Simulating Pelletization Strategies to Reduce the Biomass Supply Risk at America's Biorefineries

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Abstract

Demand for cellulosic ethanol and other advanced biofuels has been on the rise, due in part to federal targets enacted in 2005 and extended in 2007. The industry faces major challenges in meeting these worthwhile and ambitious targets. The challenges are especially severe in the logistics of timely feedstock delivery to biorefineries. Logistical difficulties arise from seasonal production that forces the biomass to be stored in uncontrolled field-side environments. In this storage format physical difficulties arise; transportation is hindered by the low bulk density of baled biomass and the unprotected material can decay leading to unpredictable losses. Additionally, uncertain yields and contractual difficulties can exacerbate these challenges making biorefineries a high-risk venture. Investors' risk could limit business entry and prevent America from reaching the targets. This paper explores pelletizer strategies to convert the lignocellulosic biomass into a denser form more suitable for storage. The densification of biomass would reduce supply risks, and the new system would outperform conventional biorefinery supply systems. Pelletizer strategies exhibit somewhat higher costs, but the reduction in risk is well worth the extra cost if America is to grow the advanced biofuels industry in a sustainable manner.

1. INTRODUCTION

Organization of the Paper

The paper begins by introducing federal biofuel policy targets initiated with the Energy Policy Act (EPAct) of 2005 and adjusted in 2007 with the Energy Independence and Security Act (EISA). Next, is a discussion of the current supply system design for herbaceous biomass and barriers associated with this type of system. Solutions are then discussed followed by a discussion of the model scope and key parameters. Several simulation scenarios present usefulness of the model design and demonstrate key findings. The conclusion will summarize the benefits as well as the drawbacks of adding pellet facilities to the supply system and include a discussion on model limitations and future work.

Background on Biofuel Policy

U.S. interest in using ethanol in vehicles began with the Ford Model-T in the early 1900's but due to the low price of gasoline the market did not develop until 1975. Then, ethanol was used mainly as an additive to replace lead (Goettemoeller, 2007). Later, programs began to focus on reduced dependence on foreign sources of petroleum while decreasing vehicle emissions. These goals were eventually revised to include the reduction of greenhouse gas (GHG) emissions from transportation (Wang et al., 2011). The growth in demand for ethanol and advanced biofuels is driven by federal policy(Sorda, 2010), emerging from this shift of focus. The main goal of current policies focuses on using ethanol as a renewable fuel.

The first iteration of the Renewable Fuel Standard (RFS) was enacted as part of the 2005 Energy Policy Act. It mandated 4 billion gallons of renewable fuels be used in 2006 with an increase to 7.5 billion gallons in 2012, this was a major step toward increased biofuel development. EISA in 2007 established the second iteration of RFS or RFS2. RFS2 set even higher goals for biofuel development while also introducing several different categories of renewable biofuels. These categories are nested and shown in figure 1.1 below, along with specific volume requirements. One of the most significant changes, other than drastic increases in overall volume requirements, was the requirement that future fuel production shift away from corn grain and toward other non-food sources (Figure 1.2, (US Department of Energy (DOE), 2011). The shift to cellulosic and advanced biofuels and away from corn grain introduced a number of technological challenges, including developing advanced supply chains that can supply a fungible, variable quality feedstock at a low cost (Hess et al., 2009).

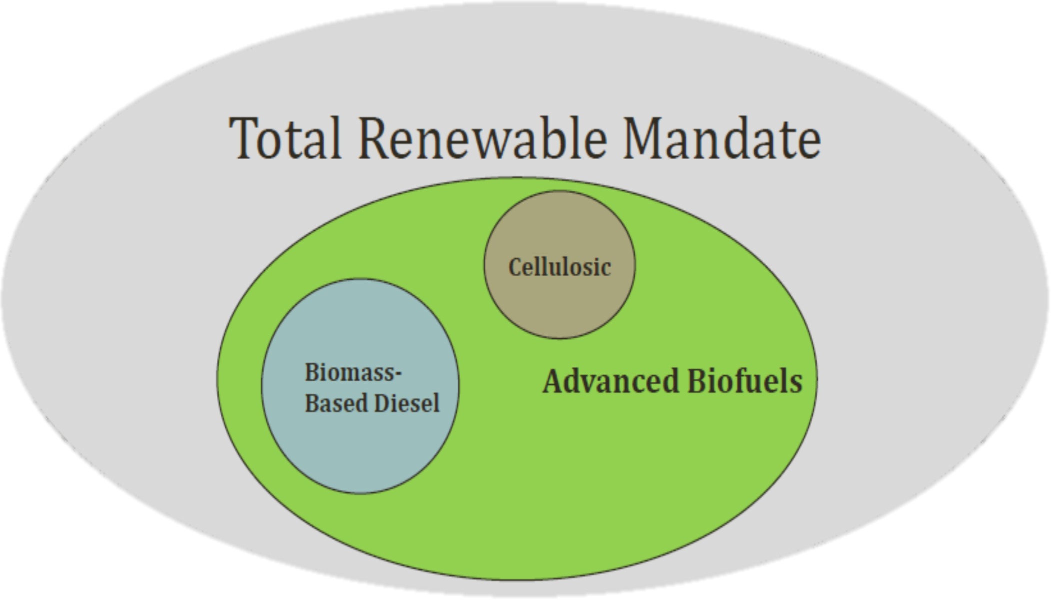

Figure 1.1: Nested structure of the renewable fuel types under RFS2.

In addition, the RFS2 standard mandates that the U.S. Environmental Protection Agency regulate the industry through penalty costs assigned to those refineries and blenders that fail to meet goals for production volumes. The shift in priority in RFS2 sets a trend in grain ethanol that is linear while cellulosic and advanced biofuels face exponential growth targets. The target under this strategy is a reduction in the percent contribution of grain ethanol production with cellulosic and advanced biofuels acting as a substitute in order to shift toward agricultural residues, woody biomass and other non-food sources (Jeffers et al., 2013).

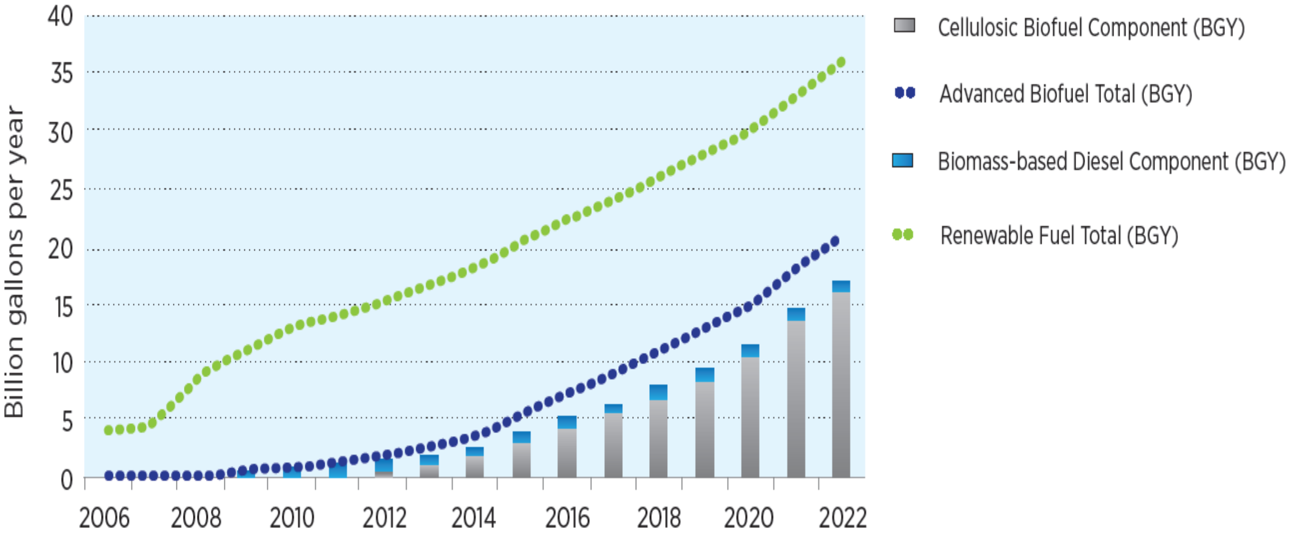

Figure 1.2: RFS2 increases over time (US Department of Energy, 2011).

Benefits of Achieving Policy Goals

Ethanol is a clean burning replacement for petroleum in motor vehicles. It has a lower energy equivalent than gasoline, but produces fewer harmful gases than petroleum based fuels(Mussatto et al., 2010). In addition, the sequestration of carbon by the growing biomass ensures that GHG produced from burning ethanol originates in GHG accumulated previously. In effect, biofuel production can become a carbon-neutral pursuit. Indeed, the reductions achieved through introducing such technologies have been recorded as high as 80% (Lashinski and Shwartz, 2006).

Early policies and available technologies lead to the development of corn grain-based ethanol. As a result the majority of ethanol produced today in the U.S. originates in food-grain. Worldwide approximately 95% of ethanol originates from agricultural products (Mussatto et al., 2010). Compared to petroleum, corn-based ethanol can reduce carbon dioxide (CO_2) emissions by as much as 15%. However, these reductions can come with considerable environmental impacts. In addition using corn-grain for fuel production competes with other industries where corn is used as a feed grain. Cellulosic ethanol or ethanol produced from the cellulose found in crop residues and elsewhere, has significant advantages over corn ethanol. Perhaps most significant among these is the possibility of reducing CO_2 emissions to virtually zero and using feedstock sources with lower economic value to drive down costs(Solomon et al., 2007). The United States has the highest per capita GHG emissions of any nation in the world. Therefore, the support of RFS could help to curb the harmful effects of global climate change.

Focus on Corn Stover

Cellulosic ethanol can be produced from a variety of feedstocks, including; various fast-growing tree species, construction wastes, municipal solid waste, paper and sewage waste as well as dedicated energy crops such as; sorghum, switchgrass and miscanthus(Solomon et al., 2007; US Department of Energy (DOE), 2011). However this study centers primarily on corn stover, an agricultural residue. Corn stover is defined as the cobs and stems remaining in the field following each corn grain harvest. Of the agricultural residues it makes up the largest fraction of collectable material. The highest abundance of corn stover in the U.S. is found in Corn Belt Region(US Department of Energy (DOE), 2011). The relative high abundance and established production of corn makes corn stover a natural choice for early cellulosic biorefineries.

2. CHALLENGES & RISKS FOR THE CURRENT SUPPLY DESIGN

Current Supply Design

The cornerstone of the conventional feedstock supply design is the local nature and wide diversity of herbaceous biomass residue. This has led to the current conventional practices employed in pilot and demonstration scale refineries today(Hess et al., 2009). Poet has a new

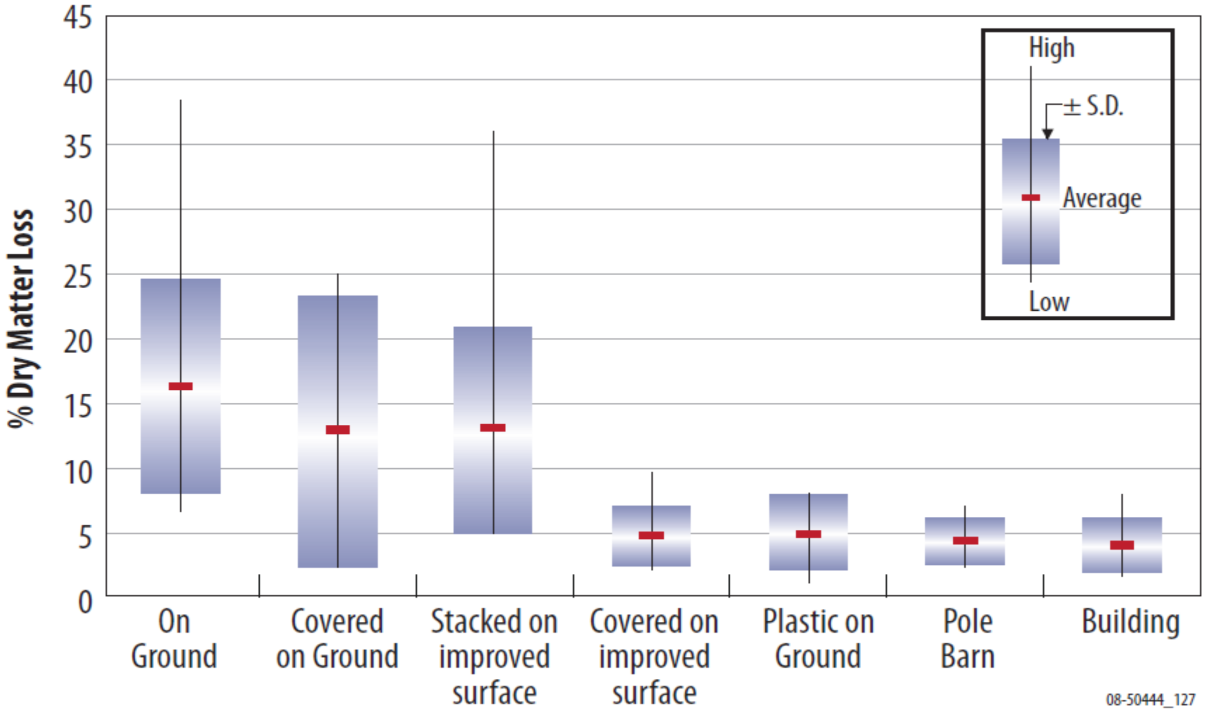

Figure 2.1: Average losses experienced under different storage configurations (Hess et al, 2009)

cellulosic plant scheduled to start operation in the summer of 2014. To effectively supply biorefineries local harvesting practices and technologies must be adapted to meet the increased demand. The current supply system uses the standard bale and transport supply system(Hirtzer, 2014). Poet has been exercising their supply system in an effort to verify a sufficient quantity of biomass for their conversion plant. Even with a lack of competition for biomass from other biofuel companies they are experiencing supply problems(Muth, 2014). DuPont is also in the process of building a cellulosic biofuel plant in Nevada, Iowa that is scheduled to come on line in the fall of 2014, their plans are also for a bale and truck conventional supply system(Lucht, 2013).

Under a conventional supply system, plants are sited close to the biomass resource in order to contend with variability, and high transportation costs of herbaceous crops. Next, contracts with the local farmers are used to establish a resource base. The biorefinery then attempts to optimize its operations to meet the unique characteristics of the local supply, including yield, moisture and other feedstock quality variables such as ash and carbohydrates(Hess et al., 2009). In order to control for these variables the majority of pre-processing takes place at the biorefinery requiring loads of bales to be delivered in a timely, efficient manner. No pelletization is used in the conventional supply design and pre-processing encompasses the breakdown of bales, drying of biomass (active or passive) and grinding to an acceptable size to facilitate fermentation into ethanol(Hess et al., 2009; Jeffers et al., 2013).

Another prominent constraint on feedstock supply is decomposition, also referred to as feedstock shrinkage or dry matter loss (DML). DML arises due to biomass exposure to variations in weather and temperature. The short harvest window for agricultural residues requires that biomass be stored for long periods of time(Epplin et al., 2007), adding to DML challenges. Depending on the region and annual weather during harvest where the biomass is located these losses can average as little as 1% or as high as 25%(Smith et al., 2013). This variation in loss is linked directly with moisture content; when bales of biomass are stored at a high moisture content, DML is accelerated(Kenney et al., 2013). Typical values for moisture content of corn stover in the corn-belt region can be less than 15 to 20%, however varying conditions during the harvest season can result in “wet” biomass containing moisture at levels reaching 50% or more(Hess et al., 2009; Kenney et al., 2013). Figure 2.1 shows cumulative dry matter loss values for a range of storage configurations. The most commonly used under the conventional baled systems are “covered on ground” and “stacked on improved surface.” Other storage strategies have a more narrow range of DML but these systems are more expensive requiring more labor and in some cases permanent structures to deliver higher performance(Darr and Shah, 2012; Smith et al., 2013).

Any loss in biomass requires additional biomass be collected or risk shutting down due to insufficient supplies. Attempting to overcome the losses incurred under current supply design, the biorefinery will contract with farmers for extra tonnage (Hess et al., 2009). This is done with the goal of buffering losses. In this design there are two possible outcomes, either: 1) The biorefinery underestimates the losses for the upcoming year when drawing up contracts and production falls short of the biorefinery’s rated capacity or 2) the biorefinery overestimates and ends up paying for biomass that cannot be used. Further, in the event of an overestimate, the refinery now must remove the excess biomass before harvest begins the following year, an added cost resulting from inefficiency.

Increasing the complexity further, the biorefinery must also contract under variable residue yield assumptions. When contracting for a supply, a biorefinery will assume a given yield from an area. This will determine the draw radius that the biomass supply will need to be procured from in order to guarantee enough supply. The yields are estimated from USDA annual harvest data for a given area(*USDA -Agricultural Statistics*, 2012). If the supply area encounters suppressed yields for a given year then the biorefinery must procure additional supplies from a farther distance which increases the cost of supply. Supply regions are subjected to a number of environmental crises that impact yield including floods, draught and tornados.

Finally, there are feedstock quality issues that can impact conversion efficiencies. Quality standards measure both ash and carbohydrates for biochemical conversion. Ash presents an issue in that it reduces conversion efficiencies, and creates a secondary waste stream that adds cost to the system. Carbohydrates can vary due to length of growing season and harvest moistures (Kenney et al., 2013; Smith et al., 2013). Both impact conversion efficiencies which in turn would require additional biomass to make up for the reduced production.

This design paradigm burdens the biorefinery with significant risk and has strong implications for the financial outcome of any such project(Jeffers et al., 2013). The conventional biomass supply system currently has only passive systems for dealing with quality issues which include modifying harvest practices to reduce loose ash and modifying storage practices to reduce DML.

Risks of the Cellulosic Biorefineries

Financing can add significant costs for the biorefinery. Interest rates tend to be high, thanks to the uncertainty in supply chain designs. The factors outlined in the previous section indicate risk to investors, which can lead to a higher fixed charge rates (FCR) for new projects (Crooks, 2007). The Idaho National Laboratory (INL) identifies several risk factors for lignocellulosic biorefineries. These risks categories include Opportunity, Market, Operational, Economic, Strategic, Climate, Compliance and Financial. Those addressed within this study are Operational, Climate and Financial risks. The following are risk categories that are explored, in part, by this modeling effort.

Operational risks involve the near term possibility for the biorefinery to fall short of contractual obligations due to reduced output, arising from any number of issues(Cafferty and Jacobson, 2013). Most of the challenges associated with the current supply design fall under this category.

Climate risks arise from the dependence of agricultural residues on consistent weather patterns during growing seasons. This risk category may be driven to even greater impact levels with climate change, which increases the likelihood of extreme weather events with potential adverse effects on crop residue harvests(Cafferty and Jacobson, 2013).

Financial risk encompasses the monetary well-being of the biorefinery and increases with the probability that liquid assets available will not cover costs. These risks do not arise independently; indeed the three defined risk categories are interdependent. In order for biorefineries to be successful in the energy marketplace these risks must be managed(Cafferty and Jacobson, 2013).

Managing risk is important in order to keep costs low for the biorefinery and increase the chances of a successful enterprise. When risk is high the fixed charge rate for the life of the loan will be higher. This leads to higher overall cost. Likewise, a project is lower risk will translate into reduced overall costs for the life of the biorefinery. For example, for a biorefinery operating over the course of 20 years with a processing capacity of 800,000 tons per year and a 10% interest rate (ignoring property taxes) will pay more than $650 Million in interest payments. With a 5% interest rate the same biorefinery would pay only $290 Million in interest, a savings of over $350 Million(Cafferty and Jacobson, 2013). This example serves to point out the importance of reducing the risk for the industry.

3. OVERCOMING CHALLENGES: INTRODUCTION TO THE BIOMASS PELLETIZATION STRATEGY SIMULATOR, DYNAMIC FEEDBACK

Overcoming Challenges

To reduce risk, moving toward a more consistent, herbaceous feedstock supply is essential. Indeed developing biomass into a commodity is recognized as a crucial step for the developing

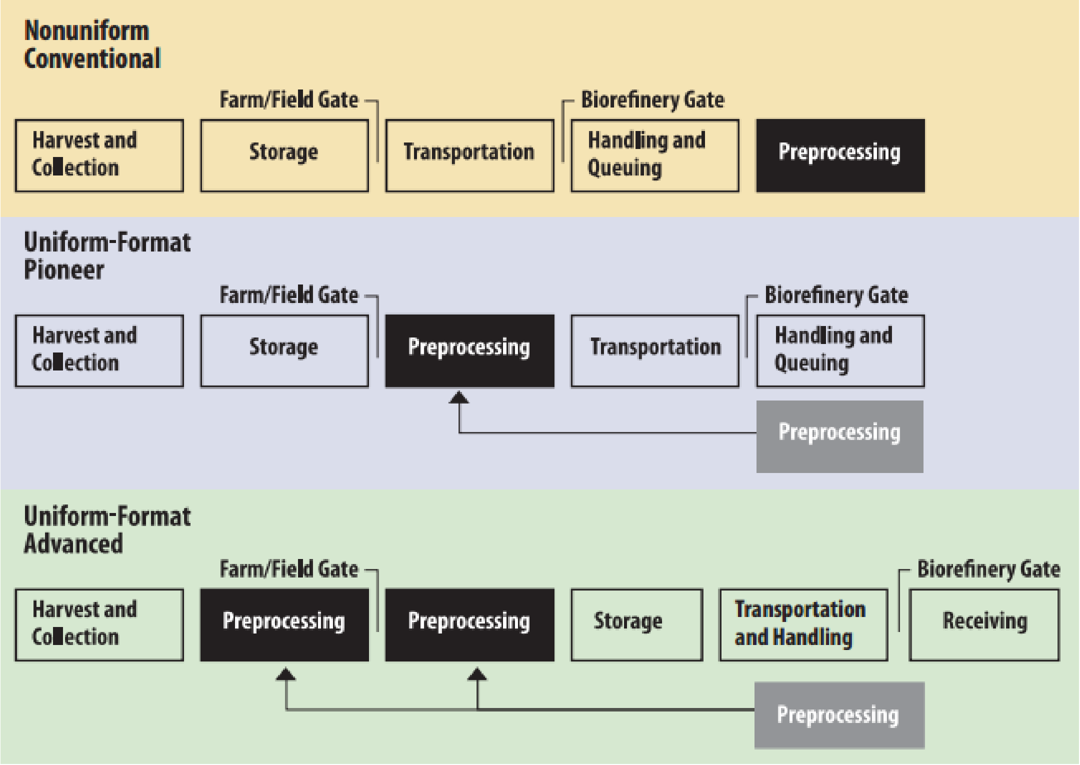

Figure 3.1: Progressive stages of the “Uniform-Format” Vision (Hess et al. 2009)

biobased industries. Several key improvements are needed to accomplish this goal for cellulosic ethanol production. These include; improved transportability, standardization of quality, higher density and aerobic stability(Sanders et al., 2009).

Pelletization, or creation of high density pellets from herbaceous biomass, has been suggested as a possible means to accomplish this goal due to its compatibility with existing grain infrastructure. In figure 3.1, progressing from a primary feedstock supply of bales (non-uniform conventional) to pellets (uniform-format advanced) requires gradual improvements(Hess et al., 2009). This incremental development pattern exemplifies the Ansoff dilemma(Sanders et al., 2009). The Ansoff dilemma is a management strategy used to protect against uncertainties by prescribing the creation of either new markets *or* new products. Attempting to develop both a product and market simultaneously is more likely to fail due to compounding uncertainty(Ansoff, 1987). Hess et al. (2009) recommends the "uniform-format pioneer" supply chain as an intermediate step. This involves limited pre-processing without pelletization to reduce transportation costs. Eranki et al. (2011) suggests early implementation of pelletization at regional depots, similar to "uniform-format advanced" supply chain design in figure 3.1. These regional biomass processing depots (RBPD) would be scaled up to match demand over time.

Despite these suggestions, the industry continues to employ the "non-uniform conventional" supply chain design (*see: Current Supply Design)*. The modeling approach for this study explores several different intermediate strategies to improve upon this design. By adding pelletization capabilities, the model introduces new storage strategies to create a feedstock buffer which can be used to manage risk.

Introduction to the Biomass Pelletization Strategy Simulator

The Biomass Pelletization Strategy Simulator (BPSS) presents the physical and economic feasibility of several scenarios for deployment of pelletization technology in the corn-belt region of the U.S. The goal of this study is to quantify the costs of managing a dynamic feedstock supply system using several different pellet storage strategies in the face of perturbations. It also demonstrates a qualitative measure of the risk under each configuration. The scope of the model is best defined as operations from the perspective of a feedstock supplier for the biorefinery. This "feedstock manager" is in charge of all operations and financial accounting for biomass from the field gate to the mouth of the biorefinery including all pre-processing and bulk handling.

The BPSS uses system dynamics (SD) modeling methods to investigate the overall economic feasibility of additional biomass processing equipment from the perspective of the feedstock supplier. SD is a methodology for the study of complex, non-linear systems over time(Ford, 2010; Forrester, 1971a, 1971b; Sterman, 2000). Pioneering work by Forrester (Forrester, 1961) established basic theory that explores socio-economic factors along with physical systems. These models provide a realistic approach to system simulations that incorporate "human error" elements such as informational delays and imperfect understanding.

Biomass supply, markets and other aspects of the bioeconomy have been recently explored using system dynamics methodology(Dyner et al., 2013; Flynn and Ford, 2005; Jeffers et al., 2013; Peterson et al., 2013). This study benefits from those combined applications as well as others exploring the boom and bust cycles occurring in supply chains of other industries(Sterman, 2000, pp. 685, 824).

Software used to create SD models relies on a graphic user interface instead of programmatic approach increasing understanding through transparency. This allows diverse groups to participate without any prior knowledge of the modeling methodology used. In addition, the SD modeler uses a variety of diagraming conventions that serve to further explain the model graphics and results. The BPSS was created using Vensim DSS (2004) software to conduct all simulations and generate results. SD models can excel in circumstances where many unknown or uncertain parameters exist to improve system design or guide policy development. The nascent cellulosic biofuel industry is indeed such a system.

Brief Overview of Stocks and Flows

To simulate the aging of biomass twelve stocks are needed. Individual numbered stocks correspond with the age of the material (in months). In figure 3.2, the aging field storage moves through subsequent stocks throughout the operational year. Each month biomass is transported from the field to the biorefinery and is placed in on-site storage. The amount of each transfer is based on the processing abilities of both the biorefinery and optional pellet mill. DML takes place unseen by the feedstock manager throughout the storage period. Until incoming trucks are weighed and the quality of material is assessed the amount of loss will be unknown. An input array with detailed monthly loss amounts is used to select between different DML scenarios. When these scenarios are activated biomass is effectively “lost” to the operator of the biorefinery, reducing the total harvest useable for biofuel production. Once biomass is delivered to the site of the biorefinery as baled storage it is put into production managed by dynamic feedback inside the model.

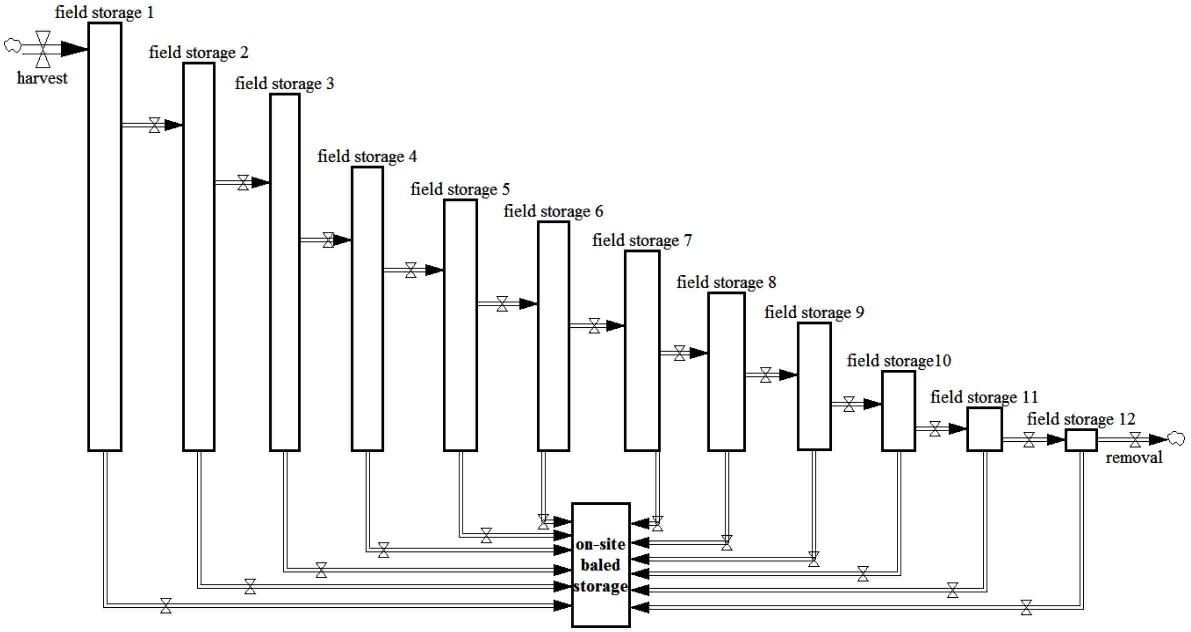

Figure 3.2: The aging chain structure of BPSS, each field storage stock number corresponds to the age of the biomass. At the end of the operational year any remaining biomass is removed.

Dynamic Feedback

Once biomass arrives at the facility it can be put to use in 3 operational combinations:

1. Conventional Configuration: Under this configuration there are no means to densify biomass through pelletization. Biomass is pre-processed directly from bales and fed into the biorefinery.

2. Hybrid Configuration: This configuration blends conventional and uniform-format configurations. Direct processing from bale to biorefinery is still a priority, however the addition of a pellet mill allows extra biomass to be converted to a densified, stable form limited by the capacity of the pellet mill and available pellet storage.

3. Uniform-Format Configuration: This configuration prioritizes pelletization of *all* biomass adding an extra step. Now biomass is converted from bale format to pellet format, before being fed into the biorefinery. This is also limited by pellet mill capacity and storage size. Choosing a larger capacity allows for pellet storage to accumulate. If the pellet mill capacity and storage does not match the monthly requirement, the system defaults supply to match the conventional configuration.

The dynamic feedback in the model is responsible for prioritizing the use of biomass as well as managing available storage. In the conventional configuration only one balancing loop is used to manage the on-site baled biomass. The hybrid configuration adds a second balancing loop with ability to pelletize. Finally, the uniform-format design contains both balancing loops found in the other two configurations but also includes a reinforcing loop

Figure 3.3 shows the feedback inside the model that manages storage and directs pelletization. The conventional and hybrid formats are displayed in figure 3.3A. Ignoring the “pellet storage balanced” loop gives the basic structure for the conventional system where the only management available lies in the “baled storage balanced” loop. Adding the pellet mills in the hybrid configuration introduces the ability to store pellets and adjust the amount available via the “desired months of pellet storage” input. The uniform format system feedback is seen in figure 3.3B. Changing the priority destination for incoming baled biomass (i.e. to the pelletizer instead of the refinery) reveals the “conversion to pellets is reinforced” loop, which drives up pellet storage. The “pellet storage balanced” loop keeps storage to a manageable size so that the volume of pellets does not overshoot the available storage infrastructure.

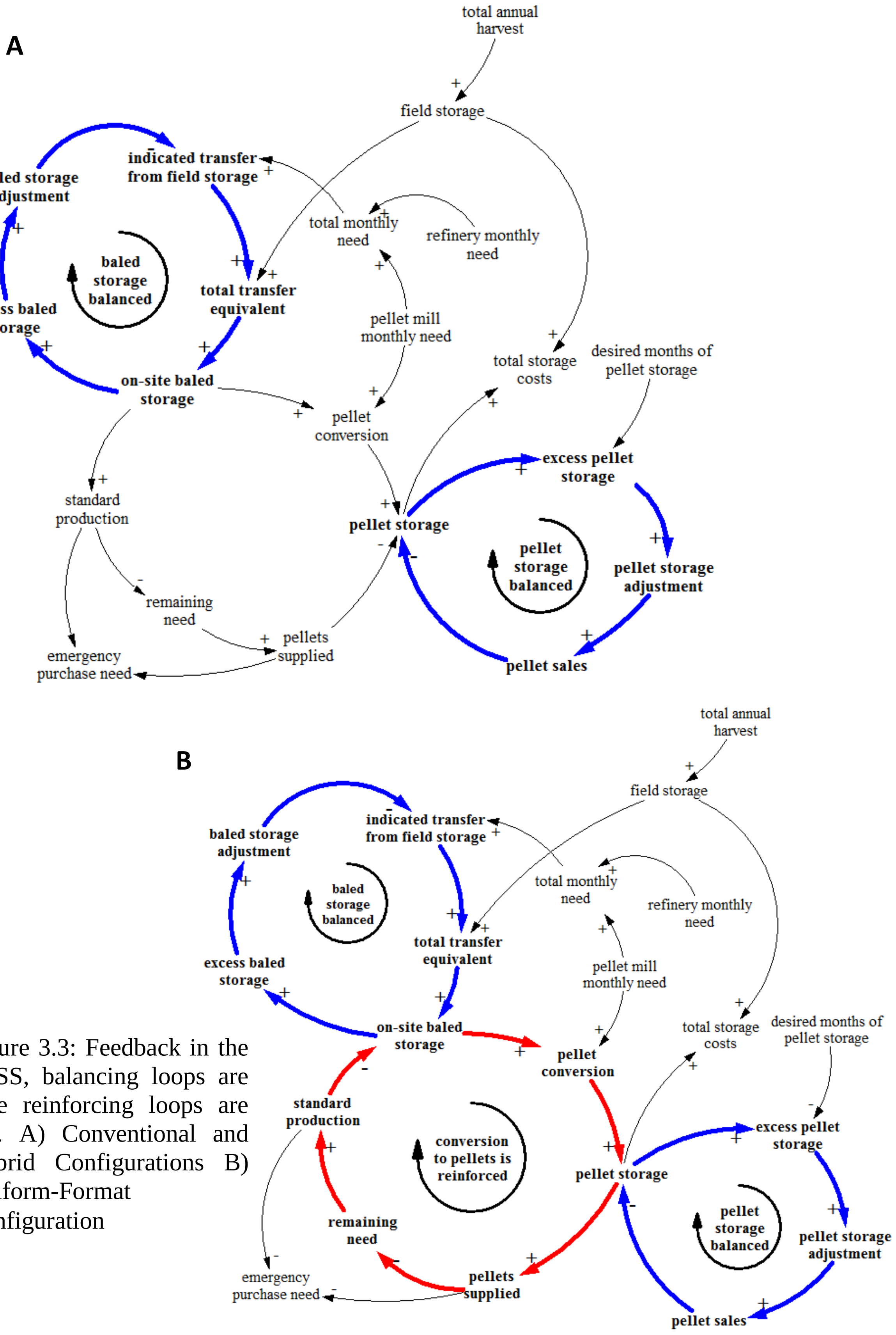

Figure 3.3: Feedback in the BPSS, balancing loops are blue reinforcing loops are red. A) Conventional and Hybrid Configurations B) Uniform-Format Configuration

4. SIMULATION SCENARIOS & SENSITIVITY ANALYSIS USING THE BIPSS

Simulation Scenarios

A comparison of the three system designs is tested in a base case scenario, risk mitigation scenario and extended risk mitigation scenario. These scenarios were chosen to test the flexibility and cost-effectiveness of the respective designs conditions that may be experienced by biorefineries in the corn-belt region of the U.S.

Base Case Comparison

Harvest estimates for the harvest base simulation case is taken from the Uniform-Format Design Report (*See: Current Supply Design).* The feedstock manager requests 60,000 tons of extra biomass tonnage (7.5% extra) to buffer the variability in supply. Another important parameter is DML; the base case assumes a conservative 20% harvest moisture. Estimates of DML are based on data from William Smith and Ian Bonner of the Idaho National Laboratory through data gathered from laboratory reactor experiments designed on a three month time-frame. These results were then stretched to fit a yearly decay rate at the assumed naturally lower reaction speeds.

The graphs in figure 4.1 show the base simulation case results. The simulation runs for 15 years with consistent harvests arriving at the beginning of each operational year. Storage appears in the field and the balancing loop prevents on-site baled storage from accumulating to an unmanageable amount, this is the blue baseline of total storage. The graph of feedstock supply shows that the biorefinery receives 100% of its supply without any shortages. The stacked storage graph colors show the biomass aging in the field from green to brown.

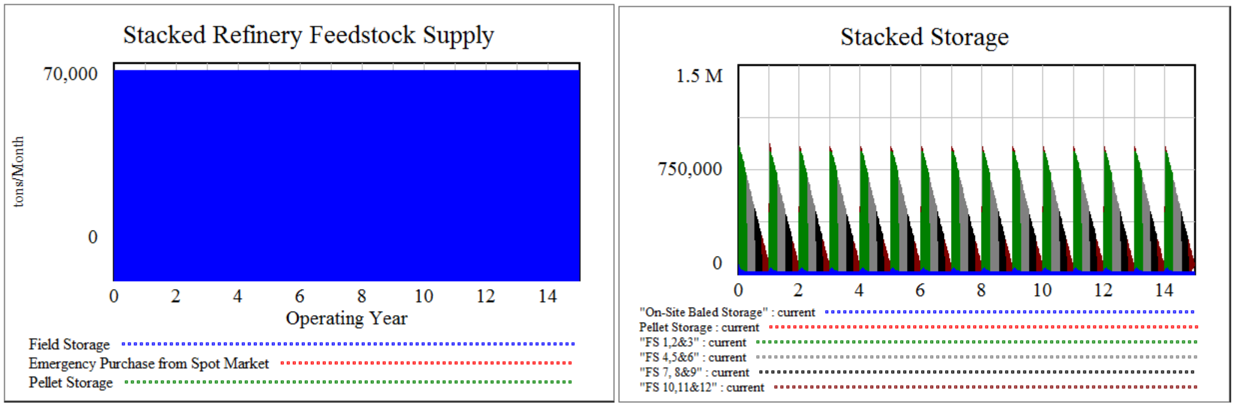

Figure 4.1: Base case simulation results, the biorefinery experiences consistent harvest values and no supply interruptions occur.

This first simulation shows that the managing feedback loops are at work and that the BPSS is moving biomass through the system in a way that is characteristic of the conventional biorefinery design. However, achieving the same level of harvest each year is unrealistic. Figure 4.2

represents 3 discrete events leading to lower than requested biomass yield under each of the system configurations. The events are as follows:

1. During operational year three – four a minor disturbance occurs that reduces the requested harvest by 15%. This may occur due to a minor drought or contract difficulties with local farmers.
2. Operational year seven –eight sees an intermediate disturbance of 20% harvest reduction. This may result from a more pronounced drought or contract difficulties.

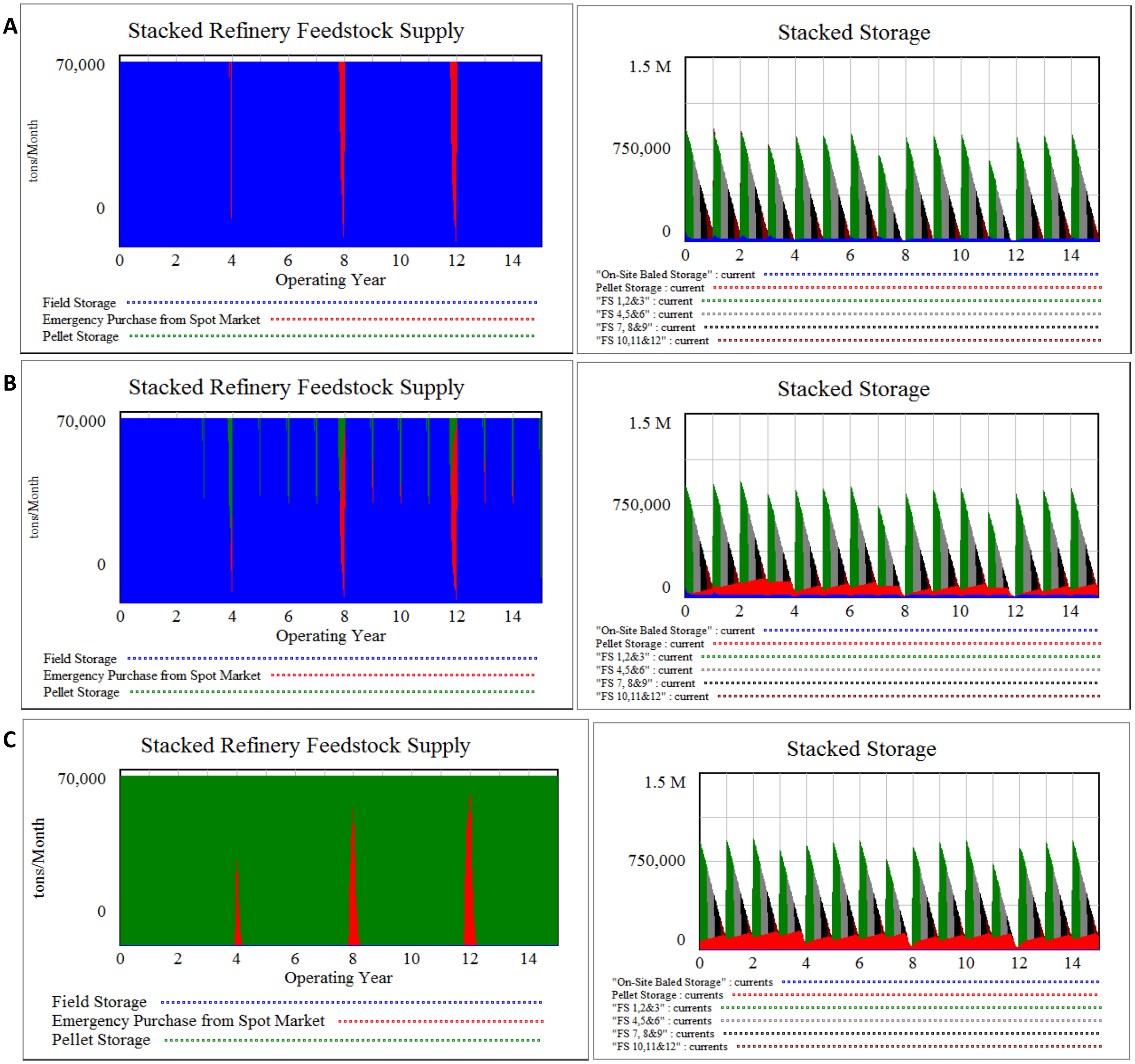

Figure 4.2: Base case model output for the three configurations under A) Conventional B) Hybrid and C) Uniform-Format Configurations

3. Finally, during operational year 11 – 12 the feedstock manager experiences a severe loss of biomass at 25% of the requested 860 Ktons.

In addition to the reduction in harvest, each scenario is accompanied by DML based on a 20% moisture level. These scenarios also make the assumption that drought years occur discretely rather than in combination for 2 or 3 seasons. Figure 4.2.A is the conventional configuration, only a 7.5% field storage buffer protects the refinery from the need to purchase biomass from an external source. As perturbations occur the biorefinery experiences shortages at the end of the operational year and red peaks appear as the source of feedstock switches over to the emergency market. Any remaining on-site baled storage is depleted in around 2 weeks leaving no choice but to purchase from a spot market. This can be risky, if weather related events have reduced the yield for the biorefinery the effect could be far reaching, beyond the local area of the biorefinery. In a competitive market this could result in higher demand for emergency tonnage leading to a higher price. The price modeled for emergency purchases is $50/ton, or double the on-contract price. In a low disturbance, prices could be lower, however, during high disturbance events (scenario 3) the price could climb even higher.

Figure 4.2.B and 4.2.C are configurations equipped with pellet mills. Figure 4.2B results show the outcome for the hybrid configuration. The pellet mill capacity is 5,000 tons/month, or large enough to process the 60,000 ton of excess, should it all arrive. Two months of pellet storage infrastructure are incorporated and the green peak around year 4 shows that there is almost enough storage to cover the first disturbance following the 3 year initialization, even though the full 2 months of storage has not yet accumulated due to DML. Since the need to purchase from the emergency market is reduced, so is the risk to the biorefinery for that season. However, the combination of DML and the relatively small amount of excess tonnage makes it difficult to stockpile pellets before the next two rounds of harvest reduction. Indeed, the red wedge in the "stacked storage" graph declines steadily and pellets make very little impact on the operations. The pellet mill is perhaps over-sized for this scenario, causing the very small green peaks in the biorefinery supply graph to appear, even in years when there is no harvest reduction. This is due to the unaccounted for DML and added difficulty of managing pellet production as well as standard biorefinery delivery.

Figure 4.2.C shows results for the uniform format configuration. Here the risk is even higher; the red peaks are larger indicating a greater amount of need to purchase from the unpredictable emergency market. This is caused by a delay in processing the pellets and lack of foresight from the feedstock manager to halt pellet production to maximize the availability of biomass.

Base Case Cost Analysis

Assessing the cost profile of each configuration under base case operations, including disturbances, the conventional system is clearly at an advantage. Figure 2 details the costs and revenue for each configuration. Overall profit for the conventional system is 7% higher than hybrid and 17% higher than uniform-format. Since both of the configurations including pellet machinery and storage still had to purchase biomass from an emergency market the reduction in risk was negligible, while costs increased due to the addition of pellet infrastructure. This harvest strategy does not provide enough of a buffer in the conventional configuration to handle even a small reduction in regional yield. However, the hybrid and uniform-format designs have a greater amount of flexibility thanks to the addition of pellets. The next section explores this flexibility in greater detail.

Table 4.1: Major costs for the feedstock supplier of a cellulosic biorefinery, under the base case design, the conventional configuration results in the highest profits.

	Conventional	**Hybrid**	**Uniform-Format**
Cost			
On-Contract Purchases	$296.48 M	$299.63 M	$299.86 M
Pre-processing of Bales	$571.92 M	$543.88 M	$10.77 M
Field Storage	$20.82 M	$18.84 M	$18.84 M
Field Storage Removal	$2.30 M		
Pellet Processing		$22.31 M	$ 378.14 M
Pellet Capital		$12.01 M	$ 174.03 M
Pellet Storage		$17.04 M	$51.29 M
Total for Pellets		$51.35 M	$603.46 M
Emergency Purchase	$13.35 M	$9.49 M	$11.44 M
Dry Matter Loss	$14.68 M	$13.37 M	$13.39 M
Total Cumulative Costs	$919.54 M	$936.56 M	$957. 76 M
Revenue			
Pellet Sales		$1.42 M	$1.225 M
Refinery Sales	$1,138.00 M	$1,138.00 M	$1,138.00 M
Total Cumulative Revenu	$1,138.00 M	$1,140.00 M	$1,140.00 M
PROFIT	**$ 218.82 M**	**$ 203.22 M**	**$181.83 M**

Risk Mitigation Case

The inclusion of pellet mills increases the number of options available to the feedstock manager but brings with it added complexity. As seen in Figure 4.2.C, simply adding the infrastructure to enable pelletization does not reduce risk. Figure 4.4 shows the same disturbance scenarios as seen in figure 4.2, but with parameter adjustments to maximize the use of pelletization capability as well as attempt a reduction in risk for the conventional configuration.

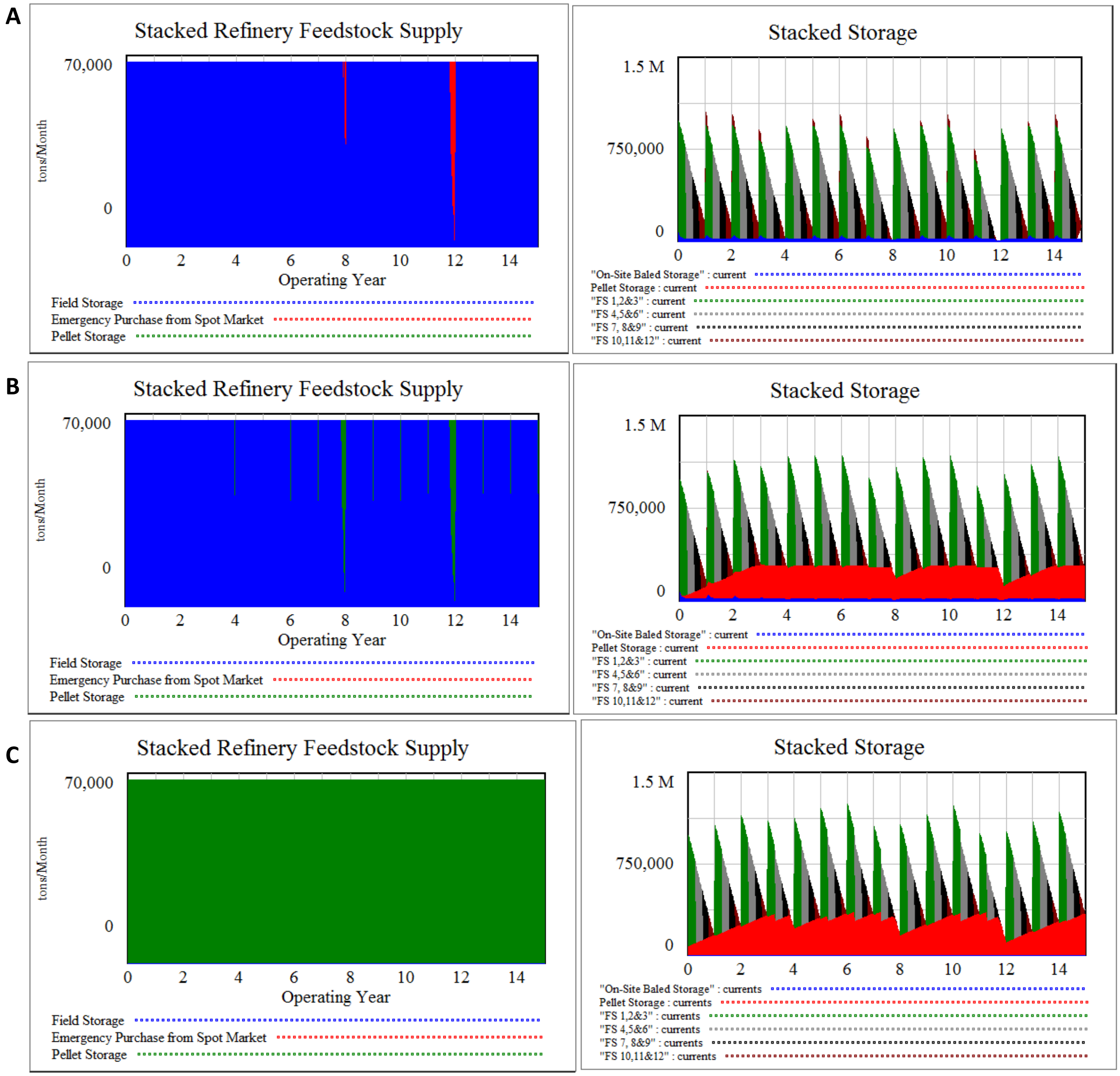

Figure 4.3: Risk can be mitigated using pellet mills and storage

Under the conventional format, the manager knows from the first scenario that the 7.5% of extra tonnage does not protect the biorefinery even during small disturbances. Likewise, the manager knows that they can put to use extra material under hybrid and uniform-format configurations. Therefore, a higher harvest contract is secured for 930,000 tons or 15% above the rated capacity of the biorefinery. For pellet-inclusive scenarios the amount of storage infrastructure has been doubled to four months. Additionally, the manager has learned that the unseen DML will guarantee a lower harvest and can reduce conversion efficiency. To reduce the mill's competition with the biorefinery's demands, the manager only installs another 3,000 ton/month, rather than 5,000 ton/month, for a total capacity of 8,000 ton/month.

The result of this parameter change shows that, in both cases involving pellet mills, the risk is lowered substantially. The stacked graph of total storage shows significant increase in the storage buffer available to the manager, thanks to the increase in pellet capacity and available storage. This added buffer prevents the biorefinery from purchasing material externally and all shortages are handled "in-house."

The conventional configuration also benefits from the change, but due to the lack of pellet infrastructure its storage capacity remains the same. The small perturbation is handled well but the 20 and 25% harvest reductions result in a need to use the emergency market once again. The risk is only lowered slightly.

Risk Mitigation Cost Analysis

Increasing the standard contract to achieve a 15% excess still favors the conventional biorefinery and hybrid and uniform-format designs are, respectively, 25% and 19% less profitable. With a standard price of $50 for every ton of biomass purchased from an emergency market the conventional biorefinery would be better off with a 7.5% over-supply seen in the base-case. In all configurations costs were higher and profits lower than in the base case scenario. For the conventional design the greatest added cost comes from removal of old field storage at the end of each operational year. The hybrid and uniform format designs suffer from the higher storage costs associated with storing pellets. However, this added storage effectively reduces risk. If such reductions can be translated into a reduction in annual percentage rate for the biorefinery, the pellet-inclusive configurations might overcome the cost of additional technology.

Table 4.2: Costs for the risk mitigation scenario. Changing the harvest parameters produces a shift in the cost hierarchy.

	Conventional	**Hybrid**	**Uniform-Format**
Cost			
On-Contract Purchases	$301.75 M	$320.36 M	$320.65 M
Pre-processing of Bales	$571.92 M	$553.05 M	$ >.01 M
Field Storage	$23.97 M	$21.04 M	$20.61 M
Field Storage Removal	$23.97 M		
Pellet Processing		$36.21 M	$ 404.41 M
Pellet Capital		$19.21 M	$ 181.34 M
Pellet Storage		$50.76 M	$57.17 M
Total for Pellets		$51.35 M	$642.92 M
Emergency Purchase	$6.46 M		$ >.01 M
Dry Matter Loss	$16.65 M	$14.89 M	$14.60 M
Total Cumulative Costs	$941.65 M	$1,016.00 M	$998.78 M
Revenue			
Pellet Sales		$24.62 M	$21.23 M
Refinery Sales	$1,138.00 M	$1,138.00 M	$1,138 M
Total Cumulative Revenu	$1,138.00 M	$1,163.00 M	$1,160.00 M
PROFIT	**$196.71 M**	**$ 147.46 M**	**$160.81 M**

Extended Risk Mitigation

The previous cases assumed that reductions in harvest, resulting in perturbations to the biorefinery system would happen discretely, by offering the biorefinery several years of reprieve to build back storage. The next series of simulations described explores harvest reduction scenarios that occur in conjunction as follows:

1. The first drought arrives in year 3, extending for three years before returning to base case assumptions for another three year period. The reduction for each drought year is equivalent to the minor reduction in the previous scenarios or 15% reduction in harvest.

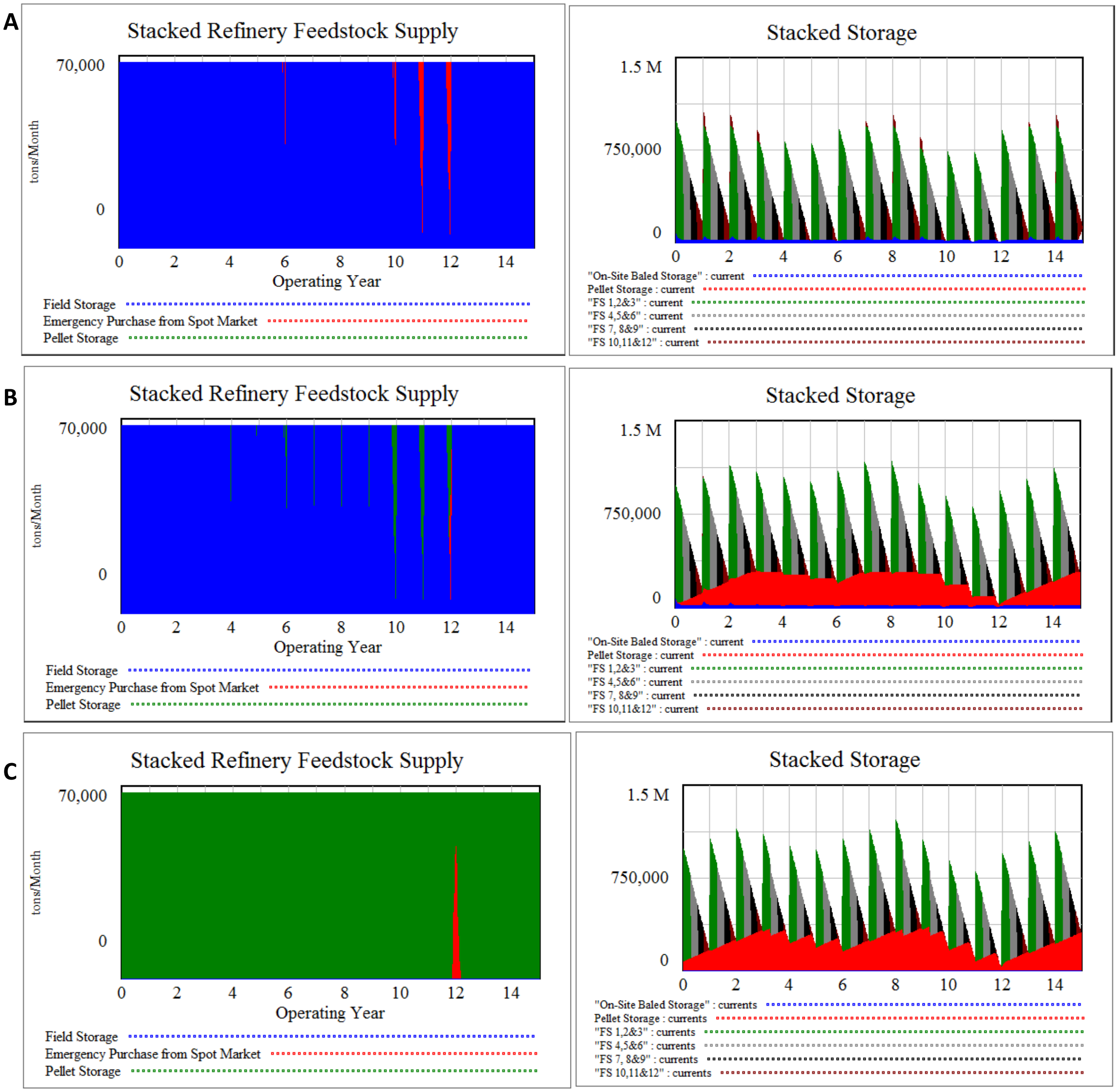

Figure 4.4: Extended drought may occur thereby placing different demands on the biorefinery.

2. The second drought cycle is a 20% reduction in harvest, occurring in years 9 to 12.

Both of these disturbances include the standard DML based on 20% moisture. All other parameters for storage and harvest remain the same as the risk mitigation scenario.

Figure 4.4 shows the outcome of the extended mitigation scenario. The conventional system fares well throughout the mild drought, however, the second extended drought produces several red peaks indicating use of the external market. Once again, the storage buffer is instrumental in fending off emergency purchases and both the hybrid and uniform-format systems handle the first series of disturbances well. However, in the final year of moderate droughts the pellet systems are forced to purchase from the external market as the pellet storage is depleted. Of the two, uniform-format is more reliant on emergency purchases. Once again, passing all material through the mill delays the delivery of biomass to the biorefinery. Looking at the supply graph for all three scenarios, the hybrid system reduces the risk better than the other two designs. However, increasing pellet storage in both scenarios has the possibility of cutting out risk entirely.

Extended Risk Mitigation Cost Analysis

Table 4 details the cost results for under the extended risk scenarios. Although the structure of disturbances in this scenario was much different, the cost results are very similar to the previous risk mitigation outcome. Because there were more years of reduced harvest the conventional design profit increases, due to the reduced need for field storage removal. However, a greater amount of emergency material was needed driving up the cost and increasing the risk. The uniform format came in at 12% lower profit than conventional while hybrid fared the worst with a 24% reduction in profit.

Table 4.3: Cost results for the extended risk mitigation scenario, once again pellet storage is the main culprit for increased costs.

	Conventional	**Hybrid**	**Uniform-Format**
Cost			
On-Contract Purchases	$298.29 M	$312.51 M	$312.31 M
Pre-processing of Bales	$571.92 M	$553.06 M	$3.41 M
Field Storage	$22.48 M	$20.46 M	$19.62 M
Field Storage Removal	$15.23 M		
Pellet Processing		$27.19M	$393.89 M
Pellet Capital		$19.21 M	$181.34 M
Pellet Storage		$42.59 M	$48.59 M
Total for Pellets		$88.99 M	$623.83 M
Emergency Purchase	$13.39 M		$3.627 M
Dry Matter Loss	$15.68 M	$14.49 M	$13.94 M
Total Cumulative Costs	$936.98 M	$991.09 M	$976.74 M
Revenue			
Pellet Sales		$10.04 M	$9.97 M
Refinery Sales	$1,138.00 M	$1,138.00 M	$1,138.00 M
Total Cumulative Revenu	$1,138.00 M	$1,148.00 M	$1,148.00 M
PROFIT	**$194.94 M**	**$ 151.31 M**	**$171.60 M**

Again it is important to consider risk reduction as well as the volatility of the emergency market. If one makes the assumption that consecutive drought years will make extra biomass less abundant, the emergency price could climb higher than indicated in the BPSS.

Summary of Key Findings

Pellet storage is critical to de-risk the biorefinery. This reduction comes at a higher price than modeled conventional format systems. However it may be well worth the added cost when long-run industry and policy goals are considered. The previous series of simulations shows the resilience of the pellet supply chain under several perturbation scenarios. Overall, the conventional system is the low cost choice while the hybrid configuration is the highest cost. This explains why current cellulosic biorefineries are opting for a conventional supply system. The hybrid configuration handles risk slightly better than the uniform format configuration. The added processing delay converting to pellets renders some material unusable during times when biomass is needed. With proactive management it may be possible to overcome this limitation and further improve the performance of a uniform-format system structure such as this. While quantifying the risk can be difficult, this model shows the qualitative difference in operation when pelletization is included as an option.

5. CONCLUSION

Conclusion & Future Work

This study presents a dynamic model to explore different feedstock supply management strategies. Simulation results indicate that significant reduction in risk can be achieved by adding pellet mill infrastructure on-site for the biorefinery. Pellet storage was the single most important variable for both cost and risk reduction. In the BPSS the storage costs for pellets were five times that of field storage. Consequently, the biorefinery interested in reducing risk should also explore lower-cost storage options. Although the conventional system design delivered the lowest costs, and therefore the highest profits, the consideration of interest paid for the lifetime of a biorefinery could make including pellet mills more attractive. Further, other cost reductions are likely to be achieved through good management practices to handle the added complexity of pellet mills in the supply chain.

The BPSS provides a qualitative assessment of risk and can be altered to reflect the challenges faced in different locations around the U.S. Allowing future investors to see system behavior for local conditions can help build confidence in the bioethanol industry. Lowering the risk of the business venture will attract greater investment in cellulosic ethanol. This will be instrumental if goals set forth in the 2007 Renewable Fuel Standards are to be met.

This anlaysis focused strictly on the operational costs of a biorefinery. Further development is needed to assess the entire business model including impacts of designs on FCR. If the FCR is reduced significantly by including pelletized biomass into the system then the overall cost of the system may be reduced versus the conventional supply system. This model analyzed a single feedstock, future analyses could include a blended feedstock approach which would increase the complexity of the supply system but also increase the local supply of biomass while improving sustainability criteria.

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