Final Report

Design and Demonstration of an Advanced Agricultural Feedstock Supply System for Lignocellulosic Bioenergy Production

April 2016

Prepared for:
The United States Department of Energy
Contract Number: DE-EE0001033

Prepared by:

ANTARES Group Incorporated

Antares Group, Incorporated
4500 Forbes Blvd, Suite 410
Lanham, Maryland 20706
(with significant contributions by the entire project team)

TABLE OF CONTENTS

TABLE OF FIGURES

1 ABBREVIATIONS

ASABE	American Society of Agricultural and Biological Engineers
BPT	Bale Picking Truck
CHST	Collection, Harvest, Storage, and Transportation
CMZ	Crop Management Zones
CVBP	Chariton Valley Biomass Project
DDGS	Distiller's Dried Grains with Solubles
DOE	U.S. Department of Energy
EERE	Department of Energy's Office of Energy Efficiency and Renewable Energy
EISA	Energy Independence and Security Act of 2007
ER	Erosion Factor
FDCE	FDC Enterprises, Inc.
FO	Field Operations Factor
FOA	Funding Opportunity Announcement
GIS	Geographic Information System
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
HDP	High Density Press
IBSAL	Integrated Biomass Supply and Analysis Logistics
INL	Idaho National Laboratory
JCB	J.C. Bamford Excavators Limited
KSU	Kansas State University
NPK	Nutrient Removal and Replacement
OEM	Original Equipment Manufacturer
OM	Organic Material (a.k.a. Biomass Factor)
ORNL	Oak Ridge National Laboratory
PTO	Power Take-Off
RFS	Renewable Fuels Standard
RUSLE2	Revised Universal Soil Loss Equation 2
SCI	Soil Conditioning Index
SLT	Self Loading Trailer
SOI	State of Industry
SPB	Self Propelled Baler
SSURGO	NRCS Soil Survey Geographic Database
USDA	U.S. Department of Agriculture
USDA-ARS	Agriculture Research Service
USDA-NRCS	National Resource Conservation Service
WEPS	Wind Erosion Prediction System
WSG	Warm Season Grasses

2 ACKNOWLEDGEMENTS

This project was managed by Antares Group, Inc. and FDC Enterprises, Inc. based in Landover, MD and Columbus, OH, respectively. It involved the efforts of a consortium of original equipment manufacturers (OEMs), end-users, researchers, consultants, and industry experts from across the nation. The accomplishments of this project are credited to the following entities that participated.

2.1 MANUFACTURING PARTNERS

Kelderman Manufacturing
Kelderman Manufacturing, Inc. was founded by Gary Kelderman in 1970 and is based in Oskaloosa, IA. They are known throughout the agricultural industry as one of the leading inventors of hay equipment, planter fold kits and rubber track systems for tractors and combines. Gary holds over 25 patents. Kelderman Manufacturing has been instrumental in the development, fabrication, and testing of custom harvesting and transport machinery to improve efficiency and performance of those operations. The Self Propelled Baler, Bale Picking Truck, and Self Loading Trailer would not exist without the innovation of Kelderman Manufacturing.

Freeman, a division of Allied Systems Company
Freeman, a division of Allied Systems Company is the OEM behind the 1592D Big Baler. The Freeman baler has always been at the forefront of baler design. From the introduction of one of the first automatic hay balers to the only self-propelled small baler on the market today. A dedicated engineering staff and flexible manufacturing team that are able to react to changing needs and design requirements make Freeman uniquely qualified to meet the needs of the biomass industry. Freeman provided a great deal of resources to the project team, including pull-type balers for testing, and engineering support staff for assistance during field demonstration activities.

MacDon Industries
MacDon Industries has 60 years of experience around the world serving grower's needs mostly in cutting forages for the livestock industry. In recent years this experience has included switchgrass, biosorghum, miscanthus, energy cane, arundo, and corn stover as biomass for various research projects across the US. They have taken seriously the need to mow and/or condition each of these crops in a manner which speeds crop dry down, reducing mowing field losses and efficiently putting the crop into a large evenly distributed windrow to enhance baler efficiencies. MacDon's wealth of expertise enabled them to design and fabricate the Heavy Crop Header, capable of mowing and conditioning dense energy crops for this project.

Vermeer Manufacturing
Based in Pella, IA, Vermeer has been successfully manufacturing quality farm, construction, and industrial equipment for more than 55 years. Vermeer manufactures a full line of haying equipment including large round balers, mowers, mower/conditioners, rakes, tedders, bale processors, silage wrappers, bale splitters, bale movers and hay handling equipment; plus a wide assortment of industrial equipment for tree, construction, environmental and underground utility service work. Vermeer supplied windrowing implements to assist the project team during harvest activities.

2.2 KANSAS-BASED PARTNERS

Abengoa Bioenergy
Abengoa Bioenergy (Abengoa) is a Spanish biotech ethanol company that is developing the first commercial-scale cellulosic ethanol biorefinery (12 million gallons per year) in the United States, located in Hugoton, KS. The company strives to become a reference as a world leader in the production of biofuels, and the development of innovative technological solutions that contribute to the sustainability of the transportation sector and in the production of bio-based chemicals

through respect for the environment, social development, and economic benefit. Abengoa supported project efforts by providing acres of corn stover to conduct equipment demonstration activities and by purchasing harvested material.

Kansas State University
Kansas State University (KSU) researchers are experts in sustainable agriculture. KSU conducted soil erosion and soil tilth-based analyses of biomass production from select agricultural crop residues and dedicated energy crops in select geo-climatic locations. Staff also provided input regarding certain field testing procedures.

2.3 FEDERAL GOVERNMENT PARTNERS

U.S. Department of Energy
The U.S. Department of Energy (DOE), through its Biomass Program, manages and provided federal cost-share funding for the Design and Demonstration an Advanced Agricultural Feedstock Supply System for Lignocellulosic Bioenergy Production. The project was launched with the assistance of a competitively awarded grant through the Department of Energy's Office of Energy Efficiency and Renewable Energy. Private-sector partners have provided over 50% cost share to match the federal funding.

Idaho National Laboratory
In operation since 1949, INL is a science-based, applied engineering national laboratory dedicated to supporting the U.S. Department of Energy's missions in nuclear and energy research, science, and national defense. The mission of the Idaho National Laboratory Bioenergy Program is to achieve the DOE vision of a national, commodity-scale feedstock supply system by developing processes and technologies—through applied science and engineering—that focus on:

- Supplying high-quality raw biomass,
- Preprocessing raw biomass into advanced bioenergy feedstocks, and
- Delivering bioenergy feedstock commodities.

INL assisted the project team by providing research support on biomass quality and recommending best management practices for sustainable biomass harvest, collection, and storage.

USDA National Resource Conservation Service (NRCS)
USDA NRCS provided staff from the Hayes, Kansas and the Stevens County, Kansas field offices to evaluate the appropriate stover removal rates. They also provided guidance on how to maintain biomass harvesting equipment settings ensure that adequate stover was left in the field to protect the soil from wind erosion. The NRSC staff explained the relationship between stover stubble height and soil type and the soils' wind erodibility.

2.4 CONSULTANTS AND OTHER PARTNERS

Antares Group, Inc.
ANTARES Group Inc. (Antares) is an engineering and development firm focused on bioenergy, renewable power, and energy efficiency projects. The company possesses a wide range of technical and analytical capabilities in electric power, cogeneration, and transportation technologies. The firm's senior principals collectively have more than 60 years of experience in developing power and transportation projects, all of which use improved conversion technologies and/or innovative resources. Antares helped to manage and coordinate all project activities including project scheduling, project management planning, harvest planning, budget and cost share management, and reporting.

FDC Enterprises, Inc.
FDC Enterprises (FDCE) leads the nation in grassland establishment services. Since 2003, it has established over 208,000 acres of native grasses across the nation. Its services also include mechanical woody removal, specialty herbicide

application, tree and shrub planting, and turnkey biomass supply services. As the project lead, FDCE supplied the manpower, equipment, and technical expertise to successfully harvest biomass feedstocks throughout the project.

Mendel Biotechnology
Mendel Biotechnology is a leader in developing high-yielding crops for sustainable bioenergy. The company has developed a durable seeded variety of miscanthus. Mendel provided the project team with access to their rare, high-value miscanthus research plots for harvesting demonstration activities.

TR Miles Consulting
T.R. Miles Technical Consultants, Inc. is a private consulting practice formed in 1997 to provide technical assistance primarily to industry for complete system design, product and process development for the wood and wood products, food, agricultural and energy industries. The firm continues the innovative consulting design engineering started by Thomas R. Miles, P.E., in 1947. T. R. Miles, Technical Consultants, Inc., retains specialized engineering firms when necessary for detailed design. T. R. Miles, Technical Consultants, Inc., and T. R. Miles, Consulting Design Engineer, have designed equipment that is used throughout the world. The special expertise of the firm is the development of energy conversion and materials handling systems for wood, straws and food processing residues. T. R Miles provided technical support throughout the project.

3 Project Scope and Objectives

The Department of Energy (DOE) awarded FDC Enterprises $4.9M to Design and Demonstrate an Advanced Agricultural Feedstock Supply System for Lignocellulosic Bioenergy Production. This project was awarded funding in order to help meet the requirements of the Energy Independence and Security Act of 2007 (EISA) Renewable Fuels Standard (RFS), which calls for the expansion of the domestic biofuels industry. The lack of logistics systems capable of handling and delivering sufficiently high tonnage year-round volumes of biomass feedstocks to support the rapid escalation of cellulosic biofuels production has been identified as a significant barrier to the expansion of a sustainable domestic biofuels industry. To help address and overcome this barrier, the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE), through its Office of the Biomass Program, released a Funding Opportunity Announcement (FOA) through which this project was selected for award. Specifically, the objective of the FOA was to stimulate the design and demonstration of a comprehensive system to handle the harvesting, collection, preprocessing, transport and storage of sufficient volumes of sustainably produced feedstocks required to achieve the rapid expansion of the nascent domestic, lignocellulose-based biofuels industry.

The 3-year project required FDC Enterprises and its team partners to design advanced biomass harvesting and transport equipment and demonstrate it in a commercial environment. The proposed equipment could significantly reduce the cost of supplying biomass to an end-user, which is one of the largest barriers to the bioenergy industry.

Based on extensive field testing and team member experience, the project team/consortium proposed to design, assemble, demonstrate, and refine a feedstock supply system for establishing and delivering dedicated agricultural energy crops and residue feedstocks to near-term cellulosic biorefineries. With minor modifications to storage strategies and techniques, this system would be transferable to any region of the country where biorefineries would rely upon agricultural (i.e., herbaceous) feedstocks. Economically maximizing harvest, staging, and delivery efficiencies, equipment reliability and operational life has been the driving objective for equipment/OEM (Original Equipment Manufacturer) selection and overall system design. The equipment designed, fabricated, and deployed for demonstration during this project would minimize labor, equipment, and fuel costs for delivering agricultural feedstocks to near-term biorefineries. The deployed system would significantly minimize the time and manpower required for biomass staging and retrieval operations (to and from interim storage locations). Compared to existing standard practices, the system would increase biomass density during all hauling and handling operations that are subsequent to harvest operations, thereby reducing fuel, labor, and equipment expenses associated with hauling and handling the biomass after harvest. All design and field operations would be conducted with consideration of the overall sustainability of the herbaceous crop feedstock supply chain. The primary targeted feedstock package will be high density large square bales (3 ft x 4 ft x 8 ft; 96 ft^3).

The project was divided into six primary tasks:

1. Equipment Design and Fabrication
2. Baseline Data Collection
3. Technical Stage Gate Review
4. Equipment Demonstration
5. Performance Evaluation
6. Project Management and Reporting

The project team/consortium had many accomplishments in each task. Some of the key accomplishments include: a fleet of advanced biomass harvesting and transport equipment was built and demonstrated; the project received high marks during a DOE peer review; equipment performance and cost data was monitored and recorded; and all project goals were accomplished on-budget with adequate cost share from project partners. An overview of the activities conducted and results from each task is provided throughout this report.

4 PROJECT BACKGROUND

4.1 TEAM GENESIS/BACKGROUND

The project team consists of a consortium of equipment manufacturers (OEMs), consultants, end users, and researchers with critical experience in biomass supply chain issues. Several of the team members conducted the scope of the Chariton Valley Biomass Project (CVBP) in Ottumwa, IA. This project demonstrated the suitability of switchgrass as a cofiring feedstock with coal at Alliant Energy's Ottumwa Generating Station (see Figure 1).

Figure 1. Ottumwa Generating Station

During this multi-year cooperative agreement with the Department of Energy (DOE), a 3 month, 24/7 test burn was conducted to demonstrate the processing and delivery system that was built on-site. This demonstration provided the industry with data and key lessons learned, which are regularly cited in industry publications. Takeaways from that biomass processing and infeed system influenced the current design of biomass infeed systems in today's processing facilities. The CVBP team gained a wealth of knowledge as to what is required to maintain a robust supply chain and what systems and equipment are required to support a commercial biomass industry.

4.2 TEAM EXPERIENCE

Abengoa is one of the key members of our project team, and their Hugoton biorefinery is the initial target for the biomass feedstock supply system developed in this project. Due to the extensive experience of our proposed team members in areas including perennial grass establishment, harvesting, storage, transportation, processing, equipment design and fabrication, business planning and operations, environmental impacts assessment and permitting, agricultural plant research, and agricultural outreach, nearly all of the members of the project team had been working closely with Abengoa since the early development stages for their Hugoton biorefinery. The objectives of the development and demonstration activities for this feedstock supply system are aimed at expediting the commercial availability of new equipment which will enable biomass end users to obtain their biomass feedstocks using the most cost-effective and reliable supply system possible in the near term.

Abengoa is a world leader in ethanol production and renewable energy project development. Their commercial-scale biorefinery in Hugoton, KS finished construction in 2014. This biorefinery includes an Enzymatic Hydrolysis plant for the production of ethanol and crude lignin, a biomass gasification plant for the production of fuel gas, and a cogeneration plant for the production of steam and power. The integration and flexibility of the biorefinery are intended to improve opportunities to replicate the plant in different geographical areas. The plant was originally designed to consume about 1,360 dry metric tons per day, or about 560,000 as-received tons per year (at 15% moisture content). Abengoa originally targeted multiple feedstocks near Hugoton, including corn stover, wheat straw, and prairie grasses such as switchgrass. However, while crop residues are expected to play a significant role in the early biomass supply for the refinery, in order to reduce their feedstock supply risks and maximize supply uniformity Abengoa planned to increase the fraction of their feedstocks that were obtained from dedicated energy crops as early as possible. These crops required establishment from a grass land establishment firm; FDC Enterprises (FDCE) fulfilled this role.

The project team is led by FDCE, the nation's leading native grass establishment company. FDCE operates in over 15 states, and has an existing business that is closely tied to activities that will be required for ramping up rapid expansion of energy crop production (i.e., the establishment of those crops on large-acre annual areas, with a guaranteed first-year installation success policy), and is adept and sophisticated in their in-field computer monitoring, reporting, and multi-regional farm equipment deployment capabilities. FDCE worked with other team members to extend their in-field computerized monitoring and controls to include systems, which will be important for harvest and environmental reporting purposes.

The project's OEMs were selected to be a part of the team because of their demonstrated foresight and innovation to develop and conceptualize the heavy-duty, industrial grade and highly efficient equipment that is required to minimize overall supply system production/operational costs and environmental impacts. Industry-leading OEMs on our team include:

- **Allied Freeman** (industrial grade hydraulic balers, roadsiding[1] vehicles for high density large square bales)
- **MacDon** (harvest innovation, including self-propelled windrowers, draper headers, pick-up headers, etc.)
- **Kelderman Manufacturing** (a leading innovator in the agricultural industry, including development of a self-propelled baler, rubber track systems for combines and tractors, corn harvesting attachments, hay raking equipment, air suspension systems, custom-built vehicle chassis, etc.)

Our core project team also includes two consulting firms with extensive experience and focus on biomass feedstocks and project applications: TR Miles Technical Consultants Inc. (formerly a lead technical reviewer for the Annual Review process for the Department of Energy's Biomass Feedstocks Program), and Antares Group Inc. (a national leader providing biomass feedstocks supply studies and technology assessments for project developers, electric utilities and ethanol producers, industry associations, and government clients).

Large-acre harvest field access for the full range of feedstocks sought for demonstration activities for this project was secured from Abengoa's local corn growers (corn stover), Mendel Biotechnologies (miscanthus), and FDCE & Kelderman Manufacturing (switchgrass). Harvest demonstration support and related technical analysis was provided by Idaho National Laboratory staff, FDCE, Kelderman Manufacturing, and Allied Freeman. The project's end-user of the material harvested and handled throughout this project was Abengoa in Hugoton, KS.

[1] Roadsiding: The act of picking up bales that lie in the field and moving them to the side of the field, typically near the field entrance, to be loaded onto an over-the-road truck and trailer; or, temporarily stacking bales from a field near the entrance of the field as a temporary storage system.

5 EQUIPMENT DESIGN AND FABRICATION

It is the consortium's belief that no single OEM offers the full range of equipment required to optimize overall biomass feedstock supply system efficiency and reliability. As such, several OEMs were involved in the effort. Critically needed upgrades to existing harvest and delivery systems that have been developed and demonstrated in this project include the development and demonstration of a single-pass harvest system utilizing a purpose-designed cutting header(s), a self-propelled baler, a bale picking truck, and a self-loading trailer. The key objectives included;

- Design, development and fabrication of improved headers that are optimized for cutting and handling the types of herbaceous feedstocks targeted by this effort, particularly the high-yielding biomass crops such as miscanthus and biosorghum.
- Improvement of an industrial grade baler capable of producing high density large square bales, and able to withstand at least five years of high-capacity operation (2000 or more hours per year) between replacements.
- Design, development and demonstration of an improved self-propelled, hydraulically actuating baler to maximize baling efficiencies over a range of terrains and field conditions and minimize overall equipment costs.
- Design, development and fabrication of a new type of Bale Pick-up Truck (BPT) and a new bale hauling trailer (Self Loading Trailer, or SLT), which will combine to significantly automate bale pick-up and delivery and drastically reduce staging time and labor requirements.

The project team proposed to design and fabricate or improve new and existing pieces of equipment under this project. These included the following:

- Self Propelled Baler, by Kelderman Manufacturing
- Bale Picking Truck, by Kelderman Manufacturing
- Self Loading Trailer, by Kelderman Manufacturing
- Heavy Crop Header, by MacDon Industries
- Freeman 1592D "Big Baler" Large Square Baler, by Allied-Freeman

5.1 SELF PROPELLED BALER

The Self Propelled Baler (SPB) is made up of a large square baler integrated into a chassis that contains all of the power and drive components. The SPB was designed to incorporate multiple windrowing implements, such as rakes or draper headers. Thus it can windrow and bale material in a single pass through the field.

The SPB entered the project in 2009 as a working prototype designed and built by Kelderman Manufacturing. By the project's end, it had evolved into a commercially viable single pass harvesting machine. Figure 2 illustrates its transformation from 2009 to 2011.

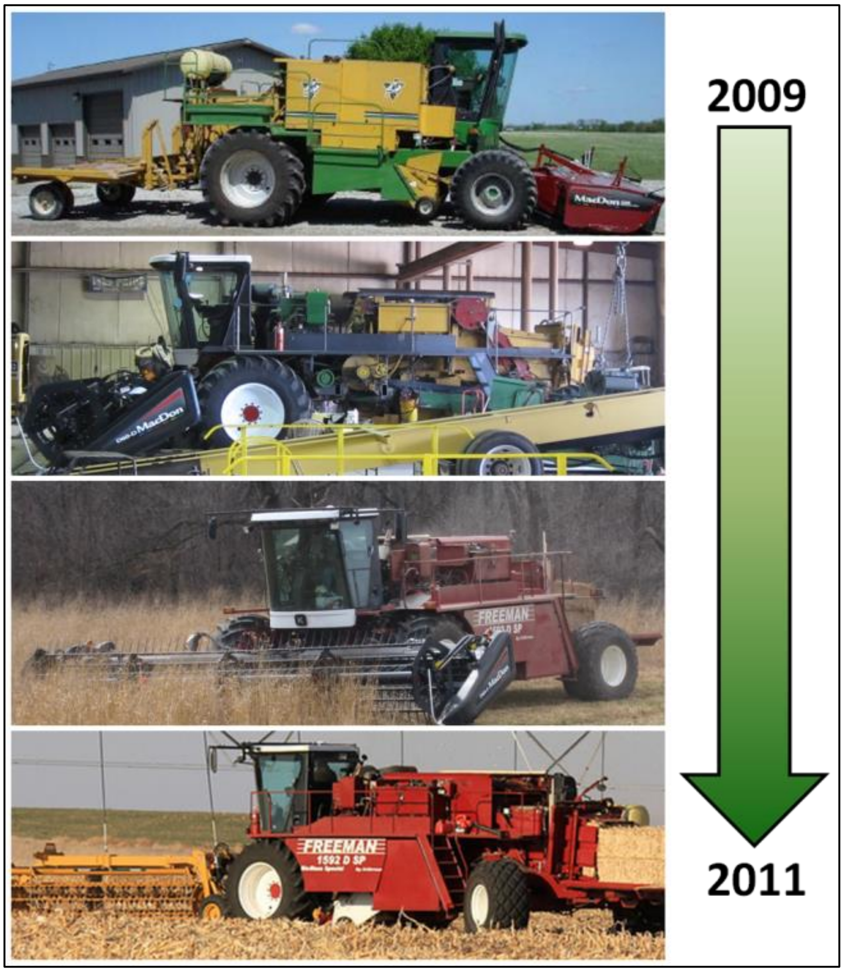

Figure 2 – Evolution of the Self Propelled Baler

The graphic in Figure 2 shows the changes made to SPB. The modifications made to the SPB during the project are summarized below:

- **Steering Modification** – The axles were reversed, allowing the machine to be steered from the rear wheels only, in the same manner as a conventional combine. This major modification provides field efficiency benefits and also minimizes field travel and soil compaction by greatly reducing the turning radius at the end of harvest rows.
- **Chassis Extension** – The chassis was extended approximately 4 feet from front to back.
- **Double-tie Knotting System** – A double-tie knotting system was installed to the baler to accommodate high density bale production.
- **Twine Bin Holder Modification** – The twine storage bins have been modified to hold twenty-four "large balls" of twine. This allows for continuous operation over a 24 hour period between twine restocking stoppages.
- **MacDon Draper Header Installed**– A mounting bracket was fabricated and installed to mount a standard MacDon draper-header to the front of the SPB. A 30' draper header rides on an airbag suspension system. A hydraulic system was also installed to allow the operator to adjust the header height and approach angle.
- **Cab Modification** – The operator's cab was moved forward for better visibility and mounted on an airbag suspension system.

- **Cat-walk Modification** – The safety catwalk was redesigned to allow easier access to key baler systems, and to accommodate a larger fuel tank.
- **Bale Accumulator Upgrade** – The bale accumulator was upgraded with a load cell driven scale which allows for bale weights to be observed in the cab and recorded during operation.
- **Rear-view Camera** – A camera was installed to allow the operator to monitor the bale accumulator for proper operation.
- **Fuel Tank Upgrade** – The size of the fuel tank was increased to 325 gallons, which will allow 24 hours of operation without refueling.

All of these modifications were completed prior to the first scheduled demonstration activities in Southwest Kansas in the Fall/Winter of 2010.

5.1.1 Front-mounted Attachments

Kelderman Manufacturing worked with other project OEMs to develop front-mounted windrowing implements for the SPB. Three implements were developed: MacDon Draper Header, Vermeer R2800 Basket Rake, and Miller Tedder Rakes. The windrowing attachements allow the SPB to harvest standing biomass such as standing warm season grasses or agricultural residues and forage crops laying flat on the ground prior to baling. MacDon Industries worked with Kelderman Manufacturing to ensure that its front-mounted MacDon draper header was optimally configured for single-pass operations. The MacDon D60-S header is 40', enabling the baler to harvest vast swaths of standing biomass in a single pass, as shown in Figure 3.

Figure 3 – Kelderman Self Propelled Baler with Front-mounted MacDon Draper Header

Vermeer Corporation worked with Kelderman Manufacturing to modify its R2800 basket rake to be outfitted to the front of the SPB. This implement is traditionally used in a pull-type manner, where it is towed behind a tractor. Kelderman and Vermeer engineers adapted it as a first-of-its-kind front-mounted implement. This hydraulically-controlled rake can be adjusted from the cab of the SPB during operations to adjust for field conditions. The resulting machine, shown in Figure 4, allowed the SPB operator to harvest agricultural residues and forage in a single pass.

Figure 4 – Kelderman Self Propelled Baler with Front-mounted Vermeer R2800 Basket Rake

Tedder rakes are commonly used in forage production to windrow material ahead of baling. This style of rake was also modified to be front-mounted to the SPB, as shown in Figure 5. The rake has a width of 19 – 22 feet and folds inward and secured for transportation.

Figure 5 – Kelderman Self Propelled Baler with Front-mounted Miller Tedder Rake

A summary of demonstration activities and results is provided on page 7-43 of this report.

5.1.2 Freeman 1592D Baler Module

The baler module on the SPB is manufactured by Freeman, a division of Allied Systems Company. This hydraulically powered module is industrial grade and is proven to have a two to three times the life expectancy of a mechanically powered baler. This increased life expectancy is due to the hydraulic operation of the baler and the ruggedness of its parts. This baler module was improved during the project as part of a separate task discussed in Section 5.5 of this report.

5.2 BALE PICKING TRUCK

When the different biomass Collection, Harvest, Storage, and Transportation (CHST) operations were evaluated for improvement areas, roadsiding and transportation were identified as high cost-saving areas. Conventional equipment was not performing at the level necessary to meet the needs of a burgeoning industry. Kelderman Manufacturing identified this gap and invented a novel concept for an industrial-scale roadsiding technology that would revolutionize the way that large square bales are handled after baling. The Bale Picking Truck (BPT) was designed to be a self-propelled machine that enabled a single operator to load bales of biomass from the field to a location at the side of the field where they can be staged or loaded onto a truck for transport. A conceptual drawing of the BPT in operation is provided in Figure 6.

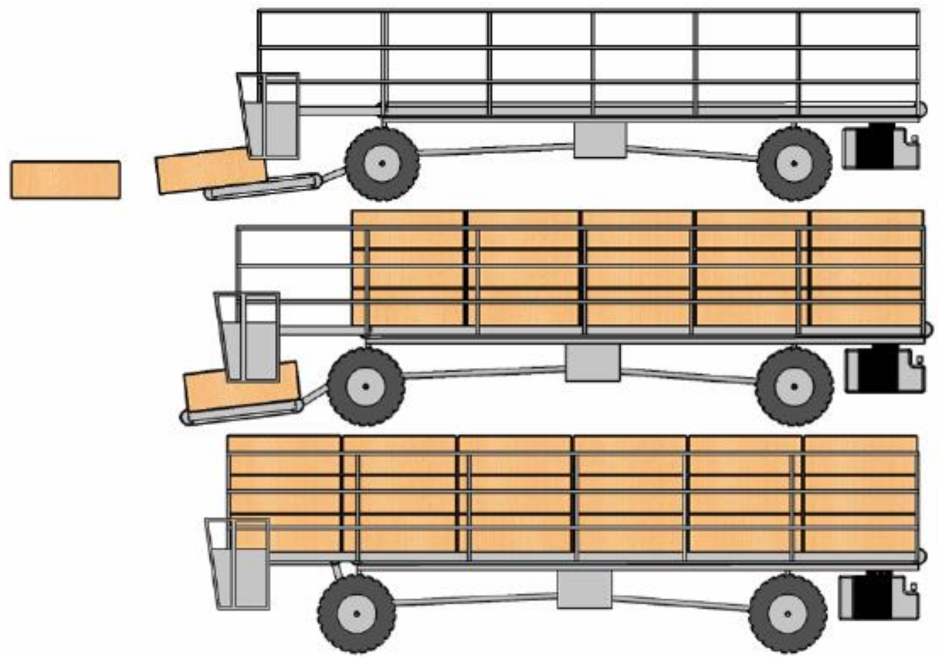

Figure 6 – Simplified Concept Drawing of the Bale Picking Truck

As shown in Figure 6, the BPT is designed to pick up the bales from the ground and create a truckload of large square bales (36 – 42 bales) measuring 3' wide, 4' tall, and 8' – 9' long. Conventional roadsiding implements are limited in the number of bales they can carry at one time, typically up to 12 per trip. With this method the bales will need to be rearranged with a loader for transport. The BPT is purposed to solve both of these issues for industrial harvesting applications. The drawing in Figure 6 conceptually shows how the BPT achieves this. First, it has the capacity to carry up to forty-two bales[2] in a single load, 350% more than conventional equipment. Secondly, it modularizes the bales. The BPT picks up bales and arranges them into six-packs, stacks of six bales (2 wide x 3 tall). Up to seven six-packs can be carried at one time in a module (arranged set of 36-42 bales stacked 3 bales high). Once a module is made, it is dropped at a roadsiding location for pickup.

The BPT is optimized when used in conjunction with the Self Loading Trailer (SLT), also developed during this project. Conventionally, bales are loaded onto a truck by a loader, six bales at a time. The module created by the BPT is designed be equal to one truckload of bales that can be loaded directly or picked up by the SLT in one step. If the bale density is maintained properly during baling, the module weight will equal the maximum load weight of the transport trailer.

Fabrication began on the BPT in the summer of 2011 and was completed in the summer of 2012. Figure 7 shows its evolution during fabrication. All of the design, development, and fabrication activities were performed by Kelderman Manufacturing in Oskaloosa, IA.

[2] The conceptual drawing only shows 6 six-packs (36 bales total) however the final design is capable of hauling up to 42 bales per load.

Figure 7 – Evolution of the Bale Picking Truck

Soil compaction is an important concern of agricultural producers. Repeated paths through the field or hauling heavy loads through a field cause this compaction. Soil is compacted when a weight of the load is transferred through the tires and onto the soil surface and is directly correlated to the size of the load and the surface area of the tire that meets the ground. Hauling a full module of bales over agricultural terrain could increase the risk of soil compaction. To counter this issue, Kelderman Manufacturing designed the BPT with eight (8) "field tires" commonly used on agricultural equipment. These tires provide a total surface contact area of 6,440 in^2. A BPT with 36 bales, weighing ~1,000 pounds each, would have a gross vehicle weight of ~90,000 pounds. Thusly, the pressure applied to the soil under that load would receive 14 psi (pounds/in^2). For comparison, grain carts and combine harvesters that are regularly used in grain harvesting have much heavier footprints of 35-40 psi. The BPT is shown during demonstration activities in Figure 8.

Figure 8 – Bale Picking Truck in Use during Commercial Operations

A summary of demonstration activities and results is provided on page 7-45 of this report.

5.3 SELF LOADING TRAILER

The Self Loading Trailer (SLT), built by Kelderman Manufacturing, was designed to reduce the time required as well as the cost of transporting large square bales of biomass. These savings come from the SLT's ability to load and unload a module of up to 42 bales without the aid of other equipment. Figure 9 illustrates how it was designed to accomplish this.

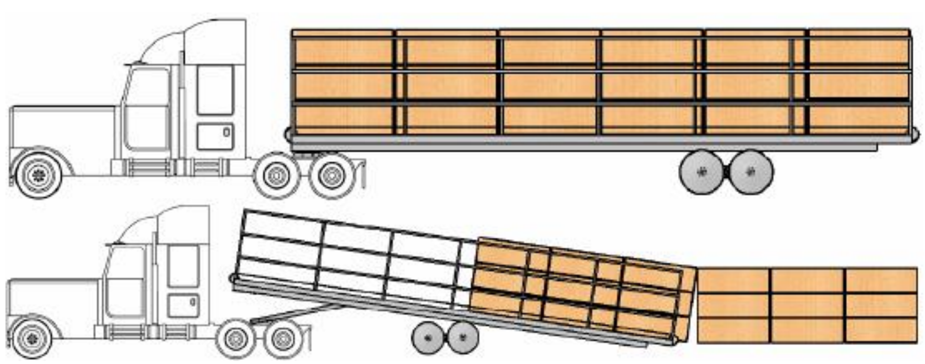

Figure 9 - Simplified Concept Drawing of the Self Loading Trailer

As shown in Figure 9, the SLT can elevate its bed to pick up or unload bales at a proper angle. Three generations of the SLT have been built to date. Figure 10 compares the original conceptual design sketch to the completed prototype trailer in operation.

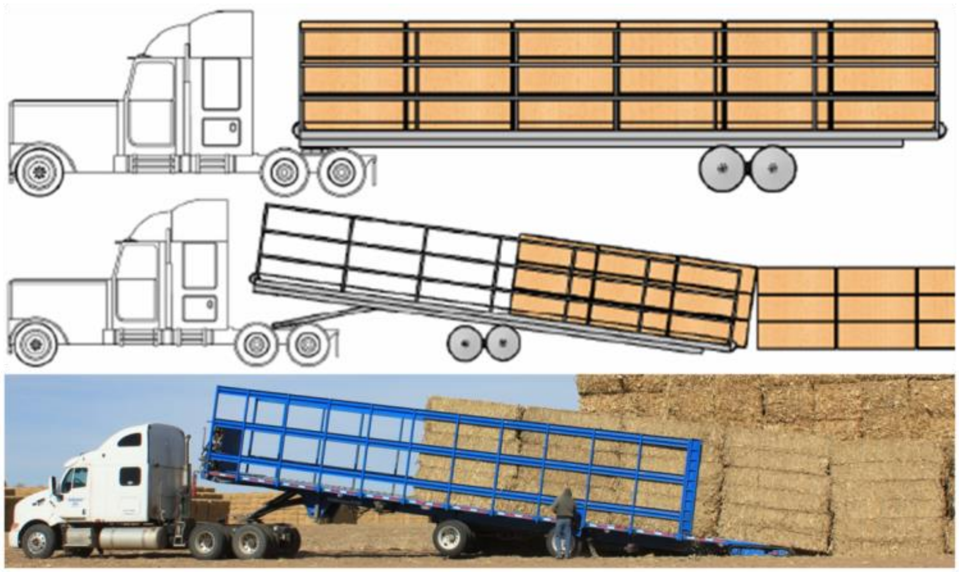

Figure 10 – Self Loading Trailer Concept Design to Finished Prototype, designed in 2010

The final design of the 1st generation self loading trailer was completed and construction on the initial prototype of the Self Loading Trailer began in September 2010. Fabrication was completed in the fall of 2011. Figure 10 compares the conceptual diagrams to the prototype unit in operation. All of the design, development, and fabrication activities were performed by Kelderman Manufacturing in Oskaloosa, IA. The bed of the 1st generation trailer utilizes toothed drag chains to grab and move the module of bales on and off of the bed. The trailer is fitted with a rack system to hold the bales in place. The racks ensure that the bale module stays tight and eliminates the need for strapping. The loading/unloading mechanism (see Figure 11) utilizes rubber tracks that are fitted onto the back end of the trailer where it meets the ground. These tracks are what move the trailer under or out from under a module of bales. All of the trailer's components are powered by hydraulics and controlled by the truck driver.

Figure 11 – Close-up View of the Loading/Unloading Mechanism

Once a bale module has been loaded, the bed of the SLT is raised back to it horizontal transport position and it is ready for transit. No strapping is required. A loaded SLT in operation is shown in Figure 12.

Figure 12 – 1st Generation Self Loading Trailer with a Full Load

Demonstration and testing of the prototype revealed a number of challenges with the bed design, specifically the use of drag chains to move the bale module on and off of the bed. This design, while effective, required more maintenance and was less reliable. The toothed drag chains were made up of hundreds of individual chain-links that stretched over time requiring regular shortening and tensioning. Reliability became an issue when the bulk density of the bales being loaded by the trailer were too low (<~11 lb/ft^3). Bales with a low bulk density are not packed tightly enough for the drag chains to adequately "grip" the bales and move them. In these instances, the chains would rip through the bottom of the bales, diminishing the integrity of the bales and causing jams and plugs on the trailer bed. The side-rails were also problematic during testing. These rails contained large gaps between the vertical structural beams that could block incoming bales as they were being loaded. This would occur when a stack of bales was picked up and not aligned adequately in parallel with the bed.

After substantial testing in the field, Kelderman Manufacturing implemented considerable design improvements in its 2nd Generation SLT, shown in Figure 13.

Figure 13 – 2nd Generation Self Loading Trailer, designed in 2012

The 2nd generation SLT was redesigned with several improvements. The drag chain bed was replaced with a walking floor, the side rails were replaced with a uniform box-style paneling, and the loading/unloading mechanism was decoupled from the rubber tracks that assist the loading/unloading operations. The photo in Figure 13 shows the SLT in loading mode with the loading/unloading bed lowered into position to receive bales from a loader. The loading/unloading bed is designed to fold up and lock into place. This reduces the trailer's overall length while providing a gate to secure the load.

Figure 14 – 2nd Generation Self Loading Trailer in Transport Mode

The trailer walls allow the bales to slide into and out of the trailer with ease. They also allow the trailer to haul bulk material, such as ground biomass to an end user. With this design, the same trailer could deliver a load of bales to a biorefinery and then haul away the biorefinery's distiller's dried grains with solubles (DDGS)[3]. These modifications improved performance and flexibility for use in different applications.

In 2013, Abengoa commissioned a 3rd generation SLT to use at its cellulosic ethanol biorefinery in Hugoton, KS. This iteration is shown in Figure 15.

Figure 15 – 3rd Generation Self Loading Trailer, designed in 2013

The 3rd iteration of the SLT was designed to meet the specifications of Abengoa's biomass handling system. The biomass receiving and processing station at the facility is designed to receive material directly from SLTs. This trailer cannot load material directly from the ground; it must be loaded by another bale handling loader. However, this SLT still provides the improved time efficiencies from lack of strapping and by unloading directly onto the biomass processing lines.

Direct Transfer of Full Truckload from BPT to SLT

The BPT and SLT were designed to work together in tandem to move full truckloads of baled biomass in the most efficient manner possible. The best example of their efficiency is with the direct transfer of a truckload of material from the BPT to a receiving SLT. This operation is showcased in Figure 16. Demonstration tests revealed that this direct transfer could be done in approximately 3 minutes under normal operating conditions.

Figure 16 – Direct Transfer of a Module of Bales from the BPT to a SLT

[3] Distiller's dried grains with solubles (DDGS) are the nutrient rich co-product of dry-milled ethanol production, which are typically sold as livestock feed.

The 2nd and 3rd generation SLTs were designed and tested to ensure that they could receive material directly from the BPT, as shown in Figure 16.

5.4 MACDON HEAVY CROP HEADER

5.4.1 MacDon Heavy Crop Header Background

MacDon offers a wide array of combinations of self propelled and pull-type implements which cut the crop with a sickle or rotary disc and convey the crop laterally into a windrow by auger, draper or rotary disc system. Their exclusive draper head technology is being deployed widely today both in the hay industry as well as on combines harvesting small grains in the United States and across the globe.

Windrowing technology needed to evolve in order to meet the growing demand of dedicated energy crops such as miscanthus, biosorghum, energy cane, and arundo. MacDon staff believe that a windrower header different from the standard design was needed to handle this type of production in a sufficiently fast, power efficient, and mechanically sound manner. The experience MacDon had logged harvesting both of these crops yielded valuable insight into developing an entirely different cutting and conditioning operation to handle these crops across a wide variety of climatic conditions. This prior experience revealed several barriers to using existing conventional equipment to harvest biomass. Energy crops presented a new set of challenges for windrowing that needed to be addressed, including:

1. Windrowing after freeze & winter harvest
2. Harvesting very stiff or frozen stalks (green stalks are more limber and can bend in the header.)
3. Cutting stubble higher when most forage is cut close to ground.
4. Conditioning very tall crops by crushing the stems and orientating them in the windrow to optimize baler pick up efficiencies
5. Minimizing dirt in windrow
6. Handling the abrasiveness of biofuel crops, not seen in forage crops harvested with conventional windrowing equipment
7. In 2008, tests in energy sorghum at Texas A&M with a conventional 13’ MacDon R-80 Rotary windrower, shown in Figure 17, revealed significant losses between rows. 6” to 8” stubble contributed to this loss but high cut is needed to reduce collection of dirt.

Figure 17 – Conventional 13' MacDon R-80 Rotary Windrower

In 2009, a conventional windrower, shown in Figure 18, was used to harvest energy sorghum, which grows up to 20' tall and has stalks 1 3/8" in diameter. By October, the crop falls down in tangled manner. These tests revealed severe losses and very poor capacity. Photos from these tests are provided in Figure 18.

Figure 18 – MacDon Conventional Windrower Attempting to Windrow 20' Tall Energy Sorghum

A 2009 miscanthus harvest in Illinois used a MacDon pull-type A-30 Windrower, shown in Figure 19.

Figure 19 – Testing a Conventional A-30 Windrower Miscanthus

This harvest showed that rigid miscanthus stems must be conditioned to enable balers to pick them up. Current model windrower field speeds were extremely limited (unacceptable for commercial harvest) and the conditioning of stems was very marginal. As such, MacDon began to design the Heavy Crop Header that would be capable of properly conditioning and windrowing these energy crops.

MacDon began testing different variations of the test header in energy sorghum and miscanthus in 2010. The test header capacity in energy sorghum was very good, but effective conditioning declined above 2 mph. These experiences revealed that there was an inability to dry most energy sorghum sufficiently for baling before the crop would spoil.

Figure 20 - MacDon Test Header in Texas Energy Sorghum

In 2011 and 2012 MacDon was able to test its header in mature miscanthus stands developed by Mendel Biotechnology. During the 2012 miscanthus harvest (see Figure 21), the test header demonstrated excellent capacity. However, miscanthus stems were too difficult to condition above 2 mph with the current power to the conditioner.

Figure 21 - MacDon Test Header in Mendel Miscanthus

MacDon upgraded the components in the test header to finalize its design of the Heavy Crop Header. The final version and its key features are highlighted in the subsequent discussion on page 7-42.

5.4.2 Key Features of the MacDon Heavy Crop Header

MacDon's goals were to develop a header that could cut at 4 to 5 mph with almost no plugging in all crop conditions as well as consistent conditioning along the full stem without unconditioned sections between nodes. The new header has a super heavy duty extended tine action pick up reel with extremely long tines and almost 4 times power to each foot of reel has been adapted to this new test header. The cutter bar can be moved to different distances from the auger. Extremely tall, robust vertical sickles cut through thick, tangled crops that extend beyond the ends of the header (especially energy sorghum). A very high adjustable lean bar is mounted near the top of the vertical sickles and a simple tall crop angled divider is on each end of the lean bar. An alternative auger lean bar has also been developed and tested.

Hydraulic drives to all components offer an opportunity to monitor pressures to help establish the level of power required to each component. Power to the reel has been almost quadrupled and almost doubled to the conditioner to cope with the super heavy bioenergy crops. Extensive studies of conditioner roll designs were performed to determine proper conditioning at 4 to 5 miles per hour.

The final implement was built and ready for testing in 2011. The prototype header is shown in Figure 22.

Figure 22 – Final Prototype of the Heavy Crop Header

Additional features of the Heavy Crop Header include:

1. 14' auger header that includes reel
2. Heavy reel & tines with 4 times power
3. Robust vertical sickles with high lean bar
4. Different conditioner roll bar design
5. All-hydraulic drives to monitor power to each component.

5.4.3 Future Improvements

MacDon successfully designed, tested, and upgraded its prototype header and determined what would be required to optimize the design for commercial operation. The primary upgrade needed in a future model is an improved ability to condition the crop at higher field speeds for both miscanthus and energy sorghum. Additionally, in good standing crop conditions, the vertical sickles may not be required so an alternative high lean bar mount would be required.

At this time, there is no major harvest of dedicated biofuel crops for cellulosic ethanol (only crop residue for the existing cellulosic ethanol processing facilitates), and there are no known plans for a major increase in dedicated cellulosic crops in the immediate future. As a result of limited known future potential of after-frost harvest of switchgrass, miscanthus, and other biofuel crops including energy cane, MacDon does not have plans to put the header into commercial production at this time. Refinement of a header and conditioner for windrowing after-frost rigid stem crops (switchgrass, miscanthus, etc.) is difficult for MacDon to justify based on limited potential of major dedicated cellulosic production for the immediate future. However, when dedicated cellulosic crop production begins to grow and a need for the Heavy Crop Header exists, MacDon will create commercial development plans.

5.5 IMPROVED INDUSTRIAL GRADE BALER

The Freeman 1592D was selected to be improved because of its potential to last much longer than existing pull-type large square balers. This baler features a hydraulic plunger system, which improves the reliability, durability and longevity of the baler module. The exclusive hydraulic drive system uses hydraulic relief valves instead of shear bolts to protect the baler during operation. This hydraulic plunger only strokes when the chamber is full, insuring a constant density bale. This feed system allows the free flow of material through the feed chute directly into the bale chamber. The feed system is reversible from the tractor seat, saving hours of labor time unplugging the baler. The baler is built with a rugged and a durable frame with replaceable wear liners and a remote control for operating the baler from the ground to make adjustments. The 1592D bale size is 38” x 46” x 96”. A photo of the 1592D being used during corn stover harvesting is shown in Figure 23.

Figure 23 – Freeman 1592D Baling Corn Stover

5.5.1 Big Baler Background

Freeman has manufactured over 600 Freeman Big Balers since 1984. This model is designed for large-scale commercial hay baling applications. Many Freeman Big Balers have produced over 500,000 bales during their service life, which is 10 times higher than other conventional square balers (over half have achieved this milestone, and some have over 1,000,000 bales). The Big Baler is unique due to its “On-demand” Plunger Control. The plunger is the part of the baler module that moves through the bale chamber and compresses the biomass into a densified bale. The plunger and flow of incoming material is shown in the diagram in Figure 24.

Conventional large square balers utilize a fly wheel to power the baler. This design requires the plunger and other key baler components to run continuously, causing unnecessary wear to the machine. The plunger on the Big Baler only plunges when the baling chamber is full. As such, there is less wear and a much longer service life. Additional benefits of this design include:

- Less frequent maintenance
- Less energy used = Less fuel used
- Uniform bale density (consistent flake size)
- When the power take-off (PTO) is idling the baler can be shut-off (less wear on the other assemblies)
- Reversible (feed fork, feeder) for unplugging which reduces the time to unplug baler and the pickup assembly

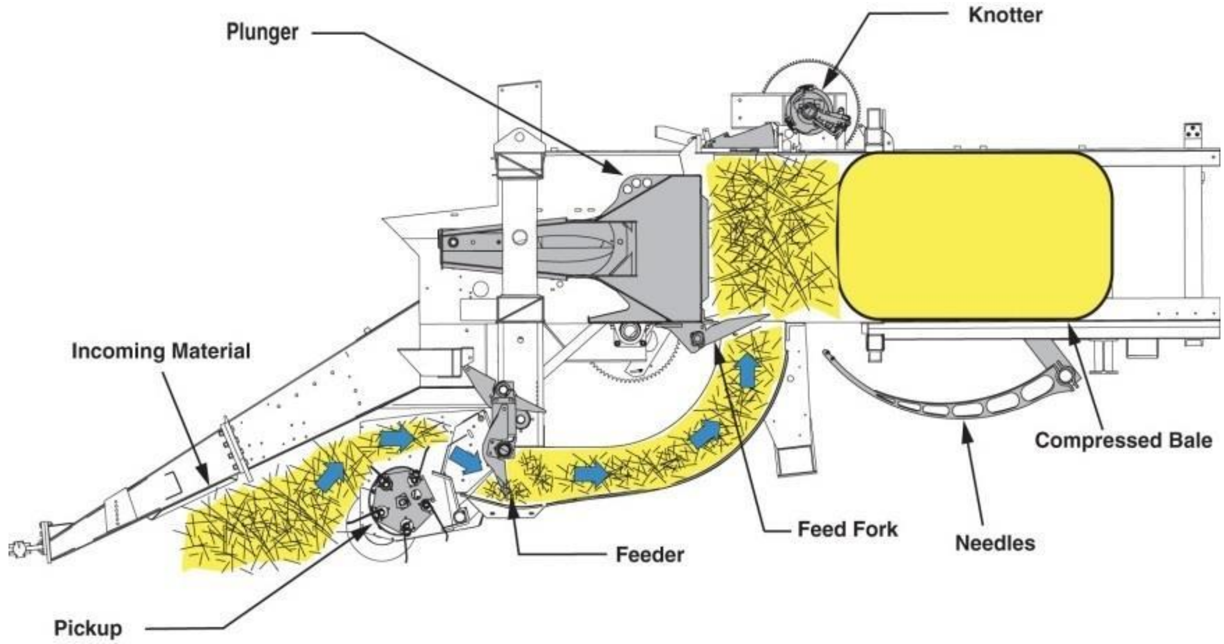

Figure 24 - Key Features of the Freeman Big Baler

5.5.2 Improvement Objectives

For its role in the project, Freeman worked to improve the existing Big Baler model into a more rugged and industrialized baler capable of reliably baling energy crops. The company planned to develop a list of operating issues for improvement and evaluate the overall reliability of the existing Freeman Big Baler design through performance tests in commercial biomass harvest operations. The information learned from these tests would then allow Freeman to develop a Big Baler configuration suitable for a production-based biomass application.

5.5.3 Equipment Demonstration

Freeman provided three of its test balers to FDC Enterprises to harvest corn stover during the harvest demonstrations of 2010, 2011, and 2012 near Hugoton, Kansas and miscanthus harvesting in Kentucky (see Figure 25).

Figure 25 – Freeman 1592D Baler Harvesting Miscanthus

Daily baling reports were given on the balers performance during that day including, production, maintenance issues, parts replaced, and downtime. The data from 2010 was used to develop the basis for future improvements. The main issues identified during those harvests are summarized for each assembly in Figure 26.

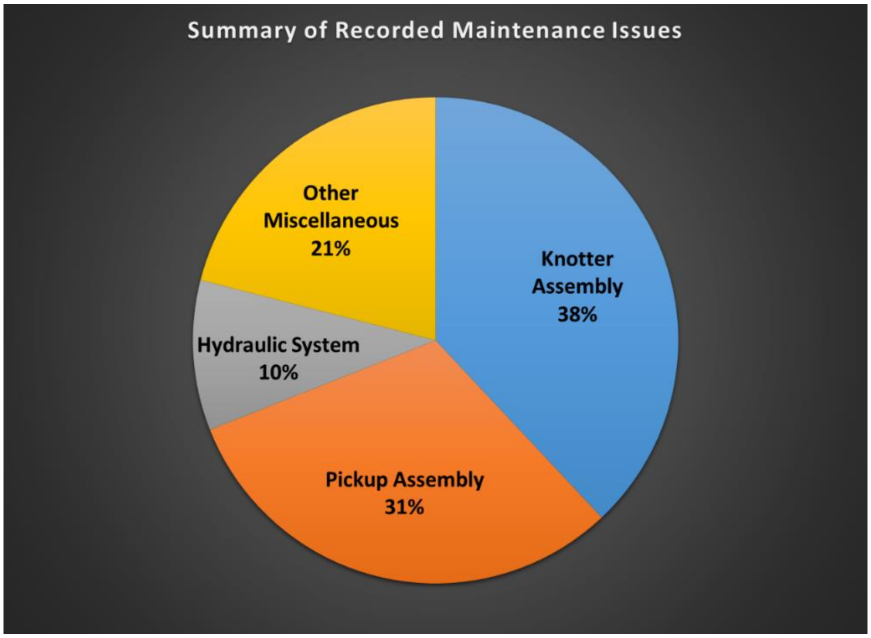

Figure 26 – Summary of Recorded Maintenance Issues

The majority of maintenance events and downtime was due to the knotter assembly, pickup assembly, and hydraulic system malfunction. As such, these areas were targeted for ongoing improvement for the duration of the project. Afterward, Freeman upgraded these assemblies to address the problems and continued to test these upgrades with each subsequent harvest operation in 2011. Similar results from the 2011 harvest were not available for comparison.

5.5.4 Future Improvements

Freeman continued work on the balers throughout the project and made plans for continual improvement of the baler reliability in each of the identified problem areas (knotter assembly, pickup assembly, and hydraulic system). Other future improvements will include: 1) increased bale density to at least 12.5 lb/ft^3 for corn stover; 2) improved reliability of the knotter from a reduction in the amount of debris that causes miss-ties; 3) improved reliability of the fingers and strippers in the pickup assembly.

5.6 EQUIPMENT DEVELOPMENT SUMMARY

The equipment manufacturers produced many innovations as a result of this project. Each machine that was proposed to be part of the project was designed, fabricated, tested, and upgraded throughout the project period. Each innovation has either been made available for commercial purchase or shelved for future market needs. The Heavy Crop Header was demonstrated and proven by MacDon's engineering team. The header will be put into production when a market for high-density dedicated energy crops is needed. Allied-Freeman continues to market the Improved Large Square Baler and the Self Propelled Baler. Kelderman Manufacturing has manufactured and sold several Self Loading Trailers and it actively looking for opportunities to manufacture and distribute its Bale Picking Truck.

The subsequent chapters of this report discuss the demonstration activities and evaluation of each machine.

6 BASELINE DATA COLLECTION

Baseline cost and performance data was compiled for each harvest and logistics operation in order to characterize the cost savings that would be achieved by the advanced biomass harvest and logistics equipment. Publicly available custom rate cost data was collected to document current market rates for large square bale harvesting (windrowing, baling, and roadsiding), storage (loading and unloading before and after transport), and transportation. This activity was completed during the first 2 years of the project.

Conventional harvest, storage, and transport equipment was used in Southwest Kansas to harvest corn stover and build upon the existing baseline dataset. Critical performance and cost data was recorded on a field basis. Wherever possible, this data was collected for each piece of equipment and operation, and summarized by operation and field. Performance and cost data from these harvest activities were compiled in conjunction with the publicly available data to create the cost basis for a conventional square bale feedstock supply chain. Performance data collected from each field included:

- Average Field Rate (acre/hr)
- Total Bale Count
- Total Tonnage
- Bale Weight (lb) and Bulk Density (lb/ft^3)
- Fuel Consumption (gal/ton, gal/hr, and gal/acre)
- Total Time in Field (hrs)
- Average Field Speed (mph)
- Average Loading & Unloading Time (min) (transport operations)

The cost data was collected and summarized by each of the following categories:

- Labor
- Fuel
- Equipment (Rental or Cost of Capital)
- Baleyard Operations
- Transportation

6.1 BASELINING APPROACH AND METHODOLOGY

Baselining activities were planned and conducted during the first year of the project prior to the Stage Gate review. Data collection included modeling the costs based on published data and in-field data collection. A thorough analysis of existing literature and datasets was performed to collect cost and performance data. This included a survey of available data from custom rates listings as well as published American Society of Agricultural and Biological Engineers (ASABE) equipment rates. Data was also collected from infield operations conducted during the project.

The baseline data collection effort focused on compiling and recording data for four primary feedstock supply operations: Windrowing, Baling, Roadsiding, and Transport. The harvest data gathered during this project was compared with the Kansas Custom Rates (2009) dataset,[4] which provided the average reported cost of each harvesting operation.

Baseline harvesting activities were conducted in the fall of 2010. These harvests utilized conventional windrowing, baling, and roadsiding equipment to harvest corn stover in southwest Kansas. Approximately 3,084 tons of corn stover were

[4] http://www.nass.usda.gov/Statistics_by_State/Kansas/Publications/Custom_Rates/custom09.pdf

harvested on roughly 1,800 acres. Some photos of these harvesting activities and the equipment used are shown below, in Figure 27 through Figure 30.

Figure 27 – Vermeer Basket Rake and Freeman 1592D Baler

Allied-Freeman manufactures the 1592D Big Baler. This pull-type baler is known for its industrial grade and extended life compared with other pull-type balers. The manufacturer has conducted years of field testing with their balers to determine the long term reliability of the equipment. These tests looked at what maintenance/parts related issues or design changes could be implemented to lengthen the lives of those balers. Data from this testing was included in the baseline data collection effort. Multiple rake designs were demonstrated during windrowing operations, including Vermeer basket and wheel rakes, as well as an H&S Wheel Rake.

Figure 28 – H&S Wheel Rake

A Krone HDP baler was also tested alongside the Freeman balers during corn stover harvests.

Figure 29 – Krone HDP Baler

Bales were roadsided using a Stinger Stacker 6500 roadsiding truck (Figure 30) and stored at the side of the field.

Figure 30 – Stinger Roadsider

When ready for pickup, a loading crew travels to the field with a telehandler (loader) and truck and trailer to load and deliver the bales to storage. Figure 31 – shows the loader preparing bales for loading onto a truck for transportation.

Figure 31 – Telehandler

Once loaded onto the waiting trailer, the loads were secured with strapping and transported to a baleyard for storage. Figure 32 shows an example of a loaded trailer being readied for transport.

Figure 32 – Loaded flatbed trailer

6.2 BASELINE COST MODELING

In order to determine the current state of the industry (SOI), a thorough review of published cost data was conducted. These data were then modeled for a biorefinery that would consume approximately 560,000 tons/year, based on real world experience from the Chariton Valley Biomass Project, Gary Kelderman's (Owner of Kelderman Manufacturing) alfalfa harvesting operations, FDC Enterprises, and custom harvesters. The resulting cost model calculated the approximate delivered cost of biomass based on the available data.

A primary driver of the cost of operations is the size of the harvest and delivery fleet. The team used equipment cost and performance data to determine the number of machines that would be required to provide Abengoa's fuel supply. The cost data was pulled from Iowa State University's Machinery Cost Calculator[5] and 2009 Kansas Custom Rates[6]. Performance data gathered from results published by ASABE (in ASAE D.497[7]) was used as the basis for machinery capital and operating costs. The data (summarized in Figure 33) was used to model the cost of a typical conventional harvest operation.

Figure 33 – Conventional Harvest and Transportation Equipment Cost Basis

ASABE Machinery Maintenance Rates Comparison; D497 standard					Lifetime Repair costs			Oil Consumption ($20/g)		
Equipment	Purchase Price	Rated HP	Expt. Life	lifespan (hrs)	(% of purchase price)	(dollar basis)	Hourly Basis	Gallons/ hr	Hourly Basis	Total R&M, Oil hourly basis
Tractor										
JCB 3230	$ 135,000	230	4	16,000	80%	$ 108,000	$ 6.75	0.05	$ 1.03	$ 7.78
Windrowing Equipment										
Vermeer Basket Rake	$ 21,900	0	2	2,500	60%	$ 13,140	$ 5.26	0.00	$ -	$ 5.26
Balers										
AGCO 7434	$ 124,960	0	3	3,000	75%	$ 93,720	$ 31.24	0.00	$ -	$ 31.24
KRONE 1290 HDP	$ 175,000	0	3	3,000	75%	$ 131,250	$ 43.75	0.00	$ -	$ 43.75
Freeman 1592	$ 250,000	0	3	3,000	75%	$ 187,500	$ 62.50	0.01	$ 0.11	$ 62.61
Roadsiders										
Stinger	$ 178,021	350	2	2,500	80%	$ 142,417	$ 56.97	0.08	$ 1.51	$ 58.48
Transportation										
Telehandler	$ 78,000	80	5	8,000	75%	$ 58,500	$ 7.31	0.02	$ 0.43	$ 7.75
Flatbed Trailer	$ 75,000	0	4	4,000	50%	$ 37,500	$ 9.38	0.00	$ -	$ 9.38

Other datasets were added in order to model "Pioneer" equipment and "Advanced" equipment. Where conventional equipment includes off-the-shelf equipment that is readily available from a local agricultural equipment dealer, "Pioneer" equipment consists of Industrial-grade pull-type balers with longer lifespans than traditional balers, advanced roadsiders, and advanced transport trailers. The "Advanced" equipment dataset is based on advanced harvest and transportation equipment only. The operating costs for "Pioneer" and "Advanced" machinery were based on preliminary field-data collection and estimates provided by the equipment manufacturers. The calculated costs for these are summarized in Figure 34 on a per-ton basis.

[5]Iowa State University Extension and Outreach, Department of Economics. Ag Decision Maker: http://www.extension.iastate.edu/agdm/crops/html/a3-29.html

[6] Kansas Department of Agriculture. Custom Rates 2009: http://www.nass.usda.gov/Statistics_by_State/Kansas/Publications/Custom_Rates/custom09.pdf

[7] American Society of Agricultural and Biological Engineers. ASAE 497.7: Agricultural Machinery Management Data, March 2011. https://elibrary.asabe.org/abstract.asp?aid=36431

Figure 34 – Summary of Modeled Harvest Costs

Source Description	Harvested Cost * $ per ton	Machinery Included
Conventional Equipment/Methods (Modeled)	$ 59.88	Typical balers, stinger roadsiders, flatbed trailers, telebooms with squeeze for loading/unloading trailers
Pioneer Equipment/Methods (Modeled)	$ 39.06	Industrial grade pull-type balers, bale picking trucks, self-loading trailers
Advanced Equipment/Methods (Modeled)	$ 33.77	Industrial grade self propelled balers, bale picking trucks, self-loading trailers

* Harvest Costs include all operating expenses to bale, roadside, and load trailers for road transport. Road transportation costs are not included.

6.3 MEASURED RESULTS FROM 2011 BASELINE DATA COLLECTION

In 2011, the second corn stover harvest was conducted in Kansas to test and demonstrate equipment and collect cost and performance data. This data was recorded from each machine/operation that was conducted. Complete datasets were collected from 26 fields, representing ~3,000 acres of corn stover in southwest Kansas. Each of these fields was harvested using the conventional harvesting equipment shown in Section 6.1, above. The cost data (equipment, labor, fuel, baleyard, and trucking) were compiled to determine the total delivered cost of the biomass from each field. Additionally, the biomass yield was calculated for each field based on the total tons of biomass harvested divided by the measured harvestable area of the respective field. Harvestable field area was measured using Geographic Information Systems (GIS) tools.

Our data collection efforts were primarily focused on corn stover, but data was also collected for the same types of harvest operations in wheat straw, and dedicated energy crops including switchgrass and miscanthus. The corn stover dataset alone includes costs and yield data from more than 8,500 acres and over 23,000 bales. The average field harvested by the project team in Kansas yielded ~1.5 tons of dry, ash-free biomass/acre (after accounting for moisture and ash).

Biomass yields in agricultural residues will vary greatly. The amount of available biomass will change based on the variety of corn planted, amount of fertilizer applied, and whether or not the crop was irrigated. The soil type can also influence the biomass yield. Yields in perennial grass stands are generally higher and tend to range from 3 to 5 times more biomass per acre with proper management.

The cost to harvest biomass is relatively unchanged on a per acre basis, regardless of biomass yield. This is due the fact that the same harvesting equipment is used and it the time and fuel required remains relatively constant. The delivered cost ($/ton or $/bale) or, the price paid by the end-user, is the focus of this project. In order to reduce the costs of biofuel production, the delivered feedstock costs must be reduced. Where the harvesting costs are fixed and the biomass yield is poor, the biomass producer (or harvesting entity) may operate at a loss.

The graph shown in Figure 35 illustrates how the delivered costs (on a per-ton basis) are affected by the available biomass yield. There are many factors which contribute to the delivered costs of herbaceous feedstocks to an end-user. This analysis includes the extensive cost data from biomass harvests that ANTARES has collected on key cost items including equipment, fuel, labor, baleyard (loading/unloading), and delivery (transportation to the baleyard). It should be noted that although the data shown in this graph is based on corn stover harvesting operations, the same trend holds true for dedicated energy crops. However, these costs must also be considered in context of productivity, which is strongly correlated to the amount of recoverable material from the site (expressed as a yield with units of tons/acre).

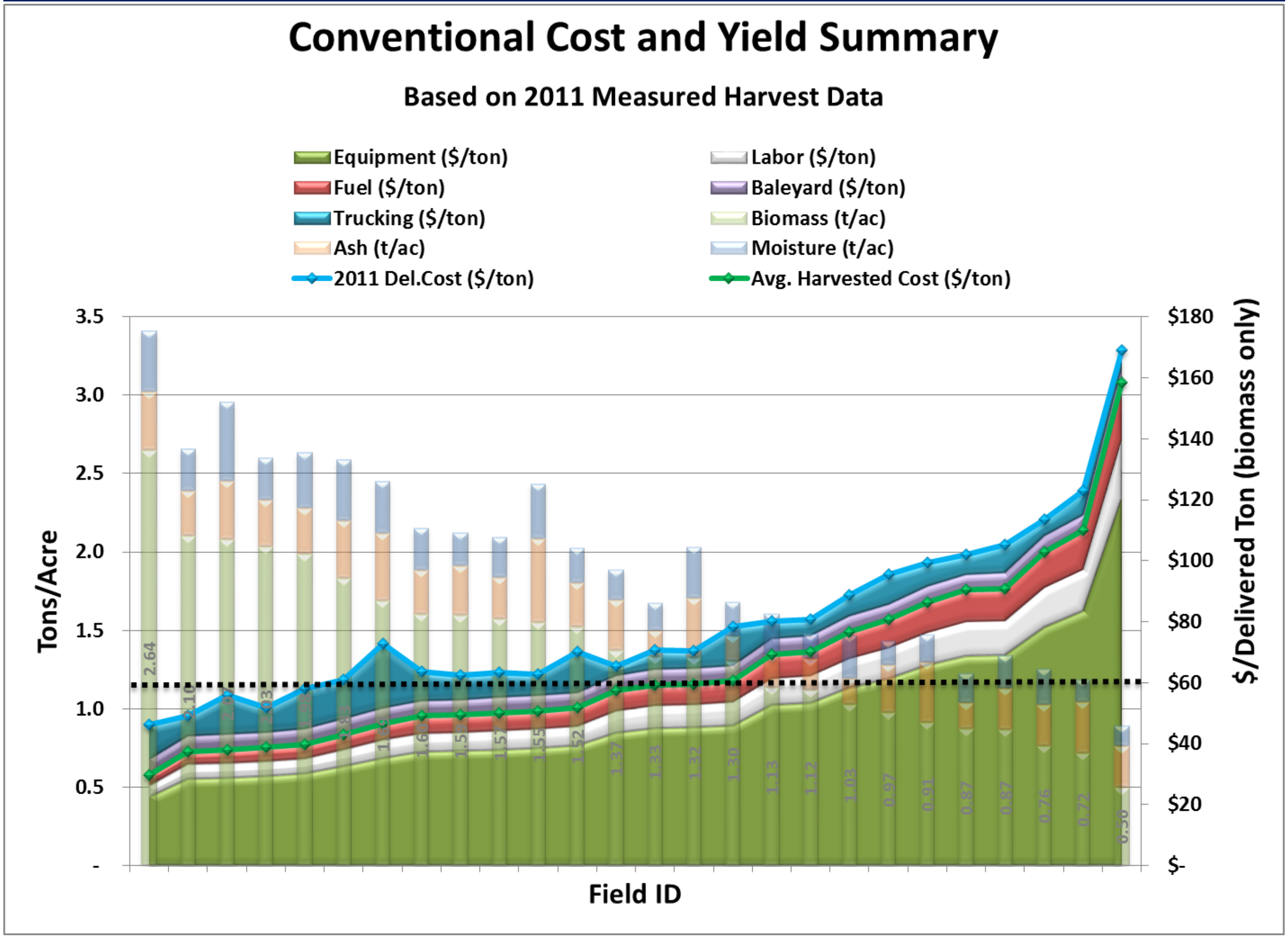

Figure 35 – Conventional Cost and Yield Summary

One of the key takeaways from this graph is the fact that ***the costs of delivered biomass increase as the yield decreases*** (on a per ton basis). This graph also provides information on two different cost data sets; the cost to harvest and the cost to deliver. All of these costs are impacted by yield in some form, but those that are directly associated with harvesting are the most affected by variation in yield. Equipment capital represents the majority of the harvesting costs, with labor, and fuel making up the (relatively small) difference.

The shape of the curve is the most telling feature, as the yield and cost data is fairly linear and inversely proportional. This is because today's harvesting costs are relatively fixed. It takes about the same amount of time to harvest a 1 ton/acre field as it does to harvest a 3 ton/acre field. Baleyard and delivery (trucking) costs are less influenced by yield. The cost drivers for these items are tied to equipment performance and skill of the loading/unloading operators. Overall, the graph paints a clear picture of two factors that have the greatest potential to reduce costs; higher biomass yields and lower cost harvesting technologies. A black, dashed line was added to the Figure to represent an approximate price paid by the feedstock end-user of $60/dry ton. This value can be used to evaluate the potential

6.4 DATA COLLECTION AND PERFORMANCE EVALUATION

As part of the data collection effort, each harvest vehicle was fitted with a GPS tracking system that incrementally recorded its location and path[8] data. The data collection team used this technology to compare different harvesting methods with their resulting biomass characteristics. In some cases, the team was able to compare the resulting ash content of harvested corn stover that was windrowed with two different methods. The results of this study are shown in Figure 36.

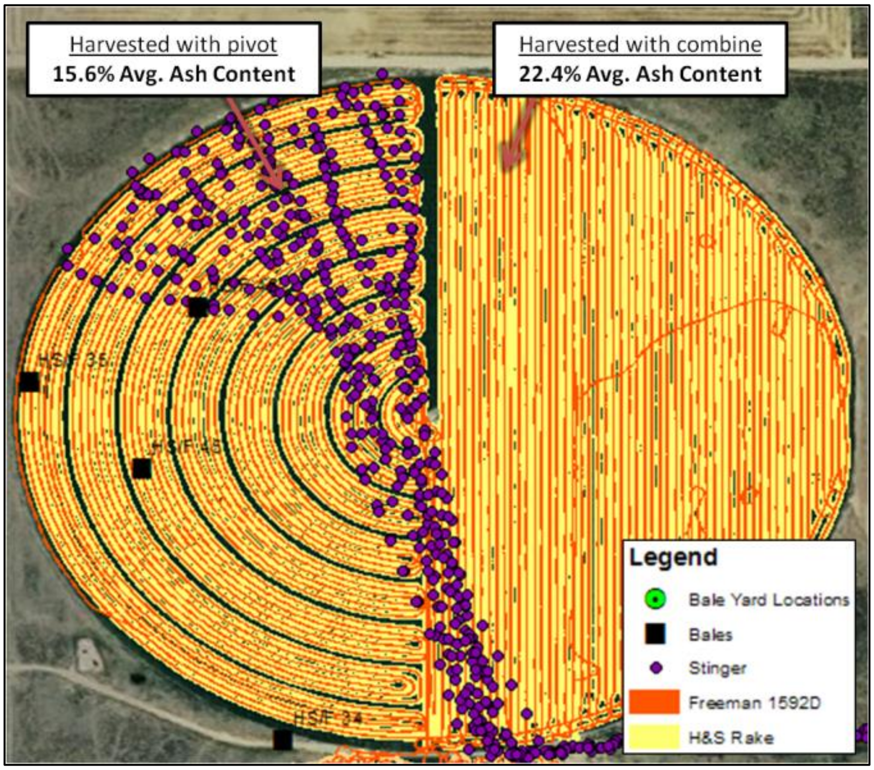

Figure 36 - Map of Equipment Tracks with Ash Content Comparison

The equipment tracks of the raking, baling, and Roadsiding operations are displayed. The particular field shown in Figure 36 had deep and wide pivot tracks. The field was harvested with and against these ditches to see the effects on ash content in the material. The area harvested with the pivot tracks (western half) had substantially lower ash content, on average, as compared to the other half of the field harvested without regard to the pivot tracks and with the same equipment. Details of this field's harvest are shown in Figure 37.

[8] The path of each machine instrumented with GPS tracking devices was recorded in order to understand the machines movements through the fields.

Figure 37 – Comparison Data from Rake Test

	West Half					East Half				
Equipment Used	H&S Rake & Freeman 1592D									
Tonnage Baled (as rec.)	94					139				
# of bales Made	220					320				
Tonnage Baled (dry, no ash)	71					97				
Removal Rate (dry ton/acre)	1.24					1.70				
Lab Analysis	**Sample Size**	**Avg**	**Min**	**Max**	**Std dev**	**Sample Size**	**Avg**	**Min**	**Max**	**Std dev**
Moisture Content	22	11%	8%	18%	2%	32	10%	8%	28%	4%
Ash Content	6	16%	14%	20%	2%	6	22%	17%	31%	6%

Similar tests were conducted and data recorded where possible to understand better the relationships between equipment used and biomass quality.

Baseline data collection was completed in 2011 and used to assess the improvements that could be gained from the advanced equipment being developed in the project. The advanced equipment was demonstrated in commercial environments, where possible, to collect similar data for comparison. These demonstration activities are discussed in Chapter 7 of this report.

7 EQUIPMENT DEMONSTRATION

A primary task for the project team was to demonstrate the newly developed prototype equipment in order to prepare it for commercial use and production. This included the MacDon Heavy Crop Header, Freeman 1592D SP Self Propelled Baler, high density pull-type balers, a Bale Picking Truck, and a Self Loading Trailer. Each piece of equipment was rigorously tested during the project period. This testing was a 3-step process that began after fabrication was completed:

1. Commission test the equipment to validate that it works
2. Demonstrate the equipment in a commercial harvest setting
3. Upgrade equipment to address faults and improve its operation

The Equipment Demonstration Cycle is showcased in Figure 38.

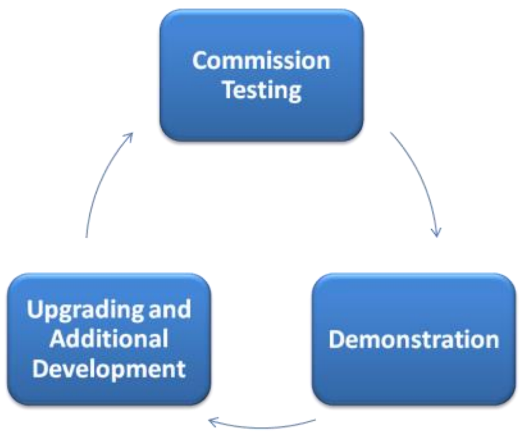

Figure 38 – Equipment Demonstration Cycle

Equipment demonstration occurred over multiple years and in various locations across the United States. The equipment was tested for agricultural residues (corn stover and wheat straw) as well as dedicated energy crops (miscanthus, biosorghum, and warm season grasses).

7.1 BACKGROUND OF HARVEST AND OBJECTIVES

The project team conducted a corn stover harvest in the fall of 2011 using conventional and advanced harvesting and transport equipment. In this harvest, a total of 7,200 tons of stover were harvested, transported, and stored for cellulosic ethanol conversion from several fields, which are marked on the map in Figure 39. The harvest was done under two separate objectives: 1) to supply biomass feedstocks to Abengoa's biorefinery in Hugoton, KS, and 2) to test and demonstrate a suite of advanced harvesting equipment. For each piece of equipment, key performance and cost data were recorded for modeling purposes and for comparison to baseline data collected previously (as discussed in Chapter 6.)

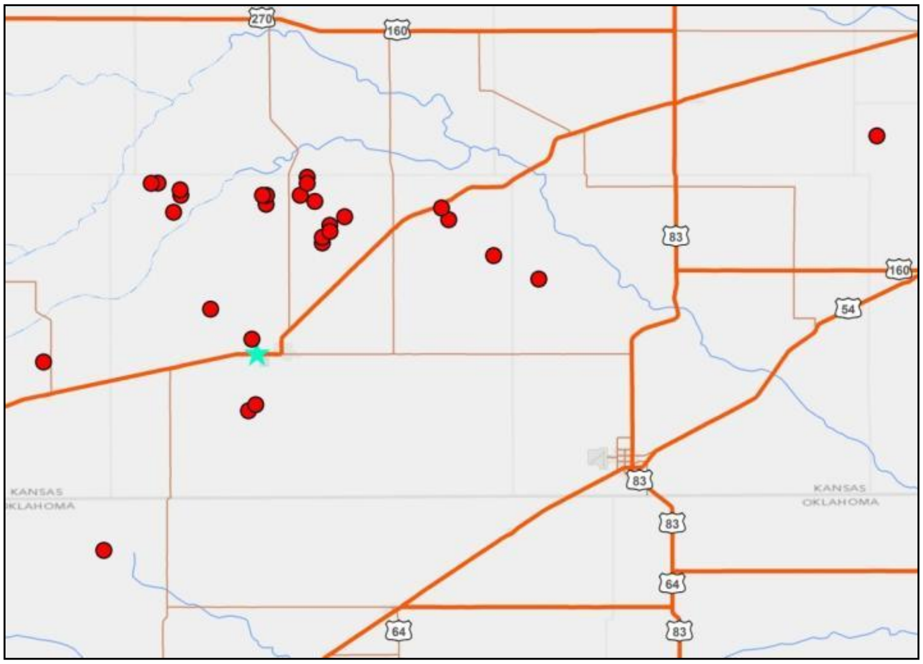

Figure 39 – 2011 Corn Stover Harvest Locations in Southwest Kansas

7.2 CONVENTIONAL HARVESTING AND LOGISTICS EQUIPMENT

Conventional harvesting and logistics operations were conducted in the fall of 2011. These operations are deemed as "conventional" because they consisted of mowing, windrowing, baling, roadsiding, and delivery of harvested material using equipment and materials that were already commercially available. The data collected from these operations was included in the baseline data analysis.

TRACTORS

JCB Fastrac™ tractors were the primary power units used for all pull-type operations. These 230 HP tractors are capable of reaching road speeds of up to 40 miles per hour. The unique four wheel suspension in JCBs allows for increased field speeds and greater operator comfort. Each tractor was fitted with precision tracking hardware that provided complete field coverage with any implement. The fleet of JCB tractors is shown in Figure 40.

Figure 40 – Fleet of JCB Tractors

MOWING

Many of the fields that were harvested during the 2011 harvest season had standing corn stalks. A Land Pride RCM5020 mower was used to cut the stover low to the ground so that it could be raked without introducing excessive dirt. Summary performance data for the mowing operations is provided in Figure 41.

Figure 41 - Mowing Performance Data

Mower Data	
Make	Land Pride
Model	RCM5020
Working Width (ft)	20
Avg. Field Rate (acre/hr)	14.3
Avg. Miles Per Field	61
Fuel Consumption (gal/acre)	0.37
Total Time in Field (hrs)	257

An image of the mower is shown in Figure 42.

Figure 42 – Land Pride RM5020 (Source: Land Pride)

WINDROWING

Rakes were used to windrow corn stover after it had been mowed. Vermeer basket and wheel type rakes were used. These rakes can be adjusted (widened) to maximize field coverage and to match the windrow size to the baler. The performance data for the rakes is summarized in Figure 43.

Figure 43 – Raking Performance Data

Windrowing Data	Basket Rake	Wheel Rake
Make	Vermeer	Vermeer
Model	R2800	WVR1428
Working Width (ft)	25	25
Avg. Field Rate (acre/hr)	13.6	12.9
Avg. Miles Per Field	41.9	31.0
Fuel Consumption (gal/acre)	0.25	0.28
Total Time in Field (hrs)	160	137

The Vermeer R2800 basket rake is shown in Figure 44.

Figure 44 – Vermeer R2800 Basket Rake in Corn Stover

BALING

Large square balers were used to package corn stover into large square bales (3'H x 4'W x 8'L) to be stored and transported more easily. Five conventional pull-type balers were used.

Three of the pull-type balers were Freeman 1592D models. Their overall performance is summarized in Figure 45 below.

Figure 45 – Summary of Freeman Pull-type Baler Performance

Baler ID	008	009	316
Avg. Field Rate (acre/hr)	4.3	5.7	3.71
Total Bale Count	636	2,952	3,691
Total Tonnage (est.)	318	1,478	1,848
Bulk Density (lb/ft^3)	9.8		
Avg. Bale Weight (lbs)	1,000		
Fuel Consumption (gal/ton)	0.80	0.46	0.50
Fuel Consumption (gal/hr)	6.05	5.62	5.57
Total Time in Field (hrs)	41.8	121.9	165.5

The remaining two balers were Krone HDP and Claas pull-types. Their performance data is summarized in Figure 46.

Figure 46 – Krone HDP and Claas Pull-Type Baler Summary

Baling Data	Krone HDP	Claas
Avg. Field Rate (acre/hr)	6.78	6.64
Total Bale Count	2,243	495
Total Tonnage (est.)	1,598	231
Bulk Density (lb/ft3)	14.0	9.2
Avg. Bale Weight (lbs)	1,425	935
Fuel Consumption (gal/ton)	0.62	0.43
Fuel Consumption (gal/hr)	9.77	5.00
Total Time in Field (hrs)	101.8	19.7

Images of the Krone Baler and Claas Baler are shown in Figure 47 and Figure 48, respectively.

Figure 47 – Krone HDP Big Pack Baler (Photo credit: Krone)

Figure 48 – Claas Baler

ROADSIDING

Once the biomass was baled it needed to be transported to side of the field, or roadsided. This operation was completed using a Stinger Stacker 6500. The Stinger Stacker 6500 is a self-propelled roadsiding unit. It is capable of carrying up to 12 large square bales (3'H x 4'W x 8' - 9'L) to the field side in each trip. At field-side it can make two organized stacks, 6 bales tall. The truck was fitted with an asset tracking device that recorded its location at all times along with speed, distance traveled, and the total time in-field. The average performance results from the truck's operations are provided in Figure 49.

Figure 49 - Summary of Roadsiding Performance Data

Roadsiding Data	Stinger Stacker 6500
Make	Stinger LTD
Model	Stacker 6500
Avg. Field Rate (bales/hr)	55
Avg. Field Rate (loads/hr)	5.5
Avg. Miles Per Field	90
Fuel Consumption (gal/hr)	3.93
Avg. Field Speed (mph)	11
Total Time in Field (hrs)	473

Figure 50 shows the Stinger Stacker 6500 in operation.

Figure 50 – Stinger Stacker 6500

Figure 51 shows the actual tracks of the Stinger through one of the fields. These equipment tracks reveal the amount of ground that the Stinger must cover to properly roadside all of the bales to a single location. For comparison, the Bale Picking Truck would reduce the number of trips through the field by more than half.

Figure 51 – Tracks of Stinger during Roadsiding (Scale: 1 inch = 0.33 miles).

LOADING/UNLOADING

Telehandlers were used to load and unload bales of material on and off of trucks. These vehicles have hydraulically extendable arms that allow the operator reach high places, such as the top of a bale stack. Each telehandler was fitted with a hydraulic squeeze attachment that enabled the operator to move up to 6 bales at a time. Average performance data is provided in Figure 52.

Figure 52 – Summary Performance Data for Loading and Unloading Operations

Loading/Unloading Data	Telehandler
Make	Caterpillar
Model	TH460B
Attachment (squeeze)	Higginbotham
Avg. Load Time[1] (minutes)	9.2
Avg. Unload Time[2] (minutes)	11.62
Total Machine Hours	785
Fuel Consumption (gal/ton)	0.11
1- Loader cycle time only, not including truck positioning, or load securing times	
2- Loader cycle time only, from truck arrival to truck empty, not including stacking	

Figure 53 – Telehandler in Operation

TRANSPORTATION

After roadsiding, the baled material was loaded on trucks and delivered to a bale storage yard. Conventional flatbed trailers and advanced self-loading trailers were used for this operation. These trailers were capable of carrying up to 42 bales, required strapping to restrain the material, and needed to be loaded and unloaded with telehandlers.

7.3 ADVANCED HARVESTING AND TRANSPORTATION EQUIPMENT

Advanced prototype equipment was used in addition to the conventional harvesting equipment in the fall of 2011 for comparison and demonstration purposes. These operations are deemed as "advanced" because they consisted of windrowing and baling in a single-pass and delivery of harvested material using equipment that is currently under development and is not commercially available.

ADVANCED WINDROWING (MACDON HEAVY CROP HEADER)

MacDon Industries tested their Heavy Crop Header in both biosorghum and miscanthus to determine what requirements would need to be met in order to windrow and condition the crops effectively. Harvesting high density energy crops such these presented several challenges that needed to be understood to develop a proper header. A photo of the header during biosorghum harvest is shown in Figure 54.

Figure 54 – MacDon Heavy Crop Header in Biosorghum

The Heavy Crop Header harvested small plots of biosorghum in the fall of 2010. Biosorghum is an extraordinarily difficult crop to windrow. At harvest it can be very dense and mangled, sometimes laying over on itself. Material would often plug up the conditioning real, due to a lack of hydraulic power and too great of speed. The dry-down time of biosorghum was prohibitive to its harvest as well. The crop's moisture content was high throughout the harvest trials, at a time of year when it should have been at its lowest. This indicated that the crop was not going to dry out enough for baling and led the project team to focus the Heavy Crop Header's demonstration and testing on available plots of miscanthus. The Heavy Crop Header is shown windrowing miscanthus in Figure 55.

Figure 55 – MacDon Heavy Crop Header in Miscanthus

Mendel Biotechnology provided the harvest team with access to over 100 acres of their miscanthus research plots across the southeastern United States. The Heavy Crop Header performed well in these 6 to 8 ton/acre stands, achieving speeds of 5 miles/hour with proper conditioning.

ADVANCED SINGLE-PASS HARVESTING (WINDROWING AND BALING)

A Freeman 1592D Self-Propelled Baler (SPB) was used to windrow and bale corn stover in a single pass through the field. Performance data was collected and is shown in Figure 56. This baler was fitted with a 3-bale accumulator. The accumulator allows the baler operator to carry up to 3 bales and drop them together at an optimal location (closer to the roadsiding area) for either stacking in a field side bale stack or loading for transportation to a bale yard.

Figure 56 – Summary Performance Data for Single Pass Harvesting Corn Stover with the SPB

Baling Data	SPB
Avg. Field Rate (acre/hr)	3.25
Total Bale Count	3,181
Total Tonnage (est.)	1,789
Bulk Density (lb/ft^3)	11.0
Avg. Bale Weight (lbs)	1,125
Fuel Consumption (gal/ton)	0.48
Fuel Consumption (gal/hr)	3.56
Total Time in Field (hrs)	241.4

Figure 57 shows the Self Propelled Baler windrowing and baling corn stover in a single pass using a front-mounted Vermeer R2800 Basket Rake.

Figure 57 – Self Propelled Baler with Front-mounted Basket Rake

Additionally, the Self Propelled Baler was outfitted with two other windrowing implements, including a tedder rake (Figure 58) for agricultural residues and hay and a draper header (Figure 59) for standing herbaceous crops.

Figure 58 – Self Propelled Baler with Front-mounted Tedder Rake

Figure 59 – Self Propelled Baler with Front-mounted Draper Header

ADVANCED ROADSIDING AND TRANSPORTATION

The Bale Picking Truck (BPT) was ready for its first demonstration in June of 2012. A photo of the BPT is shown in Figure 60.

Figure 60 – Bale Picking Truck

Performance data for the BPT had to be estimated for preliminary projections due to limited harvest opportunities available after it was ready for demonstration. The machine was demonstrated in both research and commercial settings. However, due to limited large-scale harvest opportunities, a full set of measured performance data was not documented. Spot recordings and measurements showed that the truck was able to transport between 1 and 3 loads per hour (42 to 126 bales). Fuel consumption was assumed to be comparable to existing roadsiding equipment at 1.38 gal/acre (12 gal/hr). The total empty vehicle weight was approximately 54,000 pounds. The average in-field speed was between 5 and 8 miles/hr. In-field demonstrations revealed that the BPT was highly effective at assembling a module of bales. It successfully unloaded the bales into storage "stacks" for field-side storage and as well as directly transferring its load to the Self Loading Trailer.

A Kelderman Self Loading Trailer (SLT) was used to transport material after it was roadsided. This trailer could load and unload up to 42 bales by itself. The bales had to be stacked in the proper configuration (2 wide x 3 tall x 7 long) for the trailer to pick them up properly. The average loading time for the trailer was 8 minutes while the unloading time was 5 minutes. Figure 61 shows the SLT unloading a module of bales at a storage yard.

Figure 61 – Self-Loading Trailer in Operation

The BPT is unique in that it can transfer its entire load of bales directly onto a SLT for transport. Experienced operators can transfer a full load of bales in approximately 3 minutes without strapping or the use of any additional equipment. Figure 62 shows a load of corn stover being transferred directly.

Figure 62 – Direct Transfer of Bales from BPT to SLT

CLAAS SINGLE-PASS HARVEST

In 2012, FDC Enterprises outfitted its JCB 3230x tractors with front-mounted Class mowers to harvest standing crops of warm season grasses. This was done to test the performance, and practicality of this equipment arrangement for FDCE's operations.

FDCE tested the equipment arrangement with both round (Figure 64) and square balers (Figure 65) in warm season grasses (WSG) in Virginia and Tennessee. Figure 63 shows both the round and square single pass equipment setups.

Figure 63 – FDCE Single Pass Harvest System

Figure 64 – FDCE Harvesting WSG in a Single Pass with a Claas 360 Round Baler

Figure 65 – FDCE Harvesting WSG in a Single Pass with a Claas 3300 Square Baler

This single pass harvest operation was used to harvest several thousand tons of grasses during the 2012 harvest season. The equipment performed as it was supposed to. It reduced time in field considerably, improved biomass production rates, and reduced the amount of manpower and equipment needed to do the job.

Standing warm season grasses can only be harvested after they have fully senesced and dried considerably. As such, they are generally harvested during the winter when the crop is dormant. FDCE encountered problems with the crop not going completely dormant in 2013 and 2014 due to unseasonably warm and wet winters in the areas of operation. Since the crop never senesced fully, its moisture content was too high. This meant that it could not be harvested in a single pass and no further demonstration operations were conducted with this single pass equipment arrangement during the project.

7.4 EQUIPMENT DEMONSTRATION RESULTS

7.4.1 Miscanthus Harvest Summary

Miscanthus harvests were conducted throughout the Southeast in 2011 and 2012. The harvest locations are shown in the map in Figure 66.

Figure 66 - Miscanthus Harvest Field Locations

The marker for each harvest location in the map indicates the biomass yield harvested in terms of tons per acre (tpa), when that data is available. The yield from these harvests ranged from 1 to 7 tons per acre, depending on the maturity and quality of the miscanthus stands. This data is summarized in Figure 67.

Figure 67 – Miscanthus Harvest Results by Field

Location	Bale Count	Tons	Acres	Yield (tons/acre)
Russellville, KY	672	462	65	7.1
Smithfield, KY	99	59	9	6.6
Oaktown, IN	28	18	5	3.6
Louisville, MS	44	28	24	1.2
Memphis, TN	13	8	7	1.1
Cairo, GA	34	8	N/A	N/A
Tifton, GA	N/A	N/A	N/A	N/A

Freeman 1592D and Krone HDP large square balers were used to bale the crop, and both performed well in general. Proper conditioning of the crop during the windrowing operation is vital to successful baling operations. Some baler malfunctions occurred when long stems of miscanthus were not crushed adequately, and caused knotter mis-ties or plugs in the crop pick-up components. Due to the relatively small amount of miscanthus acreage, not enough data could be collected to adequately analyze harvesting and logistics equipment performance on this crop quantitatively.

7.4.2 Corn Stover Harvest Summary

An extensive analysis was conducted to gain a better understanding of the equipment performance. The results of these analyses were used to determine the impacts of each piece of equipment on the supply chain with respect to total time in-field, total fuel consumption, cost of equipment capital, and biomass quality (ash content). The subsequent discussion addresses these analyses for the windrowing and baling operations.

2011 Baler Performance Summary

The key performance data for each of the balers was summarized. This included average corn stover bale weight, bulk density, and fuel efficiency. Charts comparing these metrics among the different balers are provided in Figure 68, Figure 69, and Figure 70, respectively.

The individual bale weight was calculated for each the balers; Class, Freeman pull-types, Kelderman's Self Propelled Baler (SPB), and Krone. The Claas baler made the lightest bales, averaging 935 pounds. The Freeman pull-types were given an estimated bale weight of 1,000 pounds based on observations in the field[9]. The SPB's bales weight 1,125 pounds on average and the Krone HDP bales average 1,425 pounds.

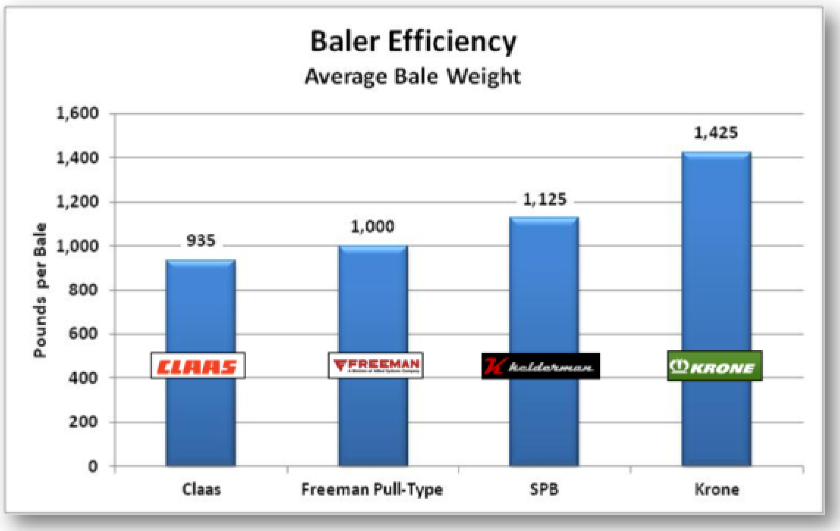

Figure 68 – Graph of Average Bale Weights by Baler

Using the average bale weights from Figure 68, the average bulk density was calculated for each of the balers based on an average bale dimension of 3' x 4' x 8.5'. The Claas baler had the lowest bulk density at 9.2 lbs/cubic foot, while the Krone HDP baler had the highest bulk density averaging 14.0 lbs/cubic foot. The Freeman pull-type figure is an estimate.

[9] There was not enough data to determine a precise average bale weight for the Freeman pull types, so an approximation is provided.

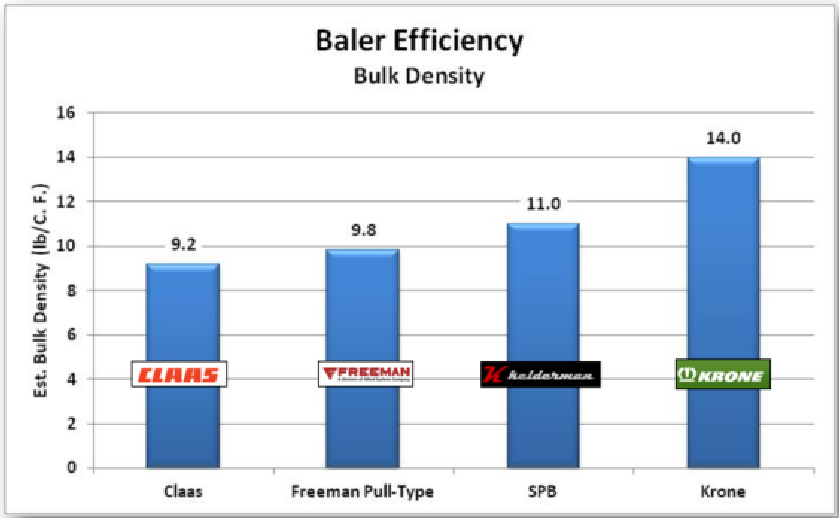

Figure 69 – Graph of Average Bulk Density by Baler

The fuel efficiency was calculated on a gallon of fuel per ton basis (gal/ton $_{\text{as rec.}}$). In this analysis we see the Claas in the lead with 0.43 gal/ton, and Krone had the worst fuel efficiency at 0.62 gal/ton. The SPB consumed 0.48 gal/ton while also conducting the windrowing operation.

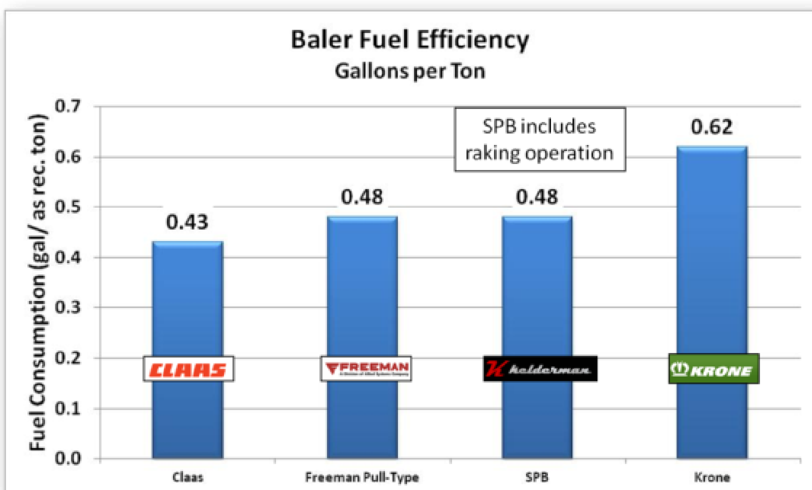

Figure 70 – Graph of Fuel Efficiency by Baler

PRODUCTION COSTS AND THE IMPACT OF BIOMASS YIELD

One of the primary takeaways from the 2011 harvest equipment demonstration was an understanding of the cost of harvesting and delivering biomass. The project team gained a more complete understanding of these costs through the collection of cost and performance data for all of the equipment. These costs were summarized for three different harvesting scenarios; Conventional Single-pass, and Advanced Single-pass. The cost of harvesting and transporting biomass is influenced by a number of variables. The most influential variable however is the actual biomass yield on a particular field, as described earlier in Section 6.3.

Figure 71 shows the actual biomass yield of each of the twenty-six corn stover fields that were harvested in Southwest Kansas. The chart also shows the respective ash and moisture contents on a ton per acre basis. The ash and moisture contents were based on the results of lab analysis on aggregate samples from each field.[10] The adjusted average biomass yield (no ash, no moisture) was 1.40 tons/acre, with a maximum of 2.64 tons/acre and a minimum of 0.50 tons/acre.

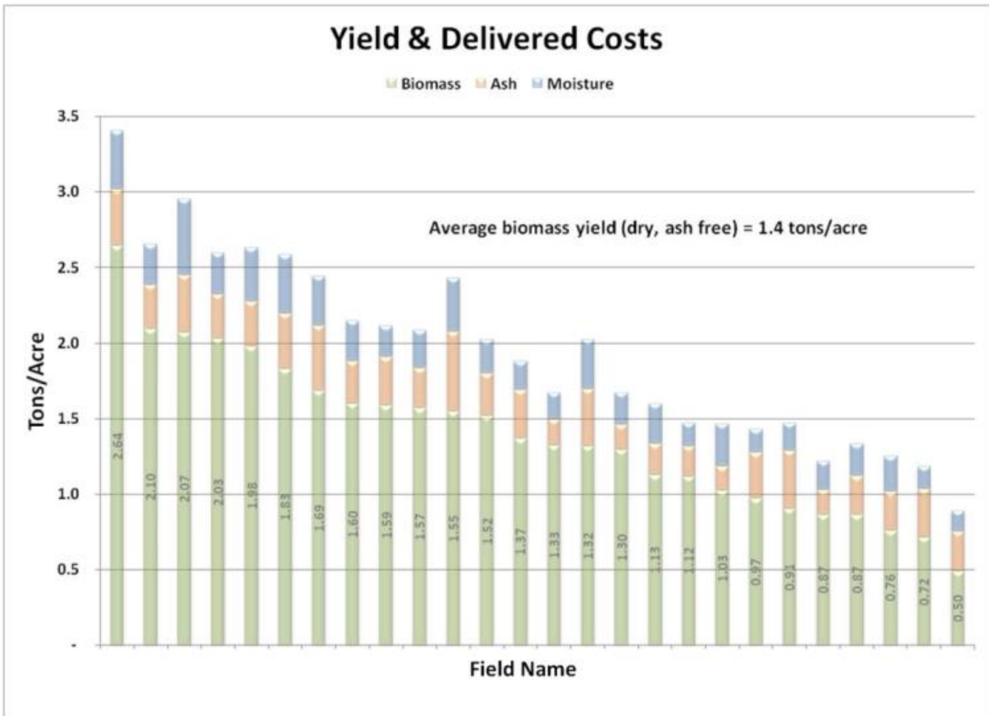

Figure 71 – Yield Summary of Harvested Fields

The equipment performance data was also recorded for each field, and used to determine the *total time-in-field*[11] and *fuel consumption* for each field. The equipment cost of capital was included in addition to the performance metrics using the equipment lease and/or rental rates that were being paid for each piece of equipment.[12] The resulting cost categories were labor costs, fuel costs, and equipment costs for each harvesting operation - mowing, windrowing, baling, and roadsiding.

Cost Analysis Methodology

The costs for each cost category and operation were normalized by the acreage of each field and averaged to a $/acre value for each cost category and operation. These averages were summed to get one overall $/acre value for the cost of harvesting corn stover.

[10] Aggregate samples consisted of $\sqrt{n}+1$ core samples, where n = the number of bales per field and one core sample was taken from each bale.
[11] Time-in-field was the primary cost driver for labor, fuel, and equipment costs that are incurred over time.
[12] Capital costs for equipment that was owned (e.g. self propelled baler) by a project member were estimated using estimated retail values and lease rates.

$\text{Avg. Harvesting Cost}\left(\frac{\$}{\text{acre}}\right) = \frac{\text{Labor}\left(\frac{\$}{\text{acre}}\right)+\text{Fuel}\left(\frac{\$}{\text{acre}}\right)+\text{Equipment}\left(\frac{\$}{\text{acre}}\right)}{n}$, where n is the number of fields that have complete harvest data.

The resulting *Avg. Harvesting Cost ($/acre)* was divided by the *biomass yield*[13] *(ton/acre)* in each field to the get the average harvesting cost on a $/ton basis for each field.

$$\text{Avg. Harvesting Cost}\left(\frac{\$}{\text{ton}}\right) = \left[\text{Avg. Harvesting Cost}\left(\frac{\$}{\text{acre}}\right) \div \text{Biomass Yield}\left(\frac{\text{ton}}{\text{acre}}\right)\right] + \text{Baleyard}\left(\frac{\$}{\text{ton}}\right)$$

Results for Conventional Harvesting

The harvesting costs for conventional biomass harvest and delivery were summarized using cost data gathered from conventional equipment and methods. The resulting average harvesting costs were overlaid onto the yield chart in Figure 72 for comparison. A dashed black line is shown on the chart to represent an assumed delivered price to an end user.

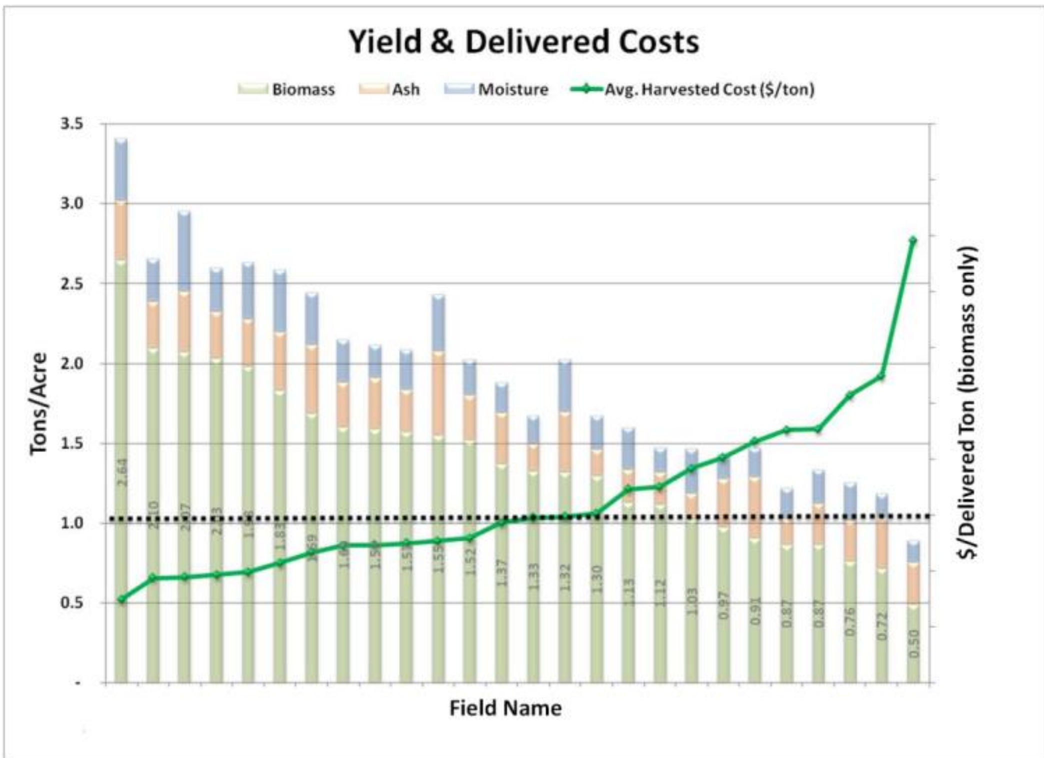

Figure 72 – Conventional Harvesting Costs by Yield

The data in Figure 72 shows an inverse relationship between the biomass yield and the cost to harvest the biomass on each field. This is expected, since the time to harvest an area of corn stover is not dependent on the tonnage in that field, but rather on the efficiency of the equipment used and its operators. This realization is fundamental to understanding the

[13] Dry, ash free material

biomass supply chain. Harvesting companies will need to look closely at a field prior to harvesting to ensure that there is enough material on it to harvest cost effectively.

Understanding the makeup of the harvesting costs is the key to driving those costs down. Figure 73 summarizes the costs of that contribute to the total average harvesting costs on each field. This chart illustrates that the greatest contributor to the biomass harvest cost is cost of the harvesting equipment itself. On average, the equipment costs for these fields represented 61% of the total harvesting cost.[14] Baleyard and labor costs averaged 14% and 15%, respectively, while fuel costs were smaller still at 10% on average. A dashed line is shown on the chart to represent an acceptable delivered price to an end user.

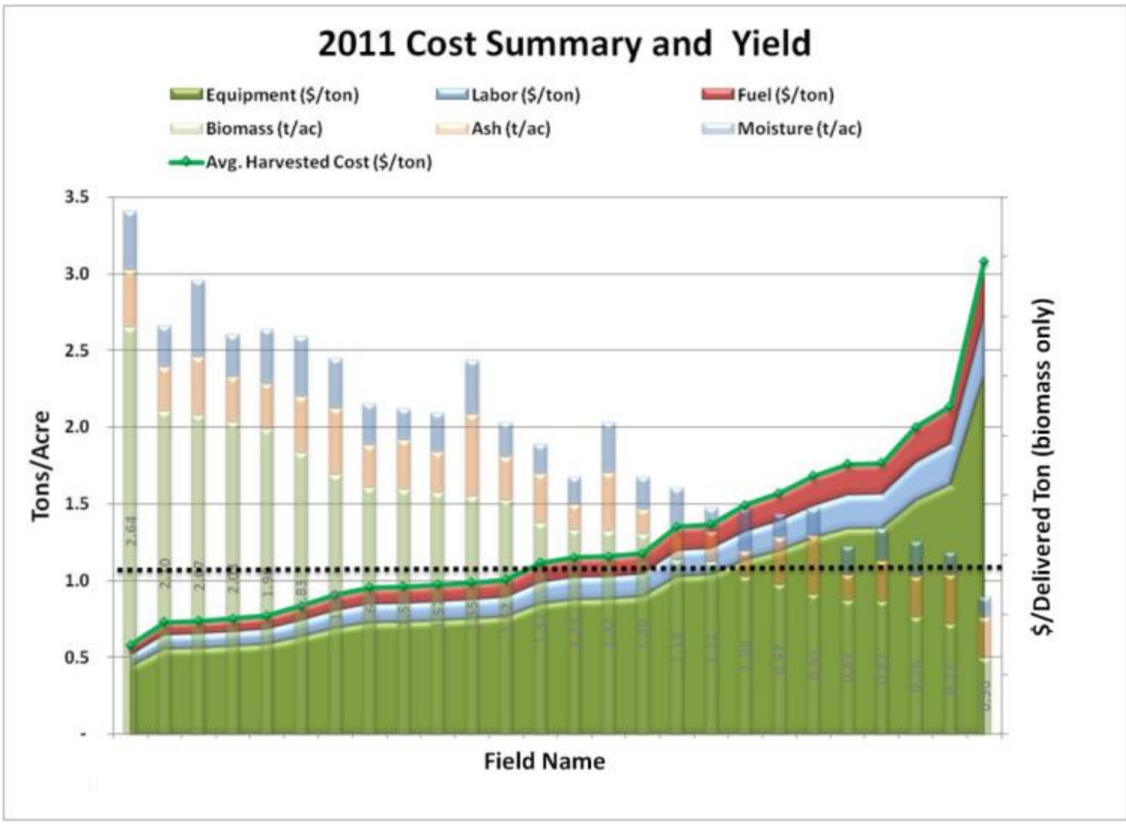

Figure 73 – Conventional Harvest Costs by Yield

After determining harvesting costs, the baleyard and transportation costs needed to be added. The baleyard costs were calculated on a $/ton basis based on the tonnage handled. These costs included the same cost categories (labor, fuel, and equipment costs). The transportation costs were based on an all-inclusive rate of $100/hr. Thus, the total trucking cost for each field was calculated, using the following equation:

[14] Equipment costs are the cost of capital to rent, lease, or own equipment.

$\text{Transport}\left(\frac{\$}{\text{ton}}\right) = \text{Total Time (hours)} * \frac{\$100}{\text{hr}}$, where “Total Time” is the sum of the times when the trucks are in operation (travel, weighing, and loading/unloading times).

Figure 74 shows the addition of the baleyard and transportation costs to the harvesting costs. This results in a complete estimate of harvest and transportation costs for corn stover based on the fields harvested in Southwest Kansas, excluding indirect, profit, equipment transportation, meals, lodging, and equipment maintenance costs. The transportation cost trends upward as the yield on a field decreases, but shows some variability due to the actual travel distance being inconsistent. The trucking distance can have a significant impact on the cost of biomass to the end-user, which biomass end-users should take into account when securing their biomass supply.

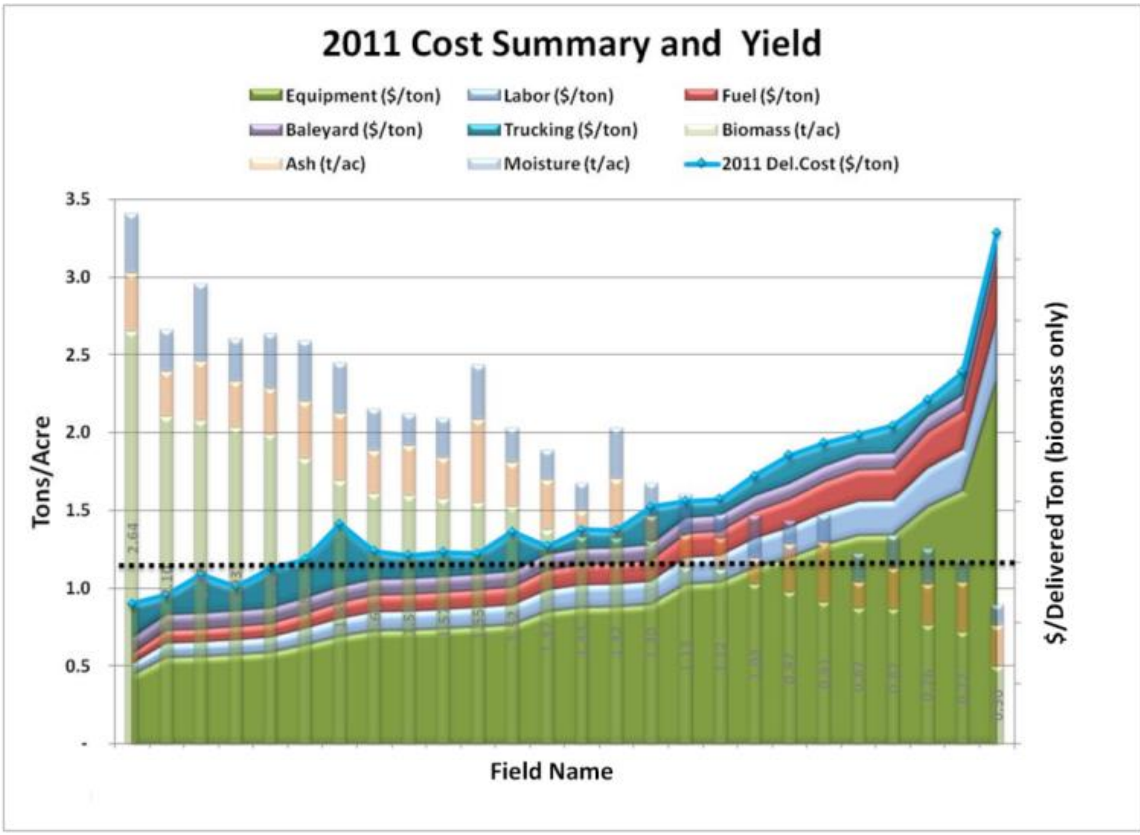

Figure 74 – Conventional Harvest and Transportation Cost Breakout by Yield

Results for Advanced Harvesting

The harvesting costs for advanced biomass harvest and delivery were summarized using cost data gathered from advanced equipment and methods in the same manner described above for *Conventional Harvesting*. The resulting average harvesting costs were overlaid onto the yield chart in Figure 75 for comparison. A dashed line is shown on the chart to represent an acceptable delivered price to an end user.

The advanced harvesting costs versus yield charts are provided in Figure 75 and Figure 76. As expected, the advanced harvesting costs are substantially lower when compared to conventional methods. On average, the advanced operations reduced harvesting costs by 37% and total delivered costs by 39%. These savings are largely from the reduced amount of equipment required to harvest the same amount of material using advanced equipment. The advanced equipment could harvest and deliver material more efficiently, taking less time, requiring fewer machines, and less manpower per ton of biomass harvested.

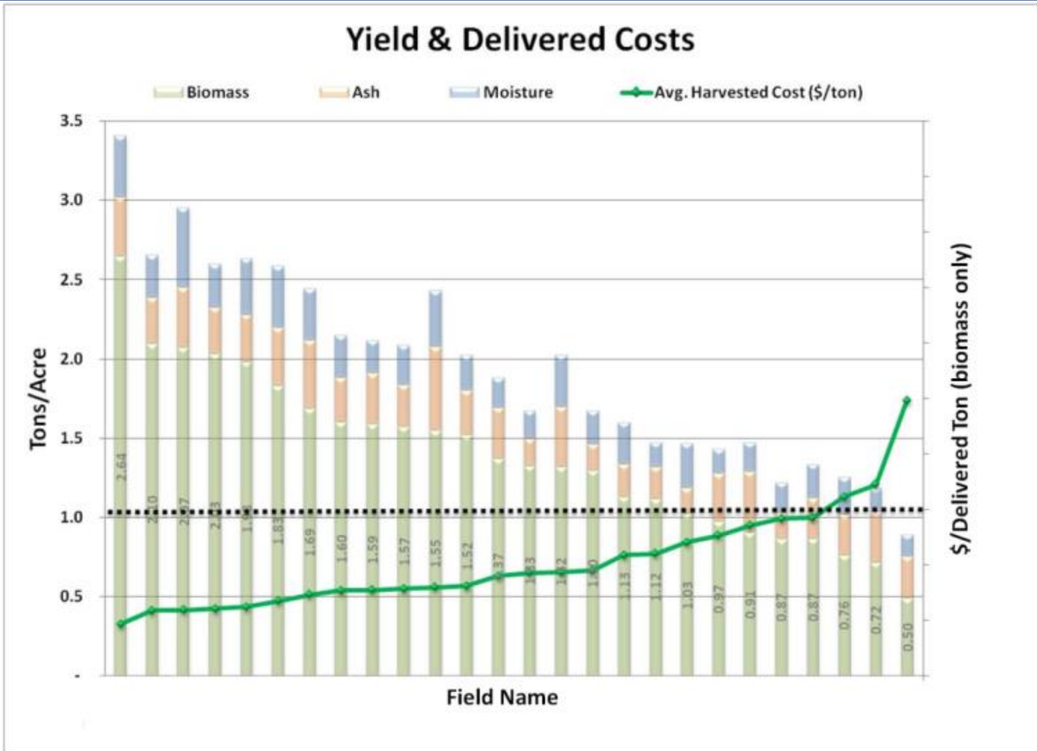

Figure 75 – Advanced Harvesting Costs by Yield

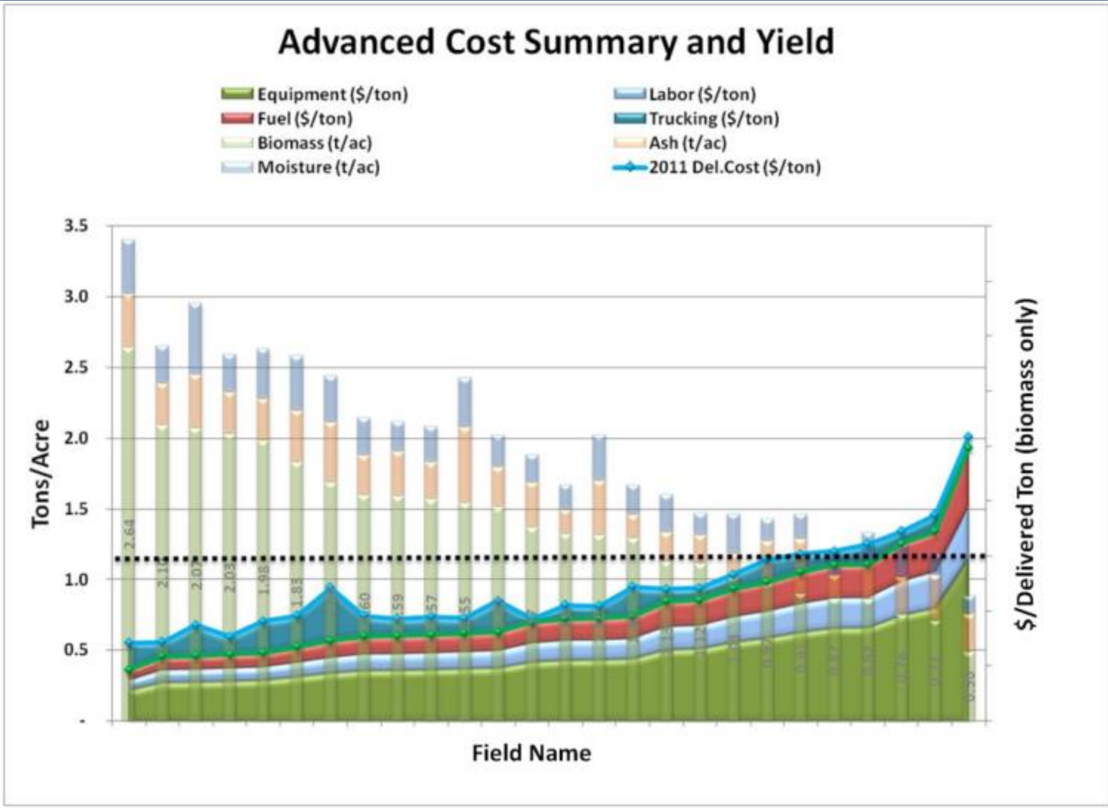

Figure 76 – Advanced Harvest and Transportation Cost Breakout by Yield

General Conclusions for Cost Reduction

In general, the following conclusions were made after the cost analyses were conducted:

- Biomass yield needs to be accurately estimated before harvesting to ensure that there is enough material to be cost effective to collect.
- The utilization of the harvesting equipment should be maximized wherever possible to drive the harvesting cost of capital downward. Equipment ownership/rental costs, being the largest cost category, can be reduced through increased use.
- The time reduction in loading and unloading baled material using a BPT and or SLT can significantly reduce the delivered biomass cost.

EQUIPMENT DEVELOPMENT AND COMMERCIALIZATION

By the end of the project period, each piece of new equipment had been demonstrated and made ready for commercial production. Every entity affiliated with the project recognized the value in the equipment being demonstrated. In some cases, purchase orders had been made for the next generation of harvesting and transportation equipment.

RAKING PERFORMANCE COMPARISON

Ash content is affected by the harvesting equipment when dirt is introduced from mechanical disturbance of windrowing and baling pickup teeth. To better understand this, the project team tracked the ash content of the material baled by each piece of equipment and found that the average ash content ranged from 9% to 34%. Raking operations were reviewed in detail to compare the two different raking types.

Two different rake types were used to windrow material; wheel and basket. The raking action of these implements physically introduces dirt into the windrow. The wheel rake (shown in Figure 77) is ground driven, meaning that it rakes material by rolling tined wheels along the ground.

Figure 77 - Vermeer WVR1428 Wheel Rake

The basket rake, shown in Figure 78, rides above the ground and uses hydraulically powered teeth to move material into a windrow.

Figure 78 – Vermeer R2800 Basket Rake

The performance metrics for these rakes are compared in Figure 79.

Figure 79 – Rake Performance Comparison Data

	WVR1428 Wheel Rake	R2800 Basket Rake
Width (ft)	25	25
Avg. Field Rate (acres/hour)	12.9	13.6
Avg. Fuel Consumption (gal/acre)	0.28	0.28
Avg. Fuel Consumption (gal/hour)	3.7	3.3
Avg. Mileage In-field	31	41.9
Avg. Mileage In-field (miles/acre)	0.25	0.28
Avg. Field Speed (miles/hour)	6.4	4.7

Eight fields were harvested exclusively with the basket rake, and three fields were harvested with the wheel rake. Core samples were taken from a representative sample of bales in each field and aggregated. These aggregate samples were combusted to determine their ash content via a laboratory analysis. The results of these tests are shown in Figure 80. The average ash content of the fields raked exclusively with the basket rake was 21% with a standard deviation of 9% and a range of 11% to 35%. The average ash content of the fields raked exclusively with the wheel rake was 18% with a standard deviation of 5% and a range of 13% to 24%. An example of how one of these fields of data was windrowed is provided in Figure 81.

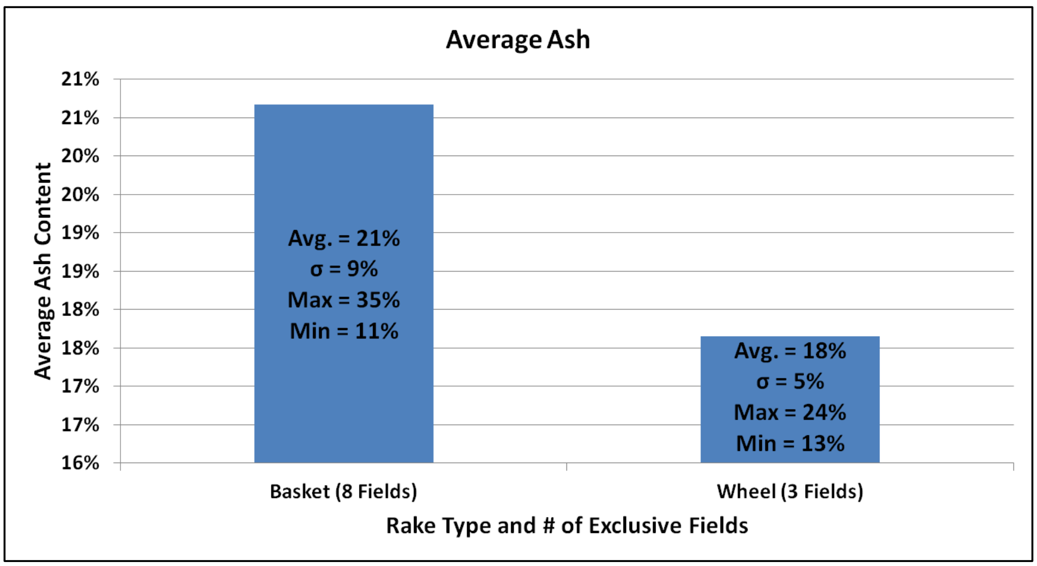

Figure 80 – Average Ash Content Comparison by Raking Type

It is important to point out that the rakes are not the sole contributor to the dirt that is collected during baling. Other variables include baler pickup, soil type, soil moisture, soil density, and stalk height. These factors were not looked at in detail during this project, as they are beyond the scope of the effort.

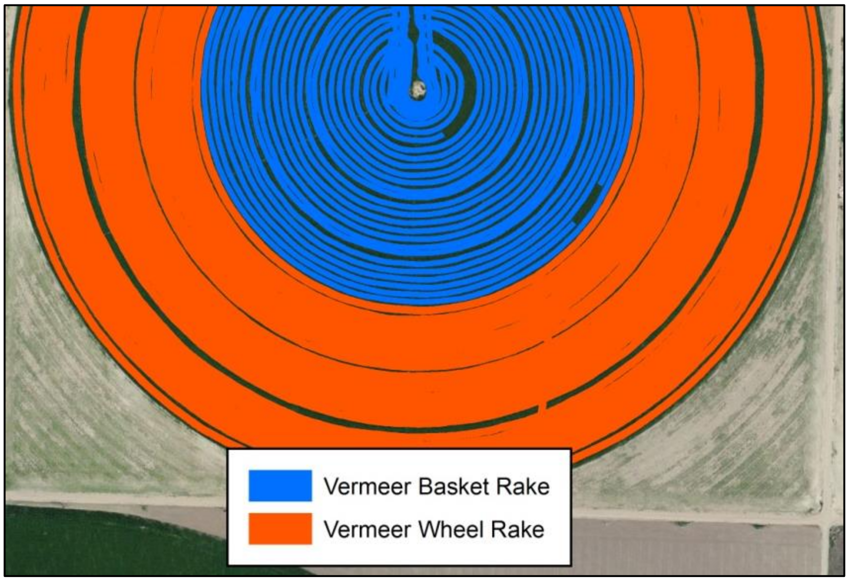

Figure 81 – Example of a field windrowed with two different rakes

7.5 INDEPENDENT ANALYSIS BY OAK RIDGE NATIONAL LABORATORY

Oak Ridge National Laboratory conducted a simulation of the FDCE harvesting system utilizing the equipment developed under this project and compared it to the same model with conventional equipment. This study is detailed in a paper which was published in 2013.[15] The objective of the report was to evaluate the impacts of improvements that would be made by the advanced harvest and logistics equipment. The ORNL team simulated the conventional (baseline) system and the advanced system using the Integrated Biomass Supply & Analysis Logistics (IBSAL) framework.[16]

The baseline system model simulated the collection of corn stover or wheat straw with equipment that is currently commercially available. With a typical corn harvesting operation, after a combine collects grain the residue is dropped on the ground and allowed to dry for a few days (typically until the wet-basis moisture content is 20% or lower), and the residue is then baled into large square bales. The bales are picked up by a conventional roadsider and delivered to a field-edge storage facility. When the bales are needed, they are loaded onto a flatbed trailer and delivered to the biorefinery 25 miles away. At the biorefinery, bales are unloaded and placed in a short-term storage facility. Bales are removed from the queue and processed to the end-user's specifications before being converted to biofuel.

The advanced system differs from the baseline system with the incorporation of a self-propelled high-density baler with a front-mounted rake and a prototype high-capacity bale pickup truck and self-loading/unloading trailer. This new equipment combination reduces costs by reducing the equipment needs in the field, reducing loading/unloading times, and improving the quality of the harvested biomass. Additionally, IBSAL model factors in improvements in the bulk density of bale material from advanced balers up to 14 lb/ft^3.

[15] Webb, et al. *Simulation of the DOE High-Tonnage Biomass Logistics Demonstration Projects: FDC Enterprises*, Oak Ridge National Laboratory, 2013.
[16] Sokhansanj S, Wilkerson EG, Turhollow AF. *Development of the Integrated Biomass Supply Analysis and Logistics (IBSAL) Model*. Oak Ridge, TN: Oak Ridge National Laboratory; 2008.

FDCE project staff and their collaborators provided the input data that was used to simulate IBSAL simulations of the FDCE baseline and advanced systems. Where data was not available from the project, it was estimated based on the herbaceous Feedstock Design Report[17] prepared in 2009 by INL. Results from the simulations are included in Figure 82 and Figure 83.

Figure 82 – Independent Analysis Cost Results

Operation	Baseline Cost by operation ($/dry ton)	Advanced Cost by operation ($/dry ton)
Combine	$0.00	$0.00
Shredding	$3.98	$3.98
Raking	$3.96	$1.32
Baling	$12.82	$9.28
In -field transportation	$2.93	$1.93
On-farm Storage	$3.23	$2.50
Transportation (incl. loading/unloading)	$8.60	$3.85
Biorefinery storage	$0.77	$0.55
Grinding	$14.48	$14.48
TOTAL COST	**$50.77**	**$37.89**
COST IMPROVEMENT		**$12.88**

[17] Hess JR, Kenney KL, Ovard LP, Searcy EM, Wright CT. *Commodity-Scale Production of an Infrastructure-Compatible Bulk Solid From Herbaceous Lignocellulosic Biomass*. Idaho National Laboratory; 2009.

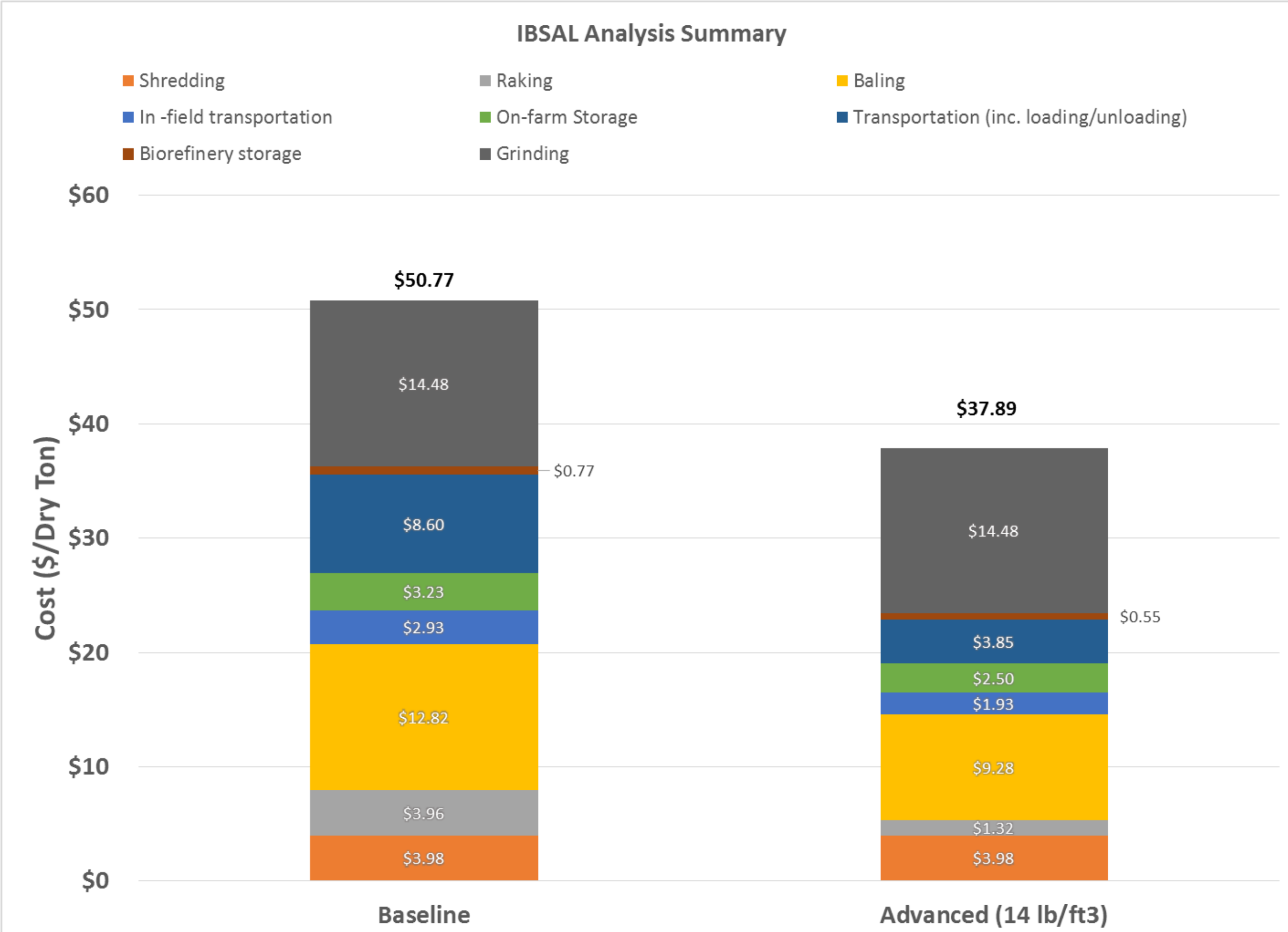

Figure 83 – Results of IBSAL Analysis

The results of this simulation analysis showed that the FDCE advanced system can deliver corn stover at a lower cost than the baseline system with bale densities of 10 lb/ft3. Achieving bale densities of 14 lb/ft^3, the advanced system would reduce the delivered costs to $37.89/dry ton. Figure 84 shows a summary of the savings by category based on the model of FDCE's advanced system relative to the baseline for 14 lb/ft^3 bale densities. It is important to point out that all of these figures are techno-economic estimates and do not include overheads or biomass production costs.

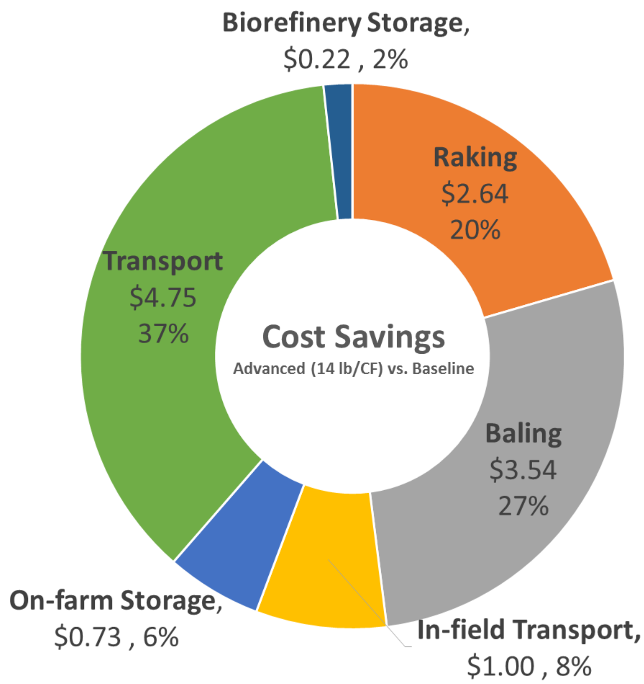

Figure 84 – Modeled Savings of the FDCE Advanced System, by Operation

8 SOIL SUSTAINABILITY EVALUATION

Biomass is championed as a fundamental piece of the sustainable energy puzzle. This is true, as long the biomass feedstocks are established, maintained and harvested sustainably. As such, all aspects of a sustainable harvest need to be well defined. This section provides a discussion of what is required of a biomass harvest to be sustainable in general. It also discusses a model used to evaluate the sustainability of the 2010 baseline corn stover harvest in Southwest Kansas.

For this project, a comprehensive environmental sustainability analysis was conducted by Kansas State University (KSU). It provides a summary of the environmental impacts of corn stover harvest in two counties in Southwest Kansas using three distinct variables – soil type, management scenario, and yield. The models consider: **3 primary soil types** in the area (best for grain production), **9 different land management scenarios** (grain yield, tillage type, windrowing type, bale), and **4 grain yield scenarios** (100, 150, 205, & 240 bushel/acre). Every combination of these variables was computed with the model, providing a total of 108 combinations for each county.

The following was computed for each combination of soil type, yield, and management scenario:

- Soil loss from wind and water erosion
- Biomass available for harvest
- Nutrient removal and replacement (NPK)
- Potential yields for herbaceous perennials
- Embodied energies of corn stover and herbaceous perennial scenarios

8.1 MODEL INPUTS

Additional information about the model inputs is provided below, organized by variable type.

Land Management Scenario

The land management scenarios listed in Figure 85 incorporate three modeled tillage and residue removal practices. The combination of tillage practice and the residue removed (or remaining) from a field are key variables to determining soil erosion.

Figure 85 – Land Management Scenarios

Crop	Tillage Scenario	Harvest Scenario
Corn grain	High yield, Fall chisel	No residue harvest
Corn grain	High yield, Fall chisel	Rake and bale
Corn grain	High yield, Fall chisel	Aggressive rake and bale
Corn grain	High yield, Strip-till	No residue harvest
Corn grain	High yield, Strip-till	Rake and bale
Corn grain	High yield, Strip-till	Aggressive rake and bale
Corn grain	High yield, No-till	No residue harvest
Corn grain	High yield, No-till	Rake and bale
Corn grain	High yield, No-till	Aggressive rake and bale

Soil Types

Each management scenario was modeled separately on the three most predominant soils in Stevens County, KS and the three most predominant soils in Seward County, KS. The soil types were selected by USDA-NRCS (Natural Resource Conservation Service) and USDA-ARS (Agricultural Research Service) personnel to be representative of soils on which corn would be grown, while also providing a range of erosion parameters. This range of soils would also reflect the variability that may be present within the southwest Kansas geo-climatic region on an annual basis.

Data used to determine representative soils in Seward and Stevens counties on which corn stover may possibly be harvested were obtained from the USDA database Soil Data Mart.[18] Soil Data Mart also contains relevant physical, chemical, acreage, and other agriculturally-based data values for all land bases in the U. S. This data was used in this study as inputs to both the RUSLE2 (Revised Universal Soil Loss Equation 2)[19] and WEPS (Wind Erosion Prediction System)[20] modeling programs to estimate soil erosion rates. This is standard practice, and state-level NRCS offices routinely perform queries for data needed to utilize RUSLE2 and WEPS. Both RUSLE2 and WEPS also have ‘built-in’ soils data based on localized field-scale analysis.

The NRCS has partitioned the US into Crop Management Zones (CMZs) which consist of geographic areas with similar cropping practices and field management practices.[21] The rotations and field management practices for all corn based crops in this analysis were derived from the CMZs for southwest Kansas, and are thought to be representative of commodity crop production in this particular region with a specific focus on: 1) production of grains, oilseeds, and other rotational crops and not residue removal; and 2) are also based on soil conservation measures that need to be in place to keep soil erosion from either rainfall or wind forces less than the tolerable limit given select ‘localized’ conditions.[22] Not all rotations are applicable to each soil type, but instead reflect general accepted practices across a geo-climatic region of the US.

Grain Yield

Yields are important to the soil erosion analysis. Higher yielding crops have a positive impact on soil erosion. The range of corn yields was used to represent historical and annual variation within the two counties, and helps demonstrate how soil

[18] http://soildatamart.nrcs.usda.gov/Default.aspx
[19] http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm
[20] http://www.weru.ksu.edu/nrcs/wepsnrcs.html
[21] http://fargo.nserl.purdue.edu/rusle2_dataweb/NRCS_Crop_Management_Zone_Maps.htm
[22] ftp://fargo.nserl.purdue.edu/pub/RUSLE2/Crop_Management_Templates/

erosion is affected over a wide range of yields that may potentially occur. Four different grain yields were analyzed in the model; 100, 150, 205, and 240 bushels/acre.

For analysis elsewhere in the United States, Soil Data Mart provides potential yields for other crops, and some on an individual soil-type basis. USDA Cooperative Extension personnel can provide more accurate, localized data as well as possible ranges in a number of crop yields within county or sub-county areas.

GREET Data

Data from the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) were used as data inputs to determine embodied energies of corn stover being harvested. Values contained in this analysis[23] include all fossil fuel (petroleum, natural gas, and/or fuel oil) input to produce a ton of end product, corn stover in this case, and are accepted values. These values are used by the U. S. Environmental Protection Agency when assessing fuel pathways and possible greenhouse gas emissions from bioenergy feedstock production systems to ethanol or biodiesel.

8.2 SOIL EROSION MODELING TOOLS USED

RUSLE2 and WEPS were used to estimate annual soil loss values under a variety of circumstances relating to both commodity crop production and corn stover removal. These programs are described below. In addition, information was derived on changes in soil tilth/quality based on the rotations and field management practices provided by the NRCS.

Rainfall Erosion and the Revised Universal Soil Loss Equation 2 (RUSLE2)

RUSLE2 predicts rainfall and runoff induced soil erosion caused by sheet and rill erosion processes. Thirty year average climate data is used within the model to make daily erosion simulations using time variable soil erodibility data; time variable cover and roughness data related to daily changes in crop canopy density, height and root growth; daily changes in soil roughness and burial and resurfacing of crop residue and roots as affected by dates and types of tillage passes and soil reconsolidation together with static slope gradient and slope lengths for the hill slopes chosen. Decay of surface and subsurface residue in five different residue type pools is also modeled daily. Support practices such as terraces, contouring and contour buffer strips can be added to the simulations as well. It does not include concentrated flow erosion from classic gullies or from ephemeral gullies subsequently filled by tillage passes and reform during the next large runoff event. Each soil is assigned a tolerable soil loss value (T), expressed in tons per acre per year, to which the RUSLE2 output is compared. Inputs to the RUSLE2 program include geographic location, soil type, topography, and land use and its management.

RUSLE2 consists of four major databases that contain all necessary information to calculate annual average soil erosion for a specific location and cropping scenario and its management. These are climate, soil, management and operations, and vegetation and residue, as described below. Data from other sources can be used as alternate model inputs.

- **Climate** – includes input values used to described weather at a particular location, county, management zone and erosivity value, 10 yr EI value, EI distribution, monthly rainfall, and monthly temperature.
- **Soil** – describes base soil conditions at a location and includes erodibility value, soil texture, hydrologic soil group of undrained soil, efficient subsurface drainage, time to full soil consolidation, and rock cover.
- **Management** – includes dates of operations, rotations used in cropping, and length of rotation. Yield, depth, and speeds of operations are also included. Operations describe events that change soil, vegetation, and residue conditions such as mechanical soil disturbance, tillage, planting, seeding, frost, burning, and harvest.
- **Vegetation and Residue** – describes live plant material and time varying residue (decomposition) as well as canopy cover percent and live ground (surface) cover percentage.

[23] http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2005-0161-3174

Wind Erosion Prediction System (WEPS)

The WEPS model has been developed by the USDA Agriculture Research Service and contains many parameters that work with both RUSLE2 and WEPS for crops and field management operations. Therefore residue amounts at different crop yields, residue burial by tillage machines, and residue harvest amounts with different biomass harvesting strategies are very similar between the two models.

WEPS is a process-based, daily time-step model that simulates weather, field conditions, and erosion, especially the field processes that modify a soil's susceptibility to wind erosion. WEPS uses a uniform simulation region surface assumed to only have one soil type (uniform soil properties), crop type (biomass properties), and management, uniformly distributed over the field. In reality, fields are often not uniform so the user may select the dominant-critical (i.e., most erodible) soil or crop condition for a simulation. The field surface is periodically updated in the model to simulate the surface changes caused by erosion.

Four types of information are entered for an analysis: 1) description of the simulation region geometry by defining the field dimensions and field orientation; 2) selection the field location for which to generate simulated weather; 3) selection of the soil type; and 4) selection of a management scenario. Field dimensions are entered as a length and width and orientation as an angle deviation from north. The user selects the barrier type and geographic location is either state and county or latitude and longitude. The interface then selects the weather stations for which historical weather parameters are used to simulate weather parameters.

The soil component is selected from a list of soils supplied by the NRCS Soil Survey Geographic (SSURGO) database for the Soil Survey Area of the simulation region. Management operation and dates are compiled in the Management Crop Rotation Editor for WEPS, a spreadsheet type table editor. Given user supplied inputs, the interface accesses five databases for climate, soils, management, barriers, and crop growth and residue decomposition for the simulation. These databases provide needed parameters for location and conditions simulated as specified by the user. Figure 86 shows the inputs required to run WEPS (e.g. location, field geometries, soil components, and field management operations).

Soil Erosion Model Outputs

The outputs of the soil erosion programs revealed the erosion impacts as a function of each land management scenario, grain yield, and residue removal. This data included the amount of soil loss as well as the soil conditioning index (SCI), a factor that indicates the health of the soil.

The SCI combines the effect of three determinants of organic matter as follows:

$$\mathbf{SCI} = \boldsymbol{OM} + \boldsymbol{FO} + \boldsymbol{ER}, \text{ where:}$$

- Organic material or biomass factor (***OM***) – This component accounts for the effect of biomass returned to the soil, including material from plant or animal sources, and material either imported to the site or grown and retained on the site. As yield increases SCI will increase, if all other factors remain constant.
- Field operations factor (***FO***) – This component accounts for the effect of field operations that stimulate organic matter breakdown. Tillage, planting, fertilizer application, spraying, harvesting, and other operations crush and shatter plant residues and aerate or compact the soil. These effects increase the rate of residue decomposition and affect the placement of organic material in the soil profile. More intensive operations will decrease the SCI.
- Erosion factor (***ER***) – This component accounts for the effect of removal and sorting of surface soil organic matter by sheet, rill, or wind erosion processes as predicted by water and wind erosion models.

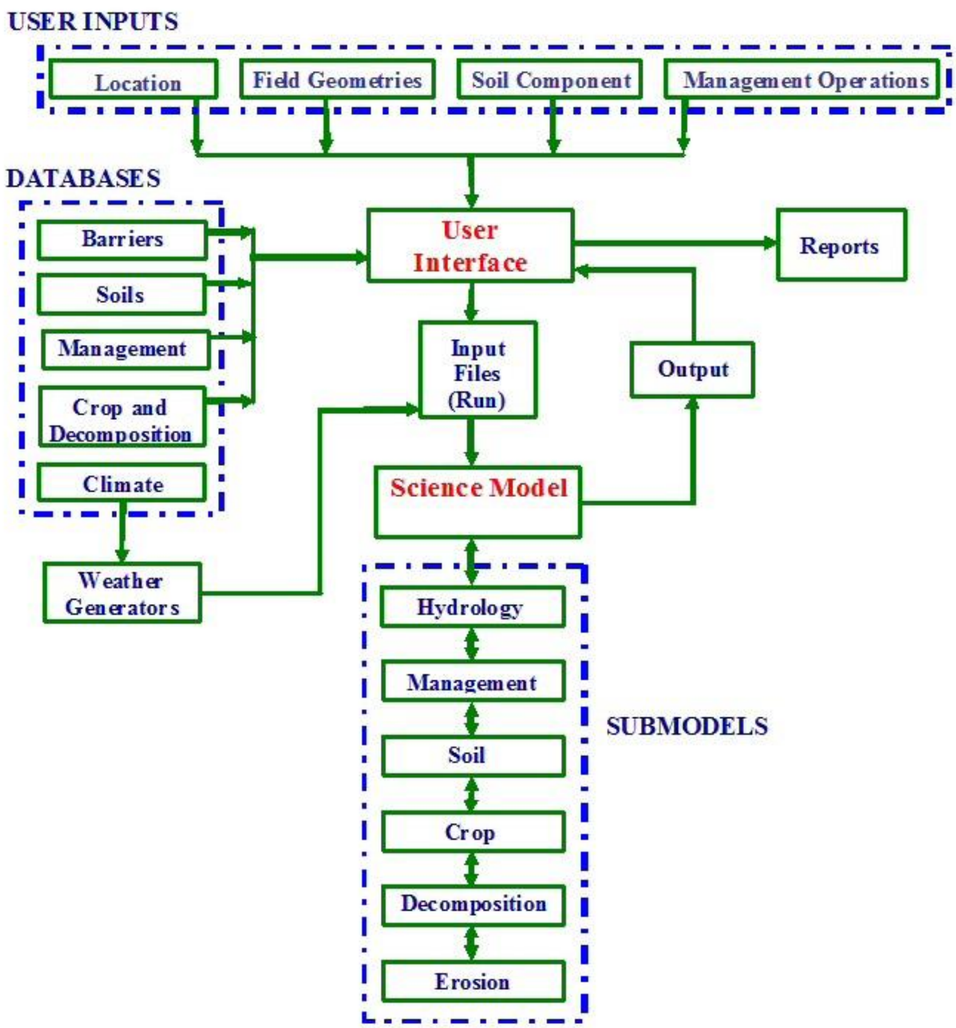

Figure 86 – Structure of the WEPS model[24]

8.3 RESULTS OF SOIL SUSTAINABILITY EVALUATION

Results obtained from the analysis follows two expected patterns:

1. Erosion decreases and soil tilth (SCI) increases as yield increases for any one particular field management practice, both with residue removal and without removal.
2. Erosion and SCI can be significantly different between two different soils with the same field management practices.

[24] Adopted from: *WEPS Technical Documentation*, 1996. http://www.weru.ksu.edu/weps/docs/weps_tech.pdf

The first point was identified when comparing soil erosion and the SCI across the No Residue Removal (baseline) harvest scenario. As the yield increases from 100 to 240 bushels per acre, erosion decreases from 0.7 tons per acre per year to 0.2 tons per acre per year and the SCI increases from 0.3 to 0.8. This is also true for those cases with residue removal such as rake and bale where the erosion rate decreased from 2.1 to 0.4 as the yield increased and the SCI became greater. This is due to increased residue on the surface being added back to the soil even as the amount of residue removed increased.

The second point involves changes as a function of soil type. Comparing differences in both erosion and SCI between Dalhart and Richfield soils in Seward County, the erosion rate is significantly different under the baseline No-Removals case (9.1 versus 0.7) and a much more pronounced difference as residue is removed under the rake and bale expect at higher yield levels. The SCI follows a similar trend of being different as yield increases between the two soils both with and without residue removal. This demonstrates the interaction of soil type, yield, and field management practices on erosion levels and soil tilth. The same trends hold true for Stevens County as well, but have different values due to varying soils and climate.

A sustainable biomass harvest ensures that the soil, among many other factors, is protected and that a biomass supply will be abundant for future harvests. Soil sustainability is one of the many pieces to the sustainability puzzle. Other environmental and socio-economic factors will need to be taken into account. As the desire for agricultural biomass grows, harvesters will need tools to plan sustainable operations prior to harvesting. These would provide the harvester with a detailed summary of how his operations will impact the land, or at a minimum, provide a simple “Go, No-Go” decision.

Two rules of thumb indicating that have been determined a corn stover biomass harvest would be unsustainable operation are:

1. Do not harvest a field with a SCI less than zero
2. Do not harvest a field with a grain yield (corn) less than 100 bu/acre

Other rules of thumb may apply for other crops such as wheat straw, milo stubble, or grasses. Determining the actual sustainability of a biomass harvest prior to harvesting is complicated, but critical for the industry. Idaho National Laboratory (INL) is developing a tool that aims to provide this service by integrating the Soil Survey Geographic Database (SSURGO) with user inputs such as crop rotation, grain yield, tillage practice, and residue removal practice at a chosen location. The tool will query the SSURGO database to gather key soil attributes for the area and incorporate erosion analysis.

9 FUTURE IMPROVEMENTS

The project team is proud of its accomplishments in completing the scope of work across all six task areas, including:

1. Equipment Design and Fabrication
2. Baseline Data Collection
3. Technical Stage Gate Review
4. Equipment Demonstration
5. Performance Evaluation
6. Project Management and Reporting

This project was able to produce new equipment and methods that successfully demonstrated potential cost reductions in the herbaceous biomass supply chain. However, ongoing future work will be needed to continue the progress that has been made and there are many segments of the industry that will need ongoing improvement. The subsequent sections highlight the key areas of that should be targeted for future improvement in this area of the bioenergy industry.

9.1 INCREASED FIELD TESTING OF ADVANCED HARVEST AND LOGISTICS EQUIPMENT

The Self Propelled Baler, Bale Picking Truck, and Self Loading Trailer were successfully prototyped, tested, upgraded, and demonstrated in a commercial harvest setting. These machines are still early in their product life cycle. During the project period, less than 15,000 tons of material was baled/handled by this equipment. Significantly more testing and performance documentation is needed for this equipment to be fully commercialized. Additionally, the machines should be tested with multiple crops. This additional testing and will lead to improved operational reliability, improved effectiveness, and extended machine life.

9.2 BIOMASS YIELD LARGELY DETERMINES THE ECONOMICS

In the discussion of the harvest results, biomass yield was stated as a determining factor in the cost-effectiveness of the project. Data collected during the project clearly demonstrates that the amount of biomass available per acre has a direct impact on the cost of harvesting and delivering the material on a per ton basis. For reference, Figure 87 shows the relationship between biomass yield and the associated cost of harvesting the biomass, by operation.

Based on this result, targeting crops and fields with high amounts of available biomass will significantly improve the economics of a biomass supply.

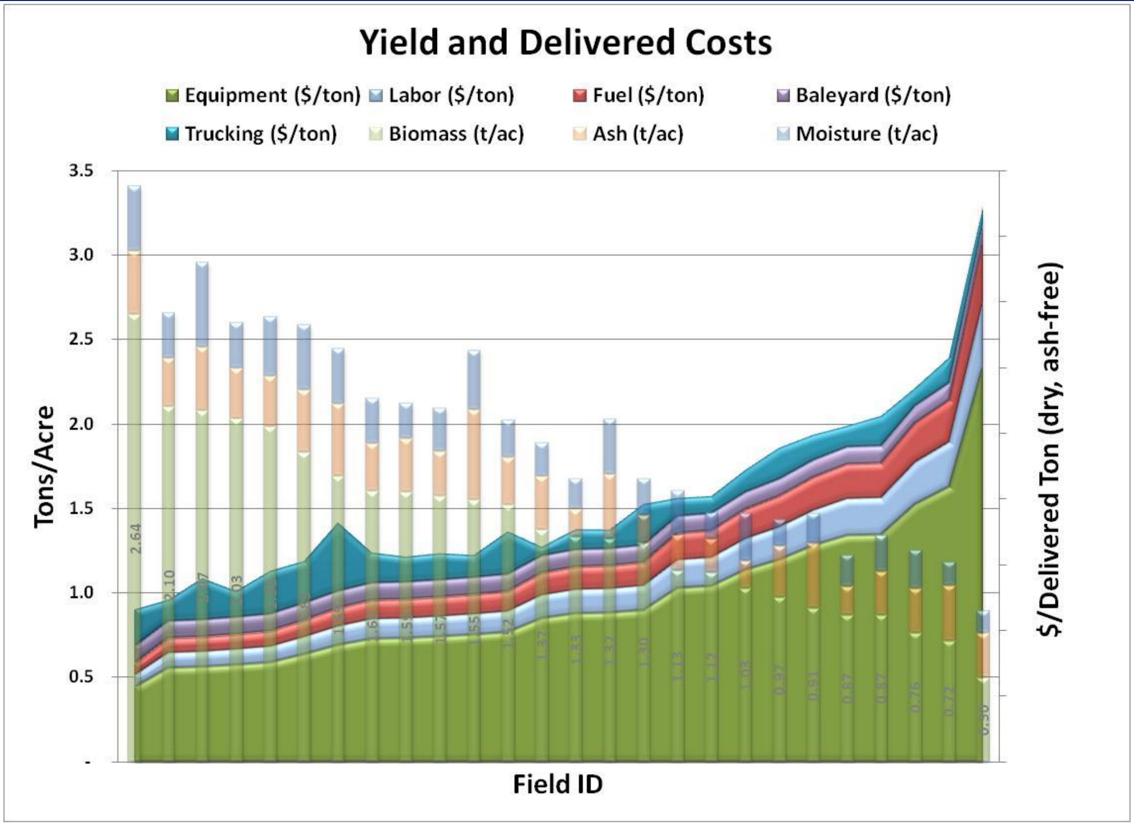

Figure 87. The Importance of Biomass Yield

9.3 ENHANCED DATA COLLECTION TECHNOLOGY

Data collection at the start of the project required a pen and paper and stopwatches. By the end of the project, the data collection group was utilizing GPS tracking devices and monitoring the equipment locations in real time. Though considerable improvements were made in the quality and quantity of data collected, the data collection and analysis methods were still manual and labor-intensive. This methodology is not practical for commercial-scale data collection for biomass harvesting fleets. As such, improved systems will be needed to monitor several elements of the biomass harvesting operation, including:

- Location
- Equipment Performance
- Fuel Consumption
- Biomass Quality, and
- Biomass Production

These data will need to be collected through the use of pre-programmed, autonomous systems, with very little input required from the operational staff in the field. Additional features of these tools would include a framework for assessing the soil sustainability of a given operation. A sustainability platform would be able to utilize key inputs such as a landowners grain yield data along with publicly available soil data to determine the amount of biomass that could be removed sustainably.

9.4 IMPROVE DIRT REMOVAL DURING BALING AND PROCESSING

Dirt is introduced into a bale during the windrowing and baling operations, and is then carried throughout the supply chain. This additional dirt increases the ash content of the biomass and reduces the life of the baler, processing equipment, and the end user's conversion process. In the future, more work will be needed to minimize the amount of dirt that is introduced into the bale. This work would include improved harvesting methods as well as baler pickup and windrower design.

9.5 PRODUCTION SCALE-UP AND TESTING

Commercial-scale biomass in-feed and processing systems will need further improvement. This equipment includes the receiving, conveyance, and processing equipment at the end-users biomass processing facility. For successful implementation at commercial scale, this equipment will require increased automation and improved efficiencies over conventional biomass handling/processing equipment.

10 PEER REVIEWS

10.1 STAGE GATE REVIEW MEETING

On April 26, 2011 a Stage Gate Review panel was convened to meet in person with the project team in Oskaloosa, Iowa to evaluate progress during the initial phase of the project. The main purpose of the review was to assess whether or not, when, and under what circumstances the project should progress and be able to utilize the remaining budget.

An independent Stage Gate review panel consisting of 3 independent industry experts was assembled. A summary of project activities to date was presented to the peer reviewers by each project team member. The results of the baselining activities were presented to the peer reviewers alongside the status of the equipment being developed.

Each peer reviewer provided commentary on the following:

- Relevance to overall objectives
- Approach to performing process engineering development
- Technical accomplishments and progress
- Success factors and showstoppers
- Proposed future research approach and relevance

In summary the reviewers stated that the project team was making excellent progress, well managed, well organized, and on track to meet all of its goals. The peer reviewers gave the project an overall score of 375/400, indicating outstanding progress. The following table summarizes the reviewers' ratings, by criterion.

Figure 88 – Results of Stage Gate Review

Criteria	Composite Score
1. Relevance to Overall Objectives (20%)	400/400
2. Approach to Performing Process Engineering Development (20%)	375/400
3. Technical Accomplishments and Progress (20%)	367/400
4. Success Factors and Showstoppers (20%)	358/400
5. Proposed Future Research Approach and Relevance (20%)	375/400
Overall Reviewer Rating	**375/400**

10.2 PEER REVIEW MEETINGS

The project's status was presented during the DOE's Biomass Peer Review Program in 2011, 2013, and 2015. During these meetings the project's progress, outcomes, and future work was discussed and evaluated by industry peers selected by DOE. Peer reviewers at each of these meetings provided commentary on the strength of the following sections:

- Project overview
- Project approach
- Technical progress and accomplishments
- Project relevance

The reviewers were also given the opportunity to provide comments on their overall impression of the project. A condensed summary of these comments and the team's responses to them are provided in the following sections. When a response from the team is provided, it is the actual response written in the voice of the responder.

10.2.1 Project Overview

Comments on the project overview evaluated the project history, its context within the portfolio, and its high level objectives.

Praise

Most reviewers provided positive comments regarding the project overview. They felt the project history and background was thorough. The team was praised for its diversity, which reviewers felt would make the outputs highly likely to be commercialized. The team was also commended for considering a range of bioenergy crops. Project goals were well defined and aligned with the high-level objectives of the FOA. Overall, reviewers felt the project and industrial partners involved were well-presented.

Criticism

The only criticism offered from the reviewers in this section was in regard to the conventional equipment. Specifically, the reviewer commented that the problems with the currently available conventional equipment was not adequately defined.

Team Response

Primary problems with existing equipment (if this comment was referring to equipment on the market today), include: 1) time and number of pieces of equipment required to gather individual bales and handle them (stack, unstack, load, strap, unload, handle at a processing facility) in small groups at every step throughout the supply chain is not optimal (too much time, labor, and equipment currently required); 2) especially for baling equipment, product longevity and durability with extended reliable operational life in the targeted applications needs to be improved; 3) reducing negative impacts of dirt (ash) on the maintenance and life of the equipment (bearing wear, lubrication, knotter longevity, bale chamber wear, etc.); and 4) bale density when these high-tonnage projects began was too low for the targeted feedstocks (significant improvements have already been made and commercialized here by several OEMs in the last ~ 5 years, in part due to DOE investments and market demand for that improvement for the feedstocks targeted for these biorefineries). Having stated these problems, today's best equipment in the hands of experienced and efficient operators is a tough target to beat--there is very good equipment on the market today. This current equipment, however, cannot (in our opinion) achieve the cost reductions targeted by DOE even when operated by the best operators.

If this reviewer comment was seeking additional input on problems with the existing prototype equipment that our team developed as part of this project, we can provide additional feedback on that topic too. The first generation of Self Loading Trailer had several primary problems that have been significantly improved in subsequent models: 1) the angle between the ground and the trailer bed during loading cycles was too steep (it could work, but this angle was cut in half on the second generation trailer to make it easier for the trailer to load bales from the ground); 2) the trailer used chains for loading and unloading that ran the entire length of the trailer bed (these chains were about 106 ft long, each)--chain tightening and maintenance was problematic, especially initially until a certain amount of tightening had been completed; 3) the guide wings on the vertical posts on the trailer still could catch bales during the loading sequence if bales were out of alignment (which will happen frequently); 4) use of a single chain did not allow the opportunity to crowd bales from one chain to the next in case there were gaps between bale columns; 5) there was no active, operator controllable mechanism to re-align bales if they were out of alignment; 6) loading biomass bales from the ground with tracks is challenging, especially during less than optimal ground conditions (wet, frozen) (it is possible, but a different pick-up mechanism is being developed that will solve this challenge). The Bale Picking Truck and Self Propelled Baler both demonstrated the ability to achieve the technical objectives targeted by their design; however, some design modifications and improvements (relatively minor improvements compared to the complexity and scale of the design and fabrication of the prototypes) and a significant amount of additional field work and testing are needed to demonstrate commercial readiness and added value. Improvements targeted by MacDon for their heavy biomass header were primarily in the cutting mechanism and systems, and in the design and operation of the crop conditioning components to ensure that the crop was dropped in a windrow in an arrangement that would allow efficient collection by a baler in the subsequent operation. MacDon solved these problems during this project.

10.2.2 PROJECT APPROACH

In this category, reviewers commented on the implementation of sound research, development, and deployment approaches. They also reviewed the project management plan, its milestones, and whether or not it included adequate methods for addressing potential risks. Finally, reviewers looked for clear, well described critical success factors regarding the project's technical and commercial viability, as well as a complete understanding of the challenges that the project must overcome.

Praise
Reviewers felt that the project objectives were clearly stated. The team was praised for demonstrating good management, engineering development, and innovation. Reviewers found the equipment development process followed a logical progression. They also noted objectives that were met, such as reduced costs, reduced trips through the field, and increased efficiency.

Criticism
One reviewer felt that while the team was interdisciplinary, it lacked a strong field operations partner. They expressed concern that this would result in the setting of unlikely goals for equipment development.

Team Response
Our team did have several strong field operations partners: FDC Enterprises and Kelderman Manufacturing both have extensive experience in baling and field operations. We welcome further involvement from other field operations companies in the future, and invited others to participate (PacificAg was one of them) when we drafted the proposal for this project. When this project began, FDC Enterprises had its strongest experience in grass establishment, field/crop maintenance, and nation-wide farm equipment dispatch, logistics, and operation. Those capabilities proved extremely valuable to our team's success, especially in helping our team with access to and operations on switchgrass and Miscanthus fields. Our team nominated FDC Enterprises to lead this project because of that experience, and because companies like FDCE will be among the types of organizations that could best utilize and deploy the type of equipment our team members are developing. Kelderman Manufacturing also has extensive experience in biomass baling and a wide range of other field operations, including consideration and implementation of system improvements targeted at increasing overall supply chain efficiencies and reliability for high tonnage biomass systems. Practical limitations on project budget and manageability, machine prototype readiness at the time (for broader exposure), and some concerns about competing OEM preferences among some other very qualified field operations companies has limited our team's direct interaction with other field operations companies to date. We hope and expect that this interaction will increase over time, and we welcome it. During the period of execution of this DOE project, that was not possible/practical. At the appropriate time, the value of the type of increased interaction with strong field operations companies cannot be understated. We agree completely.

Our presentation's stated critical success factors included: "Reduce Life Cycle Costs of Equipment -- Increase life and reliability." Still, the reviewer is correct in stating that the importance of machine uptime (or increased reliability as phrased on the slide) was not emphasized enough—this will be changed in subsequent presentations. We are well aware (painfully so in some cases) of the importance of machine uptime, especially in the types of high tonnage applications targeted by DOE for future biorefineries. Machine reliability and uptime on an almost continuous basis and over long periods of times (years) is the primary area in need of improvement and demonstration associated with some of our team's prototype equipment. The benefits of the improved features and system efficiencies targeted by our team's new equipment will be negated very quickly if the equipment is not at least as reliable as existing commercial equipment in all required working environments.

10.2.3 Technical progress and Accomplishments

This portion of the peer review assessed how much progress has been made towards completing project objectives. This included the evaluation of the achievement of milestones and technical targets. Reviewers also looked at whether or not technical barriers had been overcome.

Praise

Reviewers noted several accomplishments that they felt were impressive. These included the development of four different equipment types and effective systems integration. One reviewer stated that some of the equipment provides a fundamental advantage over previous methods. Overall, reviewers felt that critical success factors were well-described and persistently pursued.

Criticism

Reviewers brought up a few concerns, too. One highlights the fact that this project was limited by available harvest acreage. It was suggested that the project team consider seeking growers who would be willing to plant full fields of the required crops.

Team Response

Our team successfully developed adequate access to available acreage in all targeted crops with the exception of Miscanthus. We did have enough access to high tonnage Miscanthus fields for MacDon to be able to test and refine their heavy crop header design and improvements to the point that they now know what changes would be made to a new prototype or commercial header. However, MacDon has made the decision to suspend further development and commercialization efforts until a significantly larger volume of Miscanthus acres are in commercial production. For now, they have a solid design waiting on a commercial use at product sales volumes of interest to their company. During the project period, our project partner Mendel did successfully seek out growers willing to plant fields with Miscanthus in a variety of locations (latitudes). Mendel paid for the establishment and maintenance of those fields, and our team harvested them. We harvested every field Mendel provided that was large enough for the cost and effort involved. Commercial production acres of Miscanthus at this time are not enough to entice MacDon to invest further in commercialization of their header. FDC Enterprises facilitated access to quality grass fields throughout the project period, and our biorefinery team members provided access to corn stover fields. Some of the prototype equipment developed by our team members still needs significant further harvest operation and demonstration to prove commercially viable reliability and added value, but the limiter there has not been the access to the needed amount of acreage, it has been the development of improvements to the equipment that increase performance from season to season. As the equipment becomes closer to commercial levels of reliability and performance, annual harvest volumes are expected to increase significantly.

10.2.4 Project Relevance

This section of the review evaluated the degree to which this project contributes to meeting the Program/Technology Area goals and objectives put forth by the Bioenergy Technologies Office. Reviewers analyzed whether or not the project team had considered applications of the expected output, as well as how successful project completion will advance the state of technology and impact the viability of commercial bioenergy applications.

Praise

Reviewers felt that this project was highly successful and relevant. One reviewer noted the project’s commercial value, as it demonstrates an innovative, effective biomass feedstock supply chain strategy. They felt that the equipment prototypes and commercialization of the trailers will result in progress in the bioenergy field in the future.

Criticism

Reviewers expressed concerns that the project does not involve enough OEMs. Questions were raised regarding availability of the new equipment.

Team Response
In response to the comment about the need to bring more OEMs on-board, we agree to an extent. When we developed our team and proposed scope for this project, we invited other OEMs to participate. The ones who declined our invitation were submitting their own proposals (some won awards and some did not).

The long-term objective of Kelderman Manufacturing with respect to their equipment development efforts are: 1) prove commercial value and performance and manufacture equipment in-house within the manufacturing capabilities of the company, and/or 2) prove commercial value and performance and establish licensing and manufacturing agreements with one or more larger and leading OEMs to provide greater volume manufacturing capabilities and market access through world-wide distribution channels if needed. They have been successful at this with a number of other farm equipment products and inventions. Through one or both of these manufacturing routes (depending on the piece of equipment), Kelderman will be able to meet consumer demand when it develops.

10.2.5 Overall Impressions

This unscored category gave reviewers the opportunity to assess the project overall based on the preceding criteria.

Praise
Reviewers praised this project for being not only ambitious but also successful. They felt that the project team was well coordinated and that the project outputs will likely lead to advances in bioenergy.

Criticism
Several concerns were raised about this project. Some reviewers felt that the initial need was not communicated effectively. Furthermore, some suggested that the project team would have benefitted from the involvement of a commercial fields operation to guide equipment design and scope.

Team Response
The need and primary intended objective of this project was to design, fabricate, and demonstrate new equipment that has the potential to significantly reduce supply chain costs for high tonnage herbaceous biomass. This potential was successfully developed and demonstrated, and some of the equipment is now under commercial manufacturing production (ahead of original planned sales expectations). Our team included very strong and experienced field operations collaborators and there was a significant amount of interaction among our OEMs and field operations team members. Additional collaborators were invited at the outset of the project but declined participation. Our team members plan for and welcome broader collaboration with experienced field operations companies as the new equipment approaches commercial readiness.

10.3 SUMMARY OF REVIEWER COMMENTARY

Industry peers provided constructive feedback during the Stage Gate Review meeting and the 2011, 2013, and 2015 Peer Review Meetings. These reviews provided valuable insight as to what was needed and helped the project to stay on target as it progressed.