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# Uniform-Format Solid Feedstock Supply System:

## A Commodity-Scale Design to Produce an Infrastructure-Compatible Bulk Solid from Lignocellulosic Biomass

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# 4. ADVANCED UNIFORM FEEDSTOCK SUPPLY SYSTEM DESIGN

Lignocellulosic biomass feedstocks are not considered a commodity resource because of the great diversity in composition and form (Wiselogel, 2008). Additionally, low bulk densities and the perishable nature of many biomass resources constrain both the supply and demand of these resources to local independent markets and/or contracting regions. Conversely, the national renewable fuel goals to displace as much as 30% of the 2004 gasoline use with biofuels (Energy Independence and Security Act, 2007) will form a national biomass market, including biomass trading across the country (i.e., a commodity biomass market). These national goals require that the “non-commodity” characteristics of biomass to be overcome. As such, the fundamental objective of the Advanced Uniform feedstock supply system design is to preprocess the diversity of lignocellulosic biomass resources into a definable set of “uniform-format” resources that are consistent across a national biorefining market (Figure 4-1). In other words, the goal is to transform lignocellulosic biomass into a commodity resource.

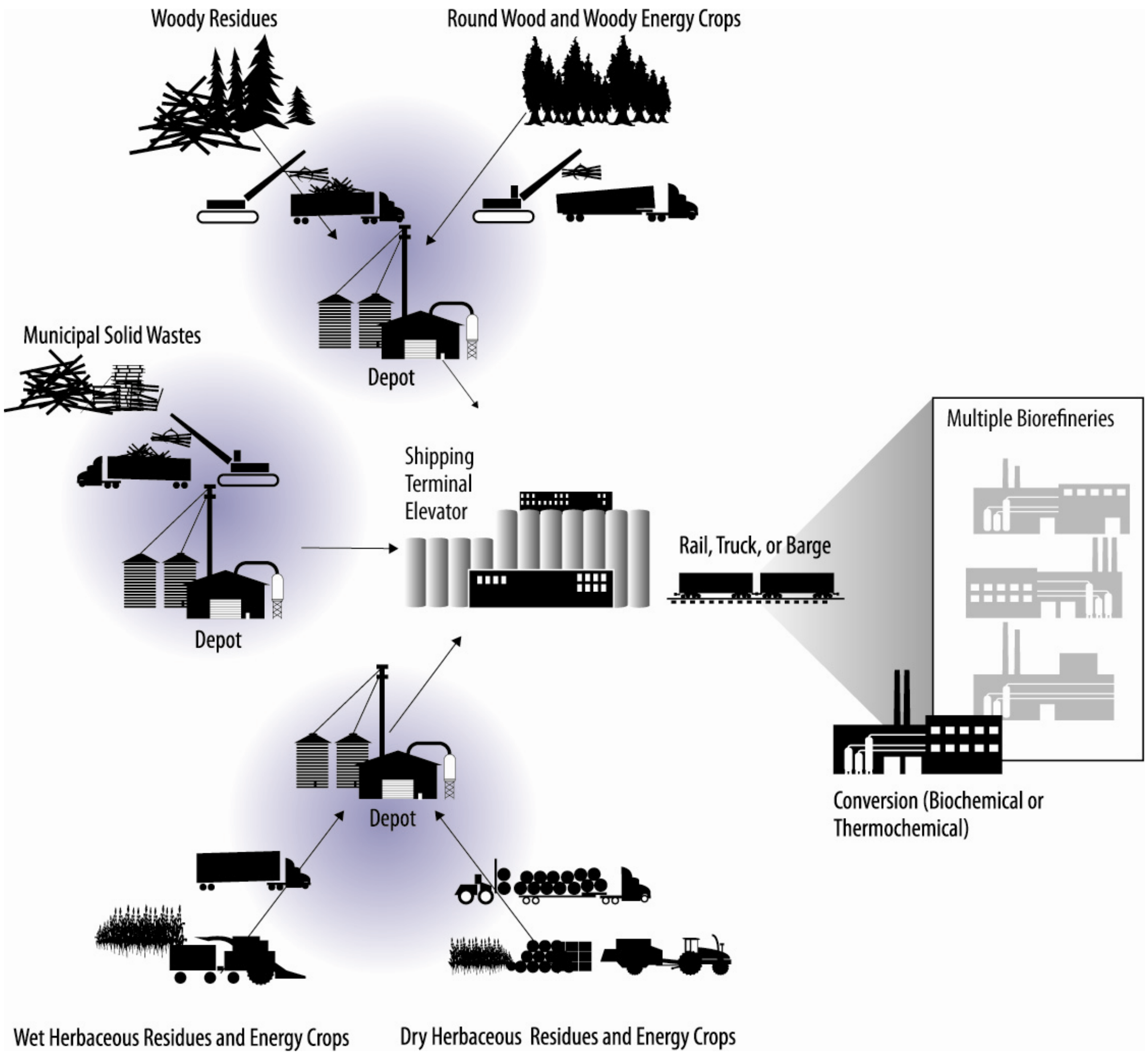


Figure 4-1. The Advanced Uniform-Format feedstock supply system (Advanced Uniform) design emulates the current grain commodity supply system, which manages crop diversity at the point of harvest and at the biomass depot/elevator, allowing subsequent supply system infrastructure to be similar for all biomass resources.

The Conventional Bale and Pioneer-Uniform supply system designs presented in Sections 2 and 3 are incapable of producing a commodity biomass resource, because they cannot achieve the required material quality standards. The primary material standard of this Advanced Uniform-Format (Advanced Uniform) design is a high-density aerobically stable bulk solid material that is compatible with the highly efficient, large-capacity, and dependable commodity-scale grain handling and storage infrastructure. An alternate commodity-scale preprocessed biomass resource would be a stable high-density liquid, or bio-crude, format, which will not be discussed here, but will be presented in a future design report. There is no alternate supply system design for solid lignocellulosic biomass that could handle such large quantities of biomass more efficiently or reliably than the existing grain handling infrastructure. An annual supply of over 400 million dry matter tons is required to support a national biorefining industry; however, this can only be accomplished through the development of harvesting and preprocessing systems that reformat lignocellulosic biomass resources into a uniform-format bulk solid that can be stored and handled in an expanded grain (i.e., bulk solids) commodity infrastructure.

Achieving the Advanced Uniform feedstock supply system design will allow lignocellulosic biomass to be traded and supplied to biorefineries as a commodity similar to grain. In addition, the Advanced Uniform system will stimulate rural economies as a vast network of biomass preprocessing depots are deployed across the nation to convert a diverse, low-density, perishable feedstock resource into a densified, aerobically stable and uniform-format bulk solid resource that can enter the existing agricultural bulk solid commodity infrastructure. This approach will advance the bioenergy industry in a logical, cost-effective manner.

## 4.1 Advanced Uniform Design Performance Targets

The key feature of the Advanced Uniform design is preprocessing the biomass in the earliest stages of the supply systems. Preprocessing depots are central to this design, which complete preprocessing operations started in harvesting and collection to produce a final uniform material that is compatible with the grain storage and handling infrastructure. Figure 4-2 shows an overview of the Advanced Uniform design concept.

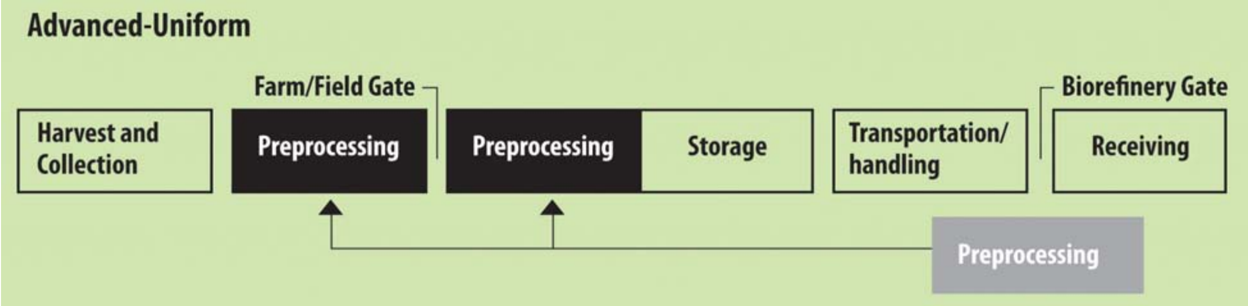


Figure 4-2. The Advanced Uniform design concept. Advanced preprocessing technologies are incorporated into the harvest/collection and depot/elevator storage operations. The preprocessed biomass is then compatible with existing bulk solid storage, transportation and handling infrastructure/technologies.

There are six fundamental barriers to implementing these advanced preprocessing concepts. The first three are associated with the physical properties of the biomass:

- Material deconstruction and formatting – changes in physical form, rheological characteristics, and progressive/final material formats;
- Density – biomass bulk density and energy density; and

- Moisture – management and removal of moisture to produce and aerobically stable material.

The remaining challenges are related to the supply system equipment, and are:

- Capacity and operational efficiency – this includes overcoming capital and energy costs associated with doing a prescribed amount of work;
- Dry matter losses – this includes dust collection/control, field losses, and biological losses, and;
- Operational window – as operations move forward in the supply system, they become constrained to harvest windows and other logistic constrains.

The full implementation of the Advanced Uniform design overcomes all of these barriers for all biomass resources and moistures. The State of Technology (SOT) implementation of the Advanced Uniform system as presented here is designed to achieve the biomass material property targets to the greatest extent possible throughout the supply system and in final form. The equipment barrier targets are secondary to material performance targets, and in most cases are not achieved in the SOT design.

## 4.2 The Advanced Uniform Supply System

The Advanced Uniform design employs preprocessing technology to remedy the density and stability issues that prevent lignocellulosic biomass from being handled in high-efficiency bulk dry solid or liquid logistic systems, changing the resource from a local bought-and-sold product to a large-scale commodity. This allows for long distance transportation (200+ miles), bulk-flowable handling, and feedstock blending achieving standardized feedstock compositional targets and other properties beneficial to the conversion process. The Advanced Uniform design does not have both wet and dry supply delivery lines. Instead, all biomass will be preprocessed into one flowable, aerobically stable format: either a high-density dry solid product (i.e., flour, granules, select pellet concepts) or a high-density liquid product (i.e., pyrolysis oil), the latter being the subject of future work at INL. The Advanced Uniform design for the production of a high-density dry bulk solid design schematic is shown in Figure 4-3.

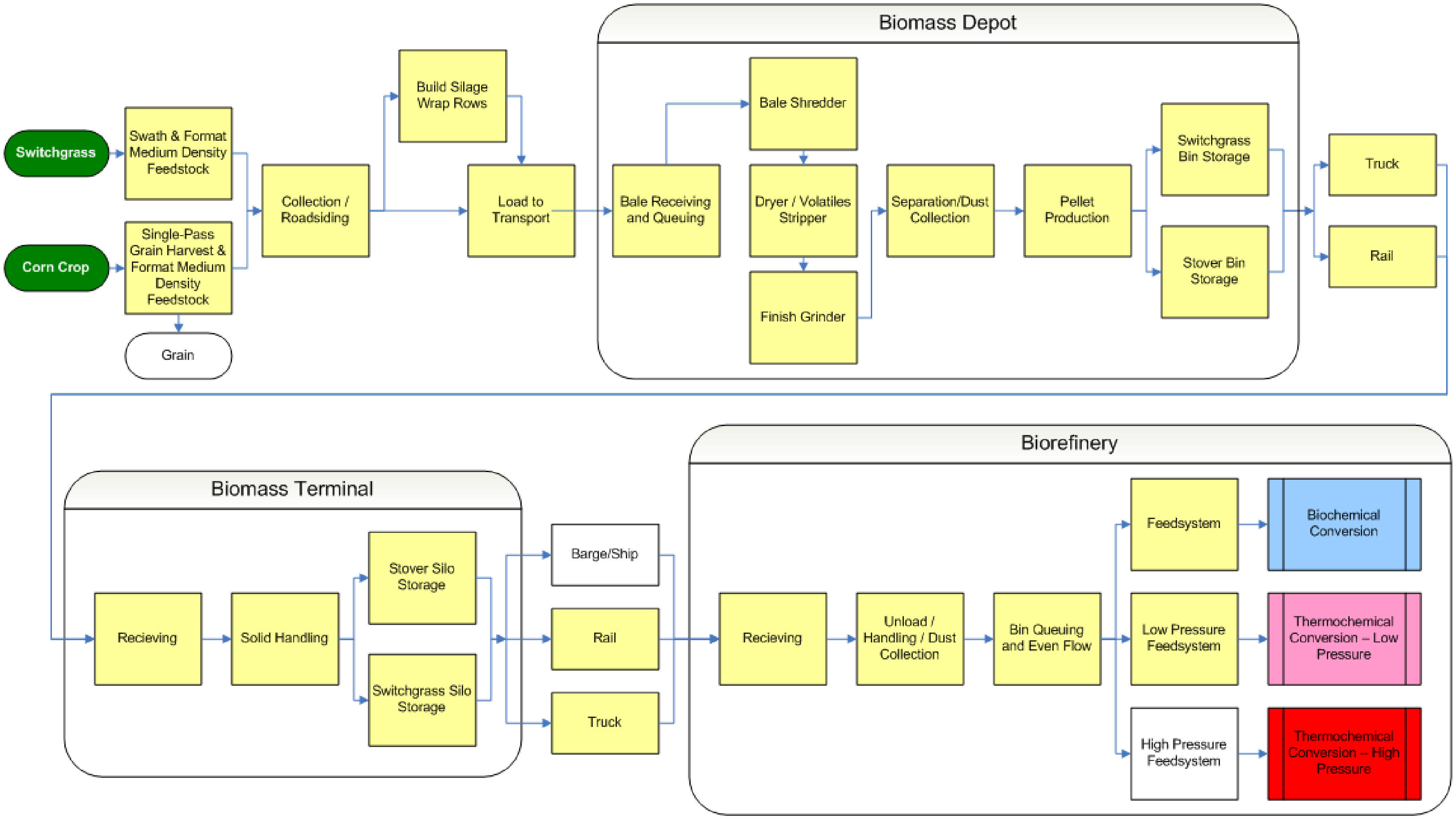


Figure 4-3. Advanced Uniform system order of unit operations for high-density dry bulk solids.

*(Note: Yellow rectangles represent unit operations modeled and white shapes represent options not modeled in this report)*

While the Advanced Uniform system can achieve material property targets using existing or near-term equipment, it cannot meet cost targets without incorporating future technologies. In this report, the Advanced Uniform system design that relies on existing or near-term equipment is referred to as the "state of technology (SOT)." The SOT presented in Section 4 is an example of an implementation of the Advanced Uniform system and incorporates pelletization to densify the biomass. (It is important to note that the production of pellets is just one example of how the Advanced Uniform system could be implemented and is not necessarily a recommended alternative.)

*High-Efficiency Bulk Solids Handling*

Existing grain commodity markets effectively move billions of tons of bulk-solid biomass to biorefineries around the globe. The key to this capability is working with bulk-solid materials that are aerobically stable, and have high dry matter bulk density and flowability characteristics. The Advanced Uniform design introduces comprehensive preprocessing that produces lignocellulosic bulk-solids with material properties comparable to those of existing grain commodities. Storage and handling systems for grain are highly replicable, scalable, and optimized for cost-effective performance. These systems are typically sold and constructed as "turnkey" products that are assembled with common interchangeable components to meet each customer's performance specification. This dynamic provides an opportunity for highly efficient and economical implementation.

The equipment used for handling and transporting grain from storage to downstream processes is similarly replicable and interchangeable. Consistent, uniform material properties of grain allow trucks and trains to seamlessly move biomass large distances to terminals or destination markets. Another important consequence of grains' material characteristics is the ability to blend, grade and efficiently track material throughout trading within the supply system. In the case of corn, distributors employ fast screening methods to test and blend feedstock to stringent specifications of individual biorefineries, while maintaining the integrity of non-genetically modified organism (GMO) food supplies. This is possible by using a uniform format material with adequate bulk density and flowability performance that allows a common, replicable set of high-capacity bulk-solids handling equipment to be employed throughout the supply system. In the case of lignocellulosic feedstocks, the testing and blending of materials will correspond to biorefinery needs based on characteristics such as sugar, lignin, ash, and BTU content. This ability leverages the existing grain commodity markets to provide the basis for the Advanced Uniform system design in terms of material specification, and equipment/process design.

On-farm queuing, depots or elevators, blending terminals, and biorefineries all work together to create a local, regional, national, and worldwide markets for grain commodities. These markets are highly efficient and effective at connecting the resource to end users within tight specifications. These connections are not limited by distance and mitigate local production risks for all uses of grain commodities by allowing wider access to resources. The Advanced Uniform design establishes material specifications for the corollary of lignocellulosic biomass to existing grain specifications to facilitate commodity-scale markets for this feedstock. Through this specification, efficient and replicable infrastructure and processes can be assembled connecting resource to biorefineries in a scalable, sustainable way.

### 4.2.1 Advanced Uniform Harvest, Collection and In-field Preprocessing

The Advanced Uniform design concept maximizes overall economic and energy efficiency by eliminating key equipment and meeting feedstock format targets early in the supply chain. Compared to the Conventional Bale and Pioneer Uniform designs, which accommodate feedstock variety with a combination of existing harvesting equipment and methods (i.e., grain combines, shredders and mowers, rakes, large round balers, large square balers, swathers, and forage choppers), the Advanced Uniform supply system eliminates multiple operations and machinery by using single-pass harvesting systems.

Two single-pass harvesting systems are envisioned: one for herbaceous crop residues and another for herbaceous energy crops (Figure 4-4).

Single-pass harvest has been the vision of advanced harvesting systems since the inception of the Biomass Roadmap published by DOE in 2003. Optimizing these next-generation harvesting machinery presents significant challenges in marrying complex mechanical systems capable of selectively collecting the desired biomass, sufficiently densifying the biomass to minimize transportation and storage costs, and appropriately packaging the biomass in a dense, durable, and easily handled form. The challenges extend beyond machinery development and include biomass quality and stability issues that include: biomass moisture and composition impacts on self-heating, microbial degradation, and overall feedstock quality.

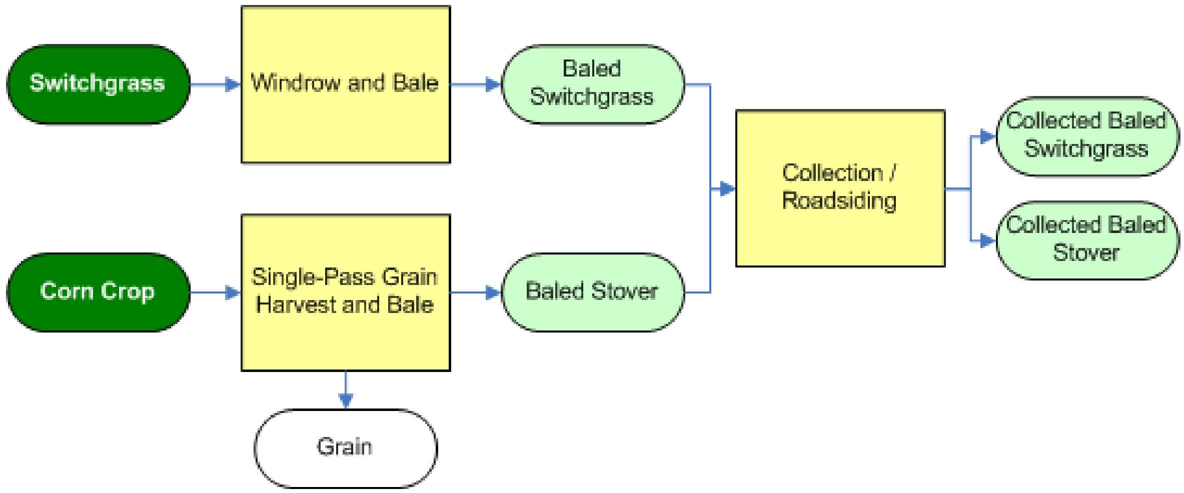


Figure 4-4. Harvest, collection, and in-field preprocessing supply logistic processes and format intermediates for the Advanced Uniform system.

*(Note: Green ovals represent format intermediates, yellow rectangles represent processes modeled in this report, and white ovals represent processes not modeled in this report).*

#### *4.2.1.1 Advanced Uniform Harvest, Collection, and In-field Preprocessing Format Intermediates Performance Targets*

**Biomass Deconstruction, Fractionation, and Yield**

The requirement for prescriptive residue removal strategies for addressing sustainability has been well established (Wilhelm et al. 2007),and the USDA/ARS and the DOE Regional Partnerships have made good progress in developing agronomic based tools for developing recommendations and protocols for establishing residue removal rates. Further, Hoskinson et al. (2007) has demonstrated a research approach for controlled, limited removal of corn stover, along with agronomic impacts and feedstock quality (moisture and composition) implications of various removal strategies. The combined efforts have produced a solid basis for limited and variable rate harvest strategies that are available today. However, the barrier to commercial-scale implementation of these strategies is the development of a robust harvesting machine that is capable of variable rate corn stover harvest.

The current state of technology is significantly lacking in the ability of variable rate and selective harvest. Stover yield may be varied by adjusting the cut height of the combine header, but the problem with this approach is that it is sometimes necessary to lower the head below what may be desired for stover collection for the purpose of harvesting lodged crop. For the SOT design, it assumed that only the cob, husk and leaf fraction are collected, totaling approximately 40% (Shinners, 2007) of the available biomass at a moisture of about 40%.

**Format and Bulk Density Impact on Supply System Processes**

Ideally, the format of the harvested biomass will match the target end-state properties of high-density (>45 lb/ft$^3$), aerobically stable and bulk-flowable to facilitate the immediate insertion into the grain handling infrastructure, thus directly mimicking the grain-commodity system. One may envision such a harvesting system as an all-in-one harvester/preprocessor or a stationary field-side preprocessing machine. A more practical harvesting system is one that minimizes capital and on-farm logistics while collecting biomass in a format that optimizes operation efficiencies of handling and transportation and facilitates cost-effective queuing, preprocessing and storage processes. Without additional supply chain requirements, the only definitive format specification that can be placed on advanced biomass harvesters at this stage is a bulk density sufficient to load a truck to the legal gross vehicle weight. The density needed to load a typical 48-ft trailer to the legal 80,000 pound gross vehicle weight limit (see Section 3.3.1.2) is about 16 lb/ft$^3$.

The format may resemble a round or square bale similar to current bale formats, much larger packages such as a loaf (e.g., Hesston Stakhand) or module, or much smaller packages such as cubes (e.g., John Deere cuber), briquettes or pellets. The particular format is immaterial as long as it meets the bulk density target of 16 lb/ft$^3$, and is easily and efficiently handled through transportation and handling systems.

For the purpose of demonstrating a current state-of-technology harvesting system that best meets the bulk density target of the advanced design, a large square baler was chosen. Specifically, a Krone Big Pack 1290 HDP was chosen based on based on field testing results that produced 3x4x8-ft. bales that ranging from 10.5 to 15.2 lb/ft$^3$ and averaging 12.1 lb/ft$^3$.

**Biomass Moisture Impact on Supply System Processes and Material Stability**

One of the primary challenges for the advanced-uniform design is the requirement to harvest wet, aerobically unstable biomass. While the advanced uniform design ultimately plans to deal with aerobic instability in the queuing and preprocessing systems, the economic constraints of biomass feedstocks support a design that accommodates field drying where ambient conditions permit. Field drying may be different than we know it today in that it may not achieve full aerobic stability, but it may be limited to short operational windows during which surface moisture is removed, but ambient conditions and operation windows are not sufficient for removal of interstitial moisture for achieving aerobic stability. In the former case biomass is collected in aerobically stable state and is handled in a normal dry system, but in the latter case the aerobically unstable biomass must be stabilized in a queuing system until full aerobic stability is achieved during preprocessing. One of the keys to a design that accommodates field drying is the development of biomass conditioning systems specifically designed for biomass crops. Mechanical conditioning of biomass is a common practice to accelerate in-field drying by allowing moisture to escape from the stem faster. Biomass conditioning systems used on modern harvesting machines were designed for grasses and forages, but given the large stems and different mechanical properties of advanced energy crops it is quite sure that hay and forage conditioning systems are not optimized for these new crops.

#### *4.2.1.2 Advanced Uniform SOT Harvest, Collection, and In-field Preprocessing Format Intermediates*

Both the stover and switchgrass SOT designs include baling with a high-density 3x4x8-ft baler. This format was chosen because the high-density bale comes closest to achieving the material property (i.e., bulk density) attributes of the Advanced Uniform design. In addition, neither design includes field drying, so the stover and switchgrass bales are produced at 40% and 34% moisture, respectively.

Table 4-1. Attributes of harvest, collection, and in-field preprocessing format intermediates for switchgrass and corn stover for the Advanced Uniform SOT.

| | Crop standing in the Field | Grain Harvest | Conditioned/ Windrowed Biomass | Baled Biomass | Collected/ Roadsided Biomass |
|---|---|---|---|---|---|
| Corn Stover | | | | | |
| Biomass Output | Whole Crop (grain and residue) | Stalk, Cob, and Husk (collectively stover) | N/A | Stover | Stover |
| Yield (DM ton/acre) | **8.52 (180 bu/ acre corn)** | **4.26** | **N/A** | **1.92** | **N/A** |
| Format Output | Standing crop | Standing stalk, cob, and husk on the ground | N/A | Randomly distributed large square 3x4x8-ft bales | Large square 3x4x8-ft bales collected at fieldside |
| Bulk DM Density Output (DM $lb/ft^3$) | N/A | N/A | N/A | 12 | 12 |
| Output Moisture (% w.b.) | 50 | 40 | N/A | 40 | 40 |
| Switchgrass | | | | | |
| Biomass Output | Whole crop | Whole crop less stubble (switchgrass) | Switchgrass | Switchgrass | Switchgrass |
| Yield (DM ton/acre) | 5.0 | N/A | 4.50 | 4.05 | N/A |
| Format Output | Standing crop | N/A | Windrow | Randomly distributed large square 3x4x8-ft bales | Large square 3x4x8-ft bales collected at fieldside |
| Bulk DM Density Output | N/A | N/A | 2.0 $lb/ft^3$ | 12 $lb/ft^3$ | 12 $lb/ft^3$ |
| Output Moisture (% w.b.) | 34% | N/A | 34% | 34% | 34% |

a. Shinners et al., 2007.

b. INL/UofIL test data, switchgrass and *Miscanthus* harvest in Illinois, January 2008.

#### *4.2.1.3 Advanced Uniform Harvest, Collection, and Storage Equipment Performance Targets*

**Equipment Capacity and Operational Efficiency**

The challenge of advanced harvesting machinery is to improve operational efficiency by combining unit processes of conventional harvesting methods while at least maintaining the capacity and productivity of current harvesting machinery. A single-pass grain and stover harvester for example, improves overall operation efficiency by eliminating separate cutting, windrowing and baling operations, but the challenge is to engineer component systems that enable improved operational efficiency without slowing the combine down due to increased power consumption or reduced field efficiencies are incurred from towing a biomass harvesting unit behind, stopping to offload the biomass, or unloading more often.

The SOT implementation of a single-pass stover harvester that pulls a large square baler behind a grain combine recognizes that the combine field efficiency will be reduced. In the SOT design, the combine field efficiency was reduced to 65% in the design case, and a normal distribution from 60 to 70% was used in the sensitivity analysis, compared to a typical combine field efficiency of 70% (ASABE D497.5).

Since the SOT implementation of a switchgrass harvester was a two-pass windrow and bale process. Machinery speeds and field efficiencies consistent with the conventional square bale design were used.

**Dry Matter Losses**

As described in Section 2.1.1.4, the collection efficiencies of current crop residue harvest methods are quite low, with only 1/3–2/3 of the available crop residues actually harvested due to field losses. Single-pass harvest will substantially reduce field losses because (1) the biomass is not deposited on the ground after it is cut and (2) the biomass is not being handled by multiple machines. Accounting for biomass left in the field as standing stubble, losses due to dust, as well as machine losses, single-pass biomass harvesters must be capable removing up to 80% of the available biomass. This does not suggest or recommend that 80% of the available biomass will be removed (see discussion of variable-rate and selective harvest above), but simply represents a machinery capability.

The SOT implementation of a single-pass stover harvester assumes a that the collection efficiency will be substantially greater than conventional systems since the combine header cuts the stalk, passes it through the combine and directly into the baler that is towed behind. Some losses will still occur in the form of standing stubble, header losses and baler losses. Overall, a harvest efficiency of 80% was assumed for this harvesting system.

Since the SOT implementation of a switchgrass harvester is a conventional windrow and bale scenario, windrower and baler losses are the same as the conventional-bale and pioneer-uniform designs and are both set at 90%.

**Operation Window**

In conventional stover harvesting systems, residue harvest and collection lags grain harvest by the amount of time required for field drying (typically 3-7 days), and additionally the operational window for stover harvest is restricted by field drying conditions. Because residue harvest and grain harvest occur simultaneously in a single-pass harvest system, the operation windows coincide, and the operation window for harvesting crop residues will be expanded since it will not be restricted by drying conditions.

Likewise, it is envisioned that advanced energy crop harvesters will employ improved mechanical conditioning systems that accelerate in-field drying. By reducing biomass dry-down time, drying conditions are relaxed and harvesting windows will be expanded.

In the SOT corn stover design, the harvest window was increased by the one week compared to the conventional-bale and pioneer-uniform designs. This expansion of the harvest window was chosen to acknowledge that in this design stover collection is not delayed by the 7-day field-drying period included in the previous designs. The switchgrass harvest window in the SOT design was left unchanged from the previous designs.

#### *4.2.1.4 Advanced Uniform SOT Harvest, Collection, and In-Field Preprocessing Equipment*

The SOT implementation of the Advanced Uniform design includes a single-pass corn stover harvester consisting of a production grain combine towing a high-density 3x4x8-ft baler. This concept has been successfully proven for harvesting wheat straw (http://www.glenvar.com/Innovation/LargeBalerProject.asp), and although this concept may be more challenging with corn residue the fact that the technology exists makes it eligible for the state-of-technology design. Other single-pass harvesting concepts and even prototype machines exist (Deere), but the combine/baler combination was chosen because the high-density bale comes closest to achieving the material property (i.e., bulk density) attributes of the Advanced Uniform design.

The SOT switchgrass design does not include any advanced harvesting concepts. Althoug the design could have included a forage chopper to capture the single-pass aspect of the Advanced Uniform design, the windrower and baling system was chosen because the high-density bale comes closest to achieving the material property (i.e., bulk density) attributes of the Advanced Uniform design.

Table 4-2. Harvest, collection, and in-field preprocessing equipment specifications for the Advanced Uniform SOT for corn stover and switchgrass.

| Operation | Grain Harvest Only | Condition and Windrow Switchgrass | Baling | Move to Field Side (Roadsiding) | Weather Protection | |
|---|---|---|---|---|---|---|
| Corn Stover | | | | | | |
| Equipment | JD 9860 Combine with JD 864, 8 row corn header | N/A | Krone BiG Pack 1290 HDP 3x4x8-ft Large Square Baler | Stinger Stacker 5500 | Stinger 4000 cube line wrapper | Caterpillar TH220B Telehandler |
| Haul Distance | N/A | N/A | N/A | 0.5 mi | N/A | N/A |
| Rated Capacity[a] | 40 tons/h | N/A | 18.1 bales/h | 98.6 bales/h | 90 bales/h | 90 bales/h |
| Field Efficiency (%)[a] | 70 | N/A | 90% | 100% | 100% | 100% |
| Dry Matter Loss (%)[b] | 0% | N/A | 0% | 0% | 0% | 0% |
| Operational Window | | | | | | |
| hrs/day | 14 | N/A | 14 | 12 | 12 | 12 |
| days/year | 36 | N/A | 36 | 36 | 36 | 36 |
| Switchgrass | | | | | | |
| Equipment | N/A | Agco Windrower 8365 with Agco Dics Header | Krone BiG Pack 1290 HDP 3x4x8-ft Large Square Baler | Stinger Stacker 5500 | Stinger 4000 cube line wrapper | Caterpillar TH220B Telehandler |
| Haul Distance | N/A | N/A | N/A | 0.5 mi | N/A | N/A |
| Rated Capacity[a] | N/A | 54.3 tons/h | 23.1 bales/h | 98.6 bales/h | 90 bales/h | 90 bales/h |
| Field Efficiency (%)[a] | N/A | 80% | 80% | 100% | 100% | 100% |
| Dry Matter Loss (%)[b] | N/A | 0% | 0% | 0% | 0% | 0% |
| Operational Window | | | | | | |
| hrs/day | N/A | 14 | 14 | 12 | 12 | 12 |
| days/year | N/A | 36 | 36.0 | 36 | 36 | 36 |

a. See machinery capacity and efficiency calculations (???).

b. Stover based on Richey et al., 1982; Switchgrass based on INL test data, switchgrass, and Miscanthus harvest in Illinois, January 2008. Harvest efficiency = 1-DM_Loss.

#### *4.2.1.5 Advanced Uniform SOT Harvest, Collection, and In-field Preprocessing Cost and Sensitivity Analysis*

**Static Model Cost Summary**

A breakdown of the costs associated with each piece of equipment used in the harvest and collection and in-field preprocessing unit operations identifies significant cost components that are valuable for making individual comparisons and recognizing areas of research potential (Table 4-3). These costs are reported in DM tons entering each process.

Table 4-3. Static model costs for major harvest and collection, and in-field preprocessing equipment in the Advanced Uniform SOT supply system for corn stover and switchgrass. Costs are expressed in $/DM ton unless otherwise noted.

| Equipment | Grain Harvest Only[a] | Condition and Windrow | Baling | Move to Field side (Roadsiding) | Weather Protection | |
|---|---|---|---|---|---|---|
| | JD 9860 Combine with JD 864, 8 row corn header | Case IH Puma 180 tractor and a Balzer 15-ft Flail Shredder with windrowing | Hesston 2170 Large Square 36" x 96" Baler | Stinger Stacker 5500 | Stinger 4000 cube line wrapper | Caterpillar TH220B Telehandler |
| Corn Stover | | | | | | |
| Installed Equipment Quantities | 124 | N/A | 124 | 51 | 51 | 51 |
| Installed Capital[b] | 52.08 | N/A | 15.80 | 8.42 | 2.42 | 4.21 |
| | | | | | | |
| Ownership Costs[c] | 2.87 | N/A | 10.88 | 1.24 | 0.36 | 0.55 |
| Operating Costs[d] | 2.76 | N/A | 12.47 | 1.11 | 5.18 | 0.50 |
| Labor | 0.27 | N/A | 0.89 | 0.31 | 0.34 | .34 |
| Non-Labor | 2.50 | N/A | 11.59 | 0.80 | 4.84 | 0.16 |
| | | | | | | |
| Dry Matter Loss Costs | N/A | N/A | 0.63 | N/A | N/A | N/A |
| | | | | | | |
| Energy Use (Mbtu/DM ton) | 151.4 | N/A | 151.4 | 22.6 | 3.5 | 5.3 |
| Switchgrass | | | | | | |
| | N/A | Agco Windrower 8365 with Agco Dics Header | Hesston 2170 Large Square 36" x 96" with CaseIH Magnum 275 hp (225 PTO hp) | Stinger Stacker 5500 | Stinger 4000 cube line wrapper | Caterpillar TH220B Telehandler |
| Installed Equipment Quantities | N/A | 60 | 126 | 46 | 46 | 46 |
| Installed Capital[b] | N/A | 7.84 | 16.05 | 7.60 | 2.19 | 3.79 |
| | | | | | | |
| Ownership Costs[c] | N/A | 1.28 | 4.46 | 1.12 | 0.32 | 0.50 |
| Operating Costs[d] | N/A | 2.00 | 8.14 | 1.00 | 4.66 | 0.45 |
| Labor | N/A | 0.37 | 0.91 | 0.28 | 0.31 | 0.31 |

Table 4-3. (continued).

| Equipment | Grain Harvest Only[a] | Condition and Windrow | Baling | Move to Field side (Roadsiding) | Weather Protection | |
|---|---|---|---|---|---|---|
| | JD 9860 Combine with JD 864, 8 row corn header | Case IH Puma 180 tractor and a Balzer 15-ft Flail Shredder with windrowing | Hesston 2170 Large Square 36" x 96" Baler | Stinger Stacker 5500 | Stinger 4000 cube line wrapper | Caterpillar TH220B Telehandler |
| Non-Labor | N/A | 1.63 | 7.23 | 0.72 | 4.35 | 0.14 |
| | | | | | | |
| Dry Matter Loss Costs | N/A | N/A | 0.53 | N/A | N/A | N/A |
| | | | | | | |
| Energy Use (Mbtu/DM ton) | N/A | 36.1 | 92.8 | 20.3 | 3.2 | 4.8 |

a. Grain harvest defines the stover harvest window and stover material input condition (Table 2-1).

b. Installed capital costs are $ per annual DM ton capacity.

c. Ownership costs include depreciation, interest, taxes, insurance, and housing (Appendix A-2, Table A-7).

d. Operating costs include repairs, maintenance, fuel, lubrication, labor, and consumable materials (Appendix A-2, Table A-7)

### Cost Sensitivity Analysis

A histogram of the harvest and collection, and in-field preprocessing cost (Figure 4-5) for corn stover shows that with 90% confidence the cost of the unit operation ranges between $19.74 and $28.04 per DM ton. Further, the mean and standard deviation of this range is $23.18 ± 2.57 per DM ton. The mode value of the harvest and collection, and in-field preprocessing cost is $20.89 per DM ton. This of the static model is $34.09 per DM ton.

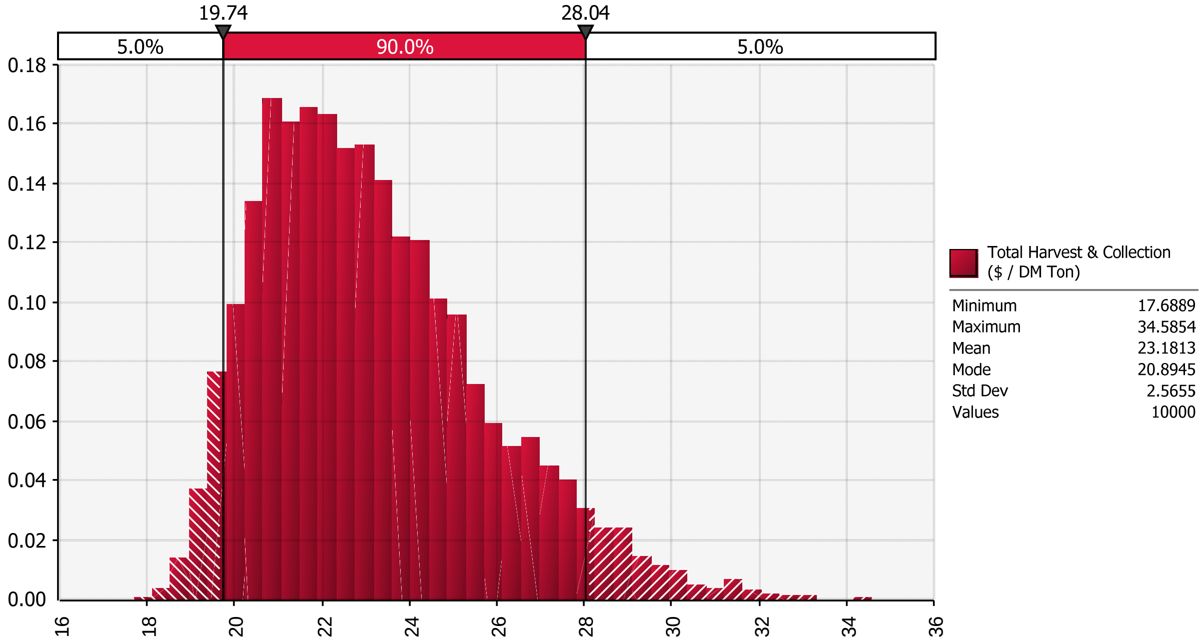


Figure 4-5. Harvest and collection, and in-field preprocessing cost distribution histogram from @Risk analysis for the Advanced Uniform SOT corn stover scenario.

A histogram of the harvest and collection, and in-field preprocessing cost (Figure 4-6) for switchgrass shows that with 90% confidence the cost of the unit operation ranges between $12.87 and $17.72 per DM ton. Further, the mean and standard deviation of this range is $15.17 ± 1.47 per DM ton. The mode value of the harvest and collection, and in-field preprocessing cost is $15.50 per DM ton. This value is near the result of the static model, which is $18.53 per DM ton, since the defined value of the parameter distributions was set equal to the static value in the model.

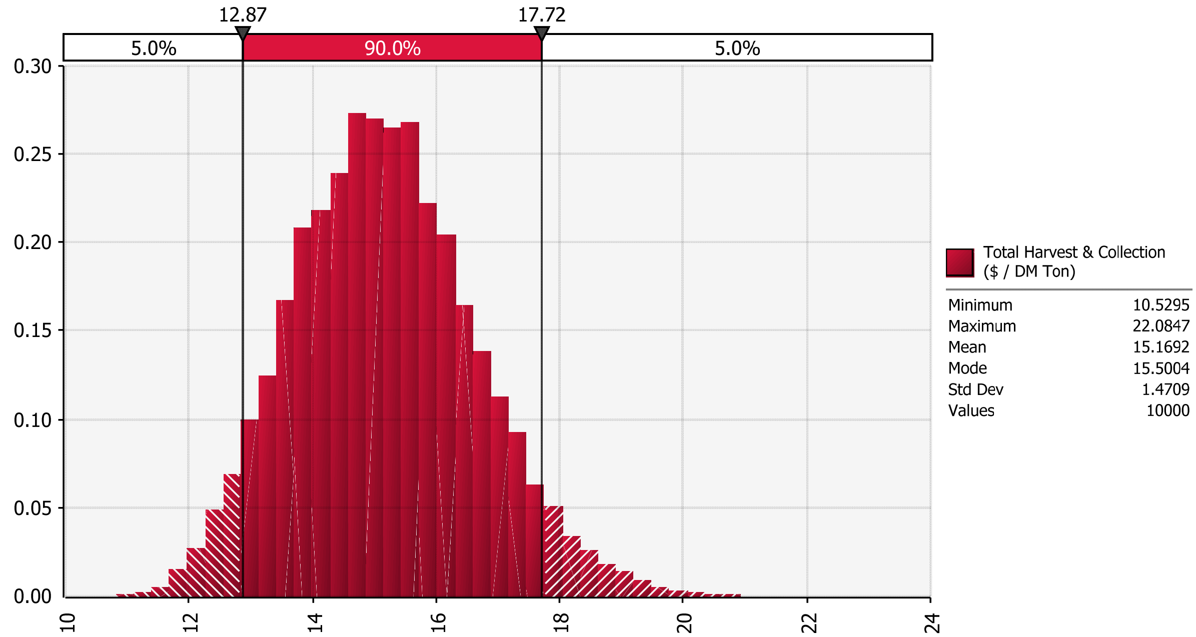


Figure 4-6. Harvest and collection, and in-field preprocessing cost distribution histogram from @Risk analysis for the Advanced Uniform SOT switchgrass scenario.

### 4.2.2 Advanced Uniform Queuing, Preprocessing and Transportation

Preprocessing in the Advanced Uniform design is expanded to include biomass stabilization and densification processes (Figure 4-7). Thus, the biomass depot can now handle a wide range of biomass moisture and produces a product that is aerobically stable (< 20% moisture content) and highly densified (~ 45 DM lbs/ft$^3$). By implementing these advanced preprocessing concepts, the Advanced Uniform design provides the means to access and format all potential biomass feedstocks enabling the establishment of a commodity-scale supply system.

#### *4.2.2.1 Advanced Uniform Queuing, Preprocessing and Transportation Format Intermediates Performance Targets*

**Biomass Deconstruction, Fractionation, and Yield**

Biomass deconstruction (size reduction) is one of the main processes that occur in the preprocessing at the biomass depot to achieve the uniform format. The vision for advanced preprocessing systems is that they will be significantly less energy consumptive processes than the tub grinders and hammer mills employed in the Conventional-bale and Pioneer-Uniform designs. In addition, advanced preprocessing systems are envisioned that combine biomass drying and comminution,

A three stage grinding and drying process is used in the SOT implementation of the Advanced Uniform design. These processes consist of bale shredding, drying to approximately 12% moisture (w.b.), and fine grinding to a 1/4-inch minus particle size. The feedstock discharged from the fine grinding process and inserted into the pellet process is assumed to have the same characteristics as the feedstock discharged from the biomass depot modeled in the Pioneer Uniform design (Section 3.3.1.1). Thus, this feedstock is actively moved from the grinding process to the pellet process due to its low flowability characteristics.

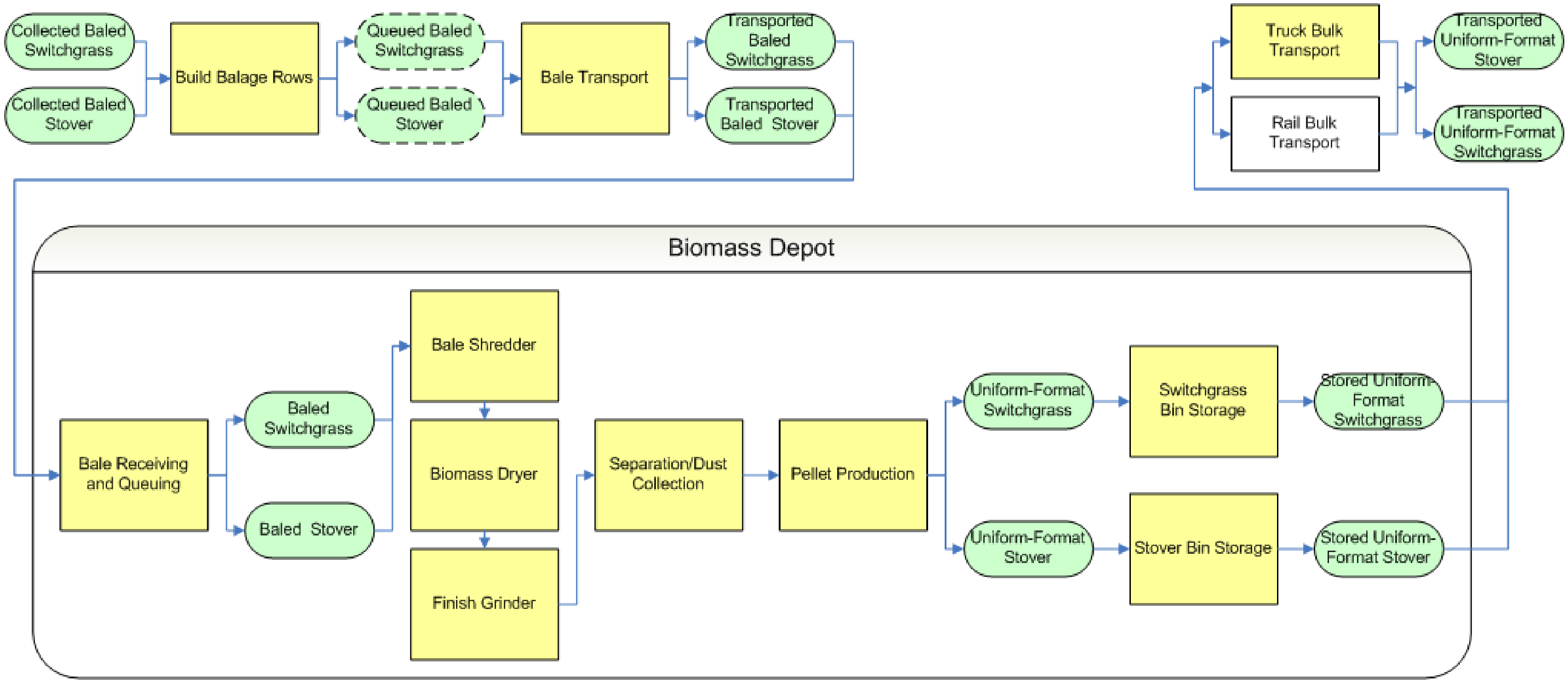


Figure 4-7. Queuing, preprocessing and transportation supply logistic processes and format intermediates for the Advanced Uniform design.

*(Note: Green ovals represent format intermediates, yellow rectangles represent processes modeled in this report, and white ovals represent processes not modeled in this report).*

**Format and Bulk Density Impact on Supply System Processes**

Preprocessing is the key to achieving "uniform-format" specification of the advanced-uniform design. Rather than specifying the morphology of the uniform format, the focus of this design is the material-properties of the uniform-format that will allow biomass to be inserted into the grain handling and storage infrastructure. Since the grain handling infrastructure has been established as the model system in which the uniform-format feedstock must operate, it is logical to establish grain as the model format. To this end, the bulk density target for the uniform format is set at 45 pounds per cubic feet, and the flowability of the uniform format feedstock must also approach that of grain. Whether the morphology resembles a pellet, a granule or something yet to be developed is immaterial as long as the material property specifications are achieved.

While the pelletizing industry is growing rapidly and large amounts of biomass (mainly woody biomass) are pelletized and exported, improvements in pelletizing technology are needed to improve quality and reduce production costs (John Macomber, 2009) before pelletizing cab be legitimately considered as a viable option for producing uniform-format feedstocks. Nonetheless, since pelletizing is a proven, commercial viable technology for producing high-density biomass feedstocks, it was chosen for the SOT design. In the SOT design a pellet density of 40 pounds per cubic foot was chosen as representative of commercially-produced herbaceous biomass pellets, and for the sensitivity analysis a pellet density range of 38 to 47 pounds per cubic foot was used (John Macomber, 2009).

**Biomass Moisture Impact on Supply System Processes and Material Stability**

Dry biomass (< 20% moisture (w.b)) is aerobically stable, and may be handled as received, whereas wet biomass (> 20% moisture (w.b.)) requires that stabilization techniques be employed. To address the latter case, a wet/dry hybrid supply chain scenario is introduced in the Advanced Uniform design where wet harvested biomass is temporarily stabilized in a biomass queuing system using chemical and biological processes prior to indefinite stabilization in the biomass depot using thermal and mechanical processes. The purpose of the wet queue is to stabilize an aerobically unstable material, but it also provides an opportunity for advanced storage techniques such as solid-state fermentation (Henk et al. 1196, Murphy et al. 2007) and pre-treatment in storage (Thomsen et al. 2008).

Although wet feedstock storage costs are estimated to be greater than dry systems, wet biomass supply chains are mandatory if all biomass resources are to be used (Hess et al., 2006). The solution to this storage dilemma revolves around balancing the costs of storing wet biomass against potential offsets from preprocessing the feedstock into a stable, uniform, and dense product. A wet/dry hybrid systems offer a competitive advantage over fully wet systems because the final product will be a dry, uniform format feedstock that will have lower handling and transportation costs.

A wet/dry hybrid supply implemented in the Advanced Uniform SOT design that incorporates silage techniques to stabilize the wet harvested biomass during queuing prior final and permanent stabilization via a rotary drum dryer at the biomass depot. The modeled processes in the SOT design will reduce the moisture of the feedstock from 40% (w.b.) for corn stover (34% for switchgrass) in the field to 12% (w.b.) after drying in a rotary drum dryer. This lower moisture will stabilize the feedstock until it is inserted into the conversion process.

#### *4.2.2.2 Advanced Uniform SOT Queuing, Preprocessing and Transportation Format Intermediates*

The biomass depot will receive high-density bales that have been immediately wrapped after the baling operation to reduce losses (Stinger wrapper shown in Figure 2-22). The wrapped bales, having a moisture content of approximately 40% (w.b.) for corn stover, are handled and transported to the biomass depot in the same manner described in the Conventional Bale design (Section 2.3.2 and Figure 2-29).

Based on the demand of the biomass depots, the wrapped bales are unwrapped, transported, received and directly inserted into the preprocessing operation.

Once unwrapped, the bales become unstable due to their moisture content. The biomass depot will manage the unstable bales by preprocessing them through a three stage grinding/drying system starting with shredding the bales into a loose format, drying the loose feedstock to less than 20% moisture (w.b.), and grinding the dry loose feedstock to a 1/4-inch minus material. The feedstock is then fed into the densification system and queued in its dense format for transportation to the biorefinery. In all, three feedstock format intermediates for corn stover and switchgrass move through the biomass depot. The characteristics of these intermediates is shown in Table 4-4.

Table 4-4. Attributes of queuing and transportation format intermediates for the Advanced Uniform SOT corn stover and switchgrass.

| | Queued Bales | Load/Unload Bale Transport | Bales Transported to Depot | Bulk Solid Storage | Bulk Queue for Transport | Transport to Biorefinery |
|---|---|---|---|---|---|---|
| Corn Stover | | | | | | |
| Yield (DM ton/day) | **N/A** | 2,600 (36 bales/ truck) | 2,600 (36 bales/ truck) | 2,600 | 2,600 | 2,600 |
| Format Output | Large square 36" x 96" bales arranged in rows at fieldside, stacked 2 bales high | Unwrapped round bales loaded on flatbed trailer | Large square high-density bales on conveyor | pellets | pellets | pellets |
| Bulk DM Density Output | 12 DM lbs/ft$^3$ | 12 DM lbs/ft$^3$ | 12 DM lbs/ft$^3$ | 45 DM lbs/ft$^3$ | 45 DM lbs/ft$^3$ | 45 DM lbs/ft$^3$ |
| Output Moisture (% w.b.) | 40 | 40 | 40 | 12 | 12 | 12 |
| Switchgrass | | | | | | |
| Yield (DM ton/acre) | N/A | 2,600 (36 bales/ truck) | 2,600 (36 bales/ truck) | 2,600 | 2,600 | 2,600 |
| Format Output | Large square 36" x 96" bales arranged in rows at fieldside stacked 2 bales high | Unwrapped round bales loaded on flatbed trailer | Large square high-density bales on conveyor | pellets | pellets | pellets |
| Bulk DM Density Output | 10.0 lb/ft$^3$ | 10 DM lbs/ft$^3$ | 10 DM lbs/ft$^3$ | 45 DM lbs/ft$^3$ | 45 DM lbs/ft$^3$ | 45 DM lbs/ft$^3$ |
| Output Moisture (% w.b.) | 34% | 34 | 34 | 12 | 12 | 12 |

Baled, unwrapped stover that is loaded and unloaded for transport (described in Section 2.3.2) has a bulk density of 12 DM lbft$^3$, and remains at this density and format until it is received at the biomass depot. Similarly, baled, unwrapped switchgrass is loaded and unloaded for transport with a bulk density of 10 DM lbft$^3$. Once the biomass (either switchgrass or corn stover) arrives at the biomass depot, the biomass is dried to a moisture content of 12% (W.b.), ground to 1 – 1/4- in. minus, and densified (described below) to a bulk density of 45 DM lb/ft$^3$. The biomass is transported to the biorefinery in this aerobically stable bulk solid format.

#### *4.2.2.3 Advanced Uniform Queuing, Preprocessing and Transportation Equipment Performance Targets*

**Equipment Capacity and Operational Efficiency**

Though grinder capacity and power requirement will vary for different types of feedstock materials (Table 2-34), the modeled capacity (14.6 DM tons/hr) and efficiency (85%) of the preprocessing systems for the Advanced Uniform design are the same as those used in the Pioneer Uniform design (Section 3.3.2). In addition, the capacity and efficiency of the handling and transportation systems are essentially maximized since the bulk density of the feedstock exiting the biomass depot (45 DM lb/ft$^3$) is much greater than the bulk density required to meet the GVW of the semi tractor-trailer unit (Table 4-5 and Figure 4-8).

Table 4-5. Bulk density required to maximize load capacity of the Advanced Uniform SOT truck configuration.

| Truck Configurations | Load Limits | | Payload | | Maximum Load Bulk Density (DM lb/ft$^3$) |
|---|---|---|---|---|---|
| | Length (ft) | GVW (lb) | Max Weight (lb) | Trailer Volume (ft$^3$) | |
| 42-ft Live-bottom Trailer | 42 | 80,000[a] | 49,540 | 2511 | 17.4 |

a. Federal minimum gross vehicle weight (GVW) that states must allow on National Network (NN) highways.

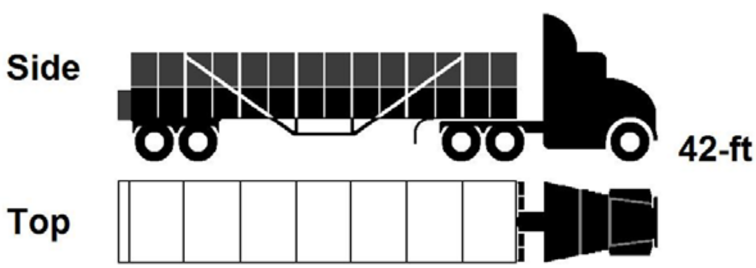


Figure 4-8. Truck configuration for a 42-ft live bottom trailer carrying pellets of bulk feedstock.

**Dry Matter Losses**

The same cyclone separation system used in the Pioneer Uniform design is used in this design to preserve all particulates being created in the grinding processes. These particulates are reintroduced into the pellet process such that no losses are modeled for the biomass depot operations.

**Operation Window**

The biomass depot will operate according to the schedule of the biorefinery, 24 hours per day, 7 days per week, 300 days per year.

#### *4.2.2.4 Advanced Uniform SOT Queuing, Preprocessing and Transportation Equipment*

The Advanced Uniform design uses the same set of bale handling and transportation equipment for all processes from the field to the biomass depot as was used in the Pioneer Uniform design (Section 3.3.2). However, significant changes in the preprocessing and bulk transport equipment have occurred in the Advanced Uniform SOT design. These changes are discussed in the following sections and shown in Tables 4-6 and 4-7.

**Queuing and Transportation**

The handling and transportation processes within the Advanced Uniform design include moving baled feedstock from the field to the biomass depot and moving the bulk feedstock from the biomass depot to the biorefinery. The processes involving baled feedstock was described in the Pioneer Uniform design (Section 3.3.2). The movement of bulk feedstock (pellets), however, is somewhat different in the Advanced Uniform design due to the increased bulk density. Nevertheless, the bulk material is still modeled as being transported with semi tractor-trailer units. Specification of the equipment used in both the bale and bulk transport of the feedstock is shown in Table 4-6.

Table 4-6. Transportation equipment specifications for all herbaceous feedstocks for the Advanced Uniform SOT.

| Operation | Bale Loading/ Unloading | Bale Transport | Bale Receiving and Queue for Preprocessing | Bulk Transport to Biorefinery |
|---|---|---|---|---|
| Equipment | Roadrunner | Kenworth T800 3-axle day cab with 48’ flat bed trailer | Scales Unlimited, Inc. Model AGETS-11711-NTEP Semi-truck Scale and Asphalt Pad | Kenworth T800 3-axle day cab with Trinity trailer Eagle Bridge 42’, 29”/4’ side |
| Haul Distance | N/A | 13 mi | N/A | 25 mi |
| Rated Capacity | 160 bales/hr | 35 bales/load | 100 ton scale, 50,000 $ft^3$ pad | 25 tons |
| Operational Efficiency (%) | 100% | 48% | N/A | 89% |
| Dry Matter Loss (%) | 0 | 0 | 0 | 0 |
| Operational Window | | | | |
| hrs/day | 14 | 14 | 24 | 24 |
| days/year | 300 | 300 | 300 | 300 |

The loading, transporting, unloading, and receiving equipment for the baled feedstock as well as the bulk queuing equipment and semi-tractor has previously been described in Section 2.3.2.1. The average distance to the biomass depot is approximately 10 miles. After preprocessing, the bulk solid material is transported from the biomass depot to the biorefinery using a Kenworth T800 3-axle day cab truck pulling an Eagle Bridge 42’ trailer, with an average haul distance to the biorefinery of approximately 25 miles. The dry matter loss during transport, both to the biomass depot and to the biorefinery, is assumed to be negligible.

**Preprocessing**

Preprocessing at the biomass depot in the Advanced Uniform design has two primary responsibilities: (1) assure aerobic stability of the feedstock throughout the rest of the supply system and (2) size reduce and densify the feedstock to ~45 lb/$ft^3$ for transport to and queuing at the biorefinery. To fulfill these responsibilities, the biomass depots have expanded to include equipment capable of drying the biomass to 12% moisture (w.b.) and densifying the biomass to 45 lb/ft$^3$. In addition, a two stage grinding system is introduced that will better handle inefficiencies of fine grinding wet biomass. This is accomplished by placing the drying system after the first stage bale shredder and before the second stage fine grinder. Other equipment in the biomass depot include those previously described in the Pioneer Uniform design (Section 3.3.2 and Table 3-16) which are the grinder loader, the grinder infeed system, and the dust collection system. There are now a total of 11 biomass depots that house all preprocessing equipment used to format the stable, dense feedstock demanded by the biorefinery. Table 4-7 shows the equipment specifications for the Advanced Uniform SOT for herbaceous feedstocks.

Table 4-7. Preprocessing equipment specifications for all herbaceous feedstocks for the Advanced Uniform SOT.

| Operation | Grinder Loader from Bale Queue | Dryer | Grinder In-feed System | Grinder | Pellet Production | Dust Collection | Bale and Twine Disposal |
|---|---|---|---|---|---|---|---|
| Equipment | Caterpillar TH 220B telehandler | Anco-Eaglin Dryer 300k | Schuon conveyor | WB G250-26-200 bale shredder with ¼ minus finish grinder | Antritz-Sprout 6 tph pellet mill with sebs pellet cooler | Cyclone, Baghouse, Conveying Equipment | Twine remover, moisture meter, electro magnet, bale rejector |
| Haul Distance | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Rated Capacity[a] | 11.5 tons/h | 16.8 | 11.0 tons/h | 15 tons/h | 6.0 tons/h | 6.0 tons/h | N/A |
| Operational Efficiency (%)[a] | 100% | 100 | 57% | 92% | 96% | 96% | N/A |
| Dry Matter Loss (%)[a] | 0 | 0 | 0 | 0 | 0 | 0 | N/A |
| Operational Window | | | | | | | |
| hrs/day | 24 | 24 | 24 | 24 | 24 | 24 | 24 |
| days/year | 300 | 300 | 300 | 300 | 300 | 300 | 300 |

a. Estimated efficiency based on the actual operating time and the amount of capacity used.

Grinder Infeed and dust collection equipment was described in Section 2.4.2.2 and shown in Figures 2-42, 2-43, and 2-44. The biomass is fed into a WB G250-26-400 grinder with a 3” cuber screen with a ¼” minus finish grinder, and then dried using a rotary drum dryer. From the dryer, the biomass is further ground to ¼ - grind size using a WB G250-26-400 grinder. The ground biomass is then densified to a bulk density of 45 lb/ft$^3$ using a Antritz Sprout 6 ton per hour pellet mill. The bale and twine disposal system was described in Section 2.4.2.2.

#### *4.2.2.5 Advanced Uniform SOT Queuing, Preprocessing and Transportation Cost and Sensitivity Analysis*

**Static Model Cost Summary**

A breakdown of the costs associated with each piece of equipment used in the queuing, preprocessing and transportation unit operation identifies significant cost components that are valuable for making individual comparisons and recognizing areas of research potential (Tables 4-8 and 4-9). These costs are reported in DM tons entering each process.

Table 4-8. Static model costs for major queuing and transportation equipment in the Advanced Uniform SOT supply system. Costs are expressed in $/DM ton unless otherwise noted.

| | Bale Loading/ Unloading | Bale Transport | Biomass Receiving and Queuing | Bulk Transport to Refinery |
|---|---|---|---|---|
| Equipment | Roadrunner | Kenworth T800 3-axle day cab with 48’ flat bed trailer | Scales Unlimited, Inc. Model AGETS-11711-NTEP Semi-truck Scale and Asphalt Pad 11’x117’, | Kenworth T800 3-axle day cab with Trinity trailer Eagle Bridge 42’, 29”/4’ side |
| Installed Equipment Quantities | 6 | 11 | 11 | 6 |
| Installed Capital[a] | 1.15 | 1.89 | 1.89 | 1.25 |
| | | | | |
| Ownership Costs[b] | 0.36 | 0.42 | 0.20 | 0.36 |
| Operating Costs[c] | 2.73 | 2.36 | 0.04 | 2.72 |
| Labor | 1.68 | 0.70 | N/A | 0.90 |
| Non-Labor | 1.05 | 1.66 | 0.04 | 1.82 |
| | | | | |
| Dry Matter Loss Costs | N/A | N/A | N/A | N/A |
| | | | | |
| Energy Use (Mbtu/DM ton) | 49.6 | 29.1 | N/A | 49.5 |
| Energy Source | Diesel | Diesel | N/A | Diesel |

a. Installed capital costs are $ per annual DM ton capacity.

b. Ownership costs include depreciation, interest, taxes, insurance, and housing (Appendix A-2, Table A-7).

c. Operating costs include repairs, maintenance, fuel, lubrication, labor, and consumable materials (Appendix A-2, Table A-7)

Table 4-9. Static model costs for major preprocessing equipment in the Advanced Uniform SOT supply system. Costs are expressed in $/DM ton unless otherwise noted.

| Equipment | Grinder Loader from Bale Queue | Biomass Dryer | Grinder In-Feed System | Grinder | Densification | Dust Collection | Bale and Twine Disposal |
|---|---|---|---|---|---|---|---|
| | Caterpillar TH 220B telehandler | Anco-Eaglin Dryer 300k | Schuon conveyor | WB G250-26-200, 3" cuber screen with ¼ minus grinder | Antritz-Sprout 6 tph pellet mill with sebs pellet cooler | Cyclone, Baghouse, Conveying Equipment | Twine remover, moisture meter, electro magnet, bale rejector |
| Installed Equipment Quantities | 11 | 11 | 22 | 11 | 22 | 22 | 11 |
| Installed Capital[a] | 0.91 | 49.88 | 7.11 | 2.36 | 8.76 | 13.10 | 3.01 |
| | | | | | | | |
| Ownership Costs[b] | 0.58 | 6.78 | 0.77 | 0.94 | 4.72 | 1.86 | 0.33 |
| Operating Costs[c] | 2.01 | 27.07 | 1.26 | 8.14 | 15.63 | 9.03 | 0.90 |
| Labor | 1.40 | N/A | N/A | 3.54 | 5.41 | N/A | N/A |
| Non-Labor | 0.62 | 27.07 | 1.26 | 4.60 | 10.22 | 9.03 | 0.90 |
| | | | | | | | |
| Dry Matter Loss Costs | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| | | | | | | | |
| Energy Use (Mbtu/DM ton) | 19.4 | 92.4 | 9.6 | 201.5 | 216.9 | 247.7 | 13.1 |
| Energy Source | Diesel | Electricity | Electricity | Electricity | Electricity | Electricity | Electricity |

a. Installed capital costs are $ per annual DM ton capacity.

b. Ownership costs include depreciation, interest, taxes, insurance, and housing (Appendix A-2, Table A-7).

c. Operating costs include repairs, maintenance, fuel, lubrication, labor, and consumable materials (Appendix A-2, Table A-7)

**Cost Sensitivity Analysis**

A histogram of the queuing cost (Figure 4-9) for corn stover shows that with 90% confidence the cost of the unit operation ranges between $5.71 and $7.21 per DM ton. Further, the mean and standard deviation of this range is $6.44 ± 0.46 per DM ton. The mode value of the queuing cost is $6.36 per DM ton. This value is similar to the result of the static model, which is $8.31 per DM ton, since the defined value of the parameter distributions was set equal to the static value in the model.

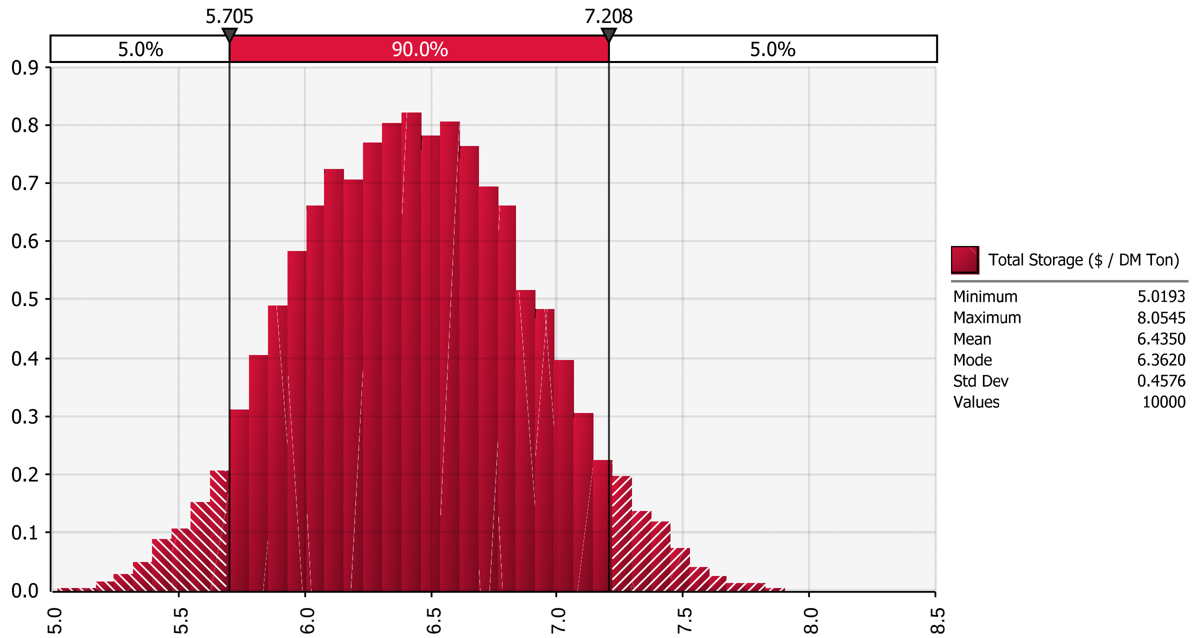


Figure 4-9. Queuing cost distribution histogram from @Risk analysis for the Advanced Uniform SOT corn stover scenario.

A histogram of the queuing cost (Figure 4-10) for switchgrass shows that with 90% confidence the cost of the unit operation ranges between $5.32 and $6.83 per DM ton. Further, the mean and standard deviation of this range is $6.07 ± 0.46 per DM ton. The mode value of the queuing cost is $6.10 per DM ton. This value is similar to the result of the static model, which is $7.43 per DM ton, since the defined value of the parameter distributions was set equal to the static value in the model.

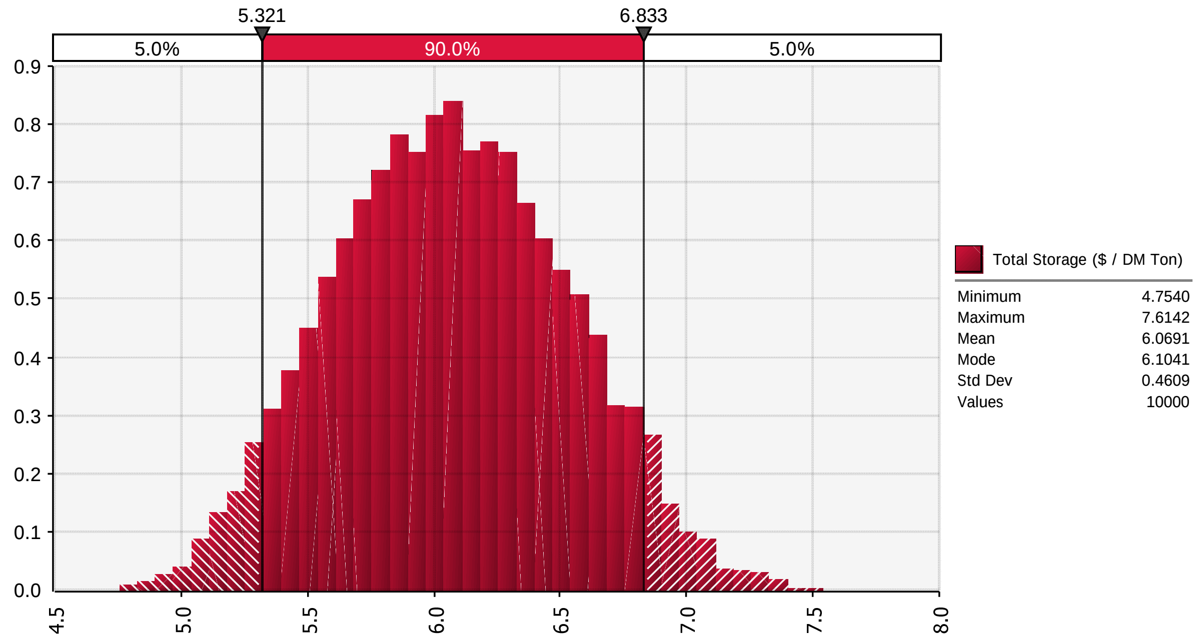


Figure 4-10. Queuing cost distribution histogram from @Risk analysis for the Advanced Uniform SOT switchgrass scenario.

A histogram of the total transportation cost (Figure 4-11) for the Advanced Uniform SOT corn stover shows that with 90% confidence the cost of the unit operation ranges between $11.88 and $18.10 per DM ton. Further, the mean and standard deviation of this range is $14.45 ± 1.94 per DM ton. The mode value of the transportation cost is $13.60 per DM ton. The result of the static model is $8.95 per DM ton.

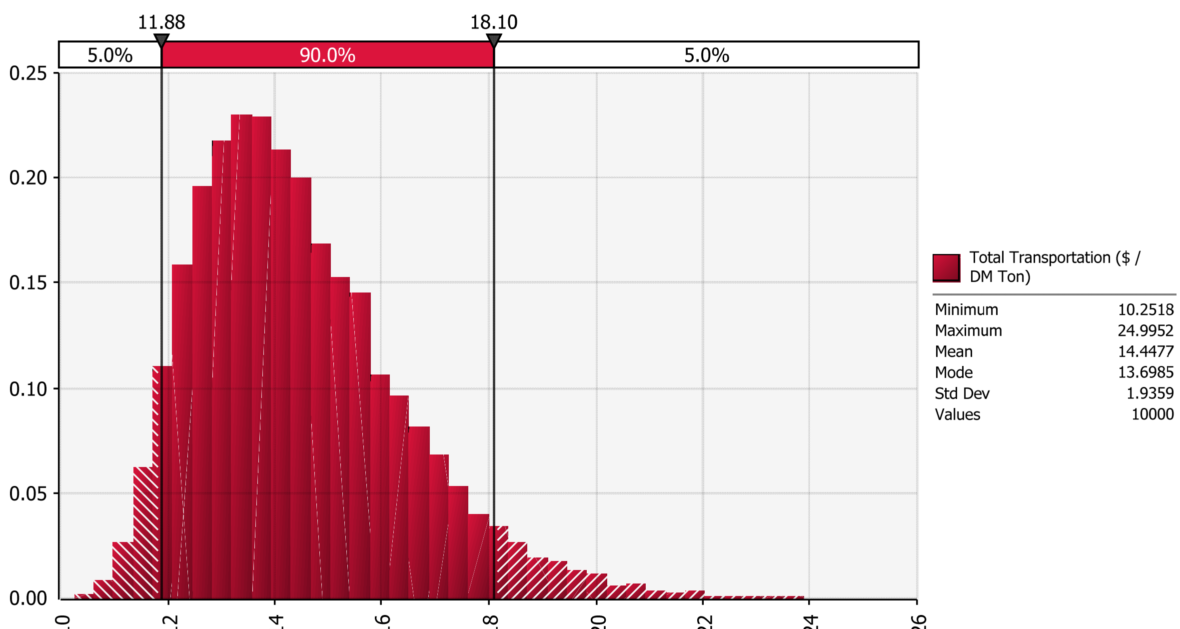


Figure 4-11. Advanced Uniform SOT total transportation cost distribution histogram from @Risk analysis for corn stover.

A histogram of the total transportation cost (Figure 4-12) for the Advanced Uniform SOT switchgrass shows that with 90% confidence the cost of the unit operation ranges between $10.50 and $16.27 per DM ton. Further, the mean and standard deviation of this range is $12.87 ± 1.81 per DM ton. The mode value of the transportation cost is $11.57 per DM ton. This value is near the result of the static model, which is $9.37 per DM ton, since the defined value of the parameter distributions was set equal to the static value in the model.

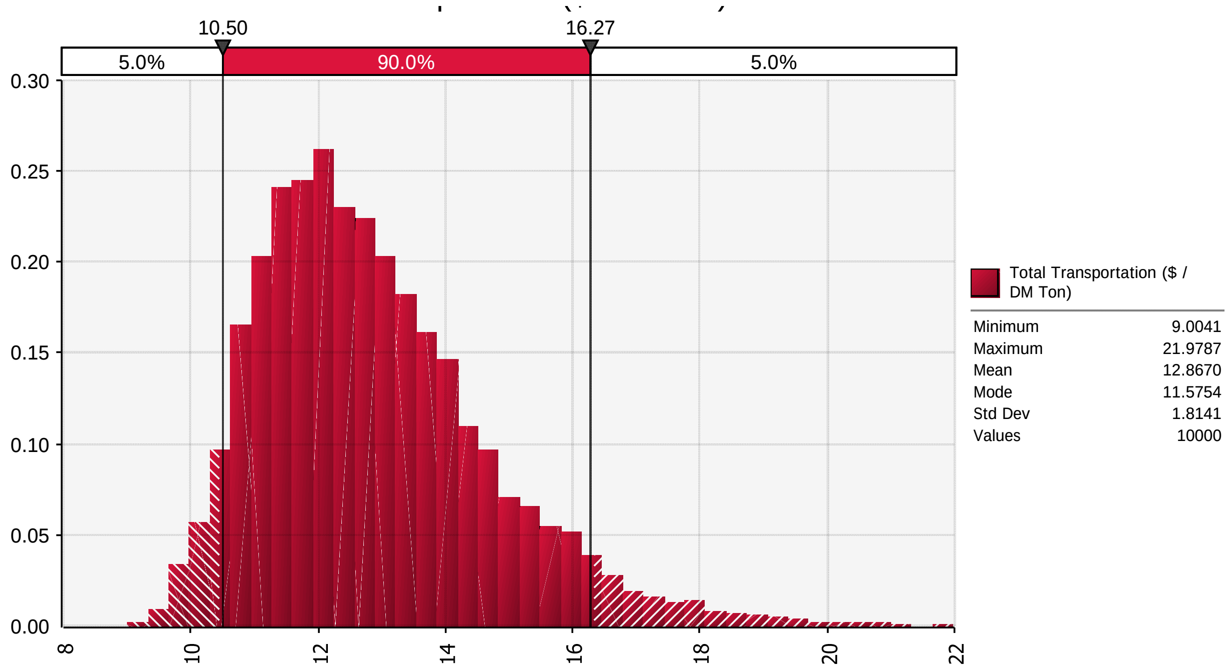


Figure 4-12. Advanced Uniform SOT total transportation cost distribution histogram from @Risk analysis for switchgrass.

A histogram of the preprocessing cost (Figure 4-13) for the Advanced Uniform SOT corn stover shows that with 90% confidence the cost of the unit operation ranges between $84.60 and $125.90 per DM ton. Further, the mean and standard deviation of this range is $95.52 ± 14.27 per DM ton. The mode value of the preprocessing cost is $86.78 per DM ton. This value closely represents the result of the static model, which is $80.28 per DM ton, since the defined value of the parameter distributions was set equal to the static value in the model.

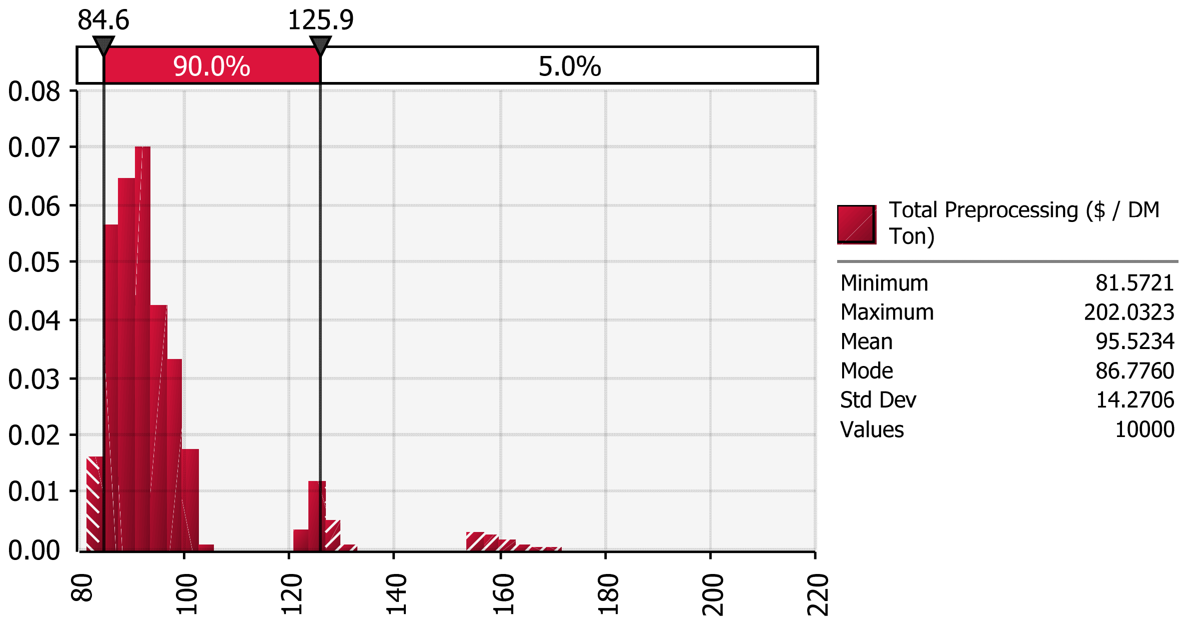


Figure 4-13. Advanced Uniform SOT preprocessing cost distribution histogram from @Risk analysis for corn stover.

A histogram of the preprocessing cost (Figure 4-14) for the Advanced Uniform SOT using switchgrass shows that with 90% confidence the cost of the unit operation ranges between $48.30 and $122.90 per DM ton. Further, the mean and standard deviation of this range is $89.43 ± 15.43 per DM ton. The mode value of the preprocessing cost is $86.36 per DM ton. This value closely represents the result of the static model, which is $80.23 per DM ton, since the defined value of the parameter distributions was set equal to the static value in the model.

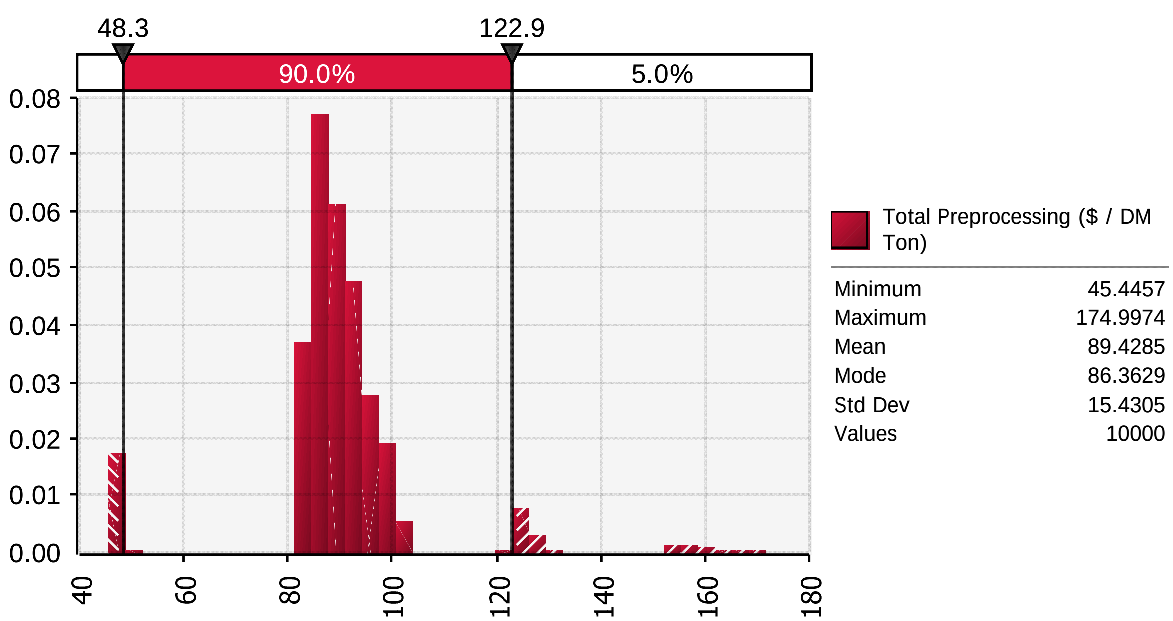


Figure 4-14. Advanced Uniform SOT preprocessing cost distribution histogram from @Risk analysis switchgrass.

### 4.2.3 Advanced Uniform Receiving and Queuing

As described in the Pioneer Uniform design (Section 3.4), the material format is well specified entering the receiving and queuing operation at the biorefinery. The Advanced Uniform format is a bulk flowable, aerobically stable, pelletized material with a bulk density of approximately 45 $lbs/ft^3$. The specific systems comprising the Advanced Uniform receiving and queuing mirror those of the Pioneer Uniform design (Figure 4-15), and include weighing and unloading incoming bulk transport trucks, storing bulk feedstock in short-term queuing, and feeding bulk feedstock into the conversion process. The Advanced Uniform material performs much like existing bulk solid commodity materials, such as grain and thus, the Advanced design employs commercially available equipment creating a highly replicable and flexible receiving and queuing system.

#### *4.2.3.1 Advanced Uniform Receiving and Queuing Format Intermediates Performance Targets*

There are no format intermediates for receiving and queuing in the Advanced Uniform design.

**Biomass Deconstruction, Fractionation, and Yield**

The Advanced Uniform design receives feedstock at the biorefinery according to the format specifications described in Section 4.2.2. This design performs no further format modifications.

**Format and Bulk Density Impact on Supply System Processes**

The Advanced Uniform material format is specified as easy to free flowing, minimum 4 ffc (Table 3-21), at a bulk density near or above 45 $lbs/ft^3$. These format characteristics clearly put the Advanced Uniform material within the operating parameters of standard commercial conveying and storage systems widely used in existing bulk solid configurations. Significant increases in bulk density above 45 $lbs/ft^3$ could potentially reduce the volume of storage required at the biorefinery to maintain the required 72 hr supply of feedstock, but the design discussed here assembles the system based on the specified format leaving the biomass depot.

**Biomass Moisture Impact on Supply System Processes and Material Stability**

The Advanced Uniform design produces an aerobically stable through the preprocessing operation at the biomass depot. Quality control testing will be part of the receiving process, but the material will be well within established moisture standards to ensure stability over the short time period prior to insertion into the conversion process.

#### *4.2.3.2 Advanced Uniform SOT Receiving and Queuing Format Intermediates*

There are no format intermediates for receiving and queuing in the Advanced Uniform design.

#### *4.2.3.3 Advanced Uniform Receiving and Queuing Equipment Performance Targets*

**Equipment Capacity and Operational Efficiency**

The discussion in section 3.4.2.1 on the Pioneer Uniform receiving and queuing system capacity and efficiency is also representative of the Advanced Uniform system. The equipment differences are limited to the on site storage mechanism, moving from the actively unloading Eurosilos, to more conventional grain storage tanks. These tanks are corrugated steel bins that unload via screw augers in the floor of the bin which are gravity fed. The storage structure chosen for the modeled scenario is 90-ft diameter bins nearly 86 ft tall, which hold approximately 358,000 bushels of grain. The ability of the advanced material format to flow like grain facilitates this design change. Capacities and operational efficiencies mirror the

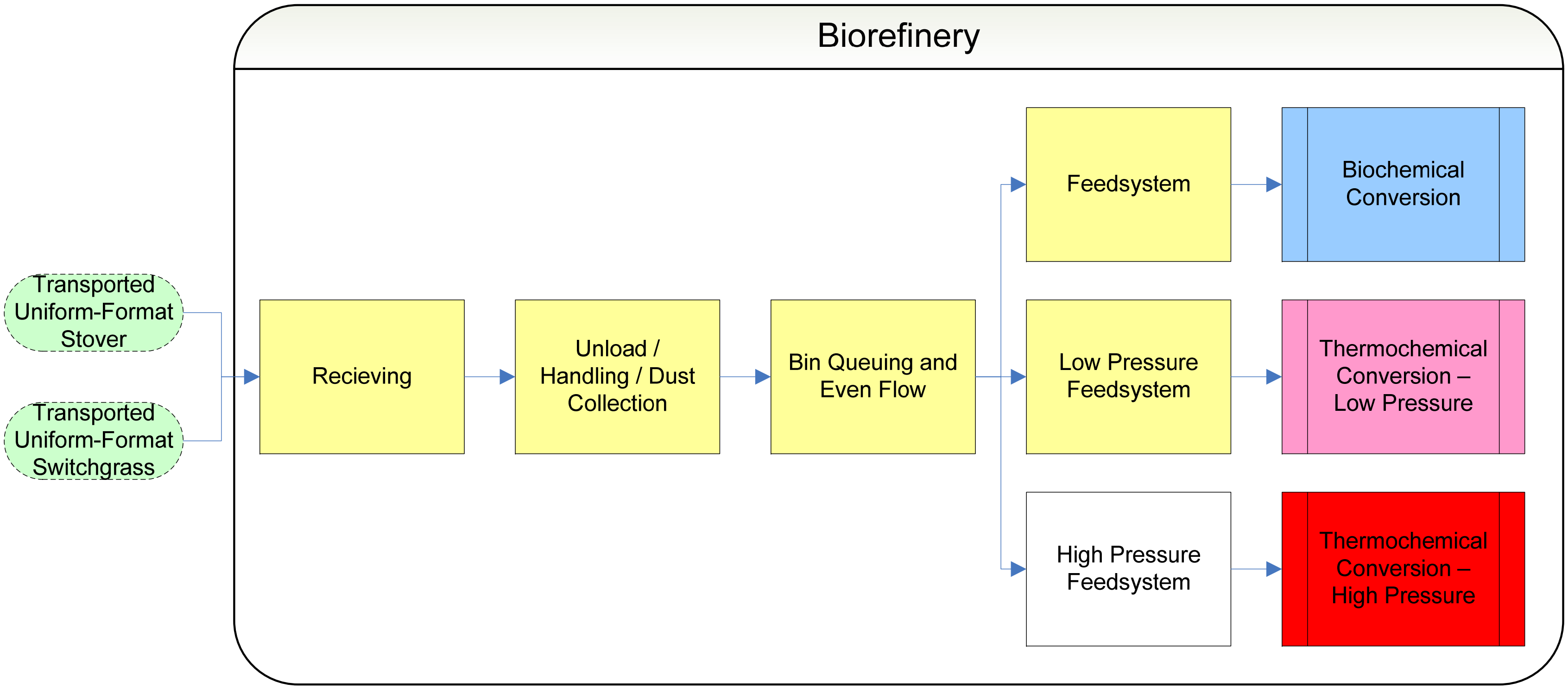


Figure 4-15. Receiving and Queuing supply logistic processes and format intermediates.

*(Note: Green ovals represent format intermediates, yellow rectangles represent unit operations modeled in this report and white rectangles represent options not modeled in this report.)*

Pioneer Uniform design with differences appearing due to bulk density increases in the advance case material. Another advantage of these structures is that existing loading and unloading equipment for grain systems can be used with little or no additional costs.

**Dry Matter Losses**

The Advanced Uniform format specifies an aerobically stable material resulting in insignificant microbial dry matter loss in receiving and queuing, and therefore mechanical dry matter losses are the remaining concern. Mechanical losses occur primarily from wind and other weather-related effects. The receiving and queuing equipment used in this design is generally enclosed, limiting environmental effects. Furthermore, as discussed previously, the equipment assembled for receiving and queuing the Advanced Uniform case material is well developed and highly effective in minimizing dry matter loss. Thus, in this design dry matter loss is considered minimal, approaching 0%.

**Operation Window**

The receiving and queuing operation will operate according to the schedule of the biorefinery, 24 hours per day, 7 days per week, 350 days per year.

#### *4.2.3.4 Advanced Uniform SOT Receiving and Queuing Equipment*

Plant receiving and queuing operations in the Advanced Uniform SOT supply system are constructed based on receiving feedstock via self unloading semi-trucks and trailers, and a 72-hour supply need is assumed for this scenario. The trucks are weighed and unloaded into pit hoppers that move the feedstock to a vertical leg system through large conveyers. The leg gravity feeds the material into two 90-ft corrugated steel bins that are capable of maintaining the required 72-hour supply. The bins are unloaded with screw augers under the bin floors. The material is then conveyed to an Even Flow metering hopper at the reactor throat. Table 4-10 contains the equipment specifications for the Advanced Uniform SOT for all herbaceous feedstocks.

Table 4-10. Receiving and queuing Advanced Uniform SOT equipment specifications for all herbaceous feedstocks.

| Operation | Receiving | Unload/ Handling | Bin Queuing and Even Flow | Feed system |
|---|---|---|---|---|
| Equipment | Phelps 40’ corn hopper | 11’x117’, 100 ton truck scale | Sukup Corrugated Steel Bin | En Masse Conveyor |
| Rated Capacity | 750 tons/h | 100 ton | 1,070,000 $ft^3$ | 565 tons/h |
| Operational Efficiency (%) | 18% | 37% | 75% | 24% |
| Dry Matter Loss (%) | N/A | N/A | N/A | N/A |
| Operational Window | | | | |
| hrs/day | 24 | 24 | 24 | 24 |
| days/year | 300 | 300 | 300 | 300 |

Truck transport the bulk-solid material to the biorefinery, where it is weighed on a 100 ton receiving scale and unloaded into a Phelps 40’ corn hopper that moves the feedstock to a vertical leg system through En Masse conveyers, fed into a Sukup corrugated steel bin. From the bin, the bulk-solid is conveyed into an Even Flow metering hopper into the refining process. Dry matter losses are considered negligible. The equipment used is the same as that used for grain handling and feeding, greatly simplifying the refinery handling costs over the Conventional Bale system.

#### *4.2.3.5 Advanced Uniform SOT Receiving and Queuing Cost and Sensitivity Analysis*

**Static Model Cost Summary**

A breakdown of the costs associated with each piece of equipment used in the receiving and queuing unit operation identifies significant cost components that are valuable for making individual comparisons and recognizing areas of research potential (Table 4-11). These costs are reported in DM tons entering each process respectively.

Table 4-11. Static model costs for major receiving and queuing equipment in the Advanced Uniform SOT supply system. Costs are expressed in $/DM ton unless otherwise noted.

| | Receiving | Unload/Handling | Bin Queuing and Even Flow | Feed system |
|---|---|---|---|---|
| Equipment | Phelps 40' corn hopper | 11'x117', 100 ton truck scale | Sukup Corrugated Steel Bin | En Masse Conveyor |
| Installed Equipment Quantities | 1 | 1 | 1 | 1 |
| Installed Capital[a] | 0.09 | 0.07 | 2.00 | 0.80 |
| | | | | |
| Ownership Costs[a] | 0.01 | 0.01 | 0.84 | 0.09 |
| Operating Costs[c] | 0.21 | 0.19 | 1.17 | 0.30 |
| Labor | 0.19 | 0.19 | 1.11 | N/A |
| Non-Labor | 0.01 | 0.00 | 0.07 | 0.30 |
| | | | | |
| Dry Matter Loss Costs | N/A | N/A | N/A | N/A |
| | | | | |
| Energy Use (Mbtu/DM ton) | N/A | N/A | N/A | 10.4 |

a. Installed capital costs are $ per annual DM ton capacity.

b. Ownership costs include depreciation, interest, taxes, insurance, and housing (Appendix A-2, Table A-7).

c. Operating costs include repairs, maintenance, fuel, lubrication, labor, and consumable materials (Appendix A-2, Table A-7)

**Cost Sensitivity Analysis**

A histogram of the receiving and queuing cost (Figure 4-16) for the Advanced Uniform SOT for corn stover shows that with 90% confidence the cost of the unit operation ranges between $1.71 and $1.73 per DM ton. Further, the mean and standard deviation of this range is $1.72 ± 0.005 per DM ton. The mode value of the receiving and queuing cost is $1.72 per DM ton. This value closely represents the result of the static model, which is $1.23 per DM ton, since the defined value of the parameter distributions was set equal to the static value in the model.

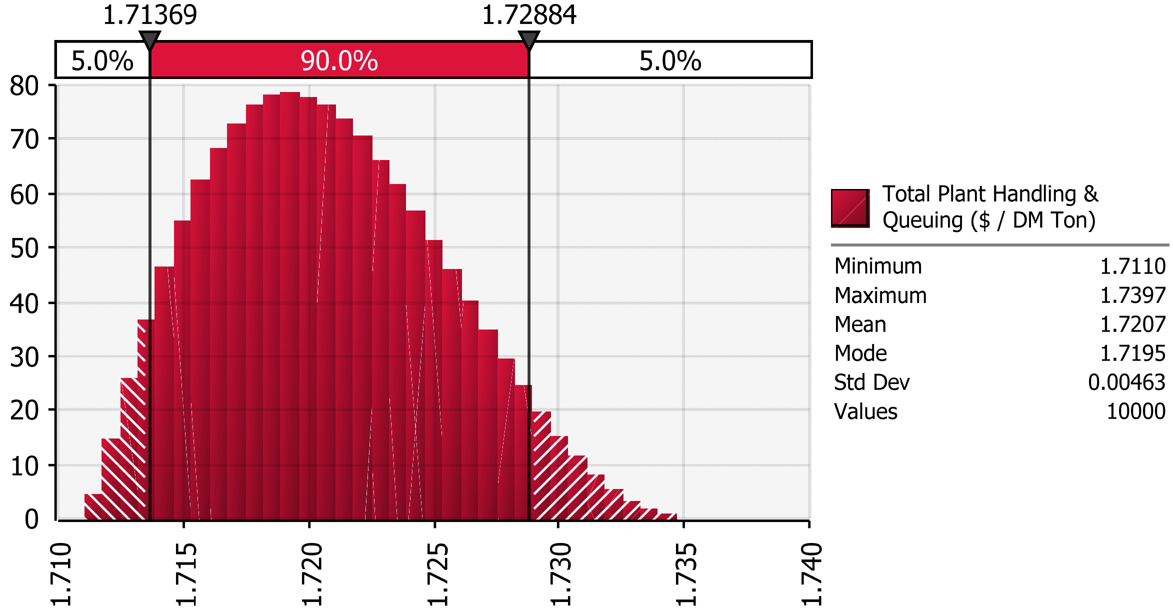


Figure 4-16. Advanced Uniform SOT receiving and queuing cost distribution histogram from @Risk analysis for corn stover.

A histogram of the receiving and queuing cost (Figure 4-17) for the Advanced Uniform SOT for switchgrass shows that with 90% confidence the cost of the unit operation ranges between $1.60 and $1.61 per DM ton. Further, the mean and standard deviation of this range is $1.60 ± 0.005 per DM ton. The mode value of the receiving and queuing cost is $1.60 per DM ton. This value is near the result of the static model, which is $1.23 per DM ton, since the defined value of the parameter distributions was set equal to the static value in the model.

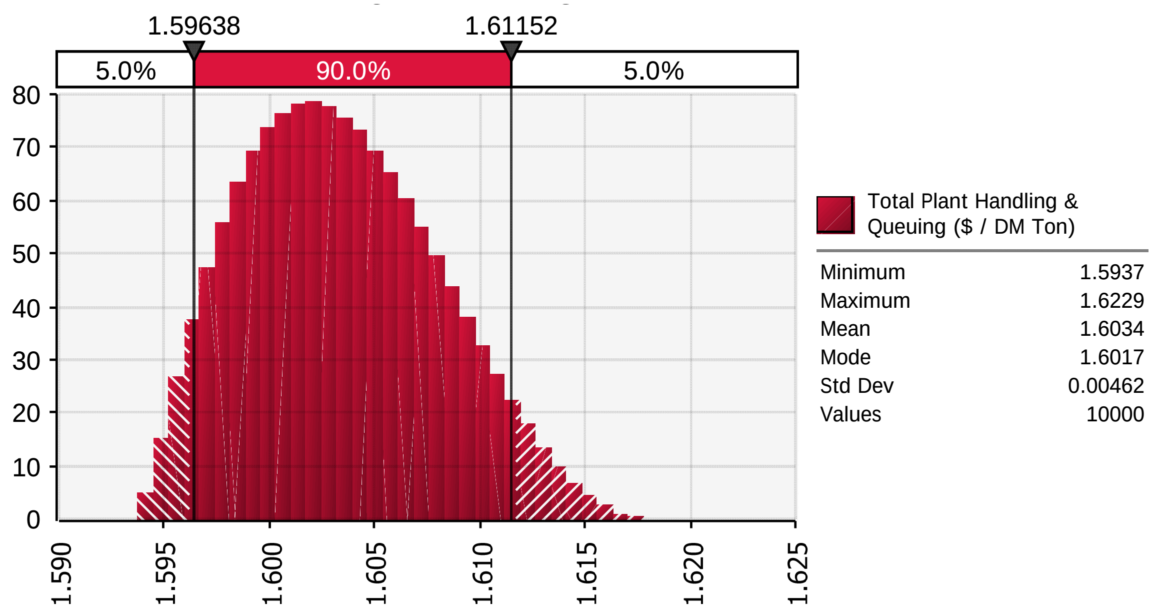


Figure 4-17. Advanced uniform SOT receiving and queuing cost distribution histogram from @Risk analysis for switchgrass.

## 4.3 Comparison of Supply System Designs

### 4.3.1 Monte Carlo Analysis

A sophisticated uncertainty analysis was conducted by allowing various input parameters to change over their respective probability distributions simultaneously, thus representing the combined impacts of the system uncertainty and the interdependence of input parameters. This analysis was conducted using @Risk, which interfaced directly with the Excel-based feedstock model. The simulation consisted of 10,000 iterations. For each iteration, all of the parameters were randomly varied, and the resulting total delivered feedstock cost as well as the incremental feedstock costs throughout each unit operation of the supply chain was recorded.

A summary of the costs for the Conventional Bale, Pioneer Uniform, and Advanced Uniform SOT feedstock supply systems are provided in Table 4-12. Both corn stover and switchgrass see the lowest immediate delivered feedstock cost in the Conventional Bale system. Preprocessing costs in the round and square bale instances of the Pioneer Uniform design increase the delivered feedstock cost, with round bales showing higher costs for both feedstocks. The Pioneer Uniform cob system shows higher costs than either bale design for both corn stover and switchgrass. The current SOT Advanced Uniform design demonstrates modeled costs considerably higher than the other systems.

Table 4-12. Unit operation cost targets and unit operation costs for the supply systems Conventional-Bale and Pioneer-Uniform systems, expressed in $/DM ton. Neither the Conventional or Pioneer systems reach the cost targets.

| | Conventional-Bale | Pioneer-Uniform Round Bale | Pioneer-Uniform Square | SOT |
|---|---|---|---|---|
| Corn Stover | | | | |
| Total Delivered Cost | 55.40 ± 4.31 $/DM ton | 61.27 ± 4.57 $/DM ton | 57.78 ± 3.72 $/DM ton | 141.31± 16.15 $/DM ton |
| Switchgrass | | | | |
| Total Delivered Cost | 49.61 ± 3.20 $/DM ton | 57.12 ± 4.92 $/DM ton | 51.58 ± 3.79 $/DM ton | 125.14 ± 16.97 $/DM ton |
| Cobs | | | | |
| Total Delivered Cost | N/A | 68.91 ± 4.11 $/DM ton | N/A | N/A |

a. Includes stacking, weather protection, as well as storage for the Conventional-Bale system

b. Includes both preprocessing and receiving

A histogram of the final cost for delivered corn stover to the throat of the conversion reactor at a biorefinery (Figure 4-18) shows that with 90% confidence the cost ranges between $126.80 and $175.50 per DM ton. Further, the mean and standard deviation of this range is $141.31 ± 16.15 per DM ton. The mode value of the final cost is $135.91 per DM ton.

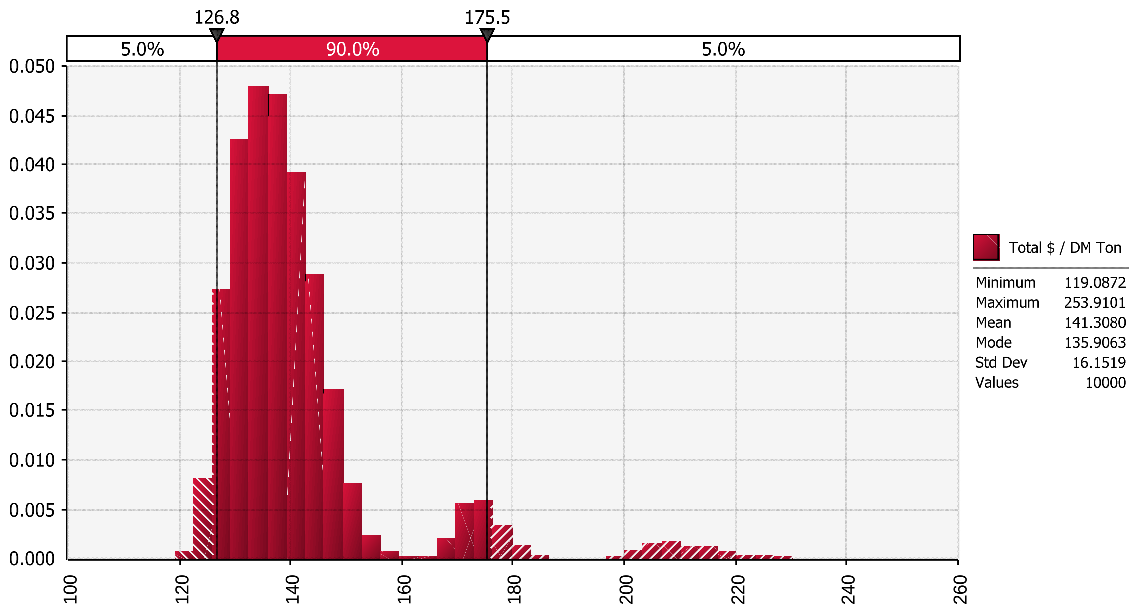


Figure 4-18. Total supply system cost for the Advanced Uniform SOT corn stover scenario.

A histogram of the final cost for delivered switchgrass to the throat of the conversion reactor at a biorefinery (Figure 4-19) shows that with 90% confidence the cost ranges between $83.90 and $157.90 per DM ton. Further, the mean and standard deviation of this range is $125.14 ± 16.97 per DM ton. The mode value of the final cost is $123.07 per DM ton.

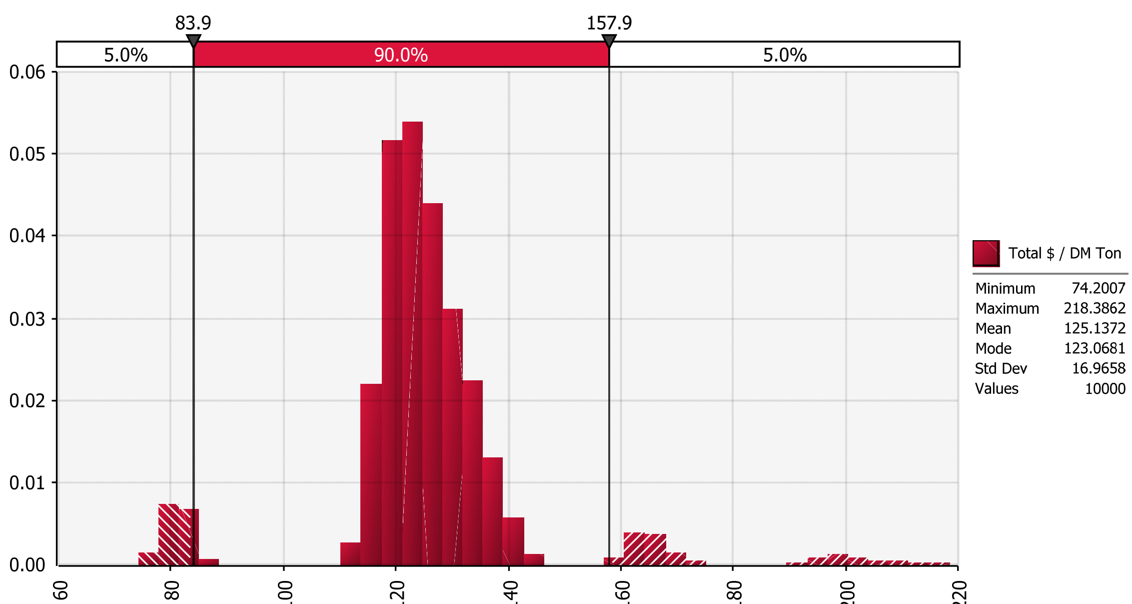


Figure 4-19. Total supply system cost for the Advanced Uniform SOT switchgrass scenario.

Although the Advanced Uniform SOT systems for both corn stover and switchgrass were designed to meet material property targets, Figures 4-18 and 4-19 show that neither SOT can meet cost targets. However, as shown in Table 4-12, neither the Conventional Bale nor Pioneer Uniform system can meet the cost targets, and theses systems also fail to meet material targets.

### 4.3.2 Meeting Targets with the Advanced Uniform Design

Progression to the Uniform-Format system may result in a long-term decrease in the delivered cost of biomass sufficient to achieve cost targets while increasing supply volume. This will be accomplished by addressing key material property and machine/engineering barriers to achieve more efficient biomass supply logistics. Table 4-13 compares attributes of the three systems and shows that the Advanced Uniform system is the only one that achieves all national cost and supply goals while overcoming material property and engineering barriers and addressing long-term sustainability issues.

Table 4-13. Comparison of the attributes of the three herbaceous feedstock supply systems. The Advanced Uniform is the only system that achieves all national goals while overcoming material property and engineering goals, and addresses long-term sustainability issues.

| | Non-Uniform | Uniform-Format | |
|---|---|---|---|
| **Design Attributes** | **Conventional** | **Pioneer** | **Advanced** |
| **National Goals** | | | |
| Can be economically scaled up to help meet DOE-projected biofuel production goal to displace 30% of 2004 gasoline use by 2030 | ○ | ○ | ● |
| Can meet 2012 ($35/DM ton) and 2017 (25% of ethanol production cost) DOE cost targets[b] for delivered biomass[c] to the conversion process | ○ | ◒ | ● |
| **Barriers: Material Properties** | | | |
| Produces aerobically stable material for all feedstock types (moisture content of 15–20% or less for all resources) | ○ | ○ | ● |
| Achieves target dry matter bulk density of >30 lb/ft³ after preprocessing | ○ | ○ | ● |
| Leverages biomass material deconstruction properties to improve capacity and efficiency of all engineered systems and matches systems to material composition | ○ | ◒ | ● |
| **Barriers: Machine/Engineering** | | | |
| Optimizes all machinery operation and capital for operational window | ○ | ◒ | ● |
| Achieves all equipment efficiency/capacity goals within cost and energy consumption targets (i.e., target harvesting efficiency of 35 DMT[d]/hr) | ○ | ◒ | ● |
| Can meet total supply chain material loss of <5% | ○ | ● | ● |
| **Commodity System Attributes** | | | |
| Ensures reliable feedstock supply (biomass can be acquired from many sources beyond 200 miles, reducing supply risk) | ○ | ○ | ● |
| Produces aerobically stable and flowable product | ○ | ◒ | ● |
| Formats material to fit all common high-capacity solids handling equipment | ○ | ◒ | ● |
| Broadens feedstock accessibility (biomass can be purchased and sold through regional and national markets) | ○ | ◒ | ● |
| **Sustainability** | | | |
| Expands regional cropping options (handles various biomass formats, moisture content, and composition) | ○ | ○ | ● |
| Enables access to remote biomass resources (able to reach DOE goal of 25 M dry ton biomass by 2012, 110 M dry ton by 2017, and 530 M dry ton by 2030) | ○ | ◒ | ● |
| Allows efficient transport of feedstock beyond a 200-mile supply radius | ○ | ◒ | ● |
| Addresses feedstock supply risks associated with weather, competition, pests, and other local issues | ○ | ◒ | ● |

[a] ○ = does not meet requirement; ◒ = partially meets requirement; ● = meets requirement
[b] DOE-EERE Office of the Biomass Program (OBP), 2007. Biomass Multi-Year Program Plan, October 2007.
[c] Includes harvesting and collection, storage and queuing, preprocessing, and transportation and handling costs, in 2007 $U.S.
[d] Dry matter ton.

*National Goals*

DOE biofuel production goals, both intermediate and long-term, will require herbaceous biomass supply systems that economically scale beyond the capability of existing systems. Effective scale-up will require feedstocks which can use consistent and replicable infrastructure and equipment. Furthermore, the material characteristics of the feedstocks need to maximize the capacity and efficiency of the equipment and infrastructure. The Conventional Bale supply system does not meet these criteria, and can be effectively implemented only at the scale of custom, feedstock specific supply systems. The Pioneer Uniform supply system begins to address the issue of feedstock uniformity, allowing for more consistent equipment and infrastructure downstream of the preprocessing unit operation. However, the Pioneer Uniform design does not yet achieve material property characteristics facilitating capacities and efficiencies that allow the system to economically scale to meet national production goals. Only the Advanced Uniform design provides the means to overcome material and engineering barriers to economic supply system scale-up. The Advanced Uniform system creates a consistent, uniform material that performs similarly to commodity bulk-solids such as corn grain, and subsequently can use existing replicable equipment and infrastructure which has been proven to scale economically. These Advanced Uniform design characteristics also provide the opportunity to meet cost targets for delivered feedstock price.

*Material Properties Barriers*

The fundamental material properties that drive supply system performance are moisture content and dry matter bulk density. Moisture content must be low enough for aerobic stability (typically <15-20%) to limit costly material losses within the system, and.dry matter bulk densities must be greater than 30 lbs/ft$^3$ to facilitate efficient transport and storage. The Conventional Bale and Pioneer Uniform designs fail to sufficiently address these barriers. Drying is not built into either system, and dry matter bulk densities do not exceed 30 lbs/ft$^3$. Within the Biomass Depots in the Advanced Uniform supply system the feedstock is dried to aerobically stable levels, and dry matter bulk density reaches 45 lbs/ft$^3$. Another important material property consideration is biomass deconstruction characteristics. Significant improvements in capacity and efficiency can be achieved by engineering systems that leverage deconstruction characteristics, as well as material composition. The Conventional Bale design fails to take full advantage of these characteristics. The preprocessing systems introduced in the Pioneer Uniform system begin to take advantage of these properties, and the Advanced Uniform design effectively leverages these properties.

*Machine/Engineering Barriers*

The key barriers with machines and equipment in the feedstock supply system are associated with operational windows, efficiency and capacity, and dry matter losses. The constraints from limited operational windows are primarily an issue for the harvest and collection operation. The specific challenge is associating high equipment costs with lower feedstock throughput due to short time windows in which an operation can be performed. This is particularly true for the Conventional Bale and Pioneer Uniform designs, where field drying is an important component of the supply system. In many locations for many feedstocks, weather and other constraints leave a short time window available for collecting a majority of the feedstock needed for an entire year's supply. The result of this dynamic is that a large, expensive fleet of equipment is necessary for deployment in a narrow time window. Then once the operation is complete this capital investment is idle. The single-pass harvest concepts introduced in the Advanced Uniform design help address this barrier by allowing equipment to process more feedstock through greater efficiencies. Thus, the capital cost of the machines is distributed across larger tonnages. Aggregate supply system efficiencies and capacities show steady improvement moving from the Conventional Bale to Pioneer Uniform, and ultimately Advanced Uniform designs. The Conventional Bale design requires several custom, application-specific components creating inherent inefficiencies.

Also, the feedstock formats in the Conventional Bale design are not conducive to maximizing system capacity, or throughput. The introduction of Biomass Depots into the Pioneer Uniform system moves the system to higher efficiencies and capacities downstream of the preprocessing operation. Higher dry matter bulk density, greater flowability, and a uniform material specification are the contributing factors for these increases. Similarly, the Advanced Uniform design further increases efficiencies and capacities by advancing these attributes to even more favorable levels. The cost of dry matter loss within the system is directly correlated with the value of the material at the point at which it is lost. Any aggregate loss within the system results in less volume delivered to the biorefinery, but as material moves through the supply system each operation incurs more cost and energy. One of the key attributes of the Advanced Uniform design is creating the ability to move the feedstock through proven, standard bulk-solid handling equipment and processes. These systems incorporate dust collection systems to minimize dry matter loss. As such, both the Advanced and Pioneer Uniform-Format systems are capable of total supply chain losses less than 5%.

*Commodity System Attributes*

Building a commodity market and trading system for lignocellulosic biomass is essential for creating a large-scale industry. As demonstrated through the current bulk-solid grain commodity system, with an aerobically stable and flowable product, replicable high-capacity equipment can be used to economically connect supplies with markets across large distances. The ability to economically connect feedstock with markets 200 or more miles away ensures reliable supply by reducing production risks, and broadens accessibility by creating regional and national markets. The Conventional Bale system design fails to produce aerobically stable and flowable materials capable of working with common high-capacity solids handling equipment capable of working in regional and national markets. The Pioneer Uniform design produces a more uniform, flowable material through the initial implementation of Biomass Depots, but does not yet achieve dry matter bulk densities that ensure each system implementation can economically move the feedstock hundreds of miles. The Pioneer Uniform system does broaden feedstock accessibility by producing a formatted material that begins to move in common high-capacity solids handling systems which creates new local markets for the feedstock. The Advanced Uniform design meets the requisite material specifications creating the ability to trade and move material several hundred miles to available markets.

*Sustainability*

Sustainability in the context of supply system design comparison is primarily driven by the ability to establish a consistently sustainable supply of feedstock material. There are four components of establishing this consistent supply relative to the feedstock supply system designs: 1) facilitating diversity in regional cropping options; 2) enabling access to remote resources; 3) allowing efficient transport of biomass beyond 200 miles; and 4) addressing supply risks associated with weather, competition, pests, and other local issues. Expanding regional cropping options requires the supply system to handle diverse material formats, moisture contents, composition, etc. This is attainable only through the Advanced Uniform design which includes Biomass Depots that have processes in place to handle the diversity. The Advanced Uniform system formats the feedstock to fit common high-capacity solids handling equipment which allows the resource to transport beyond 200 miles. The Pioneer Uniform design does not achieve desired bulk densities making long distance transport more efficient. By creating the ability to transport long distances, both systems enable access to remote resources which can not be economically accessed in the Conventional Bale system. Along with accessing remote resources, the ability to transport the feedstock long distances also mitigates supply risk associated with local issues such as weather, competition and pests. As markets become regional and national, local supply shortages can be dealt with by compensating with material from non-local production.

## 4.4 Engineering Approach to Uniform-Format Feedstock Supply System

The current Conventional Bale feedstock supply system is not capable of supplying the US DOE target of 530 million tons of biomass annually for less than 30% of the ethanol production cost. The proposed Uniform-Format supply system meets the biomass cost, quantity, and quality supply goals. Transitioning from the Conventional Bale to the Uniform-Format system, however, presents many challenges, including limitations in existing harvesting and collection equipment and incorporation of biomass depots and blending terminals early in the feedstock supply chain. Figure 4-20 shows the current least-cost feedstock supply system path and barriers that need to be overcome for the incremental progression toward meeting performance targets.

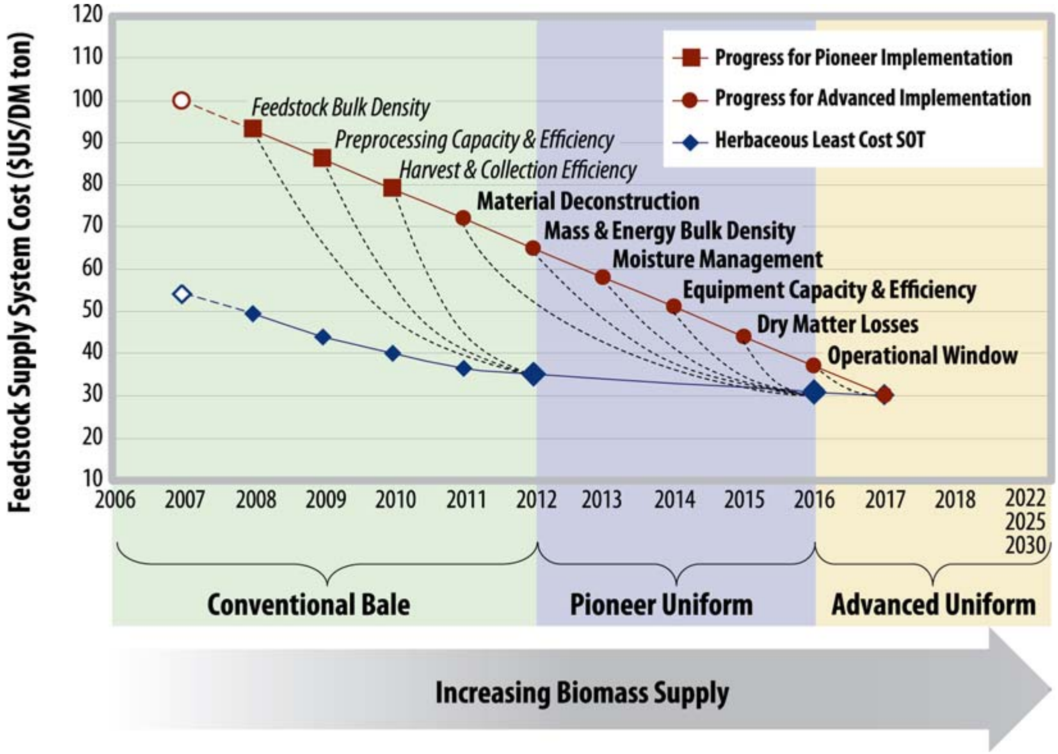


Figure 4-20. Estimated transition from the Conventional Bale design to the Advanced Uniform feedstock supply system.

The three dashed lines in the left half of Figure 4-20 represent improvements needed in bulk density, grinder capacity, and harvest and collection efficiency to transition from the Conventional Bale to the Pioneer Uniform system. The five dashed lines in the right half of Figure 4-20 represent the incremental improvements required to transition from the Pioneer Uniform to the Advanced Uniform system, the final implementation of the Uniform-Format design.

For maximum supply system efficiency, handling and transportation costs must be minimized by reducing the variety of equipment necessary to move biomass from the field to the biorefinery. For example, a Conventional Bale feedstock supply system described in Section 2 changes the biomass format at least three times from the field to the biorefinery (standing crop ⇨ bale ⇨ shredded bale). Each biomass format requires unique equipment that cannot be interchanged or used to handle other feedstock formats. To complicate the issue, there are multiple bale formats (round and square in a variety of sizes) with their respective lines of harvesting and handling equipment. Thus, managing feedstock format diversity by increasing feedstock bulk density and flowability as near to the feedstock production location as is practical can greatly improve supply logistics efficiency. However, the cost and energy inputs required to reformat biomass and achieve optimum densities and product quality must also be improved.

Supply logistics costs vary substantially between regions and are impacted by weather, crop species, moisture content, and feedstock types, as well as transportation highway load limits and other regulations. Cropping systems and storage methods also can change supply logistics costs substantially. It is necessary to manage these inherent complexities and diverse feedstock types to optimize supply logistics and minimize costs in the biofuel production system. However, Section 2 discusses an industry-wide set of feedstock supply chains; therefore, site-specific logistical solutions are not always preeminent. When considering the development of an entire industry that can be rapidly deployed, a uniform-format feedstock supply system becomes key for both conversion facilities and equipment manufacturers, who require capital assets to be broadly applicable across the industry for optimization on a national scale. Modularized feedstock supply systems, such as the Uniform-Format system, are better suited to handle feedstock diversity than capital-intensive systems located at biorefineries.

Achieving national biofuel goals can only be accomplished through development of a uniform-format feedstock supply system consisting of modularized harvesting and preprocessing systems that can be adapted to the diversity of feedstocks and yet connect to uniform-format receiving systems of standardized and highly replicable biorefinery designs.