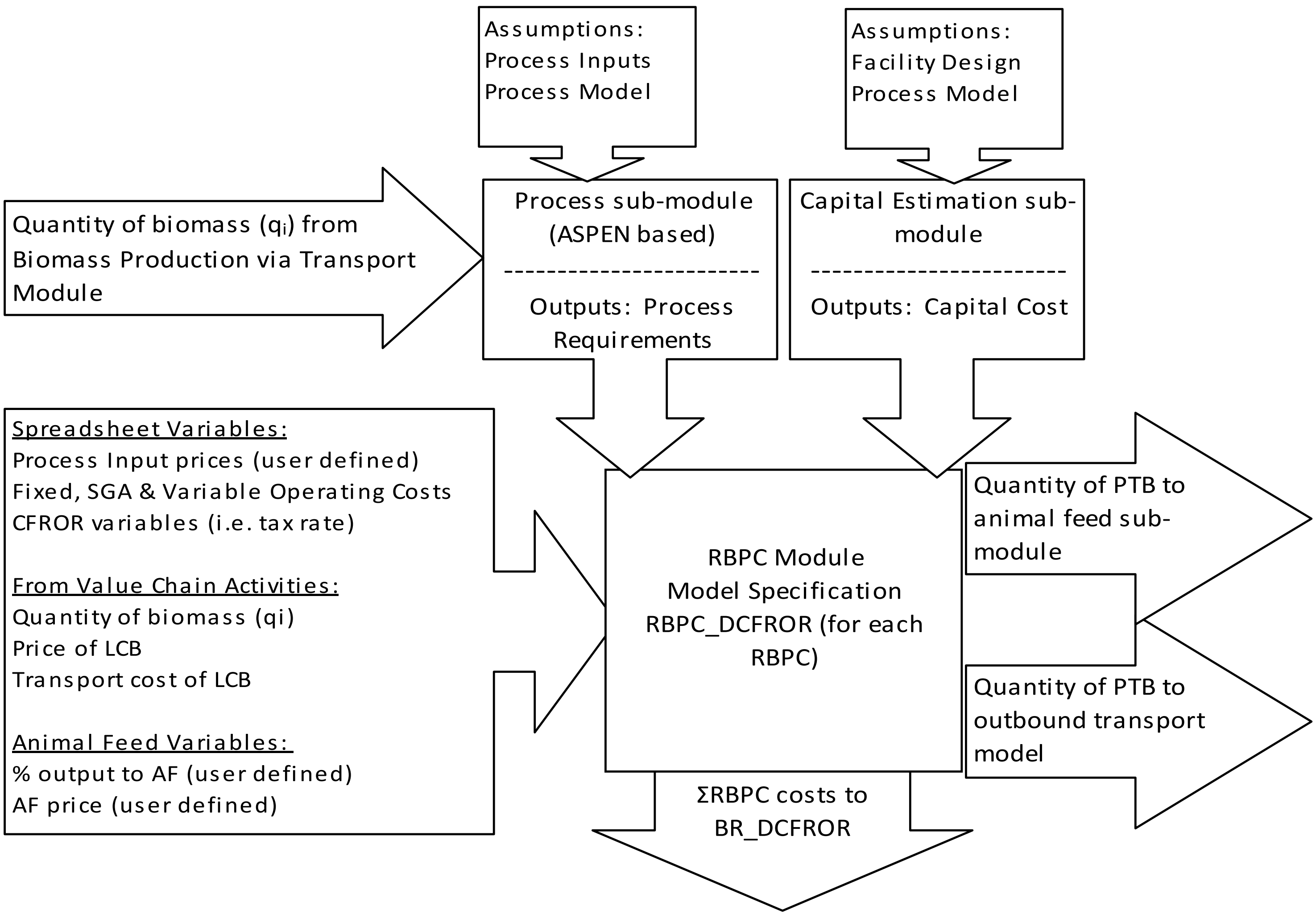

Figure 47: RBPC Module

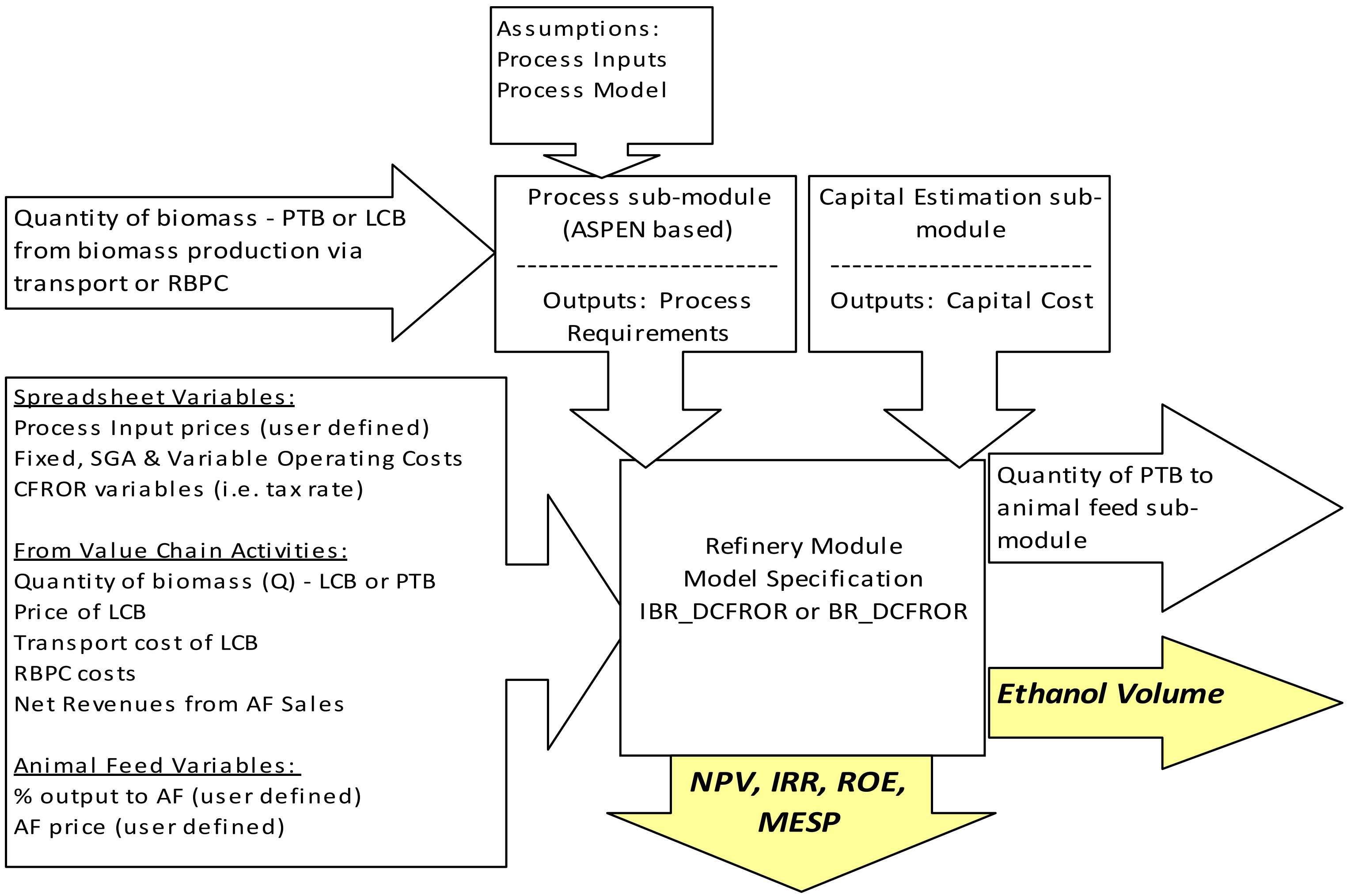

Figure 48: Refinery (IBR or BR) Modules

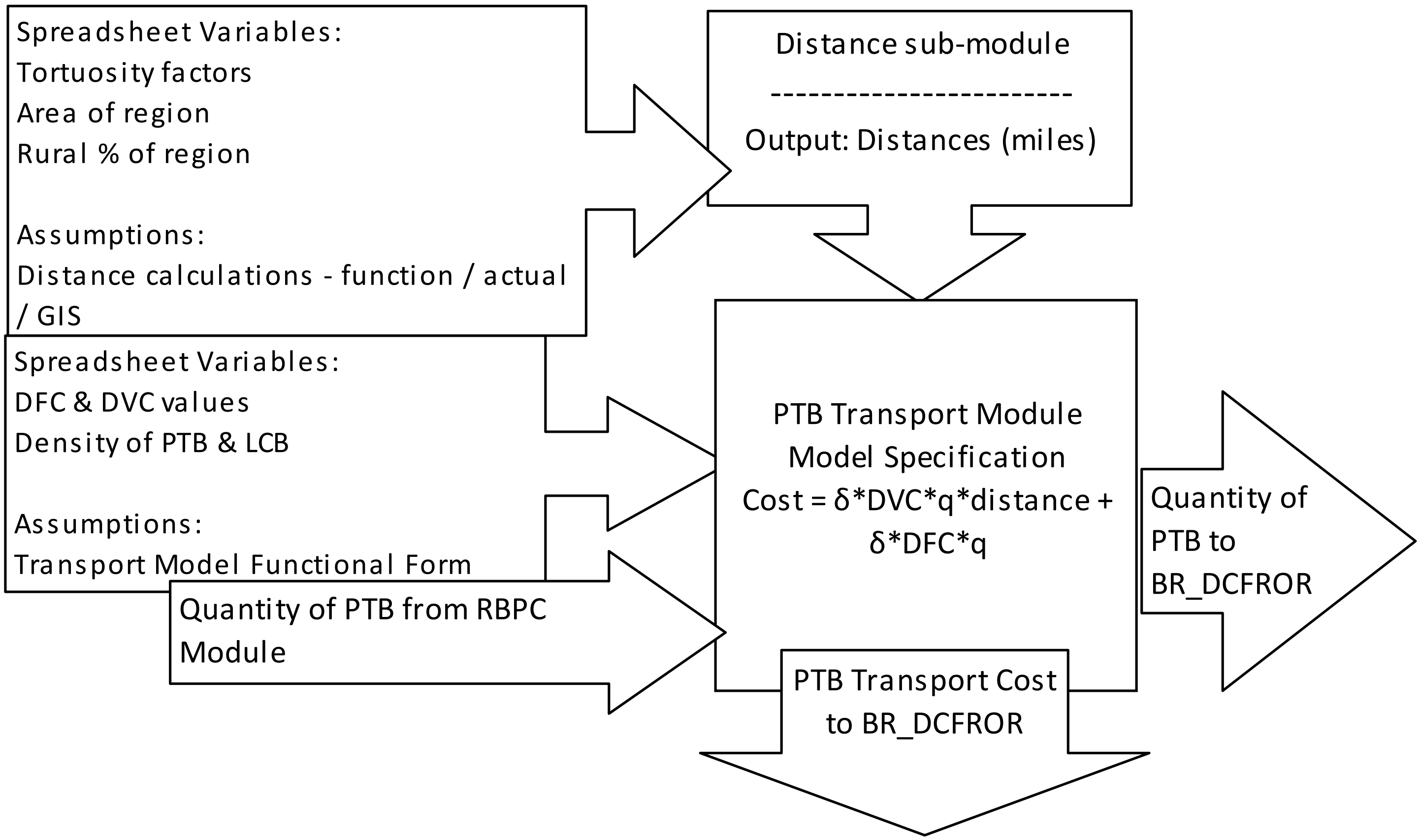

Figure 49: Animal Feed Module

Appendix B

Case Study Regional Information

Michigan

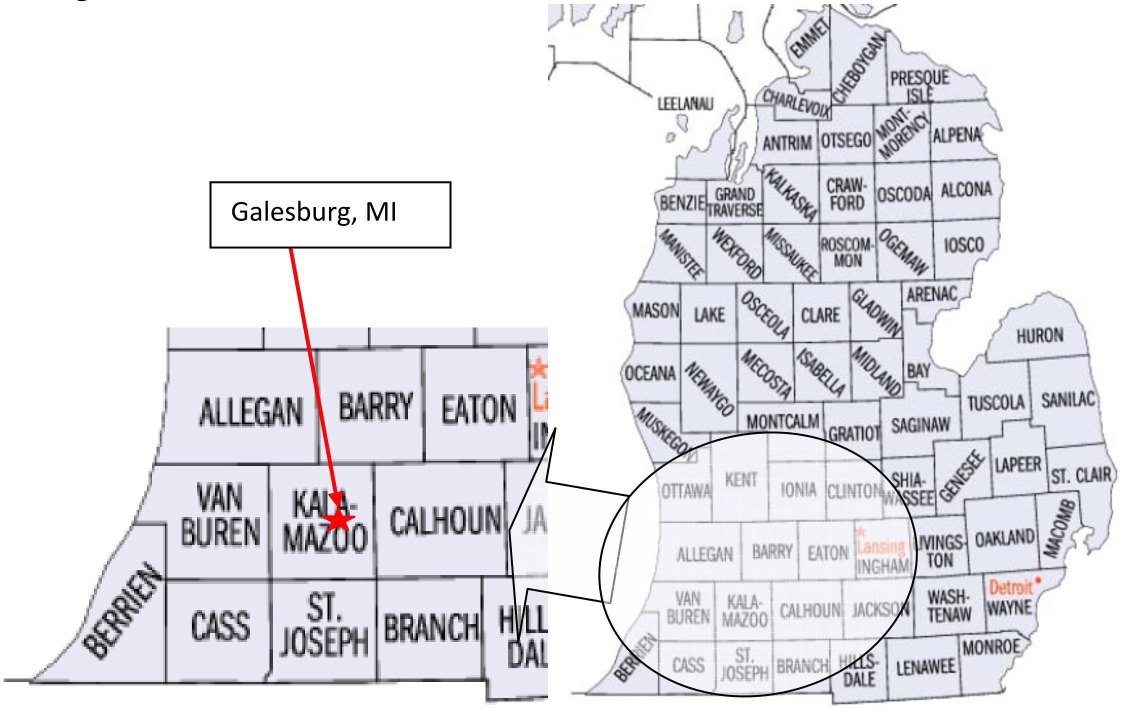

Figure 50: Maps of Michigan Case Study Region

Table 39: Area of Counties (Michigan)			
County	*Area (sq mile)*	*County*	*Area (sq mile)*
Allegan	828	Eaton	576
Barry	556	Kalamazoo	562
Branch	507	St. Joes	504
Calhoun	709	Van Buren	611
Cass	492	Region	5,345

Table 40: Michigan Residues available from crop (tons per year)

	Corn	Oat	Rye	Soybean	Wheat	Other	Available	Usable
ALLEGAN	248,691	742	413	89,897	23,777	0	363,520	127,232
BARRY	101,629	297	0	52,020	15,777	0	169,722	59,403
BRANCH	248,877	328	0	134,664	17,710	0	401,579	140,552
CALHOUN	192,934	485	0	114,110	28,174	88	335,792	117,527
CASS	222,014	89	148	90,548	11,656	0	324,454	113,559
EATON	180,871	1,160	0	137,183	62,618	0	381,832	133,641
KALAMAZOO	151,147	272	0	65,606	10,792	0	227,817	79,736
ST. JOSEPH	305,390	108	46	100,763	13,534	399	420,240	147,084
VAN BUREN	117,137	75	76	54,857	3,087	0	175,232	61,331

New York

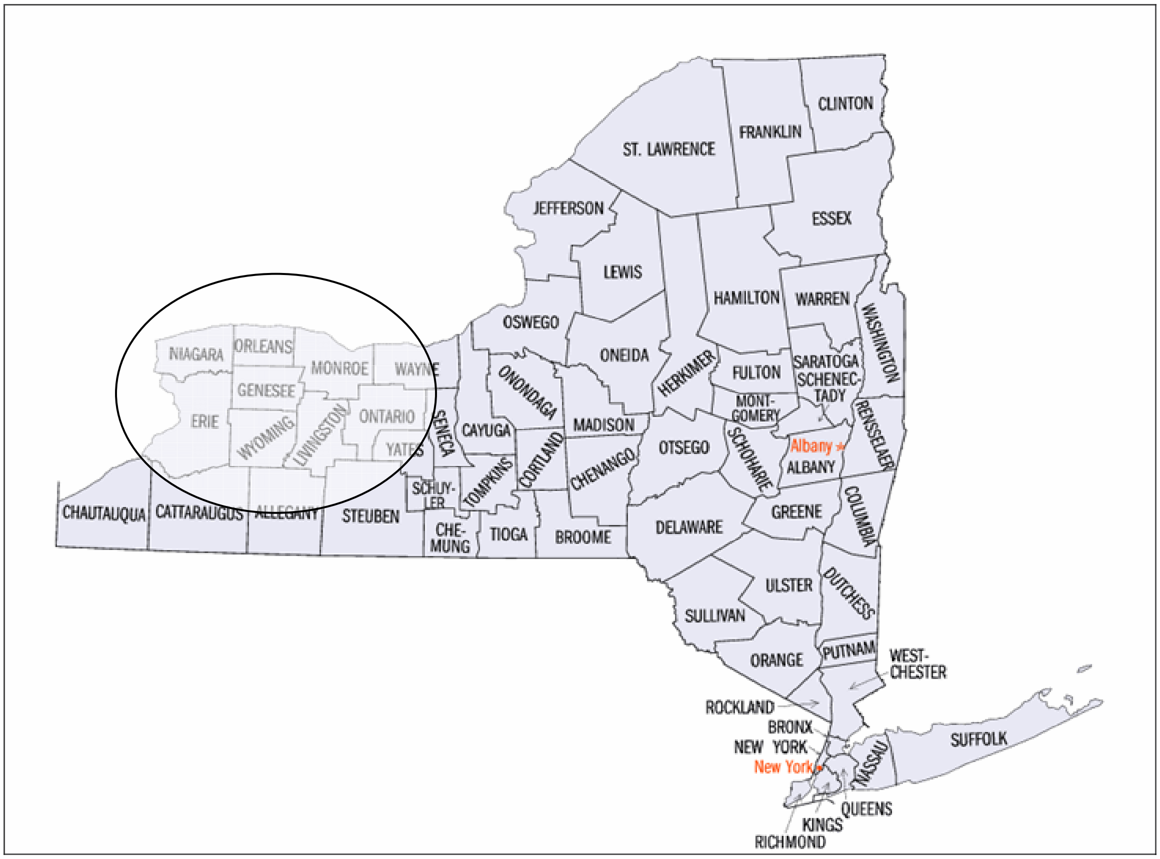

Figure 51: Maps of New York Case Study Region

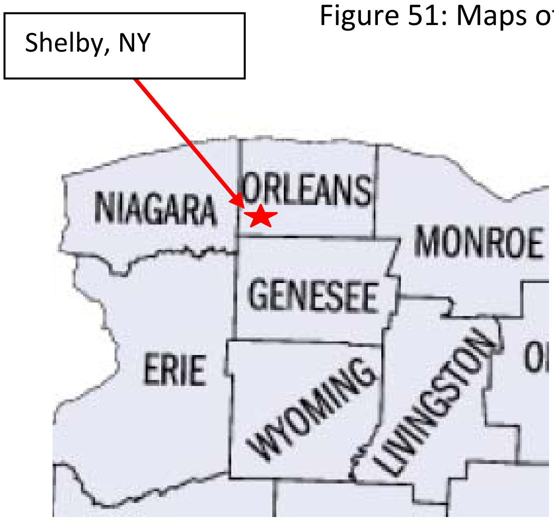

Table 41: Area of Counties (New York)	
County	*Area (sq mile)*
Erie	1,044
Genesee	494
Livingston	632
Monroe	659
Niagara	523
Orleans	391
Wyoming	593
Region	***4,336***

Pennsylvania

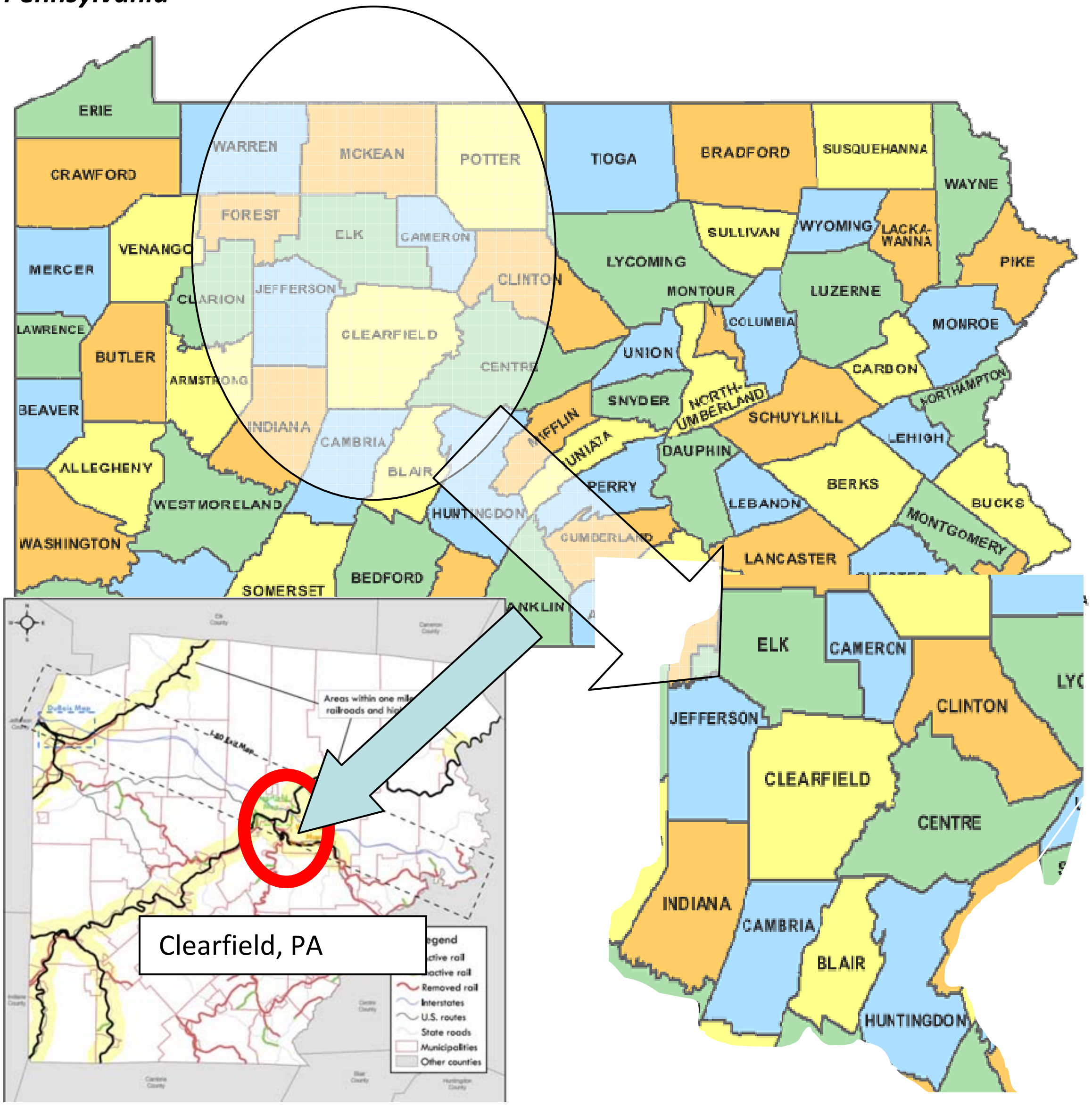

Figure 52: Maps of Pennsylvania Case Study Region

Table 42: Area of Counties (Pennsylvania)

County	*Area (sq mile)*	*County*	*Area (sq mile)*
Blair	527	Clinton	898
Cambria	693	Elk	832
Cameron	399	Huntingdon	889
Centre	1,112	Indiana	834
Clearfield	1,154	Jefferson	657
		Region	***7,995***

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