Feedstock Supply System Logistics

DOE Bioenergy Technology Office
Feedstock Platform Review
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U.S. DEPARTMENT OF ENERGY

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FEEDSTOCK LOGISTICS: Goals & Scope

Big-picture goal:

Energy security through commercialization of biofuels.

Need:

Develop simulation tools to facilitate scaling up logistical infrastructure (equipment, storage, engineering and operational resources) to an industry wide scale

- Develop IBSAL (Integrated Biomass Supply Analysis & Logistics) to project costs of feedstocks supplied by TennEra, FDCE, AGCO, SUNY and Auburn.
- The independent analysis is done through receiving input data from the five projects, assembling individual projects' data on equipment performance, crops, yield, regions, weather, as related to each of the projects.

Quad chart overview

TIMELINE

Start date: 2007

End date: 2015

Percent complete: 65%

BUDGET

Total project funding (FY11-FY13): $1,229 K
DOE Share: 100%

Funding Received
FY 11:$329K
FY12: $450K
FY13: $450K

BARRIERS

- It-A End to End Integration
- It-B Demonstration-scale Facilities
- It-C Risk of First-of-a kind Technology
- It-E Engineering Modeling Tools
- Ft-D Sustainable Harvest
- Ft-G Feedstock Quality and Monitoring
- Ft-H Biomass Storage Systems
- Ft-J Biomass Materials Properties
- Ft-K Biomass Physical State Alteration
- Ft-M Overall Integration and Scale-Up

PARTNERS

TennEra LLC

AGCO Corp.

FDC Enterprises

SUNY

Auburn University – US

Idaho National Laboratory

Simulation of the five high-tonnage projects

Three high tonnage herbaceous feedstock

AGCO
Single pass & storage of moist bale

FDCE
Large volume handling

TennEra
Bulk handling

Two high tonnage woody feedstock

SUNY
Efficiency

Auburn
Transpirational drying

IBSAL Structure

Input Data (IBSAL- Excel file)

Daily Weather Data
- Average temperature
- Snow
- Rain
- Relative humidity
- Evaporation

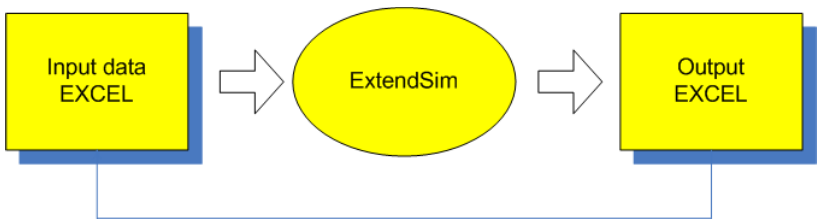
Harvest Schedule
- Harvest fraction decimal
- Moisture content fraction decimal

Crop Data
- Standard density of grain
- Standard grain moisture content
- Average biomass yield
- Yield to be deducted for conservation

Field Data
- Total crop supply area
- Distance to the side of farm

Equipment Data
- Equipment width
- Speed
- Horsepower
- Hourly cost of equipment

Storage Data
- Number and size of storage sites
- Distance from farm to storage
- Distance from storage to final destination



Simulation (IBSAL- ExtendSim file)

Simulating all operations required to deliver biomass from farm lands to the conversion plant

Mathematical equations calculating the operational performance of equipment

Mathematical equations calculating moisture content and dry matter loss

Outputs (IBSAL- Excel file)

Economic output:
- Custom Cost per ton of biomass
- Ownership Cost per ton of biomass

Energetic and environment output:
- Energy Input
- CO_2 Emission

Biomass recovery:
- Dry matter loss
- Net collected yield

Resource output:
- Number of days to complete each operation
- Number of required machines
- Utilization rate for machineries
- The harvested area

Flow of information to and from IBSAL

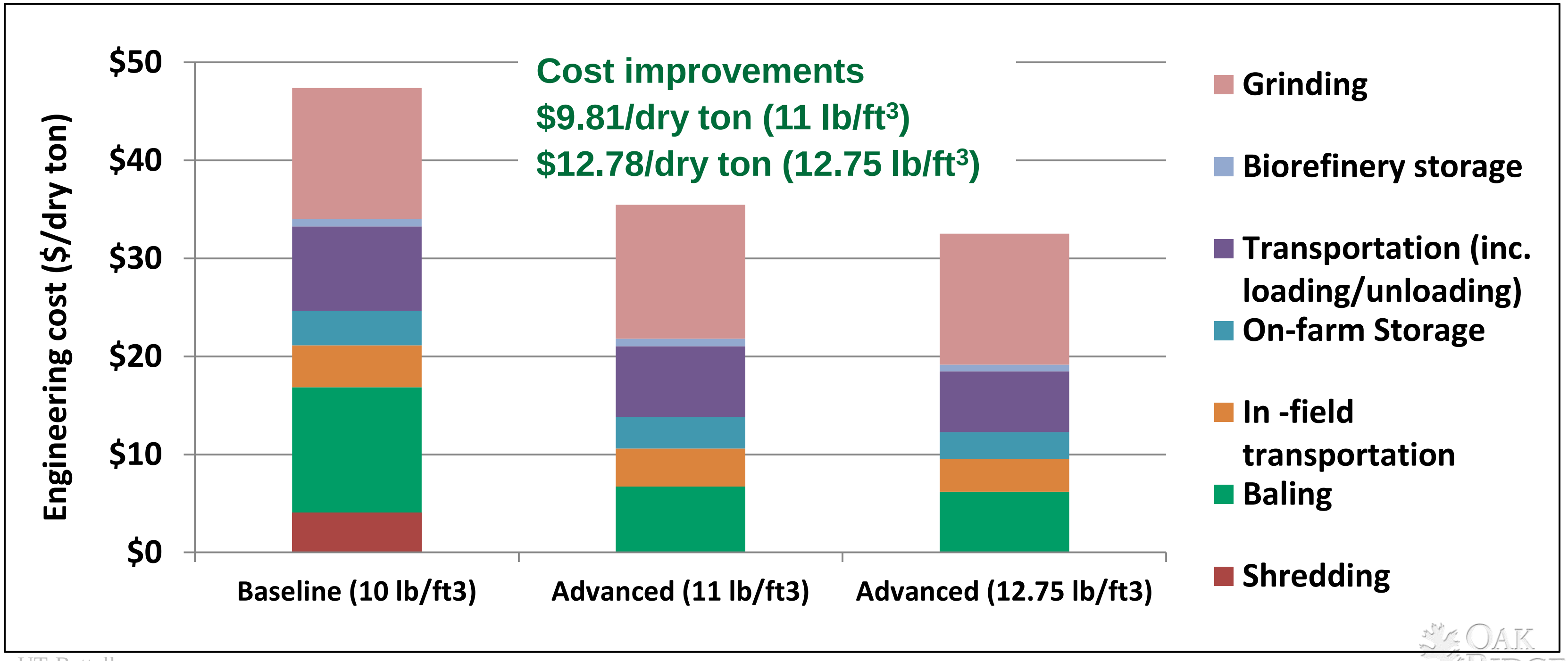
1- Approach

1. Visited 5 project sites to view equipment in operation, and discuss data for modeling (FY 11-12)
2. IBSAL model of baseline and advanced systems for each of the high tonnage projects developed
3. Data provided by three herbaceous projects (FY 12-13)
4. Analyses of baseline and advanced systems for 3 herbaceous systems performed
5. Independent internal review of assumptions and results (FY 13)
6. Results will be reviewed with project investigators to verify assumptions, results, etc. and reports prepared for DOE

Note that the estimates generated in this analysis are engineering costs, not feedstock prices. Costs do not include grower payment. Additional analysis is needed to better account for the business costs and market factors associated with implementing these designs.

Simulation of logistics demonstration projects: AGCO Results

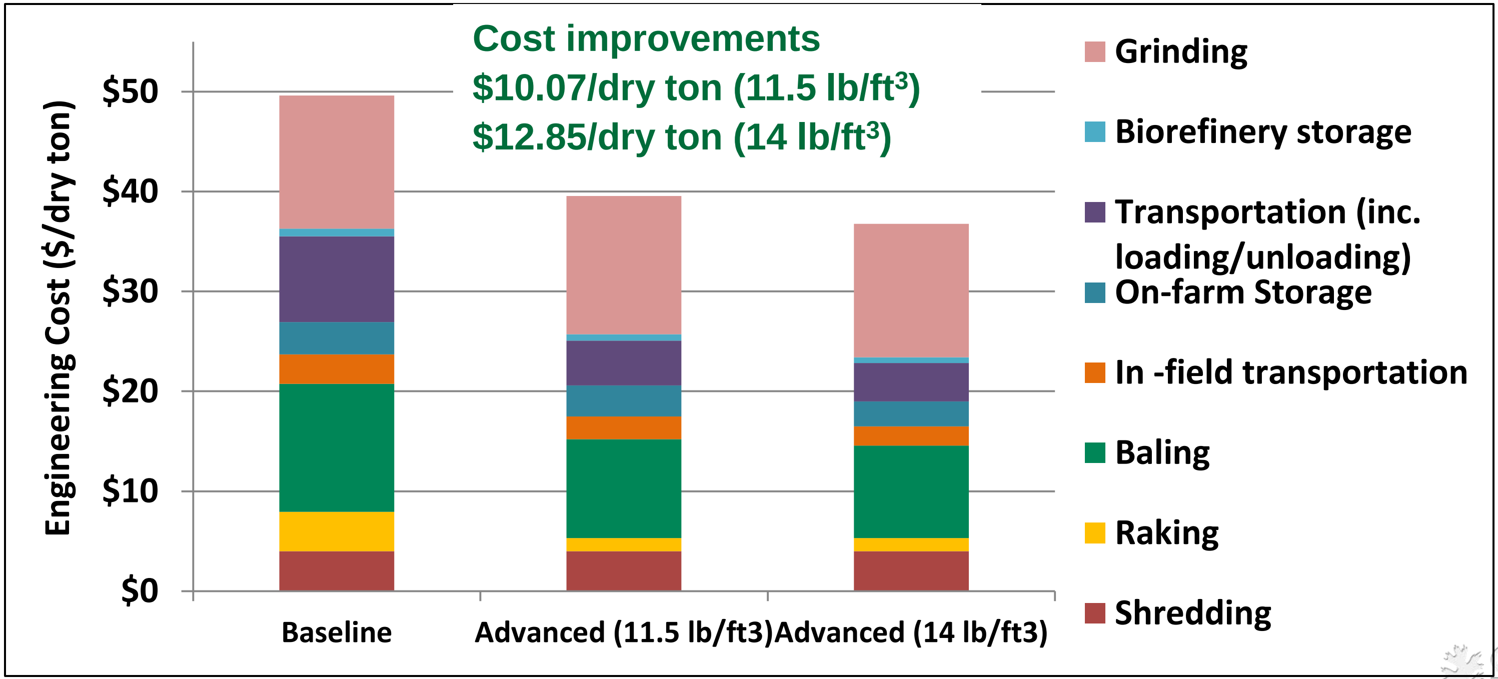
- Corn stover bales delivered to biorefinery
- Yield = 1.9 dry ton/acre
- Technical advances simulated
  - Single-pass harvest
  - High-density baling
  - Trailer with automatic load securing
- Engineering costs were reduced by 25% and 31% for bale density of 11 and 12.75 lb/ft^3, respectively



Simulation of logistics demonstration projects: FDCE Results

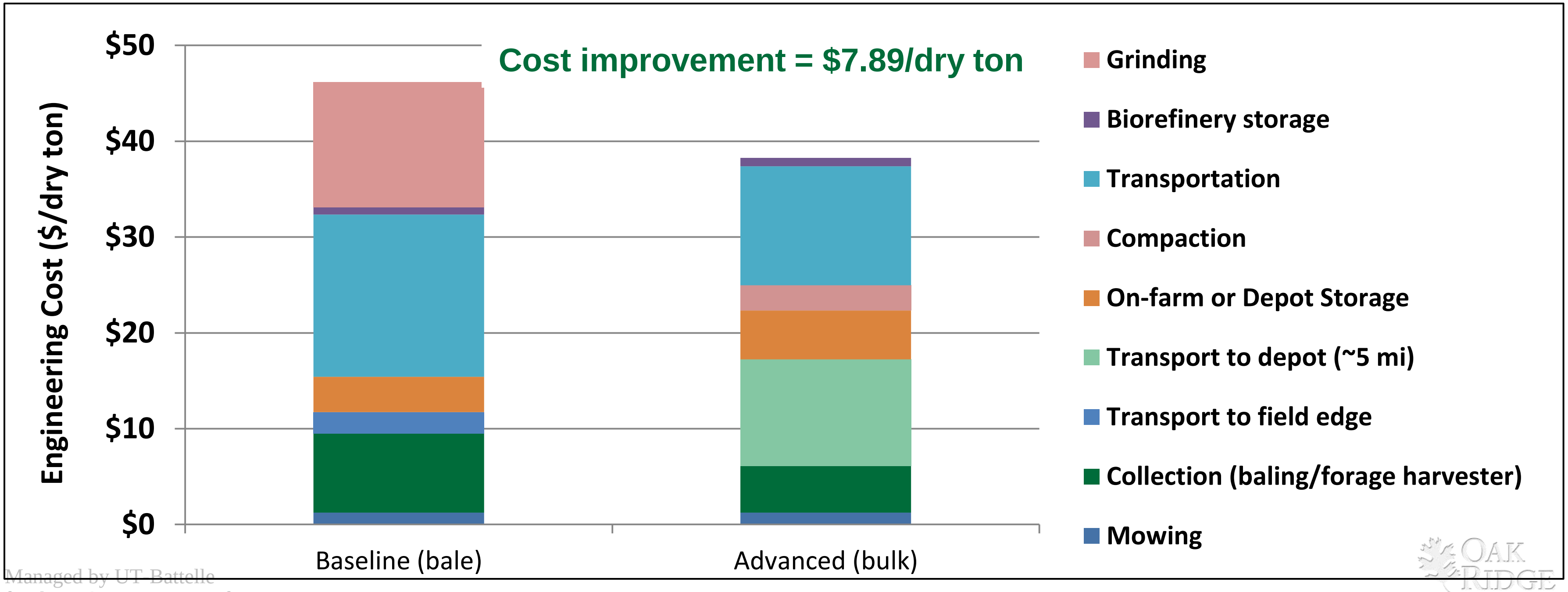
- Corn stover bales delivered to biorefinery
- Yield = 1.96 dry ton/acre
- Technical advances simulated
  - Self-propelled large rectangular baler
  - High-density baling
  - Self-propelled bale pickup truck
  - Self-loading/unloading trailer

- Engineering costs were reduced by 20% and 26% for bale densities of 11.5 and 14 lb/ft^3, respectively



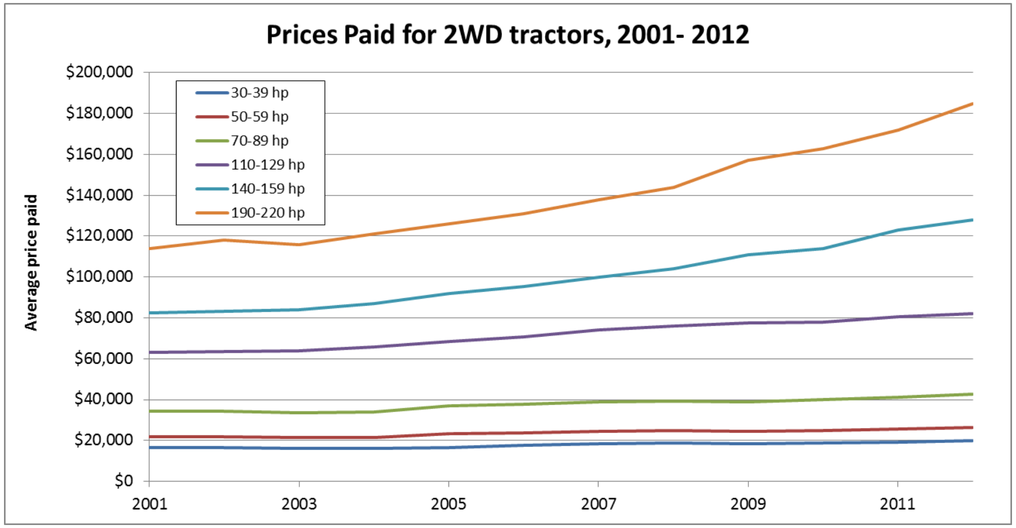
Simulation of logistics demonstration projects: TennEra Results

- Field chopped switchgrass stored at regional depot then compacted and delivered to biorefinery as needed
- Switchgrass yield = 8 dry ton/acre
- Technical advances simulated
  - Field chopping (precise length of cut)
  - Transport of chopped biomass from field to regional depots
  - Storage and handling of compacted chopped biomass
- Moving the size reduction operation from the biorefinery to the field reduced logistics costs by 17%



2 Progress
Dissemination of logistics modeling data via KDF

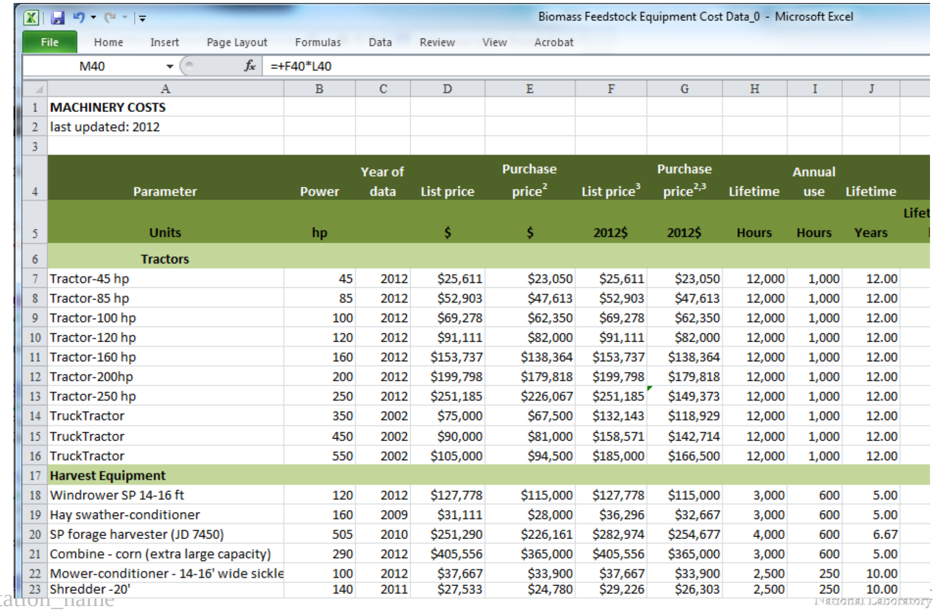
- **Maintaining current estimates of equipment pricing critical to accurate supply chain analysis**
- **Spreadsheet to calculate cost of equipment usage ($/hr) available on Bioenergy KDF**



Prices paid for 190-220 hp tractors increased by 62% from 2001 to 2011 (Source: USDA Agricultural Prices annual summaries)

Approach follows:

***Cost Methodology for Biomass Feedstocks: Herbaceous Crops and Agricultural Residues*. Oak Ridge National Laboratory. ORNL/TM-2008-105. (Also available on KDF)**


Biomass Feedstock Equipment Cost Data_0 - Microsoft Excel

M40 =+F40*L40

MACHINERY COSTS
last updated: 2012

Parameter	Power	Year of data	List price	Purchase price[2]	List price[3]	Purchase price[2,3]	Lifetime	Annual use	Lifetime
Units	hp		$	$	2012$	2012$	Hours	Hours	Years
Tractors									
Tractor-45 hp	45	2012	$25,611	$23,050	$25,611	$23,050	12,000	1,000	12.00
Tractor-85 hp	85	2012	$52,903	$47,613	$52,903	$47,613	12,000	1,000	12.00
Tractor-100 hp	100	2012	$69,278	$62,350	$69,278	$62,350	12,000	1,000	12.00
Tractor-120 hp	120	2012	$91,111	$82,000	$91,111	$82,000	12,000	1,000	12.00
Tractor-160 hp	160	2012	$153,737	$138,364	$153,737	$138,364	12,000	1,000	12.00
Tractor-200hp	200	2012	$199,798	$179,818	$199,798	$179,818	12,000	1,000	12.00
Tractor-250 hp	250	2012	$251,185	$226,067	$251,185	$149,373	12,000	1,000	12.00
TruckTractor	350	2002	$75,000	$67,500	$132,143	$118,929	12,000	1,000	12.00
TruckTractor	450	2002	$90,000	$81,000	$158,571	$142,714	12,000	1,000	12.00
TruckTractor	550	2002	$105,000	$94,500	$185,000	$166,500	12,000	1,000	12.00
Harvest Equipment									
Windrower SP 14-16 ft	120	2012	$127,778	$115,000	$127,778	$115,000	3,000	600	5.00
Hay swather-conditioner	160	2009	$31,111	$28,000	$36,296	$32,667	3,000	600	5.00
SP forage harvester (JD 7450)	505	2010	$251,290	$226,161	$282,974	$254,677	4,000	600	6.67
Combine - corn (extra large capacity)	290	2012	$405,556	$365,000	$405,556	$365,000	3,000	600	5.00
Mower-conditioner - 14-16' wide sickle	100	2012	$37,667	$33,900	$37,667	$33,900	2,500	250	10.00
Shredder -20'	140	2011	$27,533	$24,780	$29,226	$26,303	2,500	250	10.00

3 Relevance:
Scaling up a feedstock industry capable of meeting EISA targets*

- Optimizing feedstock design part of the entire system – equipment sizing, numbers, and the sequence of operations. (It-A)
- Scaling up demonstration projects to commercial scale (Ft-M)
- Managing risks of supply disruptions
  – Inclement weather- storage and blending – Multi year simulated scenarios (Ft-G)
  – Dry matter, ash tracing (Ft-G)
  – Evaluating one of a kind equipment (It-C)

*155 and 325 million DT/yr by 2017 and 2022, respectively (MYPP)

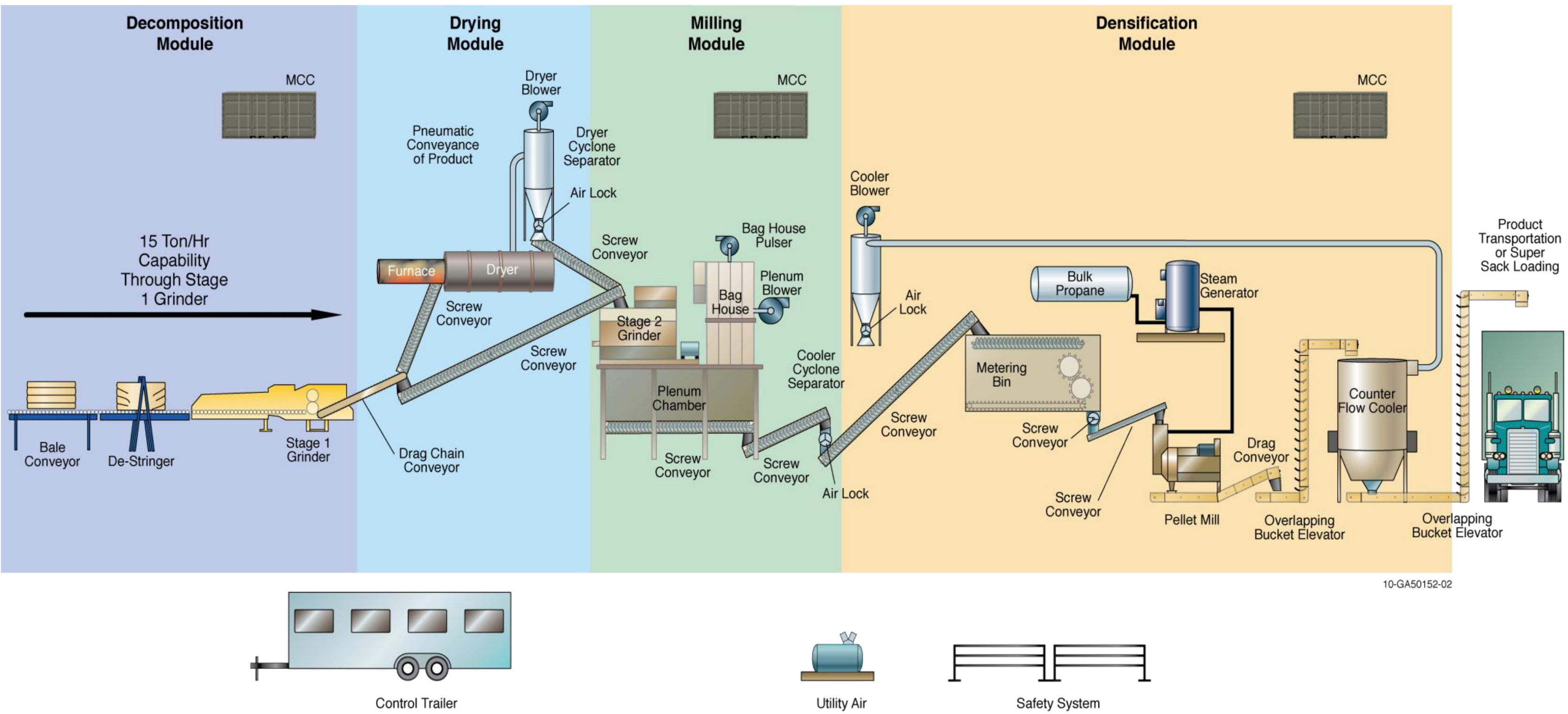
4 Critical success factors

- Simulations of the high tonnage logistics projects demonstrated the logistics cost of feedstock supply for stover residue and switchgrass decreased $8 to $13 from a base case of almost $47 per dry ton.
- The density of baled or chopped biomass is a critical factor in achieving the cost goal. The density must be maintained at over 12 lb/ft^3
- Extended field operations on newer equipment and consistent data acquisition are critical to a robust modeling, optimizing systems in search of least cost logistics
- Data and equations for other high impact crops (in addition to stover, wheat straw, switchgrass) become available

5. Future work

- Complete modeling and analysis of two woody projects SUNY and Auburn (It-B)
- Interact with stakeholders, disseminate results to DOE and others as appropriate
- Install a user version of IBSAL on KDF
  - Sensitivity analysis – effects of yield, biorefinery size, equipment availability, feedstock format, distances, and transport options (It-A).
- New supply chain modeling capabilities
  - Biomass blending and formulating (Ft-J)
  - Logging residue recovery (It-E)
  - MSW (It-C)

5- Future work – Modeling PDU and incorporating the model in IBSAL for scale up, integration with feedstock collection and pricing



A complete set of commercial size equipment for testing and developing size reduction, drying, densification, storage, and handling of biomass feedstock

Summary

1. ORNL engineering team, in collaboration with INL and members of the 5 high tonnage logistics projects developed simulation model of the 5 projects.
2. The models are validated through field observations, field data and independent evaluation.
3. Initial analysis show that the projects have resulted in innovations in equipment and up to 31% in harvest cost reductions.
4. Robustness of the data and timely exchange of data among team members are critical success factors.
5. Future modeling work will continue with sensitivity analysis, forest residues and new bioenergy crops.

Responses to Previous Reviewers' Comments

- I have a concern that thermal pretreatments may increase capital cost and decrease net energy. Program needs to better explain capital and energy implications of additional treatments being proposed or explored.
- It is not clear what the research pathway is in this project. A number of tasks are being researched, and although each appears to be important, there is not a clear linkage to a roadmap or critical path that results in higher biomass use and lower total costs.
- Concurrent, yet independent development of densification process methods and more fundamental equations for materials and operations may dilute the effort and create tension between allocation of time to tasks that are not necessarily in sync.

Response: We have separated activities related to improving the quality of feedstock from the logistical issues. Research on quality of feedstock is pursued as part of feedstock conversion and interface tasks. Feedstock logistics is focused solely on modeling effort and analysis.

- There does not appear to be triage of need for which models and algorithms are most urgent, particularly those not available in the literature.
- The model needs to be verified adequately to have confidence in the results. Who will use the model?

Responses to Previous Reviewers' Comments

- There was no description of how the technology will be transferred to potential end-users. Good collaborations with universities.

The five logistics projects have provided an opportunity to acquire real data from the field, work with the logistics projects to develop the model, test the model, and conduct analysis.

- There was no description of how the technology will be transferred to potential end-users. Good collaborations with universities.
- It was not described how the universities and industry partners were contributing to the project. Logistics is important so I was pleased to see that this project was focused on this. Weak tech transfer part of the powerpoint presentation.
- We are continuing publishing and presenting research results in various forums including holding workshops at ASABE AETC on modeling, logistics, and IBSAL.
- Efforts are underway to develop and install a user version of the IBSAL model (so called meta model) on KDF for a wider potential users.

Related publications

Publications

- Ebadian, M., Sowlati, T., Sokhansanj, S., Townley-Smith, L., Stumborg, M., 2013. Modeling and analyzing storage systems in agricultural biomass supply chain for cellulosic ethanol production. Applied Energy, 102, 840-849.

- Li, Xue, Edmund Mupondwa, Satya Panigrahi, Lope Tabil, Shahab Sokhansanj, Mark Stumborg. 2012. Agricultural residue supply in Canada for cellulosic ethanol production. Accepted manuscript: *Renewable and Sustainable Energy Reviews* February 6, 2012

- Naimi, Ladan, Shahab Sokhansanj, Xiaotao Bi, C. Jim Lim, Alvin R. Womac, Anthony Lau, Staffan Melin. 2013. Development of size reduction equations for calculating energy input for grinding lignocellulosic particles. Applied Engineering in Agriculture 29(1):93-100.

- Kaushlendra Singh, Shahab Sokhansanj, James Dooley. 2013. Wood as an advanced feedstock for bioenergy: scale matters. *Biofuels* (2013) 4(1):13–16

- Ekşioğlu ,Sandra D. Song Li, Shu Zhang, Shahabaddine Sokhansanj, Daniel Petrolia. 2011. Analyzing Impact of Intermodal Facilities on Design and Management of Biofuel Supply Chain. Transportation Research Record: Journal of the Transportation Research Board. Volume 2191 / 2010. 144-151. 10.3141/2191-18.

- Mobini, M., T. Sowlati, S. Sokhansanj. 2011. Forest biomass supply logistics for a power plant using the discrete-event simulation approach. Applied Energy 88(2011):1241-1250.

- Ebadian, Mahmood, Taraneh Sowlati, Shahab Sokhansanj, Mark Stumborg, Lawrence Townley-Smith. 2011. A new simulation model for multi-agricultural biomass logistics system in bioenergy production. Biosystems Engineering 110 (2011) 280-290.

- Pa, Ann, Jill Craven, Hsiaotao T. Bi, Staffan Melin, Shahab Sokhansanj. 2011. Environmental Footprints of 1 British Columbia Wood Pellets from a Simplified Life Cycle Analysis. International Journal of Life Cycle (DOI) 10.1007/s11367-011-0358-7

Related publications and dissemination

Submitted under review

- **Popp, M., Searcy, S., S. Sokhansanj. 2013. Weather Related Impacts on Biomass Moisture Content of Direct Harvested Forage Sorghum and Switchgrass in Arkansas and Texas. Submitted and under review for the International Food and Agribusiness Management Review**

In preparation

- **Sokhansanj, S., E. Webb, A. Turhollow. Modeling harvest and postharvest handling of whole tree plantations. 2013. Manuscript under preparation for the Applied Engineering in Agriculture.**

- **Ebadian, M. Taraneh Sowlati, S. Sokhansanj, L. Townley-Smith, M. Stumborg. 2013. Development of an integrated tactical and operational planning model for optimal supply of feedstock to a commercial-scale bioethanol plant. In preparation for Bioresource Technology journal.**

- **Mobini, M., E. Oveisi, T. Sowlati, S. Sokhansanj. 2013. Logistics of supplying woody biomass to a combined heat and power plant. Manuscript is prepared for the Transactions of the ASABE.**

- **Mobini M., T. Sowlati, S. Sokhansanj. 2013. A simulation modeling approach towards design and analysis of wood pellet production and distribution supply chain. In preparation Journal TBD.**

Thesis completed

- **Mahmoud Ebadian Ph.D. Thesis "Optimal design of agricultural biomass supply chain for a cellulosic ethanol plant." Department of Wood Science UBC. Joint supervision Professor Taraneh Sowlati and Shahab Sokhansanj (2013-04-11)**

Thesis to be completed in 2013

- **Mahdi Mobini Ph.D. Thesis "Design and analysis of wood pellet supply chain" Department of Wood Science UBC. Joint supervision Professor Taraneh Sowlati and Shahab Sokhansanj**