# Appendix A

# Modeled Costs

# Appendix A-1

# Design Cost Target

# A-1. DESIGN COST TARGET

An analysis by Duffy and Smith (2008) is used in this study to estimate the cost of corn-corn and corn-soybean crop production and logistics. Additional analyses by Shapouri and Gallagher (2002) and Rapier (2008) provide data on conversion yields and total ethanol production costs. Together these analyses form the basis of estimating the percentage of the total ethanol production cost contributed to the cost of feedstock logistics for corn-grain-based ethanol. The results, which show that feedstock logistics range between 8% and 27% of the total ethanol production costs (Table A-1), are presented for the costing years of 2002 and 2008.

Table A-1. Corn grain feedstock production and logistics costs and ethanol production cost data used to estimate the percent contribution of feedstock logistics cost to the overall production of corn grain ethanol.

| Crop Rotation | | Corn - Corn | | | Corn - Soybean | | |
|---|---|---|---|---|---|---|---|
| Costing Year | Units | 2002 | 2002 | 2008 | 2002 | 2002 | 2008 |
| Feedstock Yield | bu/acre | 120 | 120 | 145 | 135 | 135 | 160 |
| Conversion Yield | gal/bu | 2.66[a] | 2.66[a] | 2.7[b] | 2.66[a] | 2.66[a] | 2.7[b] |
| PRODUCTION | | | | | | | |
| Preharvest Machinery | $/acre | | $27.19 | $40.40 | | $22.22 | $32.70 |
| Seed, Chemicals, etc. | $/acre | | $142.34 | $271.97 | | $125.15 | $230.35 |
| Labor | $/acre | | $6.46 | $8.88 | | $4.65 | $6.39 |
| Total Production Cost | $/acre | | $175.98 | $321.25 | | $152.01 | $269.44 |
| | $/bu | | $1.47 | $2.22 | | $1.13 | $1.68 |
| | $/gal | $0.57[a] | $0.55 | $0.82 | $0.54 | $0.42 | $0.62 |
| LOGISTICS | | | | | | | |
| Harvest Machinery (combine, dry, 1st haul & handle) | $/acre | | $47.43 | $70.48 | | $51.07 | $75.18 |
| Harvest Machinery (2nd haul & handle)[c] | $/acre | | $6.14 | $9.13 | | $6.85 | $10.08 |
| Labor | $/acre | | $16.34 | $22.47 | | $16.15 | $22.21 |
| Total Logistics Cost | $/acre | | $69.92 | $102.08 | | $74.07 | $107.47 |
| | $/bu | | $0.58 | $0.70 | | $0.55 | $0.67 |
| | $/gal | $0.23[a] | $0.22 | $0.26 | $0.26 | $0.21 | $0.25 |
| TOTAL COSTS | | | | | | | |
| Total Ethanol Production Cost | $/gal | $0.96[a] | $0.96[a] | $3.00[b] | $0.96[a] | $0.96[a] | $3.00[b] |
| Percent Feedstock Production Cost of EtOH Production Cost | | 60% | 57% | 27% | 56% | 44% | 21% |
| Percent Feedstock Logistics Cost of EtOH Production Cost | | 24% | 23% | 9% | 27% | 21% | 8% |

Data presented in this table is from Duffy and Smith (2008) unless noted otherwise.

a. Shapouri and Gallagher (2002).

b. Rapier (2008).

c. Second haul and handle costs are added by this study to account for movement from the grain elevator to the biorefinery.

In order to account for the transportation and handling costs associated with moving the grain from the elevator to the biorefinery, the haul and handling costs from Duffy and Smith (2008) are conservatively doubled. In addition, two comparisons are made in the 2002 costing year since Shapouri and Gallagher (2002) provide enough data to estimate the total production and total logistics costs. However, the 2002 production and logistics costs from Duffy and Smith (2008) and Shapouri and Gallagher (2002) are reported as one value. In order to split this combined value into its respective production and logistics costs, the ratio between these two cost categories, as reported in the more detailed 2008 data of Duffy and Smith (2008), is directly applied to the 2002 values. Details of the costs presented in Table A-1 are shown in Table A-2, where the calculated 2002 costs based on the ratios of 2008 costs are identified.

Table A-2. Detailed corn grain feedstock production and logistics costs from Duffy and Smith (2008). All costs are reported in dollars per acre ($/acre).

| Crop Rotation | Corn - Corn | | | | Corn - Soybean | | | |
|---|---|---|---|---|---|---|---|---|
| Costing Year | 2002 | | 2008 | | 2002 | | 2008 | |
| | Fixed Cost | Variable Cost | Fixed Cost | Variable Cost | Fixed Cost | Variable Cost | Fixed Cost | Variable Cost |
| PRODUCTION | | | | | | | | |
| Preharvest Machinery | 13.86[a] | 13.33[a] | 20.60 | 19.80 | 11.62[a] | 10.60[a] | 17.10 | 15.60 |
| Seed, Chemicals, etc. | | 142.34 | | 271.97 | | 125.15 | | 230.35 |
| Production Sub-Total | 169.53 | | 312.37 | | 147.37 | | 263.05 | |
| LOGISTICS | | | | | | | | |
| Combine | 9.49[a] | 7.40[a] | 14.10 | 11.00 | 9.58[a] | 7.47[a] | 14.10 | 11.00 |
| 1st Haul | 2.25[a] | 2.44[a] | 3.34 | 3.62 | 2.50[a] | 2.72[a] | 3.68 | 4.00 |
| 1st Handle | 0.98[a] | 0.48[a] | 1.45 | 0.72 | 1.09[a] | 0.54[a] | 1.60 | 0.80 |
| Dry | 3.90[a] | 20.49[a] | 5.80 | 30.45 | 4.35[a] | 22.83[a] | 6.40 | 33.60 |
| Logistics Machinery | 16.62 | 30.82 | 24.69 | 45.79 | 17.51 | 33.56 | 25.78 | 49.40 |
| 2nd Haul [b] | 2.25 | 2.44 | 3.34 | 3.62 | 2.50 | 2.72 | 3.68 | 4.00 |
| 2nd Handle [b] | 0.98 | 0.48 | 1.45 | 0.72 | 1.09 | 0.54 | 1.60 | 0.80 |
| Logistics Machinery | 3.22 | 2.92 | 4.79 | 4.34 | 3.59 | 3.26 | 5.28 | 4.80 |
| Logistics Sub-Total [c] | 53.58 | | 79.61 | | 57.92 | | 85.26 | |
| Total Labor | 22.80 | | 31.35 | | 20.80 | | 28.60 | |

a. *Values calculated using the ratio of 2008 data from the same cost category or row in the table.*
b. *Second haul and handle costs are added by this study to account for movement from the grain elevator to the biorefinery.*
c. *Total logistics cost includes additional haul and handle costs assumed in this analysis and does not match total costs reported in Duffy and Smith (2008).*

# Appendix A-2

# Supply Radius

# A-2. SUPPLY RADIUS

The supply radius for a given feedstock supply system design is a function of the required annual feedstock supply to meet biorefinery demand, the allowed feedstock removal per acre, the percent of the supply area under cultivation, the percent of cultivated land planted in the target crop, and the percent of growers participating in growing the target crop for use in the biorefinery. Using the first two parameters, the required annual acres harvested are calculated by dividing the annual feedstock supply by the feedstock removed per acre according to:

$$AAH = \frac{AFS}{FR} \tag{1}$$

where

$AAH$ = annual acres harvested (acre)

$AFS$ = demanded annual feedstock supply (DM tons)

$FR$ = feedstock removed per acre (DM tons/acre)

The supply radius is then determined by calculating the area averaged radius to a supply region constrained by the percent of the supply area under cultivation, the percent of cultivated land planted in the target crop, and the percent of farmers participating in growing the target crop. Thus, the supply radius is calculated by:

$$SR = \sqrt{\frac{C(AAH)}{\pi(\%CA)(\%TC)(\%GP)}} \tag{2}$$

where

$C$ = conversion constant between acre and $ft^2$ (43560 $ft^2$/acre)

$\%CA$ = percent cultivated acres

$\%TC$ = percent of cultivated acres planted in target feedstock

$\%GP$ = percent of growers participating in supplying biomass.

Ultimately, feedstock removal limit, cultivated acres, acres planted in target feedstock, and grower participation play a large role in the final feedstock supply radius.

# Appendix A-3

# Economic Analysis

# A-3. ECONOMIC ANALYSIS

Two widely accepted engineering-economic costing methodologies for agricultural equipment are presented by the American Society of Agricultural and Biological Engineers (ASABE) and the American Agricultural Economics Association (AAEA). The two methodologies largely use the same equations and machinery data, but the AAEA method incorporates several additional cost factors that the ASABE method does not. These methods were reviewed and compared by Turhollow and Sokhansanj (2007), who compiled from these two methods a recommended standard costing methodology for biomass. While the ASABE and AAEA methods apply specifically to agricultural machinery, Turhollow and Sokhansanj (2007) extended the methodology to include buildings, shelters, and transportation and handling equipment associated with biomass supply and logistics.

## A-3.1 Implementing the Feedstock Supply Model

The cost methodologies previously discussed are programmed in an Excel spreadsheet and connected to an extensive database creating a cost and logistics model with a sophisticated user interface and succinct summary and output section. The capital and operating costs for each piece of equipment within the supply system (Eq. 3) are summed to provide a total hourly usage cost ($/hr). In addition, the capacity of each piece of equipment (ton/hr) is identified in the database taking into account field efficiency factors for each operation. In some cases, the capacity was determined from time-in-motion tests, while for others the machine capacity was determined from typical agricultural machinery speeds published in ASAE D497.4 (February 2003) or from data provided by expert operators (e.g., custom harvest operators). A cost per ton for each piece of equipment within the model is then calculated by dividing the hourly costs ($/hr) by the machine capacity (ton/hr). Finally, summing the cost per ton for each piece of equipment provides the overall feedstock cost (*FC*) for the supply system, as shown in the following set of equations:

$$N_{eq} = \frac{D_{eq}}{C \cdot t} \tag{3}$$

and

$$FC\left(\$/ton\right) = \sum_{1}^{n} \frac{\left(\$/hr\right)_n}{\left(ton/hr\right)_n} \tag{4}$$

where

FC = overall feedstock cost ($/ton)

Neq = number of equipment

Deq = processing demand for each equipment, (acre or tons)

C = equipment capacity, (acre/hr or ton/hr)

t = amount of time available for the operation, (hr)

n = number of unit operations within the supply system.

The total capital investment (*TCap*) in the supply system is determined by summing the equipment purchase price multiplied by the quantity of equipment used in each operation for all operations within the supply system. The total annual cost (*TAC*) of the supply system is determined by multiplying the overall feedstock cost by the total annual tonnage processed by the equipment. Equations 5 and 6 show these relationships.

$$TCap = \sum_{1}^{n} \left( P \cdot N_{eq} \right)_n \tag{5}$$

and

$$TAC = FC \cdot D_{total} \tag{6}$$

where

$P$ = purchase price of equipment in model year ($)

$D_{total}$ = processing demand for the entire supply system (ton).

## A-3.2 Details of Some of the Cost Elements

### A-3.2.1 Equipment and Building Costs

Feedstock costs are intrinsically linked to the performance of each machine and piece of equipment used in the supply chain. The time that an operation takes to perform its task (i.e., cover a certain growing area or process a certain tonnage of material) is an important attribute of feedstock economics. Once the time or capacity is known (represented in acres/hr, bales/hr, or ton/hr), it is divided into the cost to operate the machine (represented in $/hr) to calculate $/acre, $/bale, or $/ton.

Machine capacity is rarely provided by the manufacturer because of the variability attributed to factors like operator skill level, field conditions, feedstock type, and equipment maintenance. Consequently, machine performance can be quite difficult to identify. For the analysis conducted in this report, machine performance calculations were based on time-and-motion tests conducted by INL researchers or from time-and-motion data published in scientific and engineering papers and journals. When time-and-motion data were not available, performance information was obtained from manufacturers, dealers, other users of the equipment, or from the typical field speed data published by ASABE (ASAE, 2002) (Table A-2). Equipment capacities and other performance parameters used in the cost analyses are presented in their respective unit operation equipment specification table for each supply system design. Costing equipment and buildings account for the following factors:

- Ownership Costs
  - Capital recovery (depreciation and interest)
  - Insurance, housing, and taxes.
- Operating Costs
  - Repairs and maintenance
  - Fuel and electricity
  - Equipment Performance.

### A-3.2.2 Supply System Labor Costs

The costs associated with labor include the labor for operating the equipment as well as support tasks either directly associated with field operations (baling, roadsiding, and transportation) or feedstock storage and handling operations at the plant.

Labor rates are obtained from the U.S. Bureau of Labor Statistics (USBLS), and labor hours are based on assumed shift schedules for each unit operation. The supply system schedule is 302 day/yr, 6 day/wk, 16 hr/day, which amounts to two 8-hr shifts/day, 6 day/wk. The labor costs for the supply system operations include time-and-a-half overtime for the extended weekly schedules and 10 paid holidays per year. The plant schedule for those working the operations feeding the reactor is 350 day/yr, 7 day/wk, 24 hr/day (Table A-3). This requires three 8-hr shifts/day, and by using a weekly shift rotation of four crews, each employee works 40 hr/wk, requiring no overtime pay. These shifts are detailed in Table A-4. Other assumptions include paid lunches and identical skill requirements on all shifts.

Table A-3. Shift schedule parameters: 24 hr/day, 7 day/wk.

| | |
|---|---|
| Coverage | 168 hr/wk, continuous |
| Staffing | Balanced from shift to shift |
| Shift Length | 8-hr shifts |
| Number of Crews | Four crews |
| Skill Requirements | Equal on all shifts |
| Shift Rotation | Rotating weekly |

Table A-4. Shift schedule.

| WEEK/CREW | M | T | W | T | F | S | S |
|---|---|---|---|---|---|---|---|
| 1 | D8 | D8 | D8 | D8 | D8 | — | — |
| 2 | — | — | E8 | E8 | E8 | E8 | E8 |
| 3 | E8 | E8 | — | N8 | N8 | N8 | N8 |
| 4 | N8 | N8 | N8 | — | — | D8 | D8 |

D8 = 8-hr day shift
E8 = 8-hr evening shift
N8 = 8-hr night shift
— = day off

### A-3.2.3 Management and Overhead Costs

The supply system may be governed by multiple business entities such as individual growers, grower cooperatives, custom operators, biorefining companies, etc. These entities will likely have different business models and return on investment (ROI) requirements. For the sake of developing a management structure and bracketing the costs associated with this structure and overhead, a vertically integrated but separately managed business model was chosen. As such, the feedstock supply system will be an independent financial entity from the biorefinery, and the management structure would cover the movement of the biomass from its initial contracting with growers to delivery at the entry of the bioreactor at the biorefinery.

The estimated startup cost for the management and overhead facilities and equipment is independent of the feedstock supply system costs described in Appendix A-1 of this design document. These costs are approximately $3,000,000 (Table A-5).

The feedstock supply system business entity will require management and administrative personnel, facilities and infrastructure, and supplies and equipment (in addition to supply system unit operation equipment). Each element of the business entity is discussed in greater detail in Sections A-3.2.1, A-3.2.2, and A-3.2.3.

### *A-3.2.3.1 Management and Administrative Personnel*

Similar to the labor rates for the supply system unit operations personnel (Table A-5), management and administrative labor rates are obtained from the U.S. Bureau of Labor Statistics (USBLS), and labor hours are based on separate shift schedules for office management and field support. Office management staff is assumed to work regular 8-hr days, 5 day/wk, while the field staff will follow the plant schedule of 350 day/yr, 7 day/wk, and 24 hr/day. This requires three 8-hr shifts/day using a weekly shift rotation of four crews such that each employee works 40 hr/wk, requiring no overtime pay (Table A-4) (Hess et al. 2006).

Table A-5 shows a general list of personnel needed to operate the management and support part of the business plan. This list assumes that other upper management personnel are accounted for in the biorefinery staff (i.e., President/CEO, accounting staff, legal council staff, human resources staff, payroll staff, etc.) The shift schedules and USBLS labor codes for each worker are also shown in Table A-5.

Table A-5. Feedstock logistics management and support staff (Hess et al. 2006).

| Idaho Labor Code | Labor/personnel | $US/Hr | Annual Rate ($US) | Office Management 8 hr/day, 5 day/wk | Field Support 24 hr/day, 7 day/week 8-hr shifts |
|---|---|---|---|---|---|
| | Chief Executive | 60.00 | 124,800 | | |
| | | | | | |
| 11-1021 | General Operations Manger | 40.00 | 83,200 | X | |
| 43-6014 | Secretary | 10.39 | 21,611 | X | |
| 13-2011 | Accountant (1/2 time) | 30.00 | 31,200 | | |
| | Attorney (1/4 time) | 60.00 | 31,200 | | |
| | | | | | |
| 11-3049 | Human Resources Mgr | 28.58 | 59,446 | | |
| 13-1041 | Safety Manager | 22.07 | 45,906 | X | |
| 43-3021 | Billing Clerk | 12.15 | 25,272 | X | |
| 43-9061 | Office Clerk, General | 10.90 | 22,672 | X | |
| 41-4012 | Field Rep. Straw Buyers | 20.66 | 42,973 | X | |
| | | | | | |
| 43-5111 | Dispatcher | 10.02 | 20,842 | | X |
| | | | | | |
| 49-9041 | Mechanic | 14.87 | 30,930 | | X |
| 49-9043 | Mechanic’s Helper | 11.47 | 23,858 | | X |
| 47-2111 | Plant Electrician | 20.99 | 43,659 | | X |
| | | | | | |
| 51-1011 | Shift Supervisor | 18.90 | 39,312 | | X |
| 19-2041 | Laboratory Manager | 24.10 | 50,128 | X | |
| 43-5111 | Laboratory Technician | 10.02 | 20,842 | X | |
| | Grinder Operator | 17.64 | 36,691 | | X |
| 51-8031 | Receiving/Feed Operators | 11.74 | 24,419 | | X |
| | Bale Loader Operators | 11.47 | 23,858 | | X |
| 53-3032 | Truck Drivers | 13.77 | 28,642 | | |

A generalized organization diagram for the management and support staff is presented in Figure A-1. This organization chart assumes a number of personnel required to staff an operation the size of the feedstock supply systems scenarios discussed this design document, which is receiving 800,000 dry tons of biomass feedstock per year.

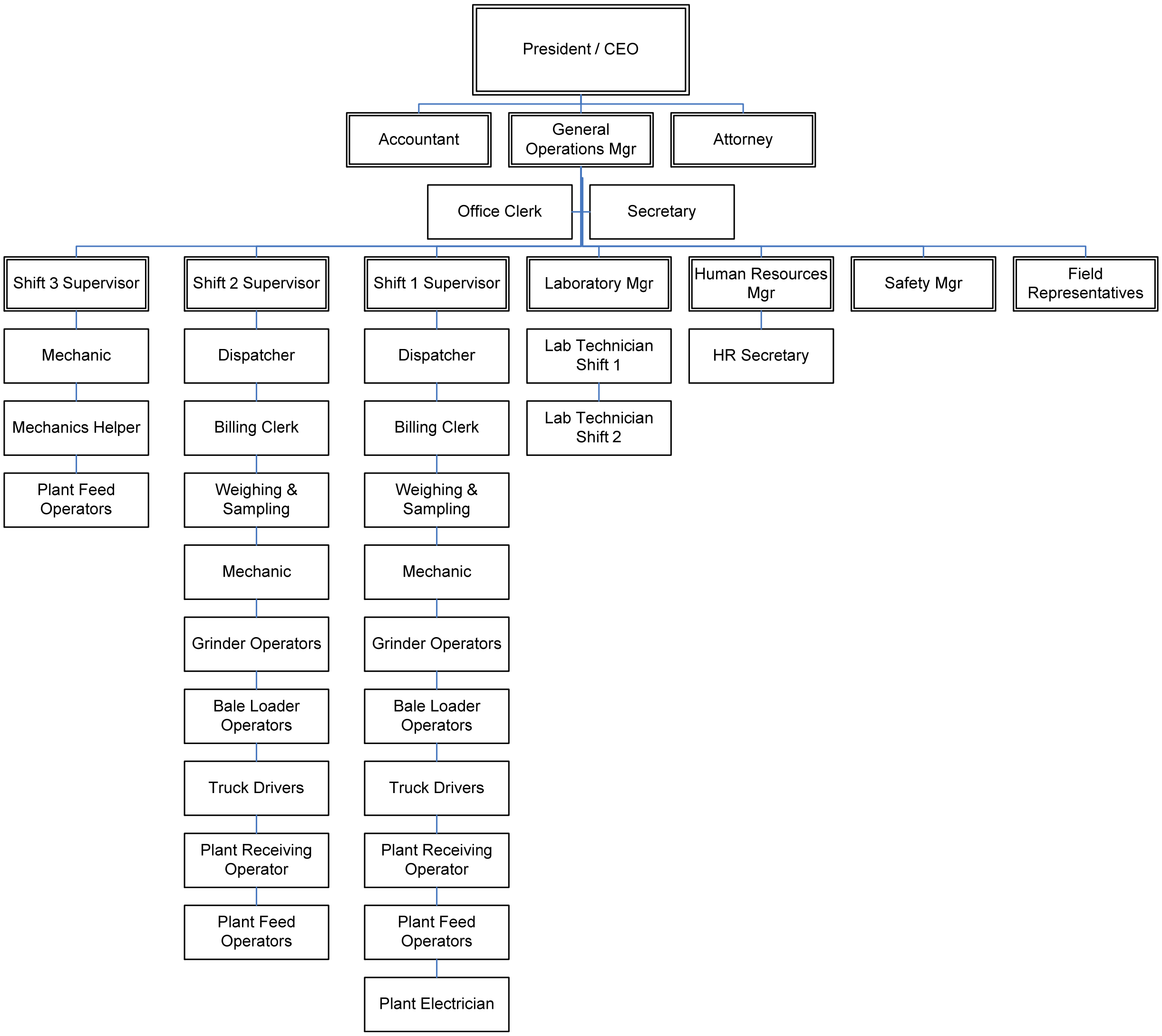



Figure A-1. Generalized organization diagram for a biomass feedstock supply business.

#### *A-3.2.3.2 Facilities and Infrastructure*

The footprint for the feedstock receiving and short-term storage is estimated to be approximately 5 acres to accommodate all the required elements. The facility will need an office building, a laboratory building, and a maintenance shop. In addition there will be a parking lot for employees and areas to park equipment. The entire facility will be fenced with a main gate and two personnel gates. Security cameras will provide coverage of the area. Table A-6 lists the assumptions behind the 5-acre design.

This model also assumes the facility will require 1,000-kVA electrical service including a transformer, switchgear, and distribution system. This will supply the material handling systems as well as facility lighting, which will include lighting for parking areas, equipment areas, open areas, and work-specific areas. Lighting will consist of both mast-mounted lights and localized lights mounted in and on buildings.

Table A-6. Footprint elements for an 800,000 ton/year receiving operation.

| Element | Req. Space ($ft^2$) |
|---|---|
| Employee Parking for 110 vehicles | 39,600 |
| Maintenance Shop | 3,200 |
| Office | 3,520 |
| Lab | 2,000 |
| Silos | 15,700 |
| Fuel Depot | 3,200 |
| Truck Unload, scales, pit, access/egress road | 40,000 |
| Truck, trailer and equipment parking/storage | 33,000 |
| Setback and Circulation | 49,000 |
| Total | 189,820 |

Construction cost for office and lab space:
Typical office space is $150/$ft^2$
Allow 100 $ft^2$/person
Allow 60% more space for other space such as closets, janitor space, storage, bathrooms, etc
Include conference and break rooms separately
A small lab will run about $900/$ft^2$, and a bigger lab would be about $700/$ft^2$.

#### *A-3.2.3.3 Supplies and Equipment*

Materials in this element would include office furniture, equipment, and all other materials and supplies necessary to run a business of this type. A site layout that covers approximately 5 acres is assumed for the feedstock delivery, handling, and short-term storage needs of the bioethanol plant. Table A-7 provides an estimate of the cost of the facilities, equipment, and supplies necessary to begin operations.

Table A-7. Estimate of facilities, equipment, materials, and supplies necessary to support management and support operations.

| Operational Support Items | $US |
|---|---|
| REAL PROPERTY | |
| Office Building ~3520 $ft^2$ @ $150/$ft^2$ | 198,000 |
| Laboratory ~600 $ft^2$ @ $400/$ft^2$ + Office and Storage ~600 $ft^2$ @ $150/$ft^2$ | 330,000 |
| Equipment/Machine Shop ~3200 $ft^2$ @ $70/$ft^2$ | 224,000 |
| Parking Lot for Employees | 170,000 |
| Parking Lot for Trucks and Trailers (gravel pad) | 16,200 |
| Security Fence & Systems | 141,550 |
| Lighting | 96,200 |
| Fuel Depot | 100,000 |
| Fire Protection | 657,500 |
| Electrical Load (1000kVA Service, transformer, switchgear, distribution system) | 200,000 |
| **Real Property Subtotal** | **2,133,450** |
| PLANT EQUIPMENT | |

Table A-7. (continued).

| Operational Support Items | $US |
|---|---|
| Tools for Mechanic & Shop | 20,000 |
| **Equipment—Mechanical Subtotal** | **20,000** |
| OFFICE EQUIPMENT & SUPPLIES | |
| Desktop computers 13 @ $1,600 + Laptop Computers 7 @ $2,400 (including software) | 37,600 |
| Laser Printers, Fax Machine/Scanner 2 each @ $600 | 2,400 |
| Copy Machine $5300 | 5,300 |
| Radios -50 @ $200 + Desk Phones 17 @ $125 + Cell Phones 27 @ $100 | 14,825 |
| GPS Units 5 @ $150 (One for each straw buyer) | 750 |
| Desk Calculators 5 @ $150 each | 750 |
| Postage Machine ($40/month lease) | 480 |
| File Cabinets 17 @ $1000 + Office Supply Cabinet 2 @ $600 + Bookshelves 8 @ $250 | 20,200 |
| Time Card System (ES1000) | 600 |
| Desks - 15 @ $800 + Computer Table and Chair 15 @ $1,000 + Guest Chairs 9 @ $ 150 | 28,350 |
| Conference Room Table 1 @ $1,000 + Chairs 12 @ $400 | 5,800 |
| Conference Room Electronics (projector and DVD player) $3,000 | 3,000 |
| Break Room Table 3 @ $200 + Chairs 15 @ $200 + Appliances @ $1,500 | 5,100 |
| Software (GPS, Dispatching and Scheduling, Maintenance, Accounting and Bookkeeping) | 12,000 |
| General Office Supplies | 10,000 |
| **Office Equipment and Supplies Subtotal** | **147,605** |
| LABORATORY EQUIPMENT & SUPPLIES | |
| NIR instruments 2 @ $90,000 | 180,000 |
| Laboratory Balances 4 @ $10,000 | 40,000 |
| Vacuum, riffle splitter 1 @ $800 | 800 |
| Wiley #4 mills 2 @ $15,000 | 30,000 |
| One Ro-tap II 12 in. shaker @ $2,250; 10 brass sieves @ $71 each (2,250 + 710 = 2,960) | 2,960 |
| Drying Oven 1 @ $10,000 | 10,000 |
| 5 Coring Tool Systems: Coring tool $150 each; Honda EU2000i Portable Generator $1,080 each; and Dewalt DW138 Heavy-Duty 3/4 in. Drill $580 each (600 + 5400 + 2900 = 8,900) | 8,900 |
| One DL77 Graphix Titrator @ $21,200 | 21,200 |
| One Rondolino DL50 Automatic Titrator (automates sample changing) @ $4,590 | 4,590 |
| Titration supplies – Approximately $5,000/yr | 5,000 |
| Cleaning supplies, Kimwipes, weigh pans, grinder consumable parts– Approximately $2,000/yr | 2,000 |
| Calibration, Spares and Repairs (1% First Year Cost) | 3,055 |
| Shelving for archiving samples | 1,500 |
| **Laboratory Equipment & Supplies Subtotal** | **310,005** |

Table A-7. (continued).

| Operational Support Items | $US |
|---|---|
| VEHICLES & FIELD EQUIPMENT | |
| General Manager - 3/4 Crew Cab Truck | 40,000 |
| Field Rep 1 - 1/2 Ton Truck | 28,000 |
| Field Rep 2 - 1/2 Ton Truck | 28,000 |
| Field Rep 3 - 1/2 Ton Truck | 28,000 |
| Field Rep 4 - 1/2 Ton Truck | 28,000 |
| Field Rep 5 - 1/2 Ton Truck | 28,000 |
| Plant Manager - 1/2 Ton Truck | 30,000 |
| Mechanic Truck - 1 Ton Truck | 50,000 |
| Plant Service Truck #1 - 1/2 Ton | 22,000 |
| Plant Service Truck #2 - 1/2 Ton | 22,000 |
| Plant Service Truck #3 - 1/2 Ton | 22,000 |
| Snowplow Attachment 2 @ $1100 | 2,200 |
| **Vehicles Total** | **328,200** |
| | |
| **TOTAL** | **2,922,110** |

### A-3.2.4 Cost Escalation

General cost escalation is used to account for changes in the reported base year and are calculated on a global basis using price indices or actual yearly data. Machinery associated with the harvest and collection, preprocessing, field storage, and transportation operations use the “Index of Prices Paid by Growers for Farm Machinery,” found in the USDA’s Agricultural Price Index (Table A-8 and Table A-9). Handling and queuing equipment at the biorefinery uses the Chemical Engineering Plant Cost Index (2010) as shown in Table A-10. Labor costs come from actual state averages reported yearly by the U.S. Bureau of Labor Statistics (USBLS). Fuel and electricity costs come from actual price data for each reporting region averaged over a calendar year reported by the Energy Information Administration (EIA) (Table A-11). In cases where model runs require out-year projections, the indices or actual yearly data are extrapolated using linear trend lines.

All costs used in the models are based on values obtained for a particular year. For example, the cost of a harvesting machine may be based on a vendor quote obtained in the year 2005, while the cost of diesel fuel for this equipment may be based on fuel prices in 2008. In order to normalize costs to a common cost basis, to perform analyses for years other than those in which the costs were obtained, and to avoid the need to update costs annually, a method was developed to allow backcasting to previous years and forecasting to future years. For cost items in which a cost database exists with current and historical costs recorded on at least an annual basis, this database is integrated with the feedstock cost model. For current year and backcasting analysis, the database is simply indexed to the appropriate cost year. For forecasting, the values in the database were regressed to a simple equation for extrapolating to future years. Items for which cost databases were generated include fuel prices, labor rates, and land rent values. The sources of this data are the EIA (2010a), U.S. DOL BLS (2006), and NASS (2009).

For other cost items (e.g., capital costs or repair and maintenance costs), historical cost records do not exist, so a representative cost index is used to estimate the backcasted and forecasted costs. The

USDA-NASS publishes Prices Paid by Farmers (NASS 2009) indexes that are updated monthly. These indexes represent the average costs of inputs purchased by farmers and ranchers to produce agricultural commodities and a relative measure of historical costs. For machinery list prices, the Machinery Index (NASS 2009) was used, and for machinery repair and maintenance costs, the Repairs Index was used (NASS 2009). These USDA-NASS indexes were used for all machinery used in the feedstock supply system analysis, including harvest and collection machinery (combines, balers, tractors, etc.), loaders and transportation-related vehicles, grinders, and storage-related equipment and structures. For the plant handling, queuing, and storage equipment, such as conveyors and storage bins, the Chemical Engineering Plant Cost Index was used.

Table A-8. USDA-NASS Prices Paid by Farmers Index (Blue shaded area indicates backcast or forecast data).

| Year | Machinery Calc. | Machinery Index Used | Cust. Rt. Calc. | Cust. Rt. Index Used | Repairs Calc. | Repairs Index Used | Supplies Calc. | Supplies Index Used |
|---|---|---|---|---|---|---|---|---|
| 1990 | 93.5 | 96.0 | 111.6 | 111.6 | 93.4 | 93.4 | 94.3 | 94.3 |
| 1991 | 98.4 | 100.0 | 112.3 | 112.3 | 96.8 | 96.8 | 96.8 | 96.8 |
| 1992 | 103.3 | 104.0 | 113.1 | 113.1 | 100.2 | 100.2 | 99.2 | 99.2 |
| 1993 | 108.2 | 107.0 | 113.8 | 113.8 | 103.6 | 103.6 | 101.7 | 101.7 |
| 1994 | 113.1 | 113.0 | 114.5 | 114.5 | 107.0 | 107.0 | 104.1 | 104.1 |
| 1995 | 118.0 | 120.0 | 115.2 | 115.2 | 110.3 | 110.3 | 106.6 | 106.6 |
| 1996 | 122.9 | 125.0 | 115.9 | 115.9 | 113.7 | 113.7 | 109.0 | 109.0 |
| 1997 | 127.9 | 128.0 | 116.6 | 116.6 | 117.1 | 117.1 | 111.5 | 111.5 |
| 1998 | 132.8 | 132.0 | 117.3 | 117.0 | 120.5 | 121.0 | 113.9 | 115.0 |
| 1999 | 137.7 | 135.0 | 118.0 | 115.0 | 123.9 | 124.0 | 116.4 | 117.0 |
| 2000 | 142.6 | 139.0 | 118.7 | 120.0 | 127.3 | 127.0 | 118.8 | 118.0 |
| 2001 | 147.5 | 143.0 | 119.4 | 121.0 | 130.7 | 131.0 | 121.3 | 121.0 |
| 2002 | 152.4 | 148.0 | 120.1 | 120.0 | 134.1 | 134.0 | 123.7 | 123.0 |
| 2003 | 157.3 | 151.0 | 120.9 | 125.0 | 137.5 | 136.0 | 126.2 | 125.0 |
| 2004 | 162.2 | 162.0 | 121.6 | 120.0 | 140.9 | 140.0 | 128.6 | 127.0 |
| 2005 | 167.1 | 173.0 | 122.3 | 121.0 | 144.3 | 146.0 | 131.1 | 134.0 |
| 2006 | 172.0 | 181.0 | 123.0 | 123.0 | 147.7 | 149.0 | 133.5 | 133.5 |
| 2007 | 176.9 | 183.0 | 123.7 | 123.0 | 151.1 | 150.0 | 136.0 | 136.0 |
| 2008 | 181.9 | 181.9 | 124.4 | 124.4 | 154.5 | 154.5 | 138.4 | 138.4 |
| 2009 | 186.8 | 186.8 | 125.1 | 125.1 | 157.9 | 157.9 | 140.9 | 140.9 |
| 2010 | 191.7 | 191.7 | 125.8 | 125.8 | 161.3 | 161.3 | 143.3 | 143.3 |
| 2011 | 196.6 | 196.6 | 126.5 | 126.5 | 164.6 | 164.6 | 145.8 | 145.8 |
| 2012 | 201.5 | 201.5 | 127.2 | 127.2 | 168.0 | 168.0 | 148.3 | 148.3 |
| 2013 | 206.4 | 206.4 | 127.9 | 127.9 | 171.4 | 171.4 | 150.7 | 150.7 |
| 2014 | 211.3 | 211.3 | 128.7 | 128.7 | 174.8 | 174.8 | 153.2 | 153.2 |
| 2015 | 216.2 | 216.2 | 129.4 | 129.4 | 178.2 | 178.2 | 155.6 | 155.6 |
| 2016 | 221.1 | 221.1 | 130.1 | 130.1 | 181.6 | 181.6 | 158.1 | 158.1 |
| 2017 | 226.0 | 226.0 | 130.8 | 130.8 | 185.0 | 185.0 | 160.5 | 160.5 |
| 2018 | 231.0 | 231.0 | 131.5 | 131.5 | 188.4 | 188.4 | 163.0 | 163.0 |
| 2019 | 235.9 | 235.9 | 132.2 | 132.2 | 191.8 | 191.8 | 165.4 | 165.4 |
| 2020 | 240.8 | 240.8 | 132.9 | 132.9 | 195.2 | 195.2 | 167.9 | 167.9 |
| 2021 | 245.7 | 245.7 | 133.6 | 133.6 | 198.6 | 198.6 | 170.3 | 170.3 |
| 2022 | 250.6 | 250.6 | 134.3 | 134.3 | 202.0 | 202.0 | 172.8 | 172.8 |
| 2023 | 255.5 | 255.5 | 135.0 | 135.0 | 205.4 | 205.4 | 175.2 | 175.2 |

Table A-8. (continued).

| Year | Machinery Calc. | Machinery Index Used | Cust. Rt. Calc. | Cust. Rt. Index Used | Repairs Calc. | Repairs Index Used | Supplies Calc. | Supplies Index Used |
|---|---|---|---|---|---|---|---|---|
| 2024 | 260.4 | 260.4 | 135.7 | 135.7 | 208.8 | 208.8 | 177.7 | 177.7 |
| 2025 | 265.3 | 265.3 | 136.5 | 136.5 | 212.2 | 212.2 | 180.1 | 180.1 |
| 2026 | 270.2 | 270.2 | 137.2 | 137.2 | 215.6 | 215.6 | 182.6 | 182.6 |
| 2027 | 275.1 | 275.1 | 137.9 | 137.9 | 219.0 | 219.0 | 185.0 | 185.0 |
| 2028 | 280.0 | 280.0 | 138.6 | 138.6 | 222.3 | 222.3 | 187.5 | 187.5 |
| 2029 | 285.0 | 285.0 | 139.3 | 139.3 | 225.7 | 225.7 | 189.9 | 189.9 |
| 2030 | 289.9 | 289.9 | 140.0 | 140.0 | 229.1 | 229.1 | 192.4 | 192.4 |

a. NASS 2010

Table A-9. USDA-NASS prices paid by farmer's index.[a]

| Year | Production Items | Farm Machinery | Self-propelled | Tractors | Other Machinery | Custom Rates | Repairs | Supplies | Diesel |
|---|---|---|---|---|---|---|---|---|---|
| 1990 | 99 | 96 | | | | | | | |
| 1991 | 100 | 100 | | | | | | | |
| 1992 | 101 | 104 | | | | | | | |
| 1993 | 104 | 107 | | | | | | | |
| 1994 | 106 | 113 | | | | | | | |
| 1995 | 108 | 120 | | | | | | | |
| 1996 | 115 | 125 | | | | | | | |
| 1997 | 119 | 128 | | | | | | | |
| 1998 | 113 | 132 | 131 | 130 | 134 | 117 | 121 | 115 | 78 |
| 1999 | 111 | 135 | 134 | 133 | 138 | 115 | 124 | 117 | 88 |
| 2000 | 116 | 139 | 138 | 137 | 142 | 120 | 127 | 118 | 136 |
| 2001 | 120 | 143 | 143 | 138 | 146 | 121 | 131 | 121 | 119 |
| 2002 | 119 | 148 | 147 | 140 | 153 | 120 | 134 | 123 | 110 |
| 2003 | 124 | 151 | 152 | 142 | 155 | 125 | 136 | 125 | 137 |
| 2004 | 131 | 162 | 168 | 147 | 164 | 120 | 140 | 127 | 165 |
| 2005 | 139 | 173 | 179 | 155 | 177 | 121 | 146 | 134 | 232 |
| 2006 | 144 | 181 | 187 | 161 | 185 | 123 | 149 | | 258 |
| 2007 | | 183 | 189 | 163 | 187 | 123 | 150 | | 238 |

Table A-10. Chemical Engineering Plant Cost Index. (http://www.che.com/pci) Linear regression results: 2.243 / -4093.18.

| | Source | Year | CE an Index | Calc Index | Ind in Calc |
|---|---|---|---|---|---|
| 1990 | (1) | 1990 | 357.6 | 370.1 | 357.6 |
| 1991 | (1) | 1991 | 361.3 | 372.4 | 361.3 |
| 1992 | (1) | 1992 | 358.2 | 374.6 | 358.2 |
| 1993 | (1) | 1993 | 359.2 | 376.8 | 359.2 |
| 1994 | (1) | 1994 | 368.1 | 379.1 | 368.1 |
| 1995 | (1) | 1995 | 381.1 | 381.3 | 381.1 |
| 1996 | (1) | 1996 | 381.7 | 383.6 | 381.7 |
| 1997 | (2) | 1997 | 386.5 | 385.8 | 386.5 |
| 1998 | (2) | 1998 | 389.5 | 388.1 | 389.5 |
| 1999 | (3) | 1999 | 390.6 | 390.3 | 390.6 |
| 2000 | (4) | 2000 | 394.1 | 392.5 | 394.1 |
| 2001 | (5) | 2001 | 394.3 | 394.8 | 394.3 |
| 2002 | (5) | 2002 | 395.6 | 397.0 | 395.6 |
| 2003 | (6) | 2003 | 402.0 | 399.3 | 402.0 |
| 2004 | (6) | 2004 | 444.2 | 401.5 | 444.2 |
| 2005 | (6) | 2005 | 466.7 | 403.8 | 466.7 |
| 2006 | | 2006 | | 406.0 | 468.9 |
| 2007 | | 2007 | | 408.2 | 471.1 |
| 2008 | | 2008 | | 410.5 | 473.4 |
| 2009 | | 2009 | | 412.7 | 475.6 |
| 2010 | | 2010 | | 415.0 | 477.9 |
| 2011 | | 2011 | | 417.2 | 480.1 |
| 2012 | | 2012 | | 419.5 | 482.4 |
| 2013 | | 2013 | | 421.7 | 484.6 |
| 2014 | | 2014 | | 423.9 | 486.8 |
| 2015 | | 2015 | | 426.2 | 489.1 |
| 2016 | | 2016 | | 428.4 | 491.3 |
| 2017 | | 2017 | | 430.7 | 493.6 |
| 2018 | | 2018 | | 432.9 | 495.8 |
| 2019 | | 2019 | | 435.2 | 498.1 |
| 2020 | | 2020 | | 437.4 | 500.3 |
| 2021 | | 2021 | | 439.6 | 502.5 |
| 2022 | | 2022 | | 441.9 | 504.8 |
| 2023 | | 2023 | | 444.1 | 507.0 |
| 2024 | | 2024 | | 446.4 | 509.3 |
| 2025 | | 2025 | | 448.6 | 511.5 |
| 2026 | | 2026 | | 450.9 | 513.8 |
| 2027 | | 2027 | | 453.1 | 516.0 |
| 2028 | | 2028 | | 455.3 | 518.2 |
| 2029 | | 2029 | | 457.6 | 520.5 |
| 2030 | | 2030 | | 459.8 | 522.7 |

Table A-11. DOE-Energy Information Agency (EIA) Average Retail Price of Electricity Index (EIA 2010b and EIA 2010c). (Linear regression results: 8E-04 / -1.56724).

| Year | Electricity | Electricity Calculated | Electricity Index Used |
|---|---|---|---|
| 1990 | | $0.0408 | $0.0408 |
| 1991 | | $0.0416 | $0.0416 |
| 1992 | | $0.0424 | $0.0424 |
| 1993 | | $0.0432 | $0.0432 |
| 1994 | $0.0477 | $0.0440 | $0.0477 |
| 1995 | $0.0466 | $0.0448 | $0.0466 |
| 1996 | $0.0460 | $0.0456 | $0.0460 |
| 1997 | $0.0453 | $0.0464 | $0.0453 |
| 1998 | $0.0448 | $0.0472 | $0.0448 |
| 1999 | $0.0443 | $0.0480 | $0.0443 |
| 2000 | $0.0464 | $0.0488 | $0.0464 |
| 2001 | $0.0505 | $0.0497 | $0.0505 |
| 2002 | $0.0488 | $0.0505 | $0.0488 |
| 2003 | $0.0511 | $0.0513 | $0.0511 |
| 2004 | $0.0525 | $0.0521 | $0.0525 |
| 2005 | $0.0573 | $0.0529 | $0.0573 |
| 2006 | $0.0616 | $0.0537 | $0.0616 |
| 2007 | | $0.0545 | $0.0545 |
| 2008 | | $0.0553 | $0.0553 |
| 2009 | | $0.0561 | $0.0561 |
| 2010 | | $0.0569 | $0.0569 |
| 2011 | | $0.0577 | $0.0577 |
| 2012 | | $0.0585 | $0.0585 |
| 2013 | | $0.0594 | $0.0594 |
| 2014 | | $0.0602 | $0.0602 |
| 2015 | | $0.0610 | $0.0610 |
| 2016 | | $0.0618 | $0.0618 |
| 2017 | | $0.0626 | $0.0626 |
| 2018 | | $0.0634 | $0.0634 |
| 2019 | | $0.0642 | $0.0642 |
| 2020 | | $0.0650 | $0.0650 |
| 2021 | | $0.0658 | $0.0658 |
| 2022 | | $0.0666 | $0.0666 |
| 2023 | | $0.0674 | $0.0674 |
| 2024 | | $0.0682 | $0.0682 |
| 2025 | | $0.0690 | $0.0690 |
| 2026 | | $0.0699 | $0.0699 |
| 2027 | | $0.0707 | $0.0707 |
| 2028 | | $0.0715 | $0.0715 |
| 2029 | | $0.0723 | $0.0723 |
| 2030 | | $0.0731 | $0.0731 |

# Appendix A-4

# Sensitivity Analysis

## A-4. SENSITIVITY ANALYSIS

Table A-12. Input parameter distributions for sensitivity analysis. Variable descriptions are shown in blue.

| Variable | Function | Min | Max | Most likely |
|---|---|---|---|---|
| MACHINE LOSS MULTIPLIER | | | | |
| Baling Efficiency (%)[b] | Uniform | 33 | 80 | 54 |
| YIELD | | | | |
| Grain Yield (bushel/acre) | Pert | 140 | 220 | 180 |
| Removal Limit (%)[b] | Pert | 25 | 80 | 50 |
| HARVEST | | | | |
| Harvest Window (wk/yr)[a] | Pert | 3 | 9 | 6 |
| Shredder (mph)[b] | Pert | 3 | 6 | 5 |
| Shredder Field Efficiency (%)[b] | Pert | 75 | 90 | 80 |
| BALING | | | | |
| Baling Window (wk/yr)[a] | Pert | 3 | 9 | 6 |
| Baling Moisture (%)[b] | Pert | 10 | 20 | 12 |
| Baler (bale/hr) | Pert | 30 | 45 | 38 |
| Baler Field Efficiency (%)[b] | Pert | 70 | 90 | 80 |
| Bale Bulk Density (lb/ft$^3$) | Pert | 8 | 12 | 9 |
| ROADSIDING | | | | |
| Roadsiding Window (wk/yr)[a] | Pert | 3 | 9 | 6 |
| Roadsiding Distance (mile) | Pert | 0.25 | 1 | 0.5 |
| Stinger Load (second/bale) | Pert | 12 | 25 | 15 |
| Stinger Unload (second/bale) | Pert | 1 | 3 | 1.5 |
| Stinger Field Speed (mph)[b] | Pert | 10 | 25 | 15 |
| Stinger Road Speed (mph)[b] | Pert | 45 | 55 | 50 |
| Stinger Field Efficiency (%)[b] | Pert | 70 | 90 | 80 |
| STORAGE | | | | |
| Storage Dry Matter Loss (%)[b] | Pert | 4 | 8 | 4 |
| Bale Wrapper (bale/hr) | Pert | 60 | 120 | 80 |
| TRANSPORT | | | | |
| Winding Factor | Pert | 1.2 | 1.5 | 1.2 |
| Transporter Semi (mph)[b] | Pert | 40 | 55 | 45 |
| Transporter Loader (bale/hr) | Pert | 44 | 83 | 80 |
| Transporter Unloader (bale/hr) | Pert | 44 | 83 | 80 |
| RECEIVING | | | | |
| Receiving (hr/day) | Uniform | 16 | 24 | - |
| Feedstock Inventory (hr) | Uniform | 72 | 168 | - |
| FDI/CDI Multiplier | Pert | 0.5 | 2 | 1 |
| YIELD | | | | |
| Grain Yield (bu/acre)b | Pert | 140 | 220 | 180 |
| Feedstock Yield[d] | Pert | 3 | 8 | 5 |
| HARVEST INPUT | | | | |
| Harvest Window (wk/yr) | Static | | | =6*Harvest_Window |
| Shredder (mph)[c] | Pert | 3 | 6 | 5 |
| Shredder Field Efficiency (%)[c] | Pert | 0.75 | 0.85 | 0.8 |

Table A-12. (continued).

| Variable | Function | Min | Max | Most likely |
|---|---|---|---|---|
| Harvest Collection Efficiency (%)[c] | Pert | 0.667 | 0.75 | 0.71 |
| Harvest Collection Efficiency (%)[d] | Pert | 0.52 | 0.9 | 0.77 |
| Mower/Conditioner[d] | Pert | 5 | 12 | 7 |
| Mower/Conditioner Field Efficiency (%)[d] | Pert | 0.75 | 0.9 | 0.8 |
| HARVEST WINDOW | | | | |
| Harvest_Window | Pert | 0.5 | 1.5 | 1 |
| FDI_CDI_Multiplier | Pert | 0.5 | 2 | 1 |
| BAILING INPUT | | | | |
| Baling Window (wk/yr) | Static | | | =6*Harvest_Window |
| Baling Collection Efficiency (%)[c] | Uniform | 0.33 | 0.75 | 0.54 |
| Baling Collection Efficiency (%)[c] | Uniform | 0.73 | 0.95 | 0.86 |
| Baling Moisture (%) | Pert | 0.1 | 0.2 | 0.12 |
| Baler (bale/hr) | Pert | 30 | 45 | 38 |
| Baler Field Efficiency (%) | Pert | 0.7 | 0.9 | 0.8 |
| Bale Bulk Density (lb/ft$^3$)[c] | Pert | 8 | 12 | 9 |
| Bale Bulk Density (lb/ft$^3$)[d] | Pert | 9 | 12 | 10 |
| ROADSIDING INPUT | | | | |
| Roadsiding Window (wk/yr) | Static | | | =6*Harvest_Window |
| Roadsiding Distance (mile) | Pert | 0.25 | 1 | 0.5 |
| Stinger Load (second/bale) | Pert | 12 | 25 | 15 |
| Stinger Unload (second/bale) | Pert | 1 | 3 | 1.5 |
| Stinger Field Speed (mph) | Pert | 10 | 25 | 15 |
| Stinger Road Speed (mph) | Pert | 45 | 55 | 50 |
| STORAGE INPUT | | | | |
| Storage Dry Matter Loss (%) | Pert | 0.01 | 0.08 | 0.05 |
| Bale Wrapper (bale/hr) | Pert | 60 | 120 | 80 |
| TRANSPORT INPUT | | | | |
| Winding Factor | Pert | 1.2 | 1.5 | 1.2 |
| Transporter Semi (mph) | Pert | 40 | 55 | 50 |
| Transport Loader (bale/hr) | Pert | 44 | 83 | 80 |
| Transport Unloader (bale/hr) | Pert | 44 | 83 | 80 |
| RECEIVING INPUT | | | | |
| Feeder Density (DM lb/ft$^3$)[c] | Static | | | =7.4*FDI_CDI_Multiplier |
| Bin Density (DM lb/ft$^3$)[c] | Static | | | =9.1*FDI_CDI_Multiplier |
| Feeder Density (DM lb/ft$^3$)[d] | Static | | | =10.3*FDI_CDI_Multiplier |
| Bin Density (DM lb/ft$^3$)[d] | Static | | | =11.9*FDI_CDI_Multiplier |

# Appendix A-5

# Conventional Bale Detailed Cost Analysis

# A-5. CONVENTIONAL BALE DETAILED COST ANALYSIS

This section includes detailed cost and logistics information not included in Section 2, Conventional Bale Feedstock Supply System. These details are presented in table format for the overall system design and for each unit operation in the order in which they appear within the design. These tables contain the input data necessary to run the model for the Conventional Bale design in a specific cost year. The cost index year is established as 2007, with tax and interest rates based in that year.

## A-5.1 Harvest and Collection

Table A-13 and Table A-14 show the Conventional Bale–Corn Stover and Switchgrass detail model input cost data for the harvest and collection operation.

Table A-13. Static input cost numbers for Conventional Bale–Corn Stover harvest and collection (INL Feedstock Model 08-14752).

| | Conditioning/ Windrowing Corn Stover | Baling | | Moving to Field Side (Roadsiding) |
|---|---|---|---|---|
| EQUIPMENT | Flail Shredder/ Windrower pulled by 180 Tractor | Baler | Magnum 275 Tractor | Stacker |
| EQUIPMENT FACTORS | | | | |
| 1. Purchase price[a] | | $12,3025 | $163,447 | $139,000 |
| 2. Useful life (hr)[b] | | 3,000 | 9,000 | 14,500 |
| 3. Salvage value[c] | | 0.35 | 0.31 | 0.15 |
| 4. Annual use (hr)[d] | | | Same as Baler | |
| OWNERSHIP COSTS | | | | |
| 5. Depreciation and interest[e] | | $41.24 | $20.90 | $46.62 |
| 6. Taxes, insurance, housing[f] | | $3.72 | $2.18 | $4.22 |
| 7. Ownership $/hr (lines 5+6) | $ | $ | $ | $ |
| OPERATING COSTS | | | | |
| 8. Repairs and maintenance $/hr[g] | | $32.59 | $11.33 | $3.46 |
| 9. Fuel consumption, gal/hr[h] | | N/A | 9.86 | 7 |
| 10. Fuel and lubrication $/hr[i] | | $24.47 | $30.59 | $21.73 |
| 11. Labor, $/hr[j] | $12.76 | N/A | $12.76 | $12.76 |
| 12. Materials, $/hr[k] | N/A | $21.89 | N/A | N/A |
| 13. Total operating $/hr (lines 8+10+11+12) | $ | $ | $ | $ |

a. Purchase price is the price paid for the machinery, whether new or used.
b. Useful life is the expected ownership period.
c. Salvage value is the expected selling price or trade-in value of the machine at the end of its ownership period.
d. Assume tractor is dedicated to the respective implement.
e. The depreciation cost reflects the reduction in value of an asset with use and time. The interest cost is an opportunity cost for the use of the money in a machine investment. An interest rate of 6% was used in these calculations.
f. The charge for taxes, housing, and insurance is calculated as 2% of the purchase price.
g. Repair and maintenance costs from Turhollow, Wilkerson, Sokhansanj (2009).
h. No. 2 off-road diesel fuel.
i. If implement does not use fuel, then represents lubrication costs only.
j. Labor is based on a wage rate of $12.50/hr, which includes benefits.
k. Material costs represent consumables (e.g., baling twine, plastic wrap, etc.).

Table A-14. Static input cost numbers for Conventional Bale–Switchgrass harvest and collection (INL Feedstock Model 08-14752).

| EQUIPMENT | Conditioning/ Windrowing Switchgrass | Baling | | Moving to Field Side (Roadsiding) |
|---|---|---|---|---|
| | Windrower with 9180 Disc Header | Baler | Magnum 275 Tractor | Stacker |
| EQUIPMENT FACTORS | | | | |
| 1. Purchase price[a] | | $123,025 | $163,447 | $139,000 |
| 2. Useful life (hr)[b] | | 3,000 | 9,000 | 14,500 |
| 3. Salvage value[c] | | 0.35 | 0.31 | 0.15 |
| 4. Annual use (hr)[d] | | | Same as Baler | |
| OWNERSHIP COSTS | | | | |
| 5. Depreciation and interest[e] | | $41.24 | $20.90 | $46.62 |
| 6. Taxes, insurance, housing[f] | | $3.72 | $2.18 | $4.22 |
| 7. Ownership $/hr (lines 5+6) | $ | $ | $ | $ |
| OPERATING COSTS | | | | |
| 8. Repairs and maintenance $/hr[g] | | $32.59 | $11.33 | $3.46 |
| 9. Fuel consumption, gal/hr[h] | | N/A | 9.86 | 7 |
| 10. Fuel and lubrication $/hr[i] | | $24.47 | $30.59 | $21.73 |
| 11. Labor, $/hr[j] | $12.76 | N/A | $12.76 | $12.76 |
| 12. Materials, $/hr[k] | N/A | $21.89 | N/A | N/A |
| 13. Total operating $/hr (lines 8+10+11+12) | $ | $ | $ | $ |

a. Purchase price is the price paid for the machinery, whether new or used.

b. Useful life is the expected ownership period.

c. Salvage value is the expected selling price or trade-in value of the machine at the end of its ownership period.

d. Assume tractor is dedicated to the respective implement.

e. The depreciation cost reflects the reduction in value of an asset with use and time. The interest cost is an opportunity cost for the use of the money in a machine investment. An interest rate of 6% was used in these calculations.

f. The charge for taxes, housing, and insurance is calculated as 2% of the purchase price.

g. Repair and maintenance costs from Turhollow, Wilkerson, Sokhansanj (2009).

h. No. 2 off-road diesel fuel.

i. If implement does not use fuel, then represents lubrication costs only.

j. Labor is based on a wage rate of $12.50/hr, which includes benefits.

k. Material costs represent consumables (e.g., baling twine, plastic wrap, etc.).

## A-5.2 Storage

The conventional-bale supply system will store large square bales at the side of the road of the field in which the feedstock is harvested. The field stack costs are an aggregate of land rent, insurance, and land preparation costs. Table A-15 shows details of the storage method and input parameters.

Table A-18 shows the total costs associated with the storage operation for both the Conventional Bale–Corn Stover and Switchgrass scenarios. The resulting storage cost is $9.66 per ton. Table A-16, Table A-17, and Table A-18 show the range of dry matter loss % for a number of plant species while biomass is in storage.

Table A-15. Static input cost numbers for Conventional Bale storage (INL Feedstock Model 08-14752).

| | Stacking | Weather Protection | Storage |
|---|---|---|---|
| Equipment | Telehandler | Cube-Line Wrapper | None |
| EQUIPMENT FACTORS | | | |
| 1. Purchase price[a] | $69,414 | $40,000 | |
| 2. Useful life[b] (hr) | 10,000 | 3,000 | |
| 3. Salvage value[c] | 0.2 | 0.42 | |
| 4. Annual use (hr)[d] | | | |
| OWNERSHIP $/HR | | | |
| 5. Depreciation and interest[e] | $6.02 | $12.28 | |
| 6. Taxes, insurance, housing[f] | $0.23 | $1.27 | |
| 7. Ownership $/hr (lines 5+6) | $ | $ | |
| OPERATING COSTS | | | |
| 8. Repairs and maintenance $/hr[g] | $0.26 | $3.09 | |
| 9. Fuel consumption, gal/hr[h] | 1.5 | 1 | |
| 10. Fuel and lubrication $/hr[i] | $4.23 | $2.82 | |
| 11. Labor, $/hr[j] | $24.12 | $12.76 | |
| 12. Materials, $/hr[k] | N/A | $226.00 | |
| 13. Total operating $/hr (lines 8+10+11+12) | $ | $ | |

a. Purchase price is the price paid for the machinery, whether new or used.
b. Useful life is the expected ownership period.
c. Salvage value is the expected selling price or trade-in value of the machine at the end of its ownership period.
d. Assume tractor is dedicated to the respective implement.
e. The depreciation cost reflects the reduction in value of an asset with use and time. The interest cost is an opportunity cost for the use of the money in a machine investment. An interest rate of 6% was used in these calculations.
f. The charge for taxes, housing, and insurance is calculated as 2% of the purchase price.
g. Repair and maintenance costs from Eq.
h. No. 2 off-road diesel fuel.
i. If implement does not use fuel, then value represents lubrication costs only.
j. Labor is based on a wage rate of $12.50/hr, which includes benefits.
k. Material costs represent consumables (e.g., baling twine, plastic wrap, etc.).

Table A-16. Range of dry matter loss % while in storage for alfalfa.

| Location | OK[a] | WI[a] | MN[a] | | OK[b] | WI[c] | WI[d] |
|---|---|---|---|---|---|---|---|
| Storage interval | | | | 9 mo | 9 mo | 12 mo | |
| Stack on ground | 13.1 | 10.9 | 11.2 | 5-20, 12.5 | 9.5 | 13 | 5-61, 33 |
| Stack on ground, net wrap | | | | | | | 6-25, 15.5 |
| Covered stack on ground | | | | 5-10, 7.5 | | | 4-46, 25 |
| Stack on improved surface | | | 10.9 | 3-15, 9 | 8 | 10 | 3-46, 24.5 |
| Stack on improved surface + pallets | | | | | 7.5 | 8.5 | |
| Covered stack on improved surface | 2 | | 4.8 | 2-4, 3 | 4 | 5 | 2-17, 9.5 |
| Covered stack on improved surface plus pallets | | | | | 3 | 4 | |
| Plastic wrap on ground | | | | | | | 4-8, 7 |
| Pole barn | | 4.6 | 2.3 | 2-5, 3.5 | | | 2-10, 6 |
| Totally enclosed shed/building | | | | <2 | 2 | 2 | |

Table A-17. Range of dry matter loss % while in storage for switchgrass, reed canary grass, and corn stover.

| Crop | | Switchgrass | Reed Canary-Grass | Corn Stover | |
|---|---|---|---|---|---|
| Location | Can[e] | WI[f] | WI[f] | | WI[g] |
| Storage interval | | | | 2002 | 2003 |
| Stack on ground | 15 | 15.4 sis tw | 14.5 | 29.1 | 38.5 |
| | | 9.3 pla tw | 8.1 | 14.3 | 19 |
| Stack on ground, net wrap | | 9 | 6.5 | 10.7 | 14.2 |
| Covered stack on ground | | | | | |
| Stack on improved surface | | | | 7 | 8.2 |
| Stack on improved surface + pallets | | | | 17.7 sis tw | 36.1 |
| | | | | 11.4 pla tw | 11 |
| Covered stack on improved surface | | | | | |
| Covered stack on improved surface plus pallets | | | | | |
| Plastic wrap on ground | | 5.7 | 1.1 | | |
| Pole barn | | | | 4.8 | 2.2 |
| Totally enclosed shed/building | 5 | 4.9 | 1.6 | | |

Table A-18. Range of dry matter loss % while in storage for hay.

| | Range of Dry Matter Loss (%) | | | | | | Row Averages | | |
|---|---|---|---|---|---|---|---|---|---|
| Crop | Hay | | | | | | Mean/S.D. | | |
| Location | KY[i] | IN[j] | KY[j] | NW KS[k] | NE KS[k] | ID[l] | | | |
| Storage interval | 12 mo | | | | | | Wet | | |
| | | | | | | | Range | Mean/S.D. | Dry |
| Stack on ground | 30 | 23.2 | 8.4 | 9.2 | 12.2 | 0.85 | 6.5–38.5 | 16.2/8.3 | 0.85–9.2 |
| Stack on ground, net wrap | 23 | | | | | | | | |
| Covered stack on ground | | | 6 | | | | 7.5–25 | 12.8/10.6 | |
| Stack on improved surface | 10 | 14.5 | | | | | 7-36.1 | 12.9/7.9 | |
| Stack on improved surface + pallets | | | | | | | | | |
| Covered stack on improved surface | 7 | | | | | | 2-9.5 | 4.7/2.3 | |
| Covered stack on improved surface plus pallets | | | | | | | | | |
| Plastic wrap on ground | 5 | | | | | | 1.1-8 | 4.9/2.9 | |
| Pole barn | 7 | | | | | | 2.3-7 | 6.0/3.7 | |
| Totally enclosed shed/building | 5 | 8 | 4.8 | | | | 2-8 | 3.8/2.0 | |

## A-5.3 Transportation and Handling

Transportation and handling is modeled as a 52-wk/yr operation. Thus, baled feedstocks will be handled and transported from field-side to the biorefinery on an as-needed basis according to the receiving schedule of the biorefinery. In general, all baled feedstock from a given field location will be moved to the biorefinery within one scheduled move, leaving that particular storage location empty until the next season.

Table A-19 shows the individual cost and logistical parameters and the total costs, respectively, for the transportation and handling operation. The resulting transportation and handling costs are $10.88/ton (see Table A-20).

Table A-19. Static input cost numbers for Conventional Bale transportation and handling (INL Feedstock Model 08-14752).

| | Unstack/Unwrap and Load | Transport | |
|---|---|---|---|
| Equipment | Telehandler | 3-axle Day Cab | 53-ft Flat Bed Trailer |
| EQUIPMENT FACTORS | | | |
| 1. Purchase price[a] | $69,414 | $110,809 | $38,000 |
| 2. Useful life [b] | 10,000 hr | 1,000,000 miles | 1,000,000 miles |
| 3. Salvage value[c] | 0.2 | 0.3 | 0.9 |
| 4. Annual use (hr)[d] | | | |
| OWNERSHIP $/HR | | | |
| 5. Depreciation and interest[e] | $6.02 | $12,199.63 | $3,213.12 |
| 6. Taxes, insurance, housing[f] | $0.23 | $6,747.15 | $3,470.72 |
| 7. Ownership $/hr (lines 5+6) | $ | $ | $ |
| OPERATING COSTS | | | |
| 8. Repairs and maintenance $/hr[g] | $0.26 | $919.50 | $763.64 |
| 9. Fuel consumption, gal/hr[h] | 1.5 | 0.17 | N/A |
| 10. Fuel and lubrication $/hr[i] | $4.23 | $27,954.30 | N/A |
| 11. Labor, $/hr[j] | $24.12 | | |
| 12. Materials, $/hr[k] | N/A | N/A | N/A |
| 13. Total operating $/hr (lines 8+10+11+12) | $ | $ | $ |

a. Purchase price is the price paid for the machinery, whether new or used.
b. Useful life is the expected ownership period.
c. Salvage value is the expected selling price or trade-in value of the machine at the end of its ownership period.
d. Assume tractor is dedicated to the respective implement.
e. The depreciation cost reflects the reduction in value of an asset with use and time. The interest cost is an opportunity cost for the use of the money in a machine investment. An interest rate of 6% was used in these calculations.
f. The charge for taxes, housing, and insurance is calculated as 2% of the purchase price.
g. Repair and maintenance costs from Eq.
h. No. 2 off-road diesel fuel.
i. If implement does not use fuel, then value represents lubrication costs only.
j. Labor is based on a wage rate of $12.50/hr, which includes benefits.
k. Material costs represent consumables (e.g., baling twine, plastic wrap, etc.).

## A-5.4 Transportation and Handling Cost Analysis Methodology

Based on the distance between field-side stacks and the bale-yard at the biorefinery, different methods of transportation can be more or less cost effective than others. The option of using a self-propelled loader and semi-tractor trailer is chosen since this system can access the various on-farm storage locations and is widely used for moving square-baled material. However, a comparison of semi-tractor-trailer and rail car transport options hauling large square 4×4×8-ft bales is provided to show their respective advantages and identify the variables that influence when to chose one system over the other (Figure A-2). This comparison uses a linear relationship between cost per DM ton of transported feedstock and transportation distance, given by (Eq. 7):

$$T_{cost} = R_{cost} \times T_{dist} + H_{cost} \tag{7}$$

where

| | | |
|---|---|---|
| $T_{cost}$ | = | total transportation cost, ($/DM ton) |
| $R_{cost}$ | = | variable rolling cost, ($/DM ton/loaded mile) |
| $T_{dist}$ | = | transportation distance from production site or storage stack to biorefinery (loaded mile) |
| $H_{cost}$ | = | fixed handling cost for loading and unloading the transportation equipment ($/DM ton). |

The variable rolling costs ($R_{cost}$) and fixed handling costs ($H_{cost}$) are represented in Figure A-2 by the slope of the lines and the value at the intersection with the y-axis, respectively. The "trans-load" curve represents moving baled feedstock by truck for the first 20 miles and then loading it from truck to rail for an additional haul beyond 20 miles. In general, this would be done when rail lines are not close to the storage stack, but the final transport distance is beyond ~100 miles, the distance at which the truck transport curve intersects with the trans-load curve in Figure A-2. The required 100-mile haul distance is due to the additional fixed cost ($12.84/DM ton) incurred by loading the rail cars with the baled feedstock, represented by the vertical part of the trans-load curve. If the transport distance is known to be beyond ~52 miles prior to loading a truck, and rail transport is close enough to load from the field, then moving the feedstock by rail alone would be the best option.

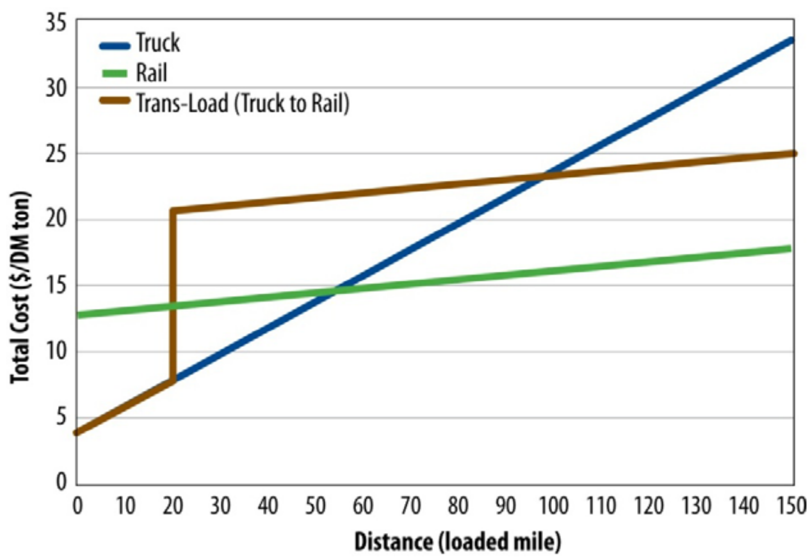



Figure A-2. Transportation cost comparison for truck and rail.

The variables used in Eq. 7 for each transportation option are identified in Table A-20. These variables are directly affected by the capacity of the transport container (variable cost contributor) and the efficiency of the handling equipment (fixed cost contributor) used to load the containers. Thus, trucking biomass has the lowest fixed costs but the highest variable costs of the two systems.

Table A-20. Transportation costs.

| Transportation Method | Cost ($/DM ton) |
|---|---|
| Truck | Cost = 0.196 × Dist + 4.33 |
| Rail[a] | Cost = 0.034 × Dist + 12.84 |

a. Searcy et al. 2007.

## A-5.5 Receiving and Preprocessing

The conventional-bale supply system uses a 72-hr inventory queuing system comprised of a series of 100-ton bale stacks (4 bales high × 5 bales wide × 10 bales long) on a paved bale yard that covers about 20 acres (see Figure 2-32). This particular layout satisfies all relevant international fire codes regulating aggregated biomass. Within this configuration, 13,714 bales, or 6,857 tons, of biomass can be stored at any time. The bale yard is set on a 950×870-ft asphalt pad. Grinders are located in the center of the bale yard to facilitate optimal feeding.

Table A-21 and Table A-22 shows the individual cost and logistical parameters for the Conventional Bale receiving and preprocessing operation. In addition, Table A-23 shows the total cost for both receiving and preprocessing.

Table A-21. Static input cost numbers for Conventional Bale receiving at biorefinery (INL Feedstock Model 08-14752).

| | Receiving | Unload and Stack | Bale Yard Queuing |
|---|---|---|---|
| Equipment | Semi-truck scale | Telehandler | 20-acre asphalt pad |
| EQUIPMENT FACTORS | | | |
| 1. Purchase price[a] | $64,900 | $69,414 | ($1.66/ft$^2$) $1,446,192 |
| 2. Useful life[b] | 15 yr | 10,000 hr | 15 yr |
| 3. Salvage value[c] | 0.1 | 0.2 | 0 |
| 4. Annual use (hr)[d] | | | |
| OWNERSHIP $/HR | | | |
| 5. Depreciation and interest[e] | $5,925.92 | $6.02 | $144,654.20 |
| 6. Taxes, insurance, housing[f] | $652.10 | $0.23 | N/A |
| 7. Ownership $/hr (lines 5+6) | $ | $ | $144,654.20 |
| OPERATING COSTS | | | |
| 8. Repairs and maintenance $/hr[g] | $1,304.21 | $0.26 | $28,098.36 |
| 9. Fuel consumption, gal/hr[h] | | 1.5 | N/A |
| 10. Fuel and lubrication $/hr[i] | | $4.23 | N/A |
| 11. Labor, $ [j] | $103,136.80/yr | $24.12 | N/A |
| 12. Materials, $/hr[k] | | | N/A |
| 13. Total operating $/hr (lines 8+10+11+12) | $ | $ | $28,098.36 |

a. Purchase price is the price paid for the machinery, whether new or used.
b. Useful life is the expected ownership period.
c. Salvage value is the expected selling price or trade-in value of the machine at the end of its ownership period.
d. Assume tractor is dedicated to the respective implement.
e. The depreciation cost reflects the reduction in value of an asset with use and time. The interest cost is an opportunity cost for the use of the money in a machine investment. An interest rate of 6% was used in these calculations.
f. The charge for taxes, housing, and insurance is calculated as 2% of the purchase price.
g. Repair and maintenance costs from Turhollow, Wilkerson, Sokhansanj (2009).
h. No. 2 off-road diesel fuel.
i. If implement does not use fuel, then value represents lubrication costs only.
j. Labor is based on a wage rate of $12.50/hr, which includes benefits.
k. Material costs represent consumables (e.g., baling twine, plastic wrap, etc.).

Table A-22. Static input cost numbers for Conventional Bale preprocessing (INL Feedstock Model 08-14752).

| | Load Grinder from Stack | Pre-processing | Dust Collection | Biochem Even Flow Feed System | Bale/Twine Disposal |
|---|---|---|---|---|---|
| Equipment | Telehandler | Twine Remover and Hammermill | Cyclone, Baghouse, Other Conveying Equipment | Surge Bin, Foreign Material Eliminators, Other Conveying Equipment | Dump Truck |
| EQUIPMENT FACTORS | | | | | |
| 1. Purchase price[a] | $69,414 | | | | |
| 2. Useful life[b] | 1,000 hr | | | | |
| 3. Salvage value[c] | 0.2 | | | | |
| 4. Annual use (hr)[d] | | | | | |
| OWNERSHIP $/HR | | | | | |
| 5. Depreciation and interest[e] | $5.87 | | | | |
| 6. Taxes, insurance, housing[f] | $0.19 | | | | |
| 7. Ownership $/hr (lines 5+6) | $ | $ | $ | $ | $ |
| OPERATING COSTS | | | | | |
| 8. Repairs and maintenance $/hr[g] | $0.26 | | | | |
| 9. Fuel consumption, gal/hr[h] | 1.5 | | | | |
| 10. Fuel and lubrication $/hr[i] | $4.23 | | | | |
| 11. Labor, $/hr[j] | $24.12 | | | | |
| 12. Materials, $/hr[k] | N/A | | | | |
| 13. Total operating $/hr (lines 8+10+11+12) | $ | $ | $ | $ | $ |

a. Purchase price is the price paid for the machinery, whether new or used.
b. Useful life is the expected ownership period.
c. Salvage value is the expected selling price or trade-in value of the machine at the end of its ownership period.
d. Assume tractor is dedicated to the respective implement.
e. The depreciation cost reflects the reduction in value of an asset with use and time. The interest cost is an opportunity cost for the use of the money in a machine investment. An interest rate of 6% was used in these calculations.
f. The charge for taxes, housing, and insurance is calculated as 2% of the purchase price.
g. Repair and maintenance costs from Turhollow, Wilkerson, Sokhansanj (2009).
h. No. 2 off-road diesel fuel.
i. If implement does not use fuel, then value represents lubrication costs only.
j. Labor is based on a wage rate of $12.50/hr, which includes benefits.
k. Material costs represent consumables (e.g., baling twine, plastic wrap, etc.).

Table A-23. Aggregated dollar investment per year for the Conventional Bale supply system design (INL Feedstock Model 08-14752).

| Cost Summary in 1,000 Dollars ($/Year) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Operating Costs | | | | |
| | Installed Capital ($/Dry Ton)[A] | Ownership Costs | Labor | Non-labor | Operating Total (Labor & Non-labor) | Dry Matter Loss | Total Cost[b] |
| Harvest and Collection | 165,317.1 | 31,915.7 | 4,007.5 | 20,512.9 | 24,520.3 | – | 56,436.0 |
| Storage | 3,742.6 | 873.6 | 405.0 | 5,118.0 | 5,522.9 | – | 6,396.6 |
| Transportation and Handling | 5,860.7 | 966.7 | 5,389.0 | 2,804.8 | 8,193.8 | – | 9,160.5 |
| Receiving and Preprocessing | 2,186.2 | 429.1 | 1,137.4 | 181.0 | 1,318.4 | – | 1,747.5 |
| Preprocessing | 7,912.8 | 1,173.3 | 2,439.3 | 3,306.5 | 5,745.8 | – | 6,919.1 |
| Total | 185,019.4 | 35,358.5 | 13,378.1 | 31,923.2 | 45,301.3 | – | 80,659.8 |

a. Installed Capital costs are $ per dry ton and are not reflected in the Total Costs.

b. Total Cost = Ownership Cost + Operating Cost + Dry Matter Loss.

The Conventional Bale supply system costs, shown in Table A-23, do not include the payment to the grower for the feedstock. This grower payment, as discussed in Section 1, is dictated by supply and demand curves and captured on a region-by-region basis. Thus, the values shown in Table A-23 are costs associated with only the engineered system such as capital, logistics, machine performance, dry matter loss, etc. The resulting feedstock cost for the Conventional Bale supply system, without a payment to the grower, is $59.80 per dry ton as-received at the biorefinery. Table A-24 through Table A-28 outline the total investment, on a per-enterprise, per-year basis, for a Conventional Bale supply system design (Section 2).

Table A-24. Harvest and collection dollar investment per year for the Conventional Bale supply system design (INL Feedstock Model 08-14752).

| Cost Summary in 1,000 Dollars ($/Year) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Operating Costs | | | | |
| | Installed Capital ($/dry ton)[a] | Ownership Costs | Labor | Non-labor | Operating Total (Labor & Non-labor) | Dry Matter Loss | Total Cost[b] |
| Class 5 Combine | – | – | – | – | – | – | – |
| Flail Shredder, 30-ft | 3,246.9 | 3,487.2 | 544.0 | 1,320.4 | 1,864.4 | – | 5,351.6 |
| 245 hp tractor | 16,538.9 | 1,442.7 | – | 1,348.3 | 1,348.3 | – | 2,791.0 |
| Wheel V-rake | 1,442.2 | 3,673.8 | 1,468.9 | 762.0 | 2,230.9 | – | 5,904.7 |
| 75 HP MFWD, CAB | 22,580.6 | 1,702.5 | – | 1,732.9 | 1,732.9 | – | 3,435.4 |
| Lg Sq 4×4×8-ft | 48,053.6 | 15,901.7 | 1,619,821 | 9,490.7 | 11,110.5 | – | 27,012.2 |
| Case IH Magnum 275 hp (225 PTO hp) | 63,842.4 | 5,009.3 | – | 5,154.9 | 5,154.9 | – | 10,164.2 |
| Stinger 5500 | 9,612.7 | 698.5 | 374.7 | 703.7 | 1,078.4 | – | 1,776.9 |
| Total | 165,317.1 | 31,915.7 | 4,007.5 | 20,512.9 | 24,520.3 | – | 56,436.1 |

a. Installed Capital costs are $/dry ton and are not reflected in the Total Costs.

b. Total Cost = Ownership Cost + Operating Cost + Dry Matter Loss.

Table A-25. Storage dollar investment per year for the Conventional Bale supply system design (INL Feedstock Model 08-14752).

| Cost Summary in 1,000 Dollars ($/Year) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Operating Costs | | | | |
| | Installed Capital ($/dry ton)[a] | Ownership Costs | Labor | Non-labor | Operating Total (Labor & Non-labor) | Dry Matter Loss | Total Cost[b] |
| Cube-line (4×4×8-ft) | 2,984.6 | 450.4 | – | 4,932.2 | 4,932.2 | – | 5,382.6 |
| Telehandler | 758.0 | 423.2 | 405.0 | 185.8 | 590.7 | – | 1,013.9 |
| Total | 3,742.6 | 873.6 | 405.0 | 5,118.0 | 5,522.9 | – | 6,396.6 |

a. Installed Capital costs are $/dry ton and are not reflected in the Total Costs.
b. Total Cost = Ownership Cost + Operating Cost + Dry Matter Loss.

Table A-26. Transportation and handling dollar investment per year for the Conventional Bale supply system design (INL Feedstock Model 08-14752).

| Cost Summary in 1,000 Dollars ($/Year) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Operating Costs | | | | |
| | Installed Capital ($/dry ton)[a] | Ownership Costs | Labor | Non-labor | Operating Total (Labor & Non-labor) | Dry Matter Loss | Total Cost[b] |
| Telehandler | 758.0 | 254.5 | 1,034.6 | 151.7 | 1,186.3 | – | 1,440.7 |
| 3-axle day cab | 3,629.9 | 554.4 | 4,354.4 | 2,418.9 | 6,773.3 | – | 7,327.7 |
| 53-ft flat bed trailer | 1,472.9 | 157.9 | – | 234.2 | 234.2 | – | 392.1 |
| Total | 5,860.7 | 966.7 | 5,389.0 | 2,80.5 | 8,193.8 | – | 9,160.5 |

a. Installed Capital costs are $ per dry ton and are not reflected in the Total Costs.
b. Total Cost = Ownership Cost + Operating Cost + Dry Matter Loss.

Table A-27. Receiving and preprocessing dollar investment per year for the Conventional Bale supply system design (INL Feedstock Model 08-14752).

| Cost Summary in 1,000 Dollars ($/Year) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Operating Costs | | | | |
| | Installed Capital ($/dry ton)[a] | Ownership Costs | Labor | Non-labor | Operating Total (Labor & Non-labor) | Dry Matter Loss | Total Cost[b] |
| 11×117-ft 100-ton truck scale | 58.7 | 6.2 | 102.8 | 2.0 | 104.8 | – | 111.0 |
| Telehandler | 758.0 | 254.5 | 1,034.6 | 151.7 | 1,186.3 | – | 1,440.7 |
| Asphalt storage pad | 1,369.6 | 168.4 | – | 27.4 | 27.4 | – | 195.8 |
| Telehandler | 758.0 | 277.4 | 1,127.9 | 165.4 | 1,293.3 | – | 1,570.7 |
| Tub grinder | 7,154.8 | 895.9 | 1,311.4 | 3,141.1 | 4,452.5 | – | 5,348.4 |
| Total | 9,186.2 | 1,229.1 | 2,437.4 | 3,281.1 | 5,718.5 | – | 7,147.5 |

*a. Installed Capital costs are $/dry ton and are not reflected in the Total Costs*

*b. Total Cost = Ownership Cost + Operating Cost + Dry Matter Loss.*

Table A-28. Aggregated dollar investment per year for the Conventional Bale supply system design (INL Feedstock Model 08-14752).

| Cost Summary in 1,000 Dollars ($/Year) | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | Operating Costs | | | | |
| | Installed Capital ($/dry ton)[a] | Ownership Costs | Labor | Non-labor | Operating Total (Labor & Non-labor) | Dry Matter Loss | Total Cost[b] |
| Harvest and Collection | 165,317.1 | 31,915.7 | 4,007.5 | 20,512.9 | 24,520.3 | – | 56,436.0 |
| Storage | 3,742.6 | 873.6 | 405.0 | 5,118.0 | 5,522.9 | – | 6,396.6 |
| Transportation and Handling | 5,860.7 | 966.7 | 5,389.0 | 2,804.8 | 8,193.8 | – | 9,160.5 |
| Receiving and Preprocessing | 2,186.2 | 429.1 | 1,137.4 | 181.0 | 1,318.4 | – | 1,747.5 |
| Preprocessing | 7,912.8 | 1,173.3 | 2,439.3 | 3,306.5 | 5,745.8 | – | 6,919.1 |
| Total | 185,019.4 | 35,358.5 | 13,378.1 | 31,923.2 | 45,301.3 | – | 80,659.8 |

a. Installed Capital costs are $/dry ton and are not reflected in the Total Costs.

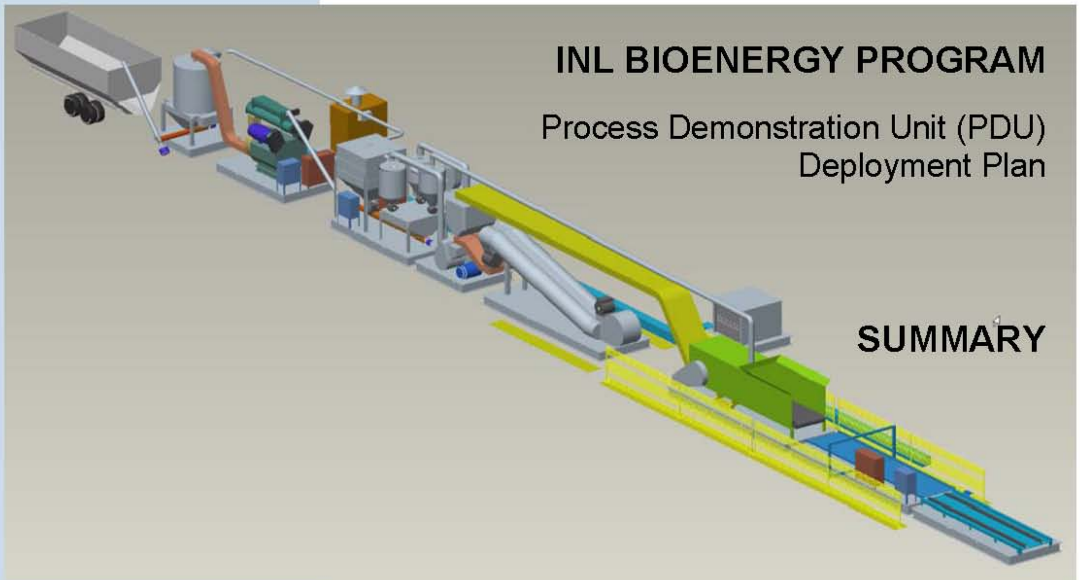
b. Total Cost = Ownership Cost + Operating Cost + Dry Matter Loss.

# Appendix A-6

# PDU Description

## A-6. PDU Description

INL/EXT-10-17849
Revision 0




March 2010

Idaho National Laboratory

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INL/EXT-10-
Revision 0

# INL BIOENERGY PROGRAM
# Process Demonstration Unit (PDU) Deployment Plan

# SUMMARY

March 2010

Idaho National Laboratory
Bioenergy Program
Idaho Falls, Idaho 83415

Prepared for the
U.S. Department of Energy
Office of Biomass Program
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

# CONTENTS

# FIGURES

# Process Demonstration Unit (PDU) Deployment Plan

# SUMMARY

## DESIGN AND CONSTRUCTION STATUS

Preliminary design of Idaho National Laboratory's (INL's) deployable Process Demonstration Unit (PDU) is complete, and procurement of equipment and components began in mid-FY09. A list of equipment, specifications, and estimated cost for the baseline, or "Pioneer," configuration is included at the end of this summary. Many of the processing equipment units require long lead times for bidding, construction, and delivery. Almost all of the equipment requires additional engineering to adapt it to the portable or modular configuration necessary to make it a "deployable" system.

At the end of the second quarter of FY10, the following equipment should be onsite at INL:

- Pellet mill
- Steam generation unit
- Pellet cooling tower
- Metering bin
- Cyclone air handling system
- Three modified cargo containers for the motor control centers (MCCs)
- Electrical components, switchgears, and electrical racks necessary to operate the various modules' MCCs
- Control trailer
- Air locks.

In addition to the equipment onsite, some of the equipment has been built by the manufacturers and is awaiting integration into the modular components or shipping. This equipment includes:

- Hammer mill.

Finally, the following are major pieces of equipment on order that should be delivered shortly after the end of the second quarter:

- Stage I grinder
- Dryer and cyclones
- Conveyors
- Plenum chamber.

## DEPLOYMENT AND SETUP

The modular design of the PDU has an optimum layout, but it can be set up in a number of different "footprint" configurations, depending on the needs of the user and deployment location variables. The proposed PDU high-bay research and development (R&D) space being built at INL will have approximately 18,000 $ft^2$ of floor space, which allows for all modules except the cyclones to be set up inside.

A proposed deployment in a Midwestern state specified a 400 × 400-ft (160,000 $ft^2$ or 3.7 acres) improved dirt pad for the PDU with an additional 94,000 $ft^2$ (2.1 acres) of bale storage space. Our current estimate is that 14 semi-truck loads will be required to move the PDU. Some of the loads will require low-boy trailers to accommodate the taller components. None of the loads are anticipated to be "oversized" in respect to federal and state transportation regulations.

The PDU is designed and constructed to be both reconfigurable (i.e. insert other pieces of processing equipment) and modular so that it can be easily deployed at various sites. Most of the components are skid-mounted or contained in specialized cargo containers, such as the one shown in Figure 1. All modules are engineered to collapse or disassemble so that they can be transported in compliance with state highway regulations (Figure 2).

Figure 1. Example of cargo container that will house various components of the PDU, providing protection during transport and access during operation.

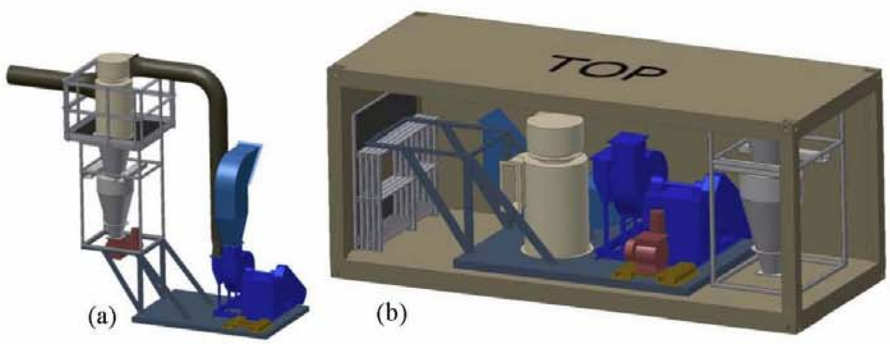


Figure 2. Cyclone system set up and ready to operate (a) and components disassembled and stored securely for transport in a cargo container to site of deployment (b).

Set up of the PDU is estimated to take approximately 3 days.

As part of the deployment plan, the PDU will support several objectives regardless of location:

1. It will demonstrate the feasibility of the depot concept by densifying material near the point where it is harvested.

2. Data gathered as part of the primary research objectives will be used to improve existing equipment, but it may also be used to design and build new concept equipment.

3. Operation of concept equipment can be evaluated by replacing one or more modules within the PDU system.

4. The system may be used to support biorefineries by generating densified material that they can use as feedstock, further demonstrating the depot concept when processed biomass is shipped to the users.

5. Lastly, the PDU can be used by vendors to test prototype equipment in production mode as part of processing line.

The wide range of R&D interests that can benefit from the PDU deployment adds significant value to this activity.

## OPERATION

Once the system is deployed and operational, it is expected that four-man crews will be required to process feedstock on a regular basis. A smaller operating crew may be possible, but until we make some actual processing runs with the unit, we are using the more conservative four-person crew for modeling.

The PDU will have state-of-the-art systems to ensure worker safety. The systems will include barriers and gates to protect workers from hot or moving hazards, as well as sensors embedded in both equipment and work areas to provide lockout capabilities to protect the workforce. Control of the PDU will generally occur from the control trailer (Figure 11), although each module will have independent controls onboard.

If the PDU is deployed in a location where three-phase 480-volt power is not available, one or more large portable generators will be required to supply the approximately 1,400 Kw of electricity needed to power the PDU modules.

# BACKGROUND

As part of the Energy Independence and Security Act of 2007, a production goal of 60 billion gal/yr of biofuel is planned to replace 30% of the 2004 gasoline use by the year 2030. One of the principle challenges of implementing this goal is the logistics of supplying the biomass feedstock in an economically and environmentally sustainable manner. A proposed solution is to produce a quality-controlled, on-spec, uniform-format feedstock material from a variety of lignocellulosic biomass resources that can be delivered to the biorefineries via existing commodity infrastructures. One implementation of this concept locates Preprocessing Depots near the source of these low-density, perishable resources (Figure 3). These Preprocessing Depots house all the operations necessary to convert the source materials to a stable, dense product that can easily be handled in the grain transportation infrastructure that currently exists in the United States.

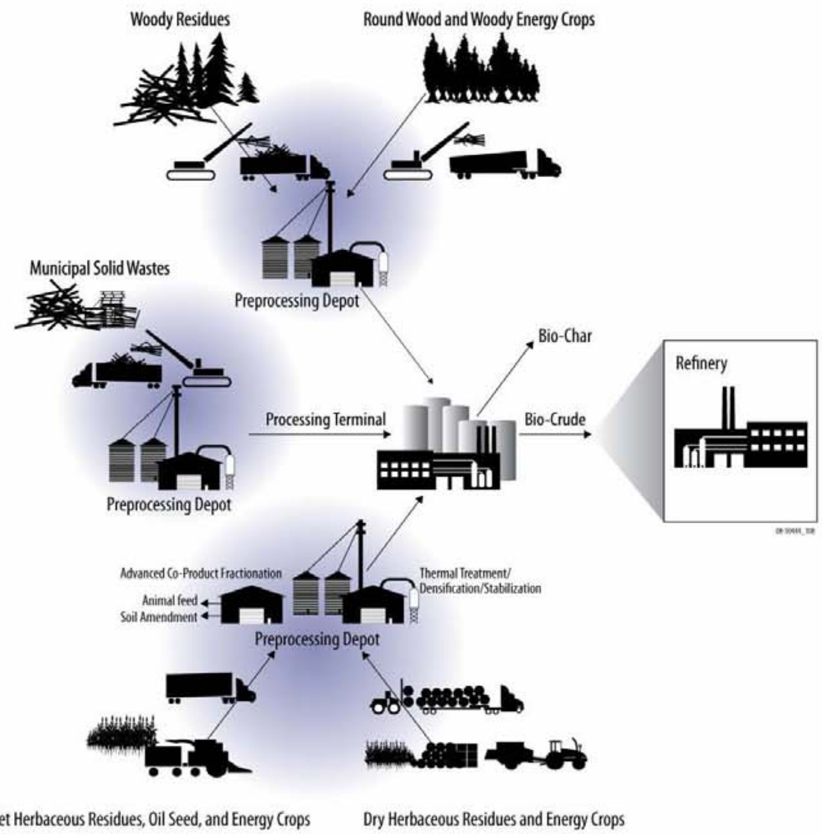


Figure 3. The Uniform-Format Feedstock Supply System design emulates the current grain commodity supply system, which manages crop diversity at the point of harvest and at the storage elevator, allowing subsequent supply system infrastructure to be similar for all biomass resources. Similarly, Biomass Preprocessing Depots are located near feedstock resources.

To accommodate R&D in feedstock preprocessing, INL has constructed a deployable Process Demonstration Unit (PDU) to model the Preprocessing Depot infrastructure and house the basic bioenergy feedstock preprocessing operation components. The goal of INL's PDU system is to process as large a variety of input materials as possible while providing a flexible interface that allows the introduction of emerging and novel processing technologies. The input material will ultimately consist of materials such as wheat straw, barley straw, rice straw, corn stover, switchgrass, miscanthus, wood products, and biowaste.

INL's PDU provides four important R&D capabilities:

1. A production-scale experimental tool for biomass feedstock processing – the PDU will demonstrate technology that can densify material to make it a commercially viable to process, ship, and trade.
2. Preprocessing system support for 931 and other DOE solicitation winners – users will operate the PDU at their locations in predetermined standard configurations and vary the biomass feedstock types to understand the impact of particular feedstock characteristics on processing and densification. Each of the products would likely require multiple runs of the same feedstock with experimental variations on specific parameters, such as preliminary moisture content. While we understand that moisture content has an impact on processing and densification, prior to development of the PDU, it has not been feasible to perform large-scale studies of multiple feedstocks to understand the extent of that impact.
3. A support platform for testing production models of similar equipment produced by multiple manufacturers – manufacturers producing similar types of equipment (such as grinders, pellet mills, hammer mills, and conveyors) have shown interest in testing the performance of their equipment in the PDU processing line. The PDU's modular format allows for introduction or substitution of off-the-shelf, production-scale equipment.
4. A support platform for testing concept equipment during R&D phase – new concepts in equipment manufacturing can be tested as prototypes are inserted into the PDU. The PDU's modular system components and standard interfaces between modules allows for operation and analysis of the whole system or specific individual components within the system. Experimental and emerging technologies can be inserted into an established processing loop, which enables equipment comparisons and provides a platform for process improvement. This will be an important feature as processing technologies advance because new developments may eliminate the need for some pioneer or intermediate operations.

## PIONEER CONFIGURATION

INL's baseline PDU configuration, or "Pioneer Configuration," uses existing and widely accepted crop and material processing technologies with equipment that is instrumented for maximum research data gathering. Included in the Pioneer configuration are bale decomposition, dryers, grinders, pellet mill, dust collection, and material handling components. Existing technologies for processing woody materials can easily be inserted into the Pioneer configuration.

The Pioneer configuration is constructed in four principal modules plus support equipment:

(1) Decomposition

(2) Grinding

(3) Drying

(4) Densification.

Power, control, safety, utilities, instrumentation, and dust management systems are included both at the module level and at the integrated system level, enabling independent control of each module or remote operation of the integrated system. Figure 4 shows the equipment process flow.

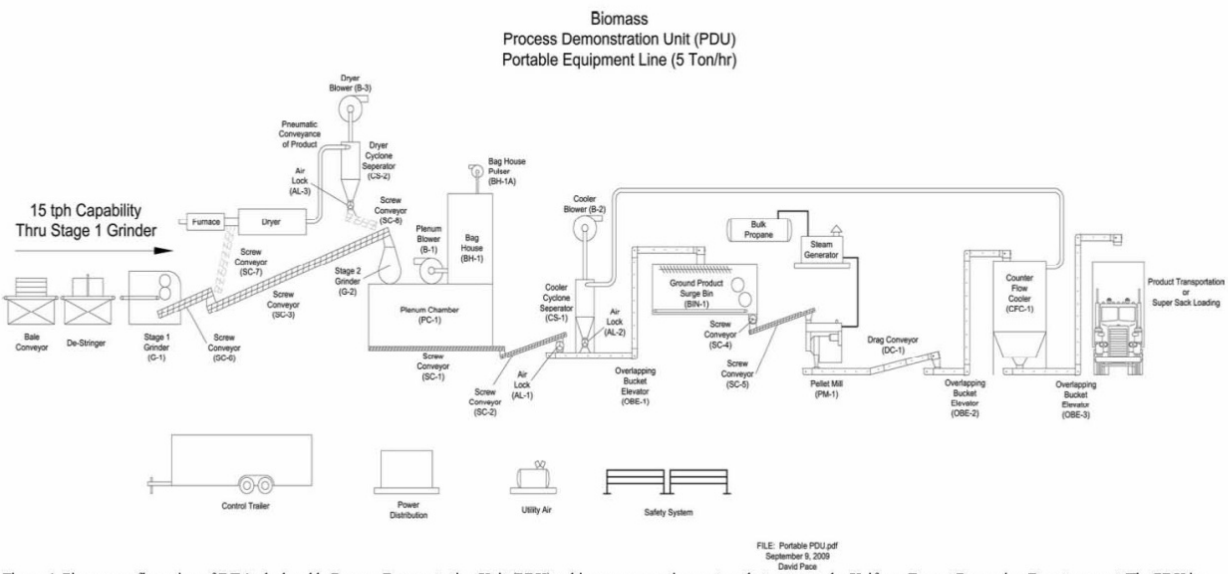


Figure 4. Pioneer configuration of INL's deployable Process Demonstration Unit (PDU), a biomass processing system that supports the Uniform-Format Processing Depot concept. The PDU is deployed to a location near biomass resources to process and densify pilot-scale quantities (~5 ton/hr throughput) of various biomass materials.

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## Operation Modules

### Module 1 – Decomposition

This module includes receiving operations such as weighing biomass materials (generally as a bale or loose materials), removal of coverings (string, netting, etc.), and conveyance into a Stage I grinder (Figure 5).

A second conveyor brings the material (now less than 2 inches in size) into a drying system (Module 3, Figure 6). Grinding and subsequent conveying in Module 1 are essentially completed in enclosed equipment with air flow to a bag house (see Module 2) for maximum dust control.

### Module 2 – Grinding

This module includes the Stage II grinder (hammer mill, Figure 7) and the dust management equipment, as well as the associated conveyors. Feed to the hammer mill is either from the Stage I grinder or the dryer (Module 3).

The output ground material is collected in a plenum chamber with sensors and fire suppression capabilities. The bottom of the chamber has a screw conveyor for removing the material. Air flow is provided by a blower that filters ground material "fines" into a bag house filtering the air through a HEPA filter.

### Module 3 – Drying

Module includes all components of the dyer system, including the burner, rotating dryer drum, cyclone separator, blower, and associated conveyors (Figure 6).

Material can exit the Stage I grinder and be fed into the dryer via a screw conveyor; the dry material is then be fed into the Stage II grinder via another screw conveyor. If the material is at the desired moisture level after the Stage I grinder, it can be fed directly into the Stage II grinder. Very wet material can also be recycled through the dryer repeatedly if necessary.

Figure 5. Prototype Stage I grinder with input conveyor.

Figure 6. Example of a drying system showing the drum and cyclone.

Figure 7. INL's Stage II grinder (hammer mill).

Figure 8. INL's steam generator.

## Module 4 – Densification

In the Pioneer configuration, the densification module includes all components for pelletization, including a steam generator (Figure 8), metering bin (Figure 9), pellet mill (Figure 10), associated conveyors (Figure 11), cooler, dust collection systems, and storage bins.

Pellets removed from the mill are conveyed to a bucket elevator, which feeds the cooler. A blower and cyclone separator are connected to the cooler for recycling fine material back into the ground product surge bin for pelletizing (Figure 12). Another bucket elevator transfers the cooled pellets to a truck, super sack, or other product storage system.

The metering bin is designed to prevent the ground material from collecting and compacting in areas within the bin by several augers that keep the material moving. It is also be capable of an even feed rate to the pellet mill for acceptable pellet production.

Figure 9. INL's metering bin for even-feeding of material to the pellet mill.

Figure 10. INL's pellet mill.

Figure 11. Examples of a bucket elevator *(left)* and drag conveyor *(right)*.

Figure 12. Grinder with air flow from blower and cyclone.

## Other Support Systems/Equipment

### Power and Control Systems

There a several items required for operating the PDU that are not part of the operation modules, such as the power and control systems. Control of the operation modules can occur from a panel at each module or from the central control trailer. Each module has an enclosure that houses the power distribution and control hardware necessary for the particular module. The enclosures are then routed to a central control trailer where remote operation of the entire PDU system can occur (Figure 13). Instrumentation for air, propane, water, and power will be provided to each module as required.

Figure 13. Control trailer, side view.

Figure 14. Modular safety system components.

### Safety Systems

The safety system is configured similarly (Figure 14). Each module has its own safety system controller and can be operated independently. The module control systems are connected to the central control system, which enables system-level safety monitoring and decision-making. The safety system is an enhancement to vendor-supplied safety controls and will not replace or disable those features. Specific applications of safety equipment depend on the equipment, vendor-provided controls, and a hazards assessment (where needed). Appropriate subject matter experts will be included in the determination of needed enhancements and may participate in the assessments. This will be performed after equipment and vendor documentation is received.

### Conceptual Equipment

Enhancements and new, improved equipment will be developed and be added to the PDU as they are available. One example is a fractionation unit, which will separate the material into fractions that either continue through the line or are returned to a collection point. This technology will reduce the cost of processing biomass that will not be used as feedstock. The technology will also allow removal of specific portions for different purposes based on energy value. Another example is a torrefaction unit, which treats the material with heat in an inert atmosphere, resulting in a high-energy-density material that requires little effort to reduce particle size.

### Biomass Material Storage and Handling Systems

A variety of biomass materials and storage formats will be required as feedstock to the PDU. Materials may be wheat straw, barley straw, rice straw, corn stover, switchgrass, miscanthus, sorghum, soybean, wood products, or biowaste. Storage formats may be square bales, round bales, wood slash, small logs, etc.

### Other Instrumentation

A variety of measurements will be performed and data collected throughout the preprocessing system. Additional instrumentation will be added over time as needs are identified.

# FUTURE "HEADQUARTERS" OF PDU R&D

## INL Testing and Demonstration Facility

Construction plans are underway for the new INL Testing and Demonstration Facility (TDF) (Figure 15). The location of the PDU "headquarters" is indicated in the upper right portion of Figure 16.

Figure 15. Conceptual rendering of the future INL Testing and Demonstration Facility (TDF), which will house the INL PDU and associated research programs.

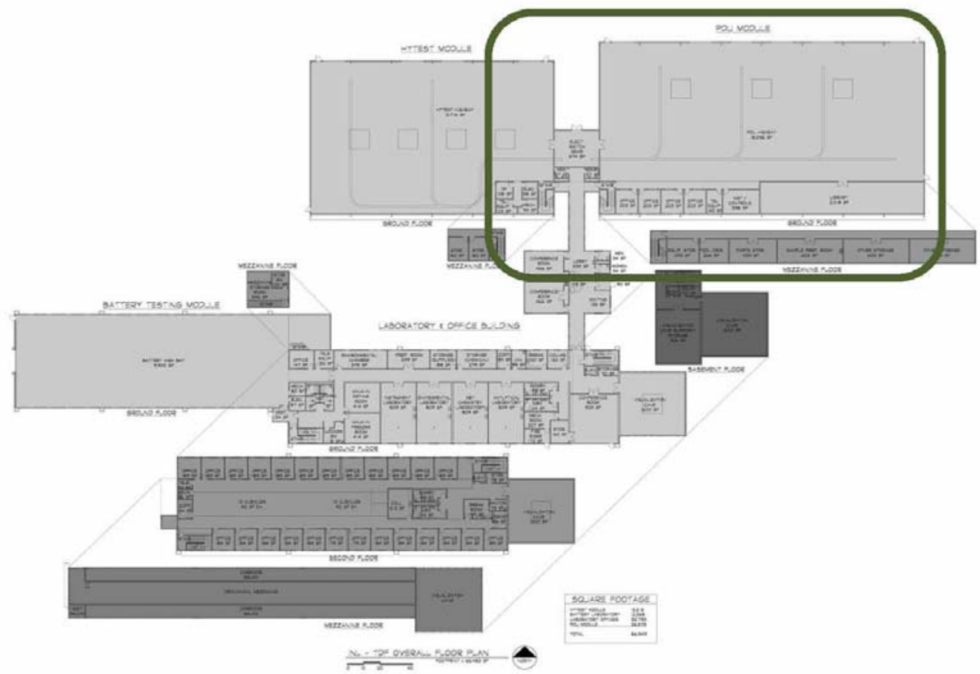


Figure 16. Birds-eye view of the INL TDF. The location of the PDU "headquarters" is indicated in the upper right of this drawing.

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## PDU "PIONEER CONFIGURATION" LIST OF EQUIPMENT, SPECIFICATIONS, AND ESTIMATED COSTS

| Equipment/ Module | Description | Motor HP | Motor Power | KW Power (1.73×480×FL) | Approximate Cost |
|---|---|---|---|---|---|
| De-Stringer | De-string/de-bale biomass prior to grinding | 20.00 | 460VAC/3ph/60hz 3.4amps | 15 | $100,000 |
| | De-stringer motor | 2.00 | 460VAC/3ph/60hz 3.4amps | 1.5 | |
| Stage I Grinder | Grinder capable of grinding 4×4×8-ft square or 6 ½-ft dia round bales, twin 200-HP motors (one per cylinder) | 2 @ 200 | 460VAC/3ph/60hz 240amps (per motor) | - | $200,000 |
| Screw Conveyor | Screw conveyor | 5.00 | 460VAC/3ph/60hz 7.6amps | 6.3 | $10,000 |
| Screw Conveyor | Screw conveyor | 5.00 | 460VAC/3ph/60hz 7.6amps | 6.3 | $10,000 |
| Screw Conveyor | Screw conveyor | 5.00 | 460VAC/3ph/60hz 7.6amps | 6.3 | $10,000 |
| MCC #1 | Bale conveyor motor controller | 2.00 | 460VAC/3ph/60hz | 2.8 | $55,000 |
| | De-stringer conveyor motor controller | 2.00 | 460VAC/3ph/60hz | 2.8 | |
| | De-stringer mechanism motor controller | 2.00 | 460VAC/3ph/60hz | 2.8 | |
| | Stage I grinder (shredder) motor controller #1 Vermeer | 200.00 | 460VAC/3ph/60hz | 166 | |
| | Stage I grinder (shredder) motor controller #2 Vermeer | 200.00 | 460VAC/3ph/60hz | 166 | |
| | Drag conveyor | 5.00 | 460VAC/3ph/60hz | 6.3 | |
| Stage I Grinder MCC #1 Cargo Container | | | | | $23,000 |
| Stage I Grinder MCC #1 Cargo Container AC | Air conditioner/heater | N/A | N/A | 16.6 | $6,000 |
| Dryer | Combustion air blower motor | 25.00 | 460VAC/3PH/60hz 34amps | 28.2 | $440,000 |
| | Dryer drum motor | 7.50 | 460VAC/3ph/60hz 11amps | 9.1 | |
| | Dryer blower motor | 75.00 | 460VAC/3ph/60hz 96amps | 79.7 | |
| | Airlock motor | 1.50 | 460VAC/3ph/60hz 3.0amps | 2.5 | |
| | Airlock motor | 1.50 | 460VAC/3ph/60hz 3.0amps | 2.5 | |
| | Dryer cyclone separator | N/A | N/A | | |
| Screw Conveyor | | 7.50 | 230/460VAC/3ph/60hz | | $15,000 |
| Stage II Grinder (Hammer Mill) | Eliminator Hammer mill, 1800 RPM explosion-proof motor for grains | 150.00 | 460VAC/3ph/60hz 180amps | | $50,000 |
| Plenum Blower | Blower, 3,025 RPM, 324T frame, explosion-proof, weatherhood | 30.00 | 460VAC/3ph/60hz/ 40amps | | $180,000 |
| Plenum Hepa Filter | Hepa filter for air return into building | N/A | N/A | | |
| Bag House | AVS air vent filter | N/A | N/A | | |
| Bag House Med Pressure Pulser | Bag house pulser, 1750 RPM, 183T frame Baldor motor | 3.00 | 230/460VAC/3ph/60hz 4.8amps | | |
| Plenum Chamber | Hammer mill collection chamber designed for 250 FPM airflow with SC-1 mounted in the bottom | N/A | N/A | | |

| Equipment/ Module | Description | Motor HP | Motor Power | KW Power (1.73×480×FL) | Approximate Cost |
|---|---|---|---|---|---|
| Air Lock | Rotary airlock (AL-1), right-angle drive, final drive is 14 RPM | 2.00 | 230/460VAC/3ph/60hz 3.4amps | | |
| Screw Conveyor | 12-in. dia×28-ft 6-in. long V-trough screw conveyor: 40 RPM dust-tight, explosion-proof motor, 1750 RPM IP55 | 5.00 | 460VAC/3ph/60hz 7.6amps | | |
| Air Lock | Rotary airlock to isolate cyclone, final drive 18 RPM | 1.00 | 230/460VAC/3ph/60hz 4.8amps | | |
| Cooler Cyclone | 30-in. dia cooler cyclone, stainless | N/A | N/A | | |
| Cooler Blower | Blower, 3554 RPM, 284T frame, explosion-proof | 40.00 | 460VAC/3ph/60hz 52amps | | |
| Plenum Chamber Fire Suppression | Fire-suppression system mounted in plenum chamber | N/A | N/A | | |
| Screw Conveyor | 16-in.-dia×15-ft 5-1/2-in.-long tubular screw conveyor 35-degree incline, 82 RPM dust-tight, explosion-proof motor | 3.00 | 230/460VAC/3ph/60hz 4.8amps | | $10,000 |
| Overlapping Bucket Elevator | Ground product overlapping bucket elevator; controller/starter is mounted on elevator skid | 1.50 | 230/460VAC/3ph/60hz 3amps | 2.5 | $35,000 |
| MCC #2 | Stage II grinder (hammer mill) motor G-2 controller | 150.00 | 460VAC/3ph/60hz 180amps | 150 | $75,000 |
| | Bag house pulser motor BH-1A controller | 3.00 | 460VAC/3ph/60hz 4.8amps | 4 | |
| | Plenum blower B-1 motor controller | 30.00 | 460VAC/3ph/60hz 40amps | 33.2 | |
| | Screw conveyor SC-1 motor controller | 5.00 | 460VAC/3ph/60hz 7.6amps | 6.3 | |
| | Screw conveyor SC-2 motor controller | 3.00 | 460VAC/3ph/60hz 7.6amps | 4 | |
| | Airlock AL-1 motor controller | 2.00 | 460VAC/3ph/60hz 2.1amps | 2.8 | |
| Hammer Mill MCC #2 Cargo Container | | | | | $23,000 |
| Hammer Mill MCC #2 Cargo Container AC | Air conditioner/heater | | | 11.2 | $6,000 |
| Ground Product Surge Bin | Product-leveling screw motor #1 | 5.40 | 230/460VAC/3ph/60hz 7.6amps | 6.3 | $190,000 |
| | Product-leveling screw motor #2 | 5.40 | 230/460vac/3ph/60hz 7.6amps | 6.3 | |
| | Doffer motor #1 | 5.40 | 230/460VAC/3ph/60hz 8amps | 6.6 | |
| | Doffer motor #2 | 5.40 | 230/460VAC/3ph/60hz 8amps | 6.6 | |
| | Floor drive motor | 1.50 | 230/460VAC/3ph/60hz 3amps | 1.7 | |
| | Leveling jack motor #1 | 1.00 | 480/3P/60hz 2.1amps | 1.7 | |
| | Leveling jack motor #2 | 1.00 | 480/3P/60hz 2.1amps | 1.7 | |
| | Leveling jack motor #3 | 1.00 | 480/3P/60hz 2.1amps | 1.7 | |
| | Leveling jack motor #4 | 1.00 | 480/3P/60hz 2.1amps | 1.7 | |
| Screw Conveyor Bin Discharge | 36-in.-wide drag chain outfeed conveyor, 5-ft discharge | 5.00 | 230/460VAC/3ph/60hz 8amps | 6.6 | |
| Screw Conveyor | Screw conveyor | 5.00 | 460VAC/3ph/60hz 7.6amps | 6.3 | $10,000 |
| Pellet Mill | 5 TPH pellet mill with two-stage belt drive transmission (each mill has two 250 HP motors) | 2 @ 250 | 460VAC/3PH/60hz 302amps per motor | | $300,000 |

| Equipment/ Module | Description | Motor HP | Motor Power | KW Power (1.73×480×FL) | Approximate Cost |
|---|---|---|---|---|---|
| | Conditioning chamber for water or steam addition with mixing screw, 1800 RPM motor | 10.00 | 460VAC/3ph/60hz 14amps | | |
| Drag Conveyor | Drag conveyor | 1.50 | 480vac/3Ph/60hz 3amps | 2.5 | $30,000 |
| Steam Boiler | | N/A | N/A | | $40,000 |
| Bulk Propane Tank | | N/A | N/A | | $3,000 |
| Overlapping Bucket Elevator | Hot pellet overlapping bucket elevator | 1.50 | 230/460VAC/3ph/60hz 3amps | 2.5 | $75,000 |
| Pellet Cooler | Counter flow cooler | N/A | N/A | | $50,000 |
| | Rotary input feeder | 1.00 | 460VAC/3ph/60hz 2.1amps | | |
| Overlapping Bucket Elevator | Pellet overlapping bucket elevator | 1.50 | 230/460VAC/3ph/60hz 3amps | 2.5 | $40,000 |
| MCC #3 | Pellet mill PM-1 motor controller #1 | 250.00 | 460VAC/3PH/60hz 302amps | 250.8 | $75,000 |
| | Pellet mill PM-1 motor controller #2 | 250.00 | 460VAC/3PH/60hz 302amps | 250.8 | |
| | Conditioner (PM-1) motor controller | 10.00 | 460VAC/3PH/60hz 14amps | 11.6 | |
| | Drag conveyor DC-1 motor controller | 2.00 | 460VAC/3ph/60hz 3.0amps | 2.5 | |
| | Pellet cooler rotary input feeder motor controller (CFC-1) | 1.00 | 460VAC/3ph/60hz 2.1amps | 1.7 | |
| | Air lock AL-2 | 1.00 | 460VAC/3ph/60hz 4.8amps | 4 | |
| | Cooler blower B-2 | 40.00 | 460VAC/3ph/60hz 52amps | 43.2 | |
| Pellet MCC #3 Cargo Container | | | | | $23,000 |
| Pellet MCC #3 Cargo Container AC | Air conditioner/heater | | | 16.6 | $6,000 |
| Control Trailer | Control trailer w/240-V HVAC and 120-V circuits | N/A | 240vac/1P/60hz 50amps | 12 | $90,000 |
| Safety System for Modules | Powered from the control trailer service | N/A | | | $90,000 |
| Instrumentation and Controls | | | | | $500,000 |
| Other Misc Components | | | | | $1,000,000 |
| **TOTAL** | | | | **1369.1** | **$3,770,000** |

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# Appendix A-7

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# A-7. REFERENCES

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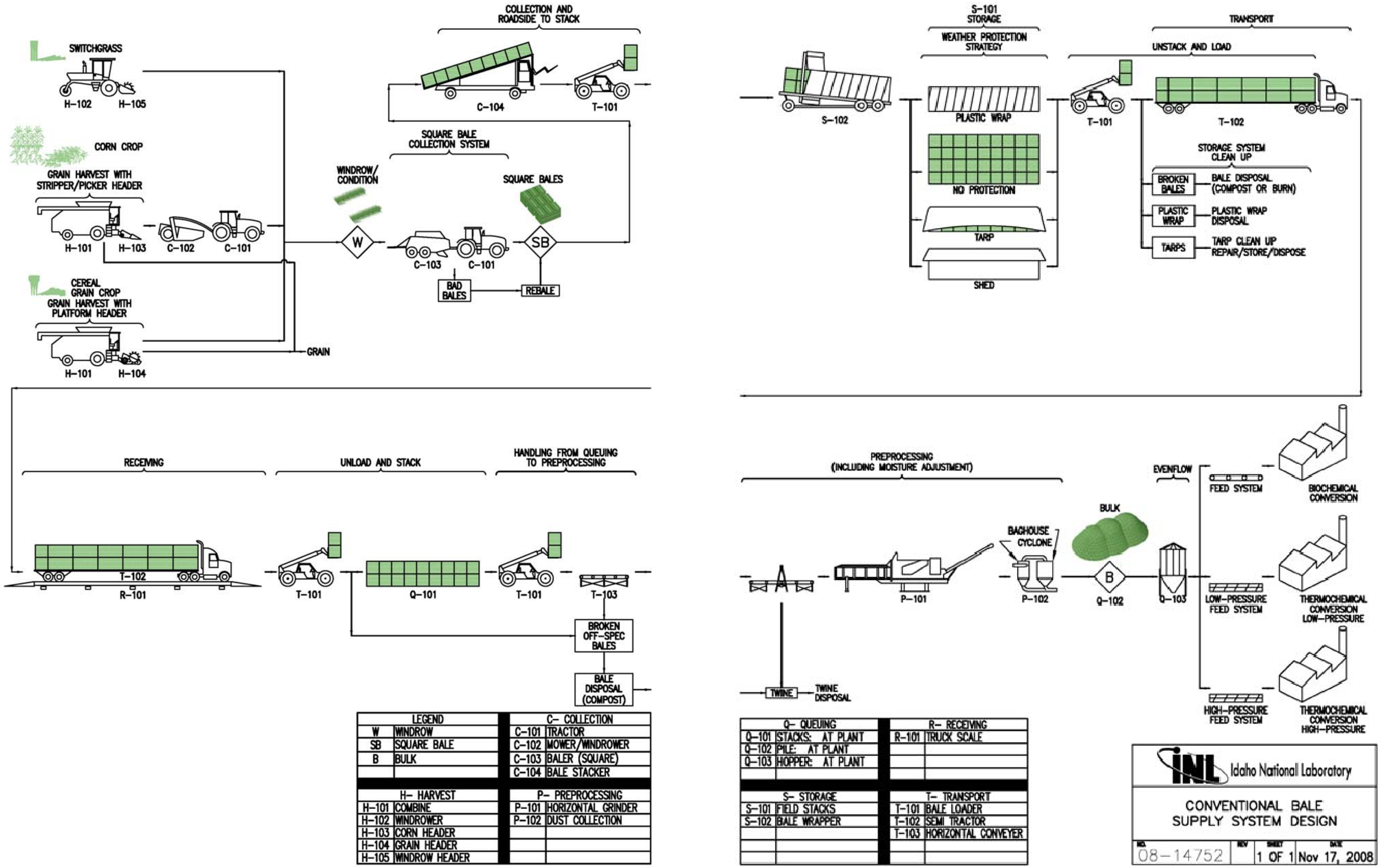
# Appendix B

# Equipment Specifications

# Appendix B-1

# Conventional Bale CAD Drawing/Equipment Database




| LEGEND | | C- COLLECTION | |
|---|---|---|---|
| W | WINDROW | C-101 | TRACTOR |
| SB | SQUARE BALE | C-102 | MOWER/WINDROWER |
| B | BULK | C-103 | BALER (SQUARE) |
| | | C-104 | BALE STACKER |

| H- HARVEST | | P- PREPROCESSING | |
|---|---|---|---|
| H-101 | COMBINE | P-101 | HORIZONTAL GRINDER |
| H-102 | WINDROWER | P-102 | DUST COLLECTION |
| H-103 | CORN HEADER | | |
| H-104 | GRAIN HEADER | | |
| H-105 | WINDROW HEADER | | |

| Q- QUEUING | | R- RECEIVING | |
|---|---|---|---|
| Q-101 | STACKS: AT PLANT | R-101 | TRUCK SCALE |
| Q-102 | PILE: AT PLANT | | |
| Q-103 | HOPPER: AT PLANT | | |

| S- STORAGE | | T- TRANSPORT | |
|---|---|---|---|
| S-101 | FIELD STACKS | T-101 | BALE LOADER |
| S-102 | BALE WRAPPER | T-102 | SEMI TRACTOR |
| | | T-103 | HORIZONTAL CONVEYER |

| Conventional Bale–Corn Stover Equipment Database | Base Year | List Price | Useful Life | Salvage Value | Insurance Housing Taxes | Misc. | Misc. | R&M Cost Factor | R&M Int. | Fuel Use | Materials | Misc. | Horse Power | Dimen-sion | GVW | Capacity | Grain Tank | Unload | Field Efficiency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Combine (0110):**<br>**04 Class 6 Combine, Grain JD 9670 STS** | 2008 | 262,444 | 3,000 hr | 0.29 | 0.02 | | | 35.15 | 1 hr | 13.36 gal/hr | | | 305 | | 32,661 lb | 2,000 bu/hr | 373.34 cu ft | 1.52 cu ft/min | 0.7 |
| **Combine Header (0110):**<br>**05 8-Row Corn Head, for use with Class 5, 6 JD 864, 8-Row @ 38-in. Spacing** | 2008 | 52,537 | 2,000 hr | 0.5 | 0.02 | | | 4.5 | 1 hr | 0 | | | | 24.00 ft | 5,462 lb | | | | |
| **Pull-Type Mowers (0210):**<br>**53 Balzer Flail Shredder/Windrower, 15 ft, Bulk, Balzer, End Drive** | 2007 | 18,676 | 2,500 hr | 0 | 0.02 | | | 6.16 | 1 hr | 0 | | | 90 | 15 ft | 4,100 lb | | | | 0.8 |
| **Tractor (0010):**<br>**02 CaseIH, Magnum 275 hp (225 PTO hp) MFWD** | 2007 | 163,447 | 9,000 hr | 0.31 | 0.02 | | | 10.62 | | 9.86 gal/hr | | | 225 | | 21,430 lb | | | | 1 |
| **Tractor (0010):**<br>**03 CaseIH, Puma 180 hp MFD** | 2008 | 115,803 | 10,000 | 0.36 | 0.02 | | | 8.11 | 1 hr | 6.57 gal/hr | | | 150 | | 15,708 lb | | | | 1 |
| **Baler (0310):**<br>**02 Hesston 2190 Lg. Sq. 4 × 8 ft** | 2007 | 123,025 | 3,000 hr | 0.35 | 0.02 | | | 30.55 | 1 hr | 0 | Twine<br>0.72 $/bale | Wrap<br>$/bale | 180 | Bale Vol.<br>128 ft3 | 22,741 lb | | Max. Speed<br>12 mph | | 0.8 |
| **Self-Propelled Bale Transporter/Stacker for Roadsiding (0410):**<br>**02 Stinger 5500** | 2006 | 139,000 | 14,500 hr | 0.15 | 0.02 | | | 3.24 | 1 hr | 7 gal/hr | | | 240 | | 25,000 lb | Load<br>sec/bale | Unload<br>sec/bale | Fld. Spd.<br>mi/hr | Rd. Spd.<br>mi/hr |
| **Semi Tractor for Transport[a] (0510)**<br>**01 Kenworth T800 3-axle day cab** | 2006 | 110,809 | 1,000,000 miles | 0.3 | 0.101 | | | 0.02 | 1 mi | 0.17 mi/gal | | | 450 | 11 ft | 20,000 lb | | | | 1 |
| **Semi Trailer for Transport[a] (0510):**<br>**07 53-ft Flat Bed Trailer, bale Fontaine Phantom** | 2006 | 38,000 | 1,000,000 miles | 0.9 | 0.101 | | | 0.02 | 1 mi | 0 | | | | 53 ft | 9,200 lb | | | | |
| **Self-Propelled Loader for Transport[a] (0040):**<br>**01 Caterpillar TH220B Telehandler, bale** | 2006 | 69,414 | 10,000 hr | 0.2 | 0.02 | | | 0.27 | 1 hr | 1.5 gal/hr | | | 100 | | 14,771 lb | 100 units/hr | | | 1 |
| **Grinder (0710):**<br>**08- Vermeer HG6000** | 2008 | 460,000 | 15,000 hr | 0.3 | 0.02 | | | 20.7 | 1 hr | 469.79 gal/hr | | | 630 | | | 17.17 ton/hr | 99.165x^-0.7711 | | 0.9 |
| **Self Propelled Loader for Grinding (0610):**<br>**01 Caterpillar TH220B Telehandler, bale** | 2006 | 69,414 | 10,000 | 0.2 | 0.02 | | | 0.27 | 1 hr | 1.5 gal/hr | | | 100 | | 14,771 lb | 100 units/hr | Capacity<br>units ld. | | |
| **Depot Conveyors**<br>**17 Schuon Twin Bale Infeed (CV), bale, tons/hr** | 2003 | 69,790 | 15 yr | 0.1 | 0.02 | Install. Factor 0.5 | Scaling Expt. 0.6 | 3.09 | 1 hr | 7.46 gal/hr | | Fxd R&M Cst. Fct. 0.01 | 10 | | | | Capacity: 10 ton/hr | | |
| **13 Schuon Bale Merge (CV), bales, tons/hr** | 2005 | 112,793 | 15 yr | 0.1 | 0.02 | Install. Factor 0.5 | Scaling Expt. 0.6 | 4.31 | 1 hr | 3.73 | | Fxd R&M Cst. Fct. 0.01 | 5 | | | | Capacity: 10 ton/hr | | |
| **12 Schuon Single Bale Infeed (CV) Bale, tons/hr** | 2003 | 46,044 | 15 yr | 0.1 | 0.02 | Install. Factor 0.5 | Scaling Expt. 0.6 | 2.04 | 1 hr | 3.73 | | Fxd R&M Cst. Fct. 0.01 | 5 | | | | Capacity: 10 ton/hr | 16 ft dimension | |

| Conventional Bale–Corn Stover Equipment Database | Base Year | List Price | Useful Life | Salvage Value | Insurance Housing Taxes | Misc. | Misc. | R&M Cost Factor | R&M Int. | Fuel Use | Materials | Misc. | Horse Power | Dimen-sion | GVW | Capacity | Grain Tank | Unload | Field Efficiency |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Depot Surge/Metering Bins** | | | | | | | | | | | | | | | | | | | |
| **06 Metering Bin (CV), tons/hr** | 2000 | 49,982 | 20 yr | 0.1 | 0.01 | Install. Factor 0.5 | Scaling Expt. 0.6 | 4.98 | 1 hr | 8.2 gal/hr | | Fxd R&M Cst. Fct. 0.01 | 11 | | | 2,000 cu ft/h | 1,296 cu ft | | |
| **Depot Dust Collection Equipment** | | | | | | | | | | | | | | | | | | | |
| **05 Large Cyclone Separator Fan Included cfm** | 2008 | 65,000 | 10,000 | 0.3 | 0.02 | | Scaling Expt. 0.6 | 18,954.54 | 1 hr | 74.57 gal/hr | | | 100 | | | 75 ton/hr | 55,290 cfm | | |
| **06 Farr Baghouse Fan (CV) ton/hr** | 2000 | 5,045 | 10,000 hr | 0.3 | 0.02 | | Scaling Expt. 0.6 | 6,071.76 | 1 hr | 111.85 | | 0.02 | 150 | | | 10 ton/hr | | | |
| **01 Farr Baghouse & Air Lock (CV) tons/hr** | 2000 | 88,234 | 10,000 hr | 0.3 | 0.02 | | Scaling Expt. 0.6 | 106,192 | 1 hr | 111.85 | | 0.02 | 150 | | | 10 ton/hr | | | |
| **Depot Miscellaneous Equipment** | | | | | | | | | | | | | | | | | | | |
| **03 W&B Twine Remover (CV)** | 2003 | 24,168 | 15 hr | 0.1 | 0.02 | 0 | 0.6 | 0.23 | 1 hr | 3.7 kW | | 0.02 | 5 | | | 10 ton/hr | | | |
| **05 Danske Moisture Meter (CV) tons/hr** | 2005 | 14,929 | 10 hr | 0.1 | 0.01 | 1.3 | 0.6 | 0.18 | 1 hr | 0 | | | | | | 10 ton/hr | | | |
| **06 Dings Electro Magnet (CV) tons/hr** | 2005 | 23,236 | 15 hr | 0.1 | 0.02 | 0 | 0.6 | 1571.4 | h hr | 0 | | | | | | 10 ton/hr | | | |
| **07 Kelderman Bale Rejector (CV) tons/hr** | 2006 | 12,500 | 15 hr | 0.1 | 0.02 | 0 | 0.6 | 252.39 | 1 hr | 3.73 kW | | 0.02 | 5 | | | 10 ton/hr | | | |
| **Storage Format (2010)**<br>**06 Bale Wrap $/sq ft** | 2006 | | 1 hr | 0 | | Land Rent $/acre: 96 | Feedstock Ins., $/ton: 0.05 | 0 | 1 hr | 0 | | 0.01 | | | | | | | |
| **Storage Option (2020)**<br>**03 Stinger 4000 Cube-Line Wrapper (4×4) bales/hr** | 2006 | 40,000 | 3,000 | 0.42 | 0.02 | Custom Rt. $/dry ton: | | 3.19 | 1 hr | 1.00 gal/hr | Material 2.79 | 0.07 | | | 13,500 lb | 120 bales/hr | | | 1 |
| **Self Propelled Loaders for Storage (2030)**<br>**01 Caterpillar TH220B Telehandler, bale** | 2006 | 69,414 | 10,000 hr | 0.2 | 0.02 | | | 0.27 | 1 hr | 1.5 gal/hr | | | 100 | | 14,771 lb | 100 units/hr | | | 1 |
| **Receiving/Queuing Infrastructure**<br>**02 Asphalt Pad, $/sq ft** | 2006 | 1,660,000 | 15 hr | 0 | | | | | 1 hr | 0 | | 0.02 | | | | | | | |
| **Loader for Receiving (2030)**<br>**01 Caterpillar TH220B Telehandler** | 2006 | 69,414 | 10,000 hr | 0.2 | 0.02 | | | 0.27 | 1 hr | 1.5 gal/hr | | | 100 | | 14,771 lb | 100 units/hr | 45.9 units/ld | | 1 |
| **Scales, Sensors, Etc.**<br>**04 11 x 117-ft, 100-ton Truck Scale** | 2006 | 64,900 | 15 hr | 0.1 | 0.02 | Install. Factor: 0 | Scaling Expt: 0.6 | | 1 hr | 0 | | 0.02 | | 117 ft | | | 100 tons | | |
| **Overhead: Semi Tractor**<br>**01 Kenworth T800 3-axle day cab** | 2006 | 110,809 | 1,000,000 miles | 0.3 | 0.101 | | | 0.02 | 1 hr | 0.17 miles/gal | | | 450 | 11 ft | 20,000 lb | | | | 1 |
| **Overhead: Semi Trailer**<br>**07 53-ft Flat Bed Trailer, Fontaine Phantom** | 2006 | 38,000 | 1,000,000 miles | 0.9 | 0.101 | | | 0.02 | 1 hr | 0 | | | | 53 ft | 9,200 lb | | | Unload, min | |
| **Overhead: Truck**<br>**01 Ford F350 1-ton w/service box** | 2006 | 35,865 | 300,000 | 0.25 | 0.101 | | | 0.2 | 1 hr | .06 gal/hr | | | 325 | | | | | | |
| **Overhead: Miscellaneous** | | | | | | | | | | | | | | | | | | | |
| **01 Office Equip. & Supplies** | 2007 | 62,894 | 5 yr | 0 | | | | | 1 hr | | | 0.02 | | | | | | | |
| **02 Lab Equip. & Supplies** | 2007 | 315,600 | 5 yr | 0 | | | | | 1 hr | | | 0.02 | | | | | | | |
| **03 Software** | 2007 | 9,700 | 3 yr | 0 | | | | | 1 hr | | | 0.1 | | | | | | | |
| **04 Mechanics' Tools** | 2007 | 20,000 | 5 yr | 0 | | | | | 1 hr | | | 0.01 | | | | | | | |

a. Fixed R&M Cost Factor

# Appendix B-2

# Modeled Equipment Specifications

# B-1. HARVEST AND COLLECTION

Table B-1. Harvest and collection equipment specifications for the Conventional Bale–Corn Stover and Switchgrass designs.

| | Grain Harvest Only | Condition/ Windrow Stover Residue | Condition/ Windrow Switchgrass | Baling | Move to Field Side (Roadsiding) |
|---|---|---|---|---|---|
| Equipment | JD 9670 STS combine with JD 608C 8-row corn header | Balzer 15-ft Flail Shredder with windrowing pulled by Case IH Puma 180 Tractor | Agco 9260 Windrower with 9180 disc header | Massey Ferguson 2190 baler pulled by Case IH Magnum 275 tractor<br>lg sq 4×4×8 ft | Stinger Stacker 5500 |
| Haul Distance | N/A | N/A | N/A | N/A | 0.5 mile |
| Rated Capacity[a] | 2000 bu/hr | 9.1 ac/hr | 12.7 ac/hr | 38 bale/hr | 90 bale/hr[a] |
| Field Efficiency (%)[a] | 70% | 80% | 80% | 80% | 80% |
| Dry Matter Loss (%)[b] | N/A | 29% | 10% | Stover = 46%<br>Switchgrass = 10% | 0% |
| Operational Window | | | | | |
| hr/day | 14.0 | 14.0 | 14.0 | 14.0 | 14.0 |
| day/yr | 36 | 36 | 36 | 36 | 36 |

a. See machinery capacity and efficiency calculations (Table 2-9).

b. Stover based on Richey et al., 1982; Switchgrass based on INL test data, switchgrass, and miscanthus harvest in Illinois, January 2008.

### Grain Harvest

The primary harvesting equipment for grain harvest is the combine (Table B-1). The basic functions of the combine are to (1) cut the biomass standing in the field, (2) separate the grain from materials other than grain (MOG); and (3) capture the grain while returning the MOG to the field. The combine can use a number of different headers that attach to the front of the combine and interface with the biomass standing in the field. For this design, the John Deere 9670 STS combine (Figure B-1a) is selected to be used with the John Deere 608C 8-Row Header (Figure B-1b). Key distinguishing characteristics of the corn header include a row-crop design developed to harvest corn at the standard 30-in. row spacing and downward-turning snapping rollers at the physical interface of the header and corn stalks. The purpose of these snapping rollers is to pull the corn plant down through the header in order to capture the ears while reducing the amount of MOG that enters the throat of the combine. It is this header design that primarily contributes to the format configuration of the stover prior to windrowing (Table 2-3).

(a) (b)

Figure B-1. (a) John Deere 9670 STS combine and (b) John Deere 608C 8-row corn grain header (Photos courtesy of John Deere).

**Conditioning/Windrowing Stover Residue**

In a standard corn grain harvest scenario, a significant amount of stover will remain standing in the field, and the MOG that passes through the combine will be deposited back onto the ground through the combine discharge spreader (assuming the combine is not equipped with a residue discharge chopper). A shredder/windrower follows the combining operation to break down the stover and collect it along with the MOG into a windrow. The basic shredder design has knives mounted on a rotor that is powered by the PTO of the draft tractor. This design uses a Balzer 15-ft flail shredder with windrowing (Figure B-2a) pulled by a Case IH Puma 180 four-wheel drive tractor, which provides 180 gross hp and 150 PTO hp (Figure B-2b). The rotating shredder knives cut the standing biomass ~8 to 10 in. above the ground and pull materials resting on the field surface into a windrow. The windrow is formed through collision-induced momentum and a vacuum effect created by the high rotational speed of the rotor and knives. The windrow will field-dry for hours to days and will then be ready for baling.


(a) (b)

Figure B-2. (a) Balzer 15-ft flail shredder with windrowing which, in the Conventional Bale model, is pulled by a (b) Case IH Puma 180 four-wheel drive tractor.
Tractor photo provided courtesy of Case IH (www.caseih.com).

**Conditioning/Windrowing Switchgrass**

For switchgrass, the windrowing operation begins with the standing crop. The equipment selected in this design is a Hesston 9260 self-propelled windrower (Figure B-3). The basic functions of the windrower are to (1) cut the biomass standing in the field, (2) condition the biomass by moving it through a set of crimping rollers, and (3) return the cut and conditioned biomass to the field in a windrow. The windrow will field-dry for hours to days and will then be ready for baling.

Figure B-3. Hesston 9260 self-propelled windrower swathing switchgrass at the University of Illinois Champaign Urbana field trials.

**Baling**

There are several bale formats that can be selected to collect the field-dried biomass from the windrow. The baler is pulled behind a tractor, and the baler's mechanical systems are powered by the tractor's PTO drive. The baler is equipped with a pick-up system that pulls the biomass from the windrow up into the stuffer, which packs the biomass into the compaction chamber. The material is then compacted into a bale, and once the bale has reached the cut-off length, the baler ties the bale together with six poly twine strings. This design uses a Massey Ferguson 2190 4×4×8-ft large square baler pulled/powered by a Case IH Magnum 275 tractor (Figure B-4). The Magnum 275 has a 275 gross hp tractor with 225 PTO hp.

Figure B-4. Massey Ferguson 2190 large square baler (4×4×8-ft bales) and Case IH Magnum 275 tractor.

**Collection and Roadsiding**

The bale accumulator attachment was not used in this design; thus, the tied bale is ejected randomly onto the field surface from the pressure of the next bale being formed. Random bale distribution is acceptable and even desirable for the efficient operation of automated bale collection and stacking equipment. Automated collection and stacking equipment picks up bales on-the-go, and the forward momentum of the stacker is necessary to properly orient and slide the bale into the pickup mechanism (Figure B-5a).

The Stinger Stacker 5500, a self-propelled bale collection and transport system, is used in this design for bale collection, transport, and stacking. With a full stacking deck that holds eight large square bales (4×4×8-ft), the Stinger can stack bales up to four rows high using hydraulic bale dumps (Figure B-5b). During standard operation, the Stinger dumps twice to unload. During the first dump, the top four bales are retained on the upper portion of the deck while the bottom four bales are unloaded from the bottom bale deck. The bottom bale deck then resets, and the top four bales slide into the bottom deck position and are placed in the stack.

In this design, the bales are loaded into a bale plastic wrapping system for storage rather than stacked by the stacker. The stacking rack gate is released, and while the machine stays in motion, the bales simply slide off the bale deck onto the ground at the unload point. Because the bales are not being stacked, the stacker can transport nine bales instead of eight to the unload point during each collection cycle. Stacking/wrapping then occurs as part of the storage unit operation.

(a)

(b)

Figure B-5. Stinger Stacker 5500 (a) picking up and (b) stacking bales.

While Conventional Bale harvest and collection processes are functionally simple, there are many equipment selection options. A primary consideration in equipment model selection is the rated machine capacity relative to the number of acres to be harvested within the operational harvest window of the crop and region (Table B-2). There are other factors to take into account in the equipment selection process, such as user preference, serviceability, and equipment features, which are not included in our analysis.

Table B-2. Storage equipment specifications for the Conventional Bale design.

| | Stacking | Weather Protection | Storage |
|---|---|---|---|
| Equipment | Caterpillar TH220B telehandler | Stinger 4000 cube-line wrapper | None |
| Haul Distance | N/A | N/A | N/A |
| Rated Capacity[a] | 120 bale/hr | 120 bale/hr | 200 ton/site |
| Operational Efficiency (%)[b] | 67% | 67% | N/A |
| Dry Matter Loss (%) | 0% | 0% | 5%[c] |
| Operational Window | | | |
| hr/day | 14.0 | 14.0 | 24[d] |
| day/yr | 36 | 36 | 365[d] |

a. Estimate of the operating time that is actually spent working and the amount of capacity used.
b. Published efficiency input into the analysis model (Appendix A).
c. Dry matter loss for wrapped bale storage.
d. Assumes that all biomass is wrapped and held in storage for 1 full year, which is a recognizably conservative assumption.

A telehandler is used to make a two-high bale stack by picking up one dropped bale and stacking it upon another dropped bale. The telehandler then picks up the two-high bale stack and loads it into the wrapper. The Caterpillar TH220B telehandler is the self-propelled loader used for bale handling in this design scenario (Figure B-6). As demonstrated in the picture, this machine has a rated load capacity of 7,000 lb and can be outfitted with a fork system appropriate for moving bales two at a time. The loader arm telescopes, and with the four-wheel drive steering, the TH220B can be used to move bales into the stack needed for the bale wrapping system.

Figure B-6. Caterpillar TH220B Telehandler.

Bale wrapping is performed with the Stinger 4000 Cube-Line Wrapper (Figure B-7). The Cube-Line 4000 will wrap 4×4×8-ft bales stacked two high (Conventional Bale design scenario), 3×3×8-ft/3×4×8-ft bales stacked three high, or single rows of round bales. The bales are loaded onto the Cube-Line platform in two-high stacks, and the wrapper pulls the stack through the wrapping hoop. The hoop rotates around the stack, using rolls of the wrapping plastic to completely encompass the bale stacks. With continuous supplying of the two-high bale stacks on the Cube-Line platform, the result is a row of fully wrapped bales (one-bale-wide by two-bales-high) as shown in Figure 2-10.

Figure B-7. Stinger 4000 Cube-line Wrapper.

Transportation and handling equipment specifications for the Conventional Bale design are shown in Table B-3.

Table B-3. Transportation and handling equipment specifications for the Conventional Bale design.

| | Unstack/Unwrap, Load, and Clean-up | Transport |
|---|---|---|
| Equipment | Caterpillar TH220B telehandler | Kenworth T800 3-axle Day Cab with Fontaine Phantom 53-ft Flat Bed Trailer |
| Rated Capacity | 100 bale/hr | N/A |
| Field Capacity | 80 bale/hr | 6.4 ton/hr[a] |
| Operational Efficiency (%)[b] | 80%[c] | 46%[d] |
| Dry Matter Loss (%) | 0% | 0% |
| Operational Window | | |
| hr/day | 14.0 | 14.0 |
| day/week | 6 | 6 |
| week/year | 50 | 50 |

a. Assumes a 38.2 mile haul distance at 50 mph and a 28-min strap time.

b. Estimate of the operating time that is actually spent working and the amount of capacity used.

c. Ratio of field capacity to rated capacity.

d. Calculated efficiency from the analysis model based on the operating time that is actually spent hauling and the amount of capacity used.

### Unstack/Unwrap, Load, and Site Clean-up: Telehandler

A Caterpillar TH220B Telehandler is used to unstack the bales, load the semi-trailer, and clean-up the storage site. This piece of equipment is shown in Table B-6. In addition to a telehandler, a standard dump truck will haul the waste plastic wrap to a disposal site (i.e., landfill). The process of site cleanup, including the use of a dump truck, is not modeled individually, but instead is included in the cost of the bale wrap process. Disposal costs are based on the following assumptions: 2 lb of plastic wrap/bale, a landfill charge of $35/ton, and a handling and transport cost of $35/ton, for a total disposal cost of $0.07/bale.

### Transport: Semi-Tractor and Trailer

The semi-tractor used in this design scenario is the Kenworth T800 3-axle day cab. It is configured with a 450-hp Caterpillar engine satisfactory for pulling a bale-loaded Fontaine Phantom 53-ft flat bed trailer (Figure B-8). The trailer is 102 in. wide and supports six rows (positioned lengthwise with the trailer) of two-high and two-across bale stacks with a seventh row of two-high bales stacked on the back of the trailer perpendicular to its length. This configuration allows for a total of twenty-six 4×4×8-ft bales per load. At 53-ft in length, the trailer pulled with the T800 will function within all U.S. federal and state vehicle length road limits. Receiving equipment specifications for the Conventional Bale design are shown in Table B-4.

Figure B-8. Kenworth T800 3-axle semi-tractor and the Fontaine Phantom 53-ft flat bed trailer used to transport twenty-six 4×4×8-ft square bales.

Table B-4. Receiving equipment specifications for the Conventional Bale design.

| | Receiving | Unload and Stack | Bale Yard Queuing |
|---|---|---|---|
| Equipment | Scales Unlimited, Inc. Model Agets-11711-Ntep Semi-truck Scale | Caterpillar Th220B Telehandler | 826,500 $Ft^2$ (~20-Acres) 3/6/12 Asphalt Pad |
| Rated Capacity | 15 truck/hr | 100 bale/hr | 13,714 bales |
| Field Capacity | 11 truck/hr; 2,667 DM ton/day | 80 bale/hr | 6,857 DM tons; 11,900 bales |
| Operational Efficiency (%)a | 75% [b] | 80% [b] | N/A |
| Dry Matter Loss (%) | 0% | 0% | 0% |
| Operational Window | | | |
| hr/day | 14.0 | 14.0 | 24.0 |
| day/year | 300 | 300 | 300 |

a. Estimate of the operating time that is actually spent working and the amount of capacity used.
b. Published efficiency input into the analysis model (Appendix A).

The truck scale implemented in this design scenario is the AGETS-11711-NTEP model from Scales Unlimited, Inc. (Figure B-9). This model is an above-ground unit with a weight capacity of 100 ton. It is 11-ft wide and 130-ft long. The truck net weight (weight of bales only) will be determined with the truck scale by weighing loaded trucks as they arrive at the receiving area (gross weight) and then subtracting the weight of the unloaded truck (tare weight). The tare weight of a truck will be taken after each load, even though the same truck may make several deliveries per day. Preprocessing and conversion equipment specifications for the Conventional Bale design are shown in Table B-5.

Figure B-9. Scales Unlimited, Inc. AGETS-11711-NTEP truck scale.

Table B-5. Preprocessing and conversion equipment specifications for the Conventional Bale design.

| | Load Grinder from Stack | Preprocessing | | | Bale and Twine Disposal |
|---|---|---|---|---|---|
| Equipment | Caterpillar TH220B Telehandler | Grinder In-feed System (Warren & Baerg D-Stringer, Conveyor) | Vermeer HG6000 Horizontal Grinder | Cyclone, Baghouse, and Other Conveying Equipment | Dump Truck |
| Rated Capacity | | | 17 ton/hr | | |
| Field Capacity | 45 bale/hr | 14.6 ton/hr | 14.6 ton/hr | 14.6 ton/hr | |
| Operational Efficiency (%)[a] | 92[a] | | 85[a] | | |
| Dry Matter Loss (%) | 0 | 0 | 0 | 0 | |
| Operational Window | | | | | |
| hr/day | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| day/year | 350 | 350 | 350 | 350 | 350 |

a. Estimated capacity based on the actual operating time and the amount of capacity used.
b. Published efficiency input into the analysis model (Appendix A).

A Caterpillar TH220B telehandler, described in further detail in Section 2.2.2 and shown in Figure B-6, is used to remove the bales from the queuing bale yard stacks and load the bales into a Warren & Baerg D-Stringer, which removes the bale strings and conveys an even flow of bales into the preprocessing grinder (Figure B-10).


Figure B-10. Warren & Baerg D-Stringer conveyor grinder in-feed system (Chariton Valley Project).

The Warren & Baerg D-Stringer conveyor feeds a Vermeer HG6000 horizontal grinder. The Conventional Bale design uses eight of these systems operating in parallel (Figure 2-32, note grinder stations B-G-101). The HG6000 is modeled with an equivalent 630 hp electric motor and has a 60-in. feed table with a 48-in. feed conveyor. The HG6000 has a feed throat height of 32 in. with a 36-in. diameter feed roller. The screen used in this scenario has 1 1/2-in. square openings. Figure B-11 shows a Vermeer HG365E electric horizontal grinder and shows what an equivalent HG6000 would look like if an electric version was in production. The model uses grinding performance parameters based on HG6000 data collected by INL but substitutes an equivalent electric energy use for the rated diesel horse power.


Figure B-11. Vermeer HG6000 630 hp Horizontal Grinder.[a]

Once the ground biomass passes through the screen, the material exits the grinder on a 48-in. continuous conveyer belt. Based on capacity and the need for redundancy, eight grinders were selected in this design (grinder configuration layout shown in Figure 2-32). The dust control system is a Koger A-B cyclone connected to a Farr GS-16 baghouse (Figure B-12). The cyclone is used as a pre-cleaner system for dust and particulate-laden air leaving the preprocessing operation. As part of a closed system, the cyclone separator reduces the final filter load before the dust-laden air moves to the attached baghouse. The cyclone used in this scenario has an inlet diameter of 20 in., a body diameter of 80 in., and a capacity of 9,150 cfm @ 2 in. static pressure (sp). In coordination with the cyclone unit, the Farr GS-16 baghouse serves as the final dust collection unit (Figure B-12). With this unit in the system, dust created and

a. Vermeer, http://www.vermeer.com/.

released during preprocessing is filtered from the air and captured. This process is important for two reasons: first, the dust is generally material with value in the conversion process, and second, dust release in ambient air is typically restricted through government regulation.

Figure B-12. High-efficiency cyclone and baghouse for dust control and filtering (Antares, 2008).

## B-2. ASAE FIELD EFFICIENCIES

Table B-6. Field efficiency, field speed, and repair and maintenance cost parameters.[a]

| | Field Efficiency (%) | | Field Speed (mph) | | Life (hr) | R&M[b] (%) | Repair Factors | |
|---|---|---|---|---|---|---|---|---|
| Machine/Equipment | Range | Typical | Range | Typical | | | $RF_1$ | $RF_2$ |
| TRACTORS | | | | | | | | |
| 2-wheel drive & stationary | | | | | 12 000 | 100 | 0.007 | 2.0 |
| 4-wheel drive & crawler | | | | | 16 000 | 80 | 0.003 | 2.0 |
| TILLAGE & PLANTING | | | | | | | | |
| Moldboard plow | 70–90 | 85 | 3.0–6.0 | 4.5 | 2 000 | 100 | 0.29 | 1.8 |
| Heavy-duty disk | 70–90 | 85 | 3.5–6.0 | 4.5 | 2 000 | 60 | 0.18 | 1.7 |
| Tandem disk harrow | 70–90 | 80 | 4.0–7.0 | 6.0 | 2 000 | 60 | 0.18 | 1.7 |
| (Coulter) chisel plow | 70–90 | 85 | 4.0–6.5 | 5.0 | 2 000 | 75 | 0.28 | 1.4 |
| Field cultivator | 70–90 | 85 | 5.0–8.0 | 7.0 | 2 000 | 70 | 0.27 | 1.4 |
| Spring-tooth harrow | 70–90 | 85 | 5.0–8.0 | 7.0 | 2 000 | 70 | 0.27 | 1.4 |
| Roller/packer | 70–90 | 85 | 4.5–7.5 | 6.0 | 2 000 | 40 | 0.16 | 1.3 |
| Mulcher/packer | 70–90 | 80 | 4.0–7.0 | 5.0 | 2 000 | 40 | 0.16 | 1.3 |
| Rotary hoe | 70–85 | 80 | 8.0–14.0 | 12.0 | 2 000 | 60 | 0.23 | 1.4 |
| Row-crop cultivator | 70–90 | 80 | 3.0–7.0 | 5.0 | 2 000 | 80 | 0.17 | 2.2 |
| Rotary tiller | 70–90 | 85 | 1.0–4.5 | 3.0 | 1 500 | 80 | 0.36 | 2.0 |
| Row-crop planter | 50–75 | 65 | 4.0–7.0 | 5.5 | 1 500 | 75 | 0.32 | 2.1 |
| Grain drill | 55–80 | 70 | 4.0–7.0 | 5.0 | 1 500 | 75 | 0.32 | 2.1 |
| HARVESTING | | | | | | | | |
| Corn picker/sheller | 60–75 | 65 | 2.0–4.0 | 2.5 | 2 000 | 70 | 0.14 | 2.3 |
| Combine | 60–75 | 65 | 2.0–5.0 | 3.0 | 2 000 | 60 | 0.12 | 2.3 |
| Combine (SP) | 65–80 | 70 | 2.0–5.0 | 3.0 | 3 000 | 40 | 0.04 | 2.1 |
| Mower | 75–85 | 80 | 3.0–6.0 | 5.0 | 2 000 | 150 | 0.46 | 1.7 |
| Mower (rotary) | 75–90 | 80 | 5.0–12.0 | 7.0 | 2 000 | 175 | 0.44 | 2.0 |
| Mower/conditioner | 75–85 | 80 | 3.0–6.0 | 5.0 | 2 500 | 80 | 0.18 | 1.6 |
| Mower/conditioner (rotary) | 75–90 | 80 | 5.0–12.0 | 7.0 | 2 500 | 100 | 0.16 | 2.0 |
| Windrower (SP) | 70–85 | 80 | 3.0–8.0 | 5.0 | 3 000 | 55 | 0.06 | 2.0 |
| Side-delivery rake | 70–90 | 80 | 4.0–8.0 | 6.0 | 2 500 | 60 | 0.17 | 1.4 |
| Rectangular baler | 60–85 | 75 | 2.5–6.0 | 4.0 | 2 000 | 80 | 0.23 | 1.8 |
| Large rectangular baler | 70–90 | 80 | 4.0–8.0 | 5.0 | 3 000 | 75 | 0.10 | 1.8 |
| Large round baler | 55–75 | 65 | 3.0–8.0 | 5.0 | 1 500 | 90 | 0.43 | 1.8 |
| Forage harvester | 60–85 | 70 | 1.5–5.0 | 3.0 | 2 500 | 65 | 0.15 | 1.6 |
| Forage harvester (SP) | 60–85 | 70 | 1.5–6.0 | 3.5 | 4 000 | 50 | 0.03 | 2.0 |

Table B-6. (continued).

| Machine/Equipment | Field Efficiency (%) | | Field Speed (mph) | | Life (hr) | R&M[b] (%) | Repair Factors | |
|---|---|---|---|---|---|---|---|---|
| | Range | Typical | Range | Typical | | | $RF_1$ | $RF_2$ |
| Sugar beet harvester | 50–70 | 60 | 4.0–6.0 | 5.0 | 1 500 | 100 | 0.59 | 1.3 |
| Potato harvester | 55–70 | 60 | 1.5–4.0 | 2.5 | 2 500 | 70 | 0.19 | 1.4 |
| Cotton picker (SP) | 60–75 | 70 | 2.0–4.0 | 3.0 | 3 000 | 80 | 0.11 | 1.8 |
| MISCELLANEOUS | | | | | | | | |
| Fertilizer spreader | 60–80 | 70 | 5.0–10.0 | 7.0 | 1 200 | 80 | 0.63 | 1.3 |
| Boom-type sprayer | 50–80 | 65 | 3.0–7.0 | 6.5 | 1 500 | 70 | 0.41 | 1.3 |
| Air-carrier sprayer | 55–70 | 60 | 2.0–5.0 | 3.0 | 2 000 | 60 | 0.20 | 1.6 |
| Bean puller/windrower | 70–90 | 80 | 4.0–7.0 | 5.0 | 2 000 | 60 | 0.20 | 1.6 |
| Beet topper/stalk chopper | 70–90 | 80 | 4.0–7.0 | 5.0 | 1 200 | 35 | 0.28 | 1.4 |
| Forage blower | | | | | 1 500 | 45 | 0.22 | 1.8 |
| Forage wagon | | | | | 2 000 | 50 | 0.16 | 1.6 |
| Wagon | | | | | 3 000 | 80 | 0.19 | 1.3 |

a. ASABE (American Society of Agricultural and Biological Engineers) (2006) Agricultural Machinery Management Data. ASAE D497.5.
b. Total lifetime repair and maintenance (R&M) costs as a % of equipment list price.

# Appendix C

# Nomenclature

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# Nomenclature

*20 in 10 Plan.* Plan outlined by President Bush in 2007, which proposes legislation to reduce gasoline consumption in the United States by 20% in the next 10 years (by 2017). This goal is nearly 5 times the current target. The plan outlines a portfolio of technologies, processes, and practices for energy production, and targets for improved rates of feedstock conversion and efficiency of energy use. It also states that a significant portion of the nation's 2017 energy supply, especially transportation fuel, will come from conversion of biomass feedstock to liquid fuels.

*30 × 30 Scenario.* Goal to reduce gasoline consumption in the United States by 30% by the year 2030.

*Advanced Uniform System.* A design concept which maximizes overall economic and energy efficiency by eliminating key equipment and meeting feedstock format targets early in the supply chain; this system eliminates multiple machinery operations and machinery by using single-pass harvesting systems standardizing all feedstocks to one format prior to delivery at the receiving gate using single-pass harvesting systems.

Having a biomass moisture content of < 15–20%, limiting the ability of organisms to live or grow where free oxygen is present.

*Ambient Temperatures.* The surrounding temperatures.

*Arching.* Problem decreasing the flowability of granular materials. Arching is where the material forms a bridge that supports the granular matter again preventing free-flow.

*Auger.* A rotating spiral shaft for conveying material.

*Baghouse Dust Collection System.* A system in which a chamber containing fabric filter bags removes particles from furnace stack exhaust gases; used to eliminate particles greater than 20 microns in diameter.

*Billion Ton Study.* Similar in scope to the 20 in 10 Plan and the 30 by '30 Scenario. It found that the biomass feedstock resource potential in the United States is more than sufficient to meet the 30 × 30 goal.

*Biofuel.* Fuel made from biomass resources, or their processing and conversion derivatives. Biofuels include ethanol, biodiesel, and methanol.

*Biomass.* An energy resource derived from organic matter. These include wood, agricultural waste, and other living-cell material that can be burned to produce heat energy. They also include algae, sewage, and other organic substances that may be used to make energy through chemical processes.

*Biomass Feedstocks.* Any organic matter that is available on a renewable or recurring basis, including agricultural crops and trees, wood and wood residues, plants (including aquatic plants), grasses, animal manure, municipal solid wastes, manufacturing wastes, and other residue materials. Biomass is generally produced in a sustainable manner from water and carbon dioxide by photosynthesis. There are three main categories of biomass – primary, secondary, and tertiary.

*Biorefinery.* A facility that processes and converts biomass into value-added products. These products can range from biomaterials to fuels such as ethanol or important feedstocks for the production of chemicals and other materials. Biorefineries can be based on a number of processing platforms using mechanical, thermal, chemical, and biochemical processes.

*British thermal unit (Btu)*. A non-metric unit of heat, still widely used by engineers. One Btu is the heat energy needed to raise the temperature of one pound of water from 60°F to 61°F at one atmosphere pressure. 1 Btu = 1055 joules (1.055 kJ).

*Bulk Density.* Weight per unit of volume, usually specified in pounds per cubic foot.

*By-product.* Material other than the principal product generated as a consequence of an industrial process or as a breakdown product in a living system.

*Capital Cost.* A fixed annual cost that includes fixed costs of annualized capital costs plus other fixed costs, such as machinery storage and insurance.

*Cellulosic.* Containing or derived from cellulose, which is A complex carbohydrate, (C6H10O5)n, that is composed of glucose units, forms the main constituent of the cell wall in most plants, and is important in the manufacture of numerous products, such as paper, textiles, pharmaceuticals, and explosives.

*Cereal Straws.* Wheat straw, barley straw, rice straw, soybean straw, etc.

*Conservation Reserve Program (CRP)*. CRP provides farm owners or operators with an annual per-acre rental payment and half the cost of establishing a permanent land cover in exchange for retiring environmentally sensitive cropland from production for 10 to 15 years. In 1996, Congress reauthorized CRP for an additional round of contracts, limiting enrollment to 36.4 million acres at any time. The 2002 Farm Act increased the enrollment limit to 39 million acres. Producers can offer land for competitive bidding based on an Environmental Benefits Index (EBI) during periodic signups, or can automatically enroll more limited acreages in practices such as riparian buffers, field windbreaks, and grass strips on a continuous basis. CRP is funded through the Commodity Credit Corporation (CCC).

*Conventional Bale System.* A primary objective that drives the conventional feedstock supply system (Conventional) design is the selection of technologies that are adaptable to existing local feedstock resources and biomass/forage infrastructures. Conventional designs represent feedstock supply system technologies, costs, and logistics that are achievable today for supplying lignocellulosic feedstocks to pioneer biorefineries. The general architecture of these designs locates the preprocessing operation inside the receiving gate of the biorefinery.

*Corn Stover.* See “stover.”

*Crop Residue.* There are two types of agricultural crop residues. Field residues are materials left in an agricultural field after the crop has been harvested. These residues include stalks and stubble (stems), leaves, and seed pods. Process residues are those materials left after processing of the crop into a usable resource. These residues include husks, seeds, bagasse, and roots. Crop residues can be used as animal fodder and soil amendment, and in manufacturing.

*Cyclone Separation.* A method of removing particles from a fluid stream without using filters. Rotation and gravity are used to separate mixtures of solids and fluids.

*Drag-Chain Conveyors.* Farm machinery that may have one or more endless chains to which flighting is mounted to drag bulk materials in a trough.

*Dry Biomass.* Biomass at a moisture concentration that is aerobically stable. For most biomass, this is typically less than 15 to 20% moisture wet-basis (w.b.). This biomass may be stored and handled without stabilization techniques due to its ambient aerobic stability.

*Dry Matter Loss.* In preprocessing, this is the quantity of feedstock material that is not recovered from dust emissions and equipment leaks during the fractionation and discharge processes.

*Dry Ton.* 2000 lb of moisture-free biomass.

*Energy Crop.* Crops grown specifically for their fuel value. These include food crops such as corn and sugarcane, and nonfood crops such as poplar trees and switchgrass. Currently, two energy crops are under development: short-rotation woody crops, which are fast-growing hardwood trees harvested in 5 to 8 years, and herbaceous energy crops, such as perennial grasses, which are harvested annually after taking 2 to 3 years to reach full productivity.

*Enzymatic Hydrolysis.* A chemical reaction or process in which a chemical compound reacts with water to break down polymers.

*Ethanol (cellulosic ethanol).* Also known as cellanol, it is a general term for ethanol fuel produced from lignocellulose, a structural material that comprises much of the mass of plants.

*Evenflow Bin.* Can be used as a holding container; allows for continuous flow of material.

*Feedstock.* A product used as the basis for manufacture of another product.

*Feedstock Supply System.* A system that exists to provide cellulosic feedstock to biorefineries.

*Flowability.* A measure of the capability of a liquid or loose particulate solid to move by.

*Flow Function (ffc).* Determined by using the yield strength of the material, measured as a function of consolidating stresses, and is a measure of the frictional properties of the material. Jenike (YEAR) proposes using the ratio of the maximum consolidating stress at steady state flow to the unconfined yield strength. Five flowability categories are identified ranging from hardened and non-flowing (ffc > 1) to free-flowing material (ffc>10).

*Forage.* Food for horses or cattle; fodder, provender.

*Forward-Deployed Preprocessing Unit.* A preprocessor (for example, a drier, densifier, or grinder) that formats biomass prior to conversion at the biorefinery.

*Fossil Fuels.* A hydrocarbon deposit, such as petroleum, coal, or natural gas, derived from living matter of a previous geologic time and used for fuel.

*Fractionation.* The process of dividing or separating into parts.

*Genomic.* Genetic.

*Glucan.* A polysaccharide; cellulose, starch, and glycogen are glucans.

*Grower Payment.* The financial compensation paid to the producer to cover the costs of producing the biomass.

*Herbaceous.* Not woody, but having the texture, color, etc. of an ordinary foliage leaf, such as grasses; generally dies back at the end of each growing season.

*Herbaceous energy crops.* Perennial non-woody crops that are harvested annually, though they may take two to three years to reach full productivity. Examples include: switchgrass (*Panicum virgatum*), reed canarygrass (*Phalaris arundinacea*), miscanthus (*Miscanthus x giganteus*), and giant reed (*Arundo donax*).

*Interstitial Moisture.* Water being held in the pores and tissues of bulk solid materials and is not easily evaporated out; not free water.

*Lignocellulosic Biomass.* Biomass composed primarily by lignin and cellulose. Examples of lignocellulosic biomass are all types of trees, grasses, agricultural residues such as corn stover, sugarcane bagasse, straw, etc.

*Live-Bottom Trailer.* An alternative to a dump truck, it has a conveyor belt in the bottom that pushes material out at a constant pace. The benefit is that there is no need to lift the tub as with a dump truck.

*Moisture content (MC).* The weight of the water contained in wood, usually expressed as a percentage of weight, either oven-dry or as received.

*Moisture content, dry basis.* Moisture content expressed as a percentage of the weight of oven-dry wood, i.e.: [(weight of wet sample - weight of dry sample)/weight of dry sample] × 100.

*Moisture content, wet basis.* Moisture content expressed as a percentage of the weight of wood as-received, i.e.: [(weight of wet sample - weight of dry sample) / weight of wet sample ] × 100.

*Moisture Free Basis.* Biomass composition and chemical analysis data is typically reported on a moisture free or dry weight basis. Moisture (and some volatile matter) is removed prior to analytical testing by heating the sample at 105°C to constant weight. By definition, samples dried in this manner are considered moisture free.

*Monte Carlo Analysis.* An analytical technique for solving a problem by performing a large number of trial runs, called simulations, and inferring a solution from the collective results of the trial runs.

*Operating Costs.* Operating costs are variable annual expenses that include fuel, general maintenance, and repairs.

*Perennial.* Plants which live for more than two growing seasons.

*Pioneer Uniform-Format System (a.k.a. Pioneer Uniform).* The Pioneer-Uniform system is a transition from the Conventional-Bale and Advanced-Uniform feedstock supply system, gradually incorporating technological improvements as they arise.

Preprocessing – An operation that formats biomass prior to conversion at the biorefinery. Preprocessing operations may include moisture management, size reduction, and densification, but does not include baling.

*Queue.* To form into a line.

*Rat-holing.* Allows material to tunnel through rather than flow evenly (when a channel forms).

*Residues.* Byproducts from processing all forms of biomass that have significant energy potential. For example, making solid wood products and pulp from logs produces bark, shavings and sawdust, and spent pulping liquors. Because these residues are already collected at the point of processing, they can be convenient and relatively inexpensive sources of biomass for energy.

*Rheology.* Science dealing with the deformation and flow of matter.

*Roadsiding.* The process of moving the collected biomass to a location that is generally next to a road that borders the field or is nearby.

*Salvage Value.* The expected selling price or trade-in value of the machine at the end of its ownership period.

*Screen Analysis.* Method for measuring a proportion of variously sized particles in solid fuels. The sample is passed through a series of screens of known size openings. Biomass fuel screen sizes usually range from 5 to 100 openings per inch.

*Senescence.* The combination of processes of deterioration which follow the period of development of an organism; aging.

*Sensitivity Analysis.* Examining the impact of changing one or more parameters or values on other parameters.

*Solid-State Fermentation.* A process in which an insoluble substrate is fermented with sufficient moisture but in the absence of free (liquid) water.

*Sorghum.* A genus of numerous species of grasses, some of which are raised for grain and many of which are utilized as fodder plants either cultivated or as part of pasture. The plants are cultivated in warmer climates worldwide.

*Stover.* Corn stalks, cobs, and leaves.

*Supply System Logistics.* The processes, capital, and operating costs associated with getting the stover resource from its production location to the in-feed system of the conversion process at the biorefinery.

*Switchgrass.* A panic grass (Panicum virgatum) of the western United States that is used for hay.

*Tamping.* To pack down lightly by tapping or using light blows.

*Ted.* To spread out in order to dry; scatter.

*Thermochemical conversion.* The use of heat to chemically change substances from one state to another, e.g., to make useful energy products.

*Tilth.* Refers to a soil’s ability to support root growth.

*Tipper and Hopper System.* These systems are used to unload trailers. A truck drives onto the tipper, which lifts the truck up on an angle and causes the material in the trailer to pour out into a hopper.

*Ton.* One U.S. ton (short ton) = 2,000 pounds. One Imperial ton (long ton or shipping ton) = 2,240 pounds. One metric tonne (tonne) = 1,000 kilograms (2,205 pounds). One oven-dry ton or tonne (ODT, sometimes termed bone-dry ton/tonne) is the amount of wood that weighs one ton/tonne at 0% moisture content. One green ton refers to the weight of undried (fresh) biomass material - moisture content must be specified if green weight is used as a fuel measure.

*Tub grinder.* A shredder used primarily for woody, vegetative debris. A tub grinder consists of a hammermill, the top half of which extends up through the stationary floor of a tub. As the hammers encounter material, they rip and tear large pieces into smaller pieces, pulling the material down below the tub floor and ultimately forcing it through openings in a set of grates below the mill. Various sized openings in the removable grates are used to determine the size of the end product.

*Turnkey.* A project in which separate entities are responsible for setting up a plant or equipment (e.g., trains/infrastructure) and for putting it into operation.

*Two-Stream System.* A system having more than one flow path.

*Uniform-Format System.* The fundamental premise of the Uniform-Format feedstock supply system design concept is that the high-capacity and high-efficiency supply logistic systems already exist (e.g., grain and petroleum crude) and that handling low-density/aerobically unstable material is inherently inefficient. As such, advanced implementations of the Uniform-Format concept employ 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.

*Walking-Floor Trailer.* A self-unloading trailer with a conveyor in the bottom that pulls material out. These trailers do not require tipping to be emptied.

*Waste Stream.* Unused solid or liquid by-product of a process.

*Wet Biomass.* Biomass at a moisture concentration that is aerobically unstable. For most biomass, this is typically greater than 15 to 20% w.b. Because of the entrained moisture, this biomass requires stabilization techniques to be implemented.

*Windrow.* Long rows of cut hay or grain left to dry in a field before being bundled.

*Windrower.* A farm implement used to mow a field and arrange the mown crop in windrows.

*Windrowers.* A farm implement used to mow a field and arrange the mown crop in windrows, which are long rows of cut hay or grain left to dry in a field before being bundled.

*Xylan.* A polysaccharide found in plant cell walls and some algae. It is found in almost all parts of the plant.