Advanced Feedstock Supply System Development at the Idaho National Laboratory

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Idaho National Laboratory

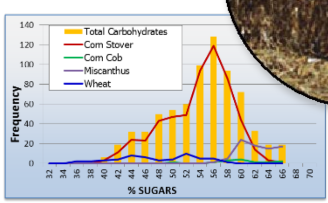
Core Competencies

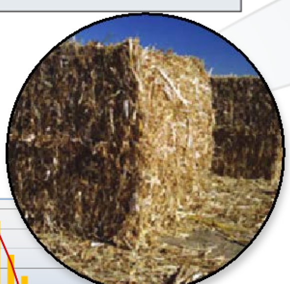
Performance Science Approach of Converting Raw Biomass into Consistent Feedstocks @ Scale helps establish the U.S. Bioeconomy

Biological/Bioprocess Science & Engineering
Identifying how biomass attributes translate to supply chain performance (logistics, preprocessing, feed handling and conversion performance)

Applied Materials Science & Engineering, Chemical Engineering
Developing consistent, conversion-ready feedstocks from variable and diverse biomass reso

Mechanical Design & Engineering, Large-Scale User Facilities/Advanced Instrumentation
Improving operability and reliability of feed handling





Biomass Characterization

Feedstock Engineering (Preprocessing)

Integration & Scale-up

Biomass Mobilization

- Informs feedstock selection, development, and valuation
- Informs equipment and process design, selection, and operability
- Accelerates scale-up and start-up
- Reduces risk and costs

Partnerships

- Industry: Shell, DuPont, UOP, Cogent, Coolplanet, Repreve Renewables
- Federal: DOE-BETO, USDA-USFS, USDA-ARS, BLM
- State: ISDA

Biomass variability makes it a uniquely challenging feedstock compared to other energy feedstocks such as coal or crude

Facilities

Recognizing a core-competency in biomass scale-up and integration, DOE-EERE established a National User Facility around these capabilities

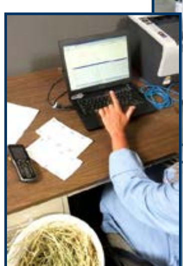
What we do:

- Composition
- Grindability
- Stability
- Flowability
- Convertibility

To inform:

- Biomass valuation
- BMPs
- Preprocessing requirements
- Integrated pathway dev.

Biomass Characterization Laboratory



Process Demonstration Unit (PDU)

Integrated biomass processing pilot facility: grinding, drying, torrefaction, chemical preprocessing, pelleting, cubing, and multiple packaging options

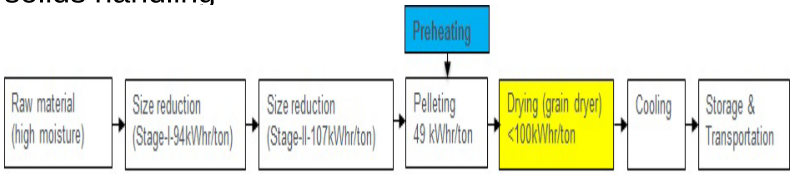
- Preprocessing R&D
- Process development
- 3rd party testing & validation
- Toll processing & piloting

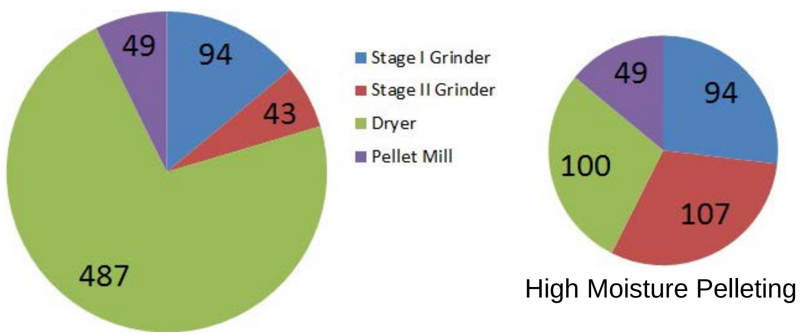
Projects/Outcomes

Bridging the gap between the biomass supply and conversion through development of drop-in, conversion-ready feedstocks

High-Moisture Densification

Reduces cost of moisture management and improves solids handling





Conventional Pelleting

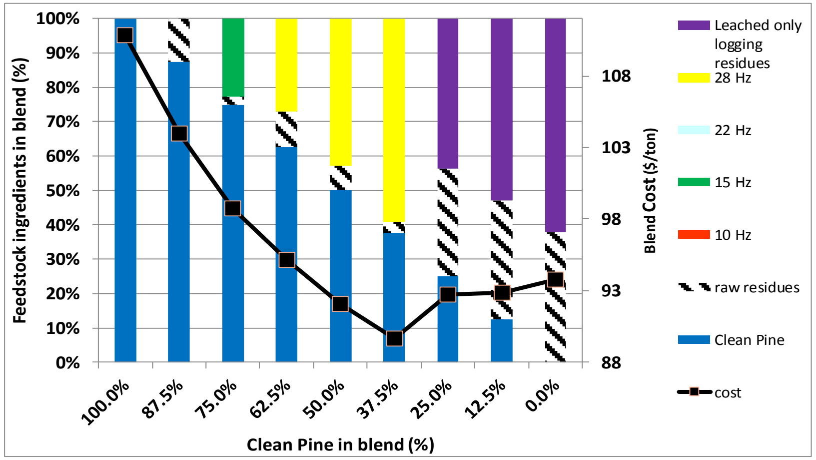
Energy consumption in kWhr/ton

Approach: Pellet biomass at > 3x normal moisture content, using preheating, frictional heat, and energy-efficient pellet drying

Results: Lignin glass transition temp is lowered at high moisture resulting in reduced energy inputs and up to 40% cost reduction

Blended Feedstock Development

Reduces supply chain risk and feedstock cost by coupling location-specific resource use with biofuel production



Approach: Developing blended feedstocks using empirical models to predict blend composition and performance

Results: Tests show that blend performance (sugar and bio-oil yields) can be predicted and therefore models can be used to develop least-cost blends

Both of these INL projects were selected for DOE Lab Corps

Bale Feedstock Supply System

- Same as the Livestock Forage System
- 10 material intermediates, 3 biomass format changes
- 14 process steps, 21 different types of equipment
- Supply system is bale format specific

The Rand Study

- Rand Corporation study from 1980's showed that plants that process bulk solids typically operate at less than 50% of design capacity the first year of operation
- DOE sponsored study followed significant difficulties in the start-up of new synthetic fuel plants
- Performance of 37 new plants using data provided by 25 companies
- Problems generally relate to an inadequate understanding of the behavior of particle systems (Bell 2005)

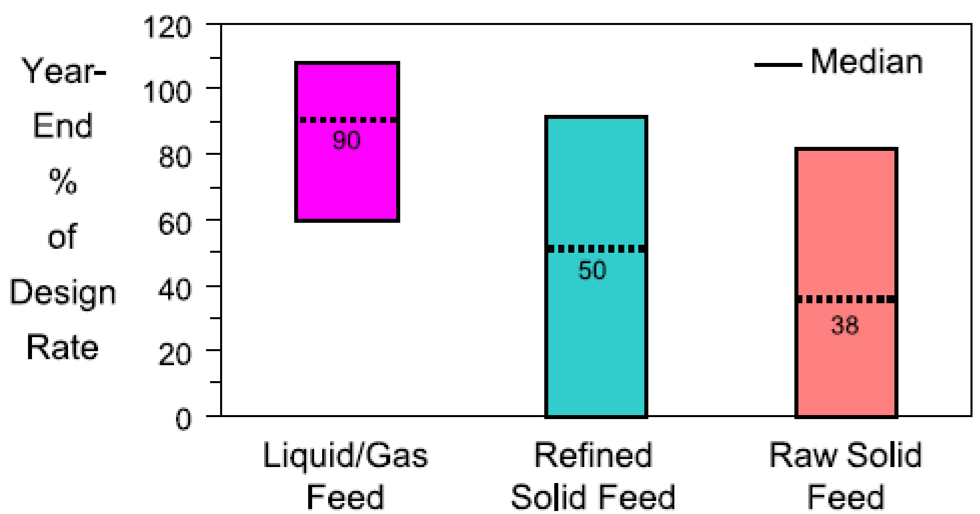


Image source: Merrow 1985

Why particle processes are so difficult

- A particle system is more likely to be inconsistent than consistent
- Particles can almost be described as a fourth state of matter
  - They can develop cohesive strength and transfer stresses like a solid
  - They can retain air and take on fluid-like properties
  - They are often compressible and elastic like a gas
  - Unlike liquids and gases, particles often remember where they have been and never forget
  - Gases and liquids do not grow, agglomerate, aggregate or suffer attrition, particles do
- Materials process differently after being aged or subjected to repetitive handling
- Particle behavior often does not scale

Particle morphology effect on flowability

Feeding chopped & ground switch-grass

Material	Feed rate (Dton/hr)	Duty cycle (%)
Chop	31.0	0 (flood)
Chop	29.8	35
Grind	4.9	99

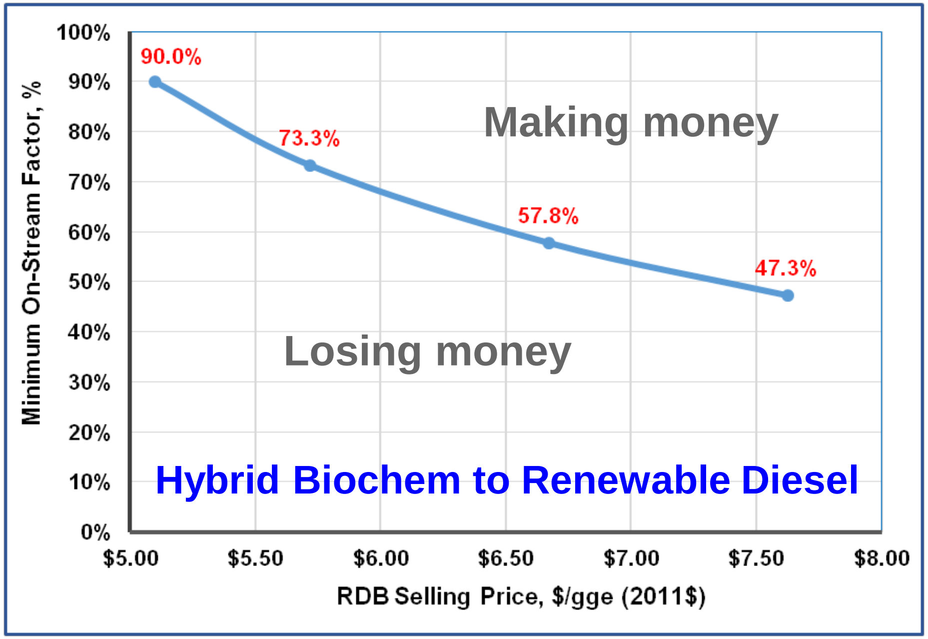
Womac, et al. Appl. Engin. Agric. 2015.

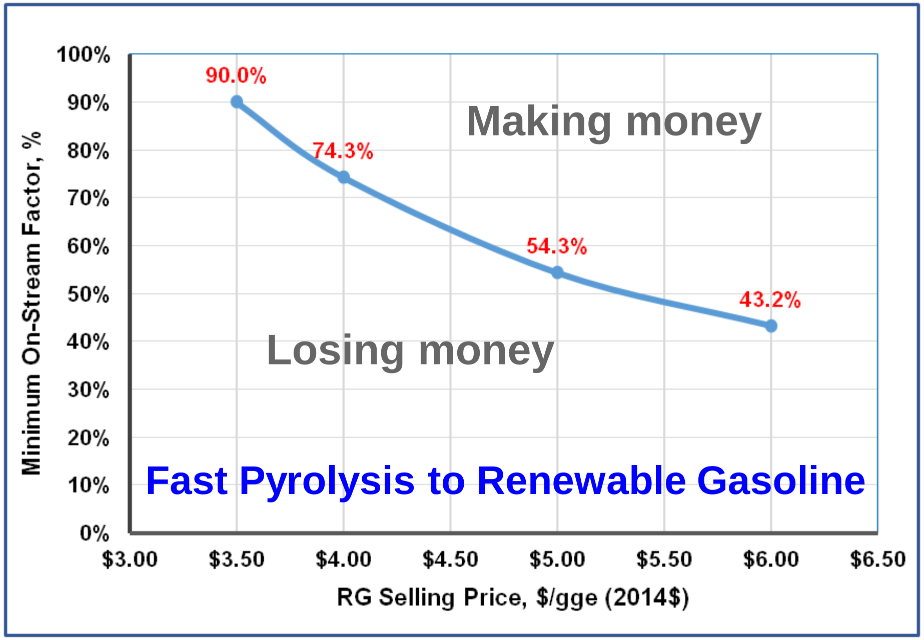
Across a range of particle sizes and shapes the only consistent difference was morphology of particle tips

Westover, et al. Biofuels 2015

Pioneer biorefinery lessons learned

- The Rand study was a long time ago, hasn't this improved?
- Look at the data…
  - In 2015, 2.0 million RINS generated from cellulosic ethanol; estimated ~3% of production capacity
- Inadequate understanding of the behavior of particle systems
- Feedstock variability and the limitations of current systems to handle it are significant factors





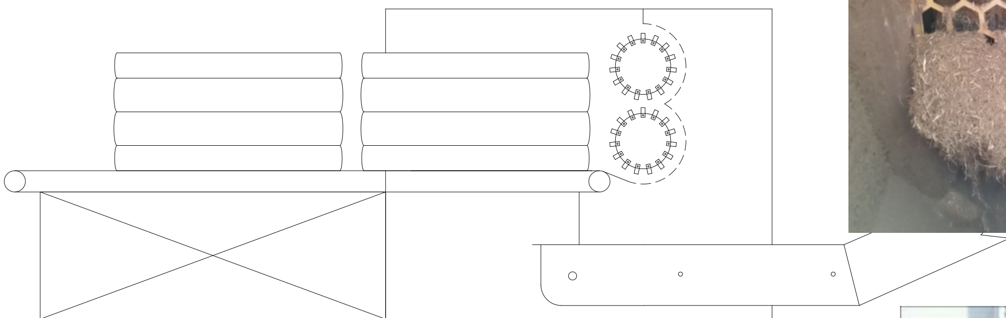
Industry Feed Handling Problems

- Moisture
  - Grinder throughput
  - Particle size variability
  - Variation causes inconsistent mass and heat transfer in conversion
- Particle Size
  - Large particles (aka pin chips)
    - Cause plugging problems in bins, augers
    - Do not fully cook – plugging in downstream equipment, microbial contamination
  - Fine particles
    - High in ash
    - Dust – fire, explosion, and health hazards
    - Plugging of weep holes in digesters
    - Buffering capacity, increase chemical usage
  - Variation causes inconsistent mass and heat transfer in conversion
- Foreign material (dirt, metal)
  - Plugging, equipment wear

Example: ABBK Plant in Hugoton, KS

Plugging Stage 1 Grinder Screens

- Root Cause: Variation in Moisture
- Solution: NONE in Extreme Cases, otherwise Slow!!



Horizontal Grinder Configuration

4” Screen

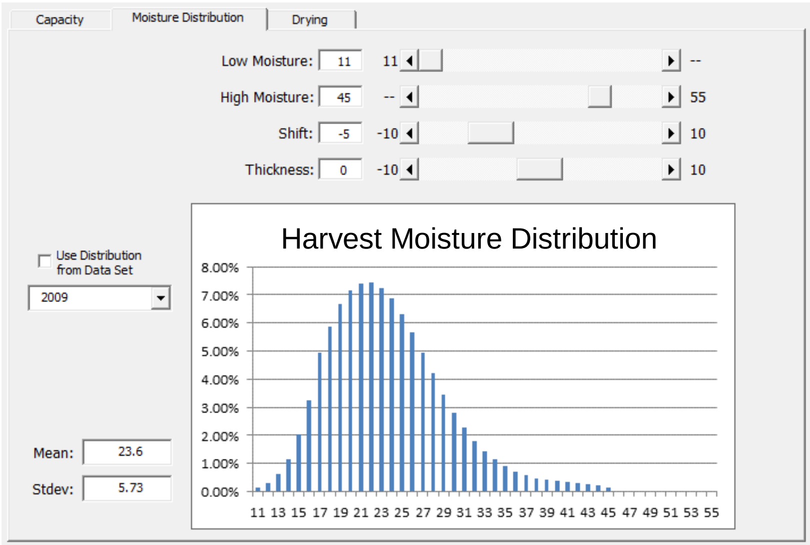
Bridging in Feedstock Bin

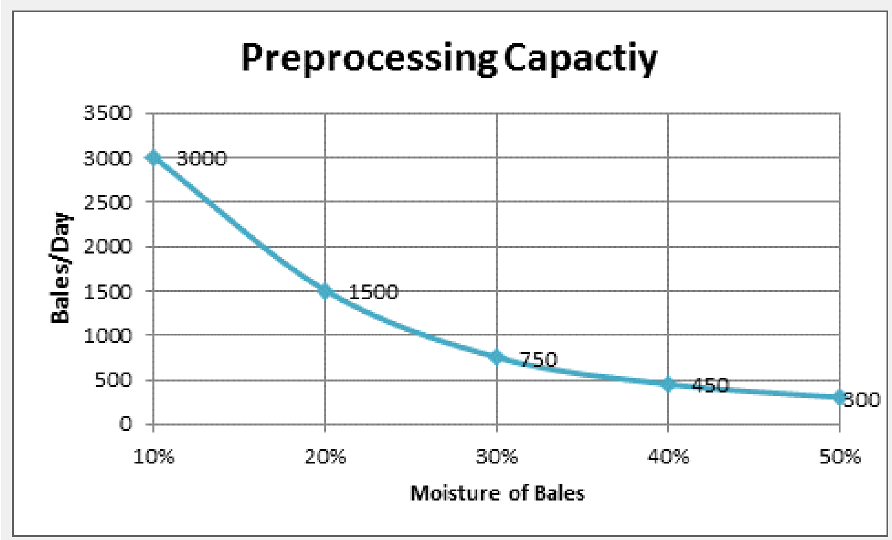
Corn Stover Bridging in Drop Chute

Unplugging a Conveyor

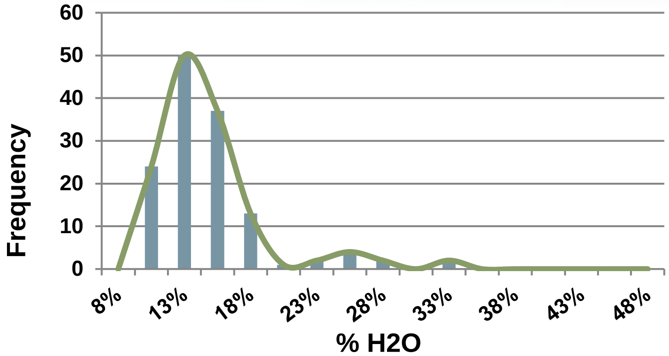
Example: Modeling Variability in Preprocessing Capacity

- Plant with a required production rate of 1440 bales a day (1 bale/min)
- Feedstock supply has range of moisture content
- Preprocessing rate is a function of moisture content
- The grinder capacity function is based on PDU experience
- Bale moisture content of 20% yields 1440 bales/day through preprocessing
- Using a daily time step, with different moistures being brought to the facility each day
- Modelled a 60 day snapshot of the facility's bale processing rate



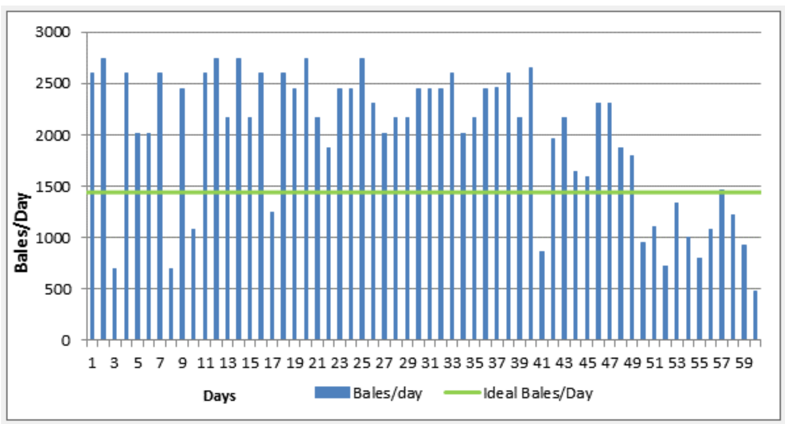


Scenario #1: 2010 NW Iowa Corn Stover

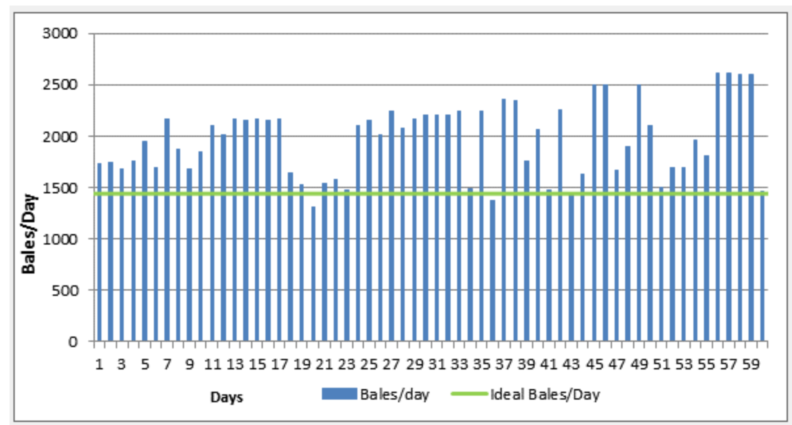


Dry Year
Bale Moisture (%)
Mean: 15.1
Stdev: 4.7

Random



Blend

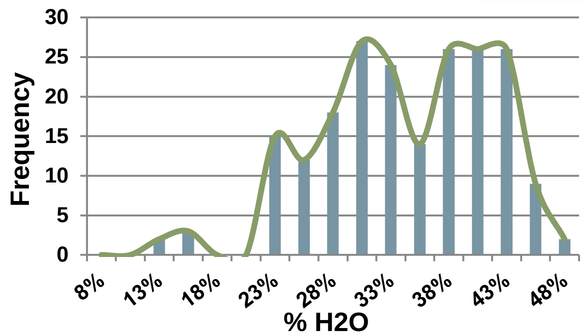


Minimum daily production relative to the required 1440

Maximum daily production relative to the required 1440

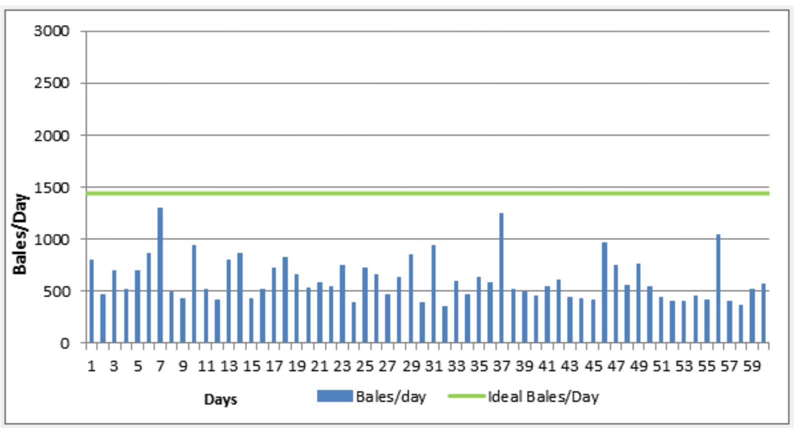
	Random	Blended
Average bales/day	1960	1960
Stdev of bales/day	664	382
Low %	48%	86%
High %	190%	179%

Scenario #2: 2009 NW Iowa Corn Stover

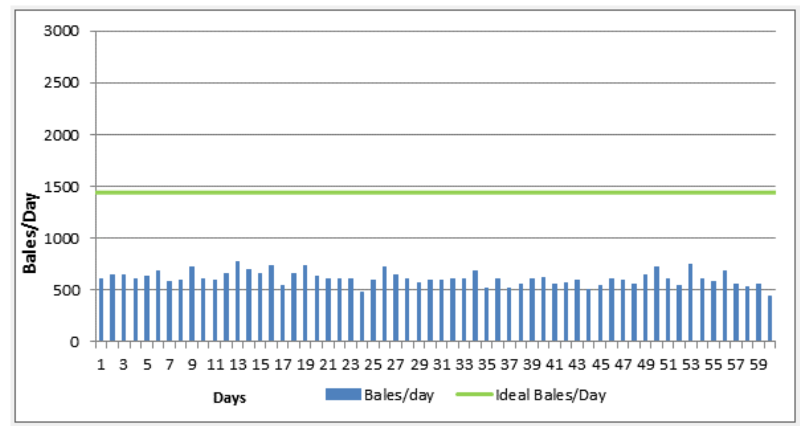


Wet Year
Bale Moisture (%)
Mean: 32.6
Stdev: 7.7

Random

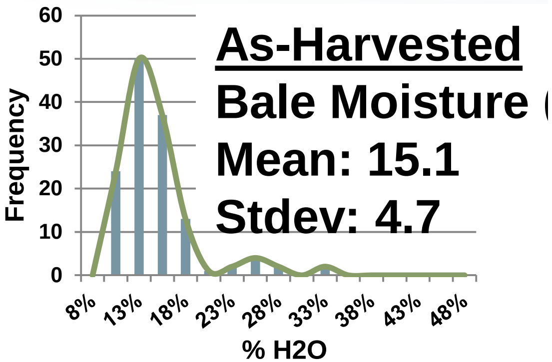


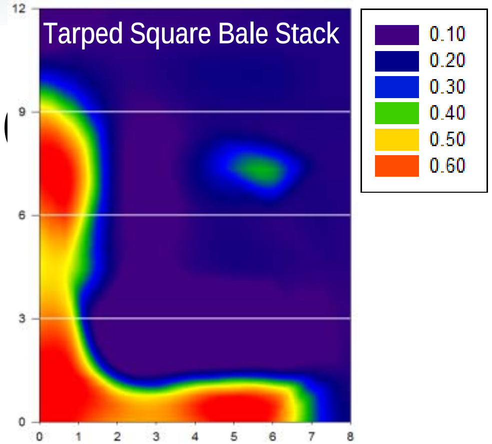
Blend

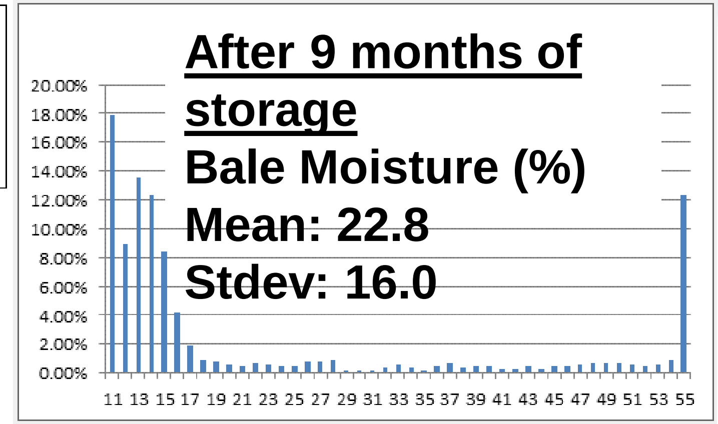


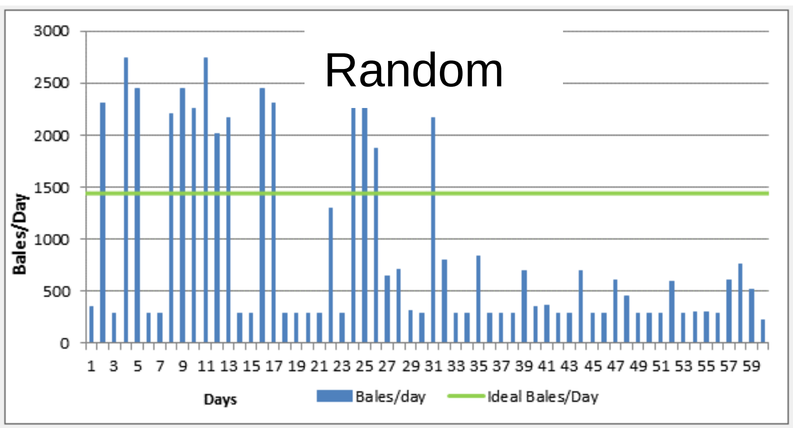
	Random	Blended
Average bales/day	612	612
Stdev of bales/day	212	76
Low % of req'd prod	25%	33%
High % of req'd prod	90%	61%

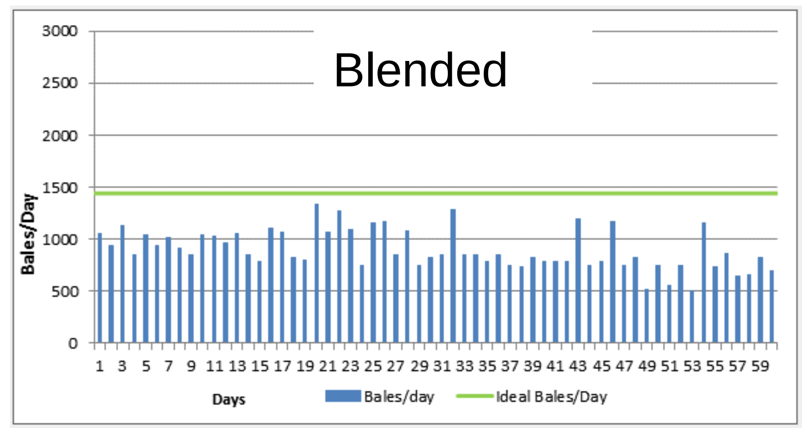
Scenario #3: 2010 NW Iowa, Post Storage







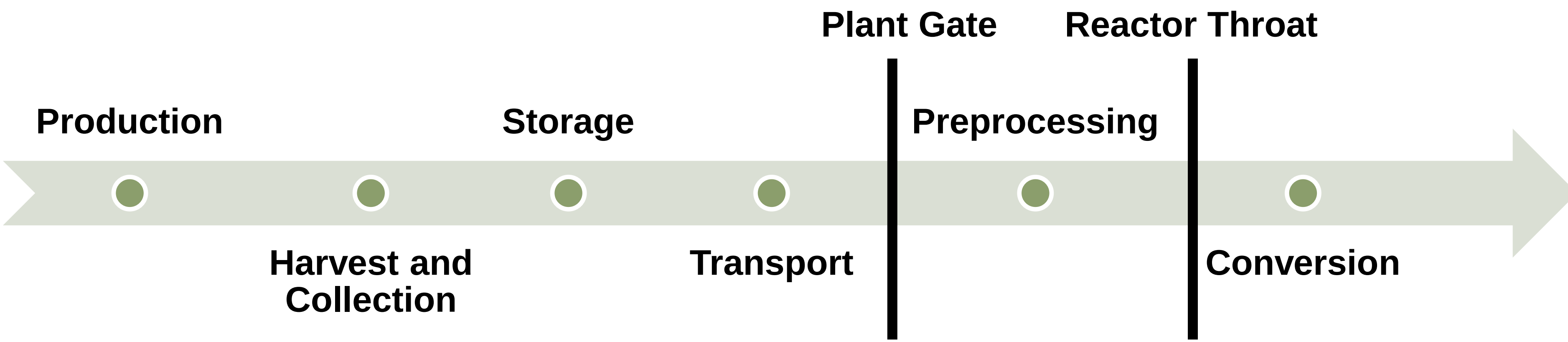




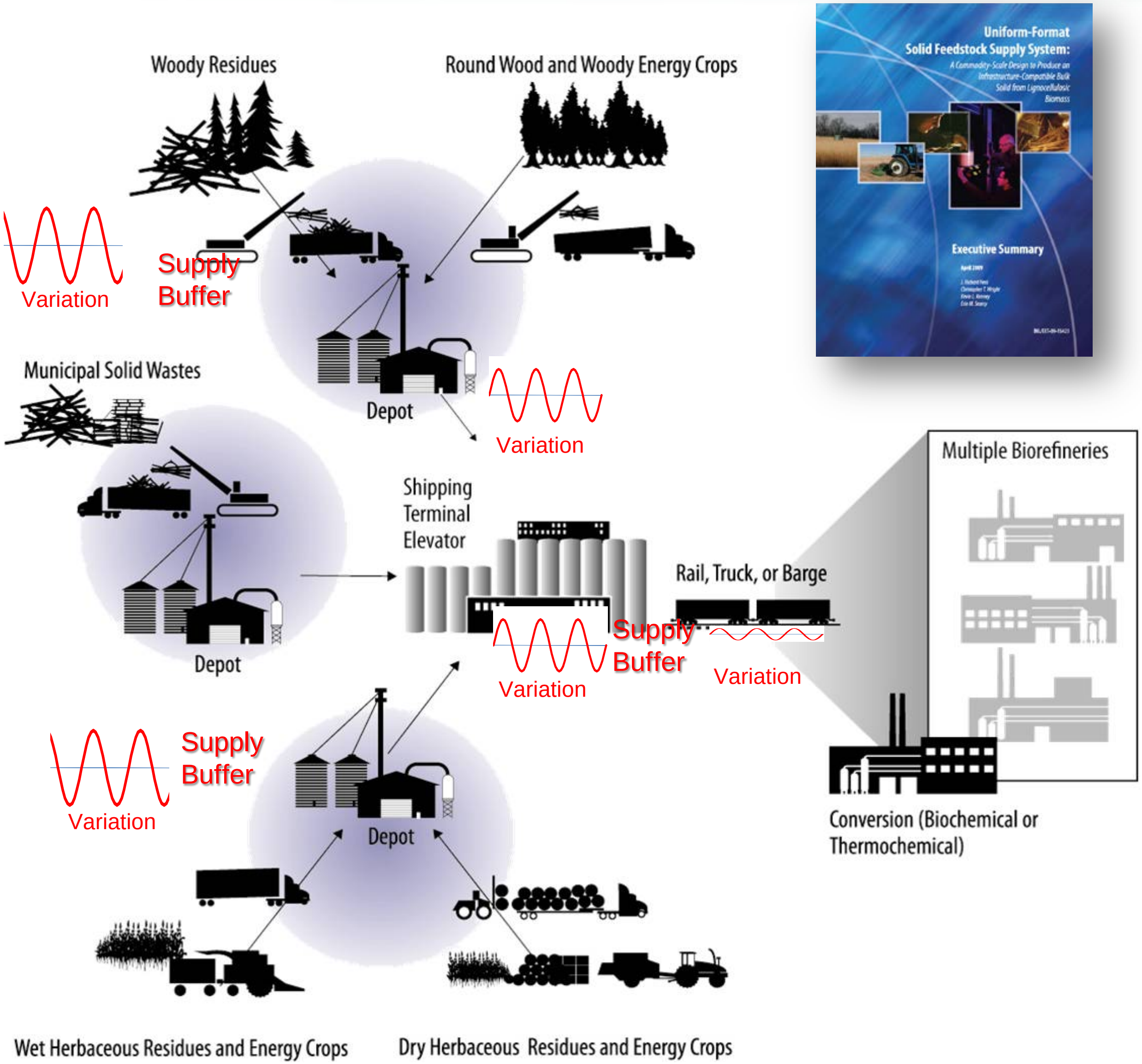
	Random	Blended
Average bales/day	897	897
Stdev of bales/day	871	198
Low %	20%	32%
High %	190%	100%

What are low cost feedstocks?

- There is more to feedstock cost than purchase price
- Biomass is difficult because it is compressible, elastic, and cohesive
- These properties vary among types and physical and chemical properties
- Consistency = Reliability = Lowest Cost
- The role of preprocessing is not grinding or drying or densifying. It is to produce a consistent feedstock



Decoupling Feed Processing from Conversion



- Wide-spread, interconnected supply network
- Stable, flowable, consitent, and <u>conversion-ready</u> feedstocks
- Reduced feedstock variability in quantity, quality, cost

Decoupling does not eliminate the feed handling problem, but it does reduce conversion plant downtime.

Conversion-Ready Feedstock Properties

Predicted Performance

Stover Pellet Meal	¼ minus Stover
	

10-ft Bin Diameter 2-ft Opening	Advanced Material	Corn Stover	
Flow Rate (lb/min)	2432	345	↑
Feed Density (lb/ft³)	26.9	7.4	↑
Bin Density (lb/ft³)	30.0	9.1	↑
Compressibility (%)	12.8	28.1	↓
Permeability (ft/sec)	0.24	0.18	↑
Springback (%)	3.76	4.72	↓
Hausner Index	1.13	1.28	↓
Cohesion (kPa)	3.83	6.61	↓
Angle of Repose	39.2°	35.3°	↓
Flowability Factor	5.8 easy flowing	1.2 very cohesive	↑

↑ or ↓ Indicate desired direction of change

Truck Load of Barley Straw Pellet Meal

Other Preprocessed Products:

- Fractionated (Stover Fiber)

- Thermal Treated

- Various Densification Formats

- Blended

Equipment Engineering Solutions

- Improve the design of biomass processing and handling equipment
  - Designed to biomass material properties
  - Robust to handle variability
- Limitations
  - Limited options for existing installations
  - Potential of fixing a symptom (handling), not the problem, so problem cascades
  - Empirically based designs based on subjective judgements of material properties and flow behavior
  - Must design to worst case scenario (can be costly)
- Benefits
  - Wide range of options from simple fixes to new technologies
  - Improved design and selection are “easy” fixes

Material Engineering Solutions

- Insert processes to alter biomass material properties and enable use of existing equipment
- Examples
  - Blending: variability
  - Densification: compressible, elastic behavior
  - Flow Additives: cohesiveness
  - Heat Treatment: mild deconstruction of cell structure to alter properties
- Limitations
  - Limited range of application
  - Often includes additional unit ops that add cost (need to fully understand cost:value)
  - Changing mat'l properties may fix one problem and create another (example, densification/fines)
- Benefits
  - Fixes the problem and keeps it from cascading
  - Scalable solution – only use it when and as much as needed

High Density Bulk Receiving and Handling

Installed Capital Costs ($/dry ton)	Ownership Costs ($/dry ton)	Operating Costs ($/dry ton)	Total Costs ($/dry ton)	Energy Use (Mbtu/dry ton)
$ 1.38	$ 0.19	$ 0.80	$0.99	6.2

Notable Assumptions:

- 72-hr. inventory - 469,000 ft^3 (377,000 bushels)
- Conveyor density 23.8 lb/ft^3, bin density 29.2 lb/ft^3
- Stored in conventional bin, 90 ft diameter
- Handled with grain handling equipment
- Truck unloading 14 hrs/day, 6 days/wk

Control System Solutions

- Develop control systems that monitor and adjust processing conditions to maintain consistent production rate and feedstock quality
- Examples
  - Reactive Control: Maintain constant mass flow
  - Adaptive Control: Maintain feed specs as infeed properties vary
- Limitations
  - The most difficult
    - Requires best understanding of particle systems
    - Particle interactions with process equipment can be unpredictable
  - Adds complexity (software, sensors, actuators)
  - Development requires a fully integrated system
- Benefits
  - Get the most performance from any equipment
  - Data and understanding of particle systems will benefit equipment and material engineering solutions

DOE Biomass National User Facility (BFNUF)

Capabilities that Span the Biofuels Supply Chain

Production
- Feedstock characterization (chemical, solid fuel properties)
- Pairing feedstock to pathways
- Storage
- Pellet properties

Logistics
- Techno-economic assessments

Preprocessing
- Independent testing, development, & scale-up of preprocessing technologies

Conversion
- Feedstock Supply
- Scale-up & integration of preprocessing systems
- Feedstock Feasibility Studies

Feedstock Supply/Logistics Demonstration

Supply Chain Development

- Feasibility studies and techno-economic assessments
- Storage performance characterization (unique in-lab capability)
- Characterization of biomass resources
- Feedstock product characterization
- Supply chain design

Our understanding of cost, quality, and risk tradeoffs helps customers establish a successful supply chain

Scale-up and Integration

- Expertise and capabilities to meet a customer's lab- and pilot-scale testing needs
  - Sourcing for common and unique feedstocks
  - Process development, testing, and design
  - Feedstocks processed to partner specifications
  - Feedstock characterization datasheets
  - Packaging and shipping for partner testing

Working with industrial feedstocks during process design, scale-up, and integration can accelerate commercial-ization and prevent costly delays during commissioning and start-up

Process Demonstration Unit (PDU)

- Full-scale, integrated biomass processing system
  - Hammer mill grinding
  - Rotary drying and torrefaction
  - Pelleting and cubing
  - Multiple packaging options
- In operation since October 2013
  - Toll processing & characterization
  - Process Development
  - Preprocessing RD&D
- More than 500 tons of feedstock processed
  - Ag residues (corn stover, sugarcane bagasse)
  - Energy Crops (switchgrass, miscanthus)
  - Woody biomass (clean and whole tree chips)
  - Municipal Solid Waste
  - Cellulosic co-product

Reconfigurable PDU is located in 27,000-ft^3 high bay at INL's Energy Systems Laboratory

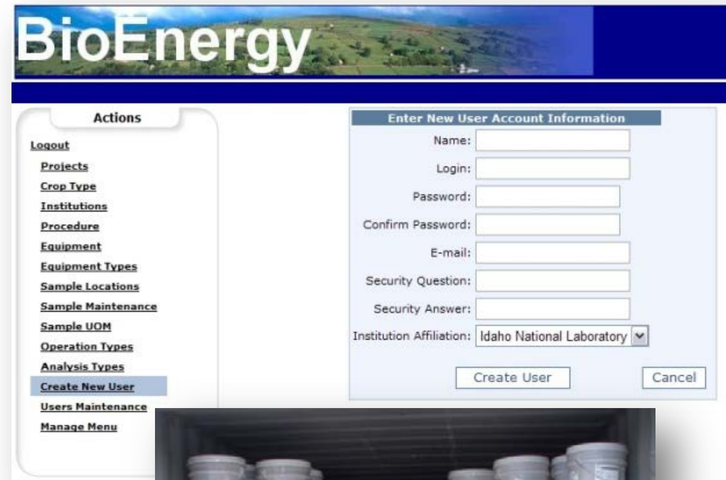
Working with Industry

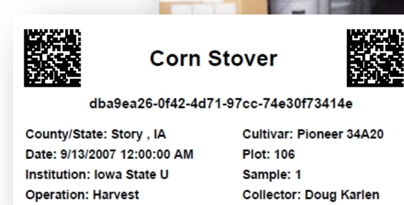
- **Example (DuPont)**
  - Scale-up and demonstration of co-product production
  - Engaged User Facility for drying capability and reconfigurable design to accommodate a unique process flow and additional third-party equipment
  - ~ 350 hours PDU operation: 3 months, up to 12 hours/day, 6 days/week
- **Results**
  - Collaboration supported process validation with industrial feedstocks
    - Supplied product for combustion trial
    - Produced processing data and information to inform commercial design
    - Accelerated commercialization

National Biomass R&D Library

Integrated knowledge management that:

- Facilitates physical storage and tracking of research feedstocks
- Assimilates biomass sample data into a single data system
  - Feedstock pedigree information
  - Harvest and storage information
  - Operational data from the PDU and field trials
  - Physiochemical characterization data
  - Lab-based biological data
  - Lab-scale conversion data
  - Full-scale conversion data from the conversion platforms
- Enables better understanding supply chain processes and feedstock performance.





Library Overview

Parent Samples
- Harvest
- Stored
- Intermediates

Process Demonstration Unit
- Drying
- Grinding
- Densification
- Splitting

Analytical Laboratory
- Composition
- Ash
- Prox. & Ult.
- Elemental

Raw Samples

Harvest Data

Processed Samples

Operations Data

Prepared Samples

Quality Data

Library

Samples:
Raw
Processed
Reference Matls.
Bulk resources

Data:
Crop
Harvest
Operations
Locations
Characteristics

Tools:
Sample Tracking
Data Processing
Least Cost

Samples

Data/ Analysis

Regional Feedstock Partnership

National Labs

Universities

Industry

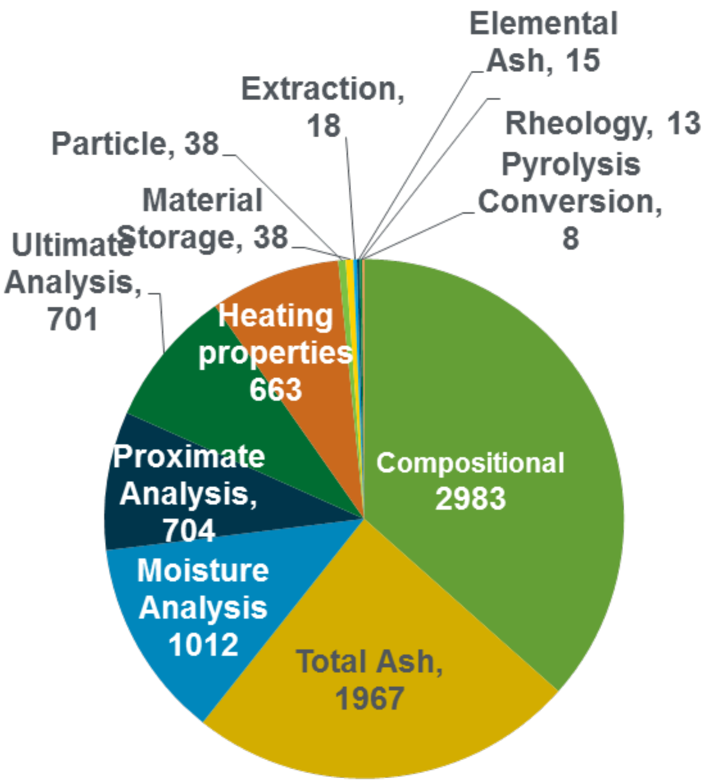
International Researchers

Other Gov. Researchers

Data Collection

- Over 62,000 samples tracked
  - (23,000 originals + children)
- Over 1,200,000 sample information data points
- Over 65,000 analysis data points
- Over 80 projects (tracking unique datasets)
- Over 100 crop types

- Sample information
  - Crop type, location, harvest information, field information, etc.
- Analysis information
  - Chemical composition, fuel properties, ash, etc.
- Operations
  - grinding, pelleting, leaching, storage, etc.

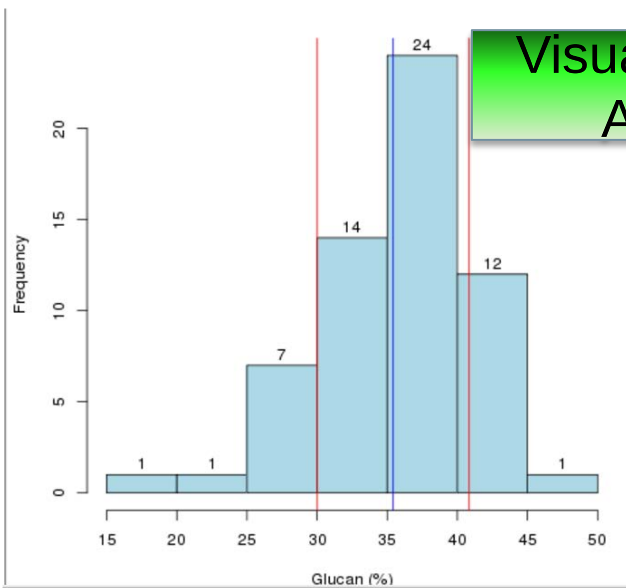


Tools – Attribute Graphs

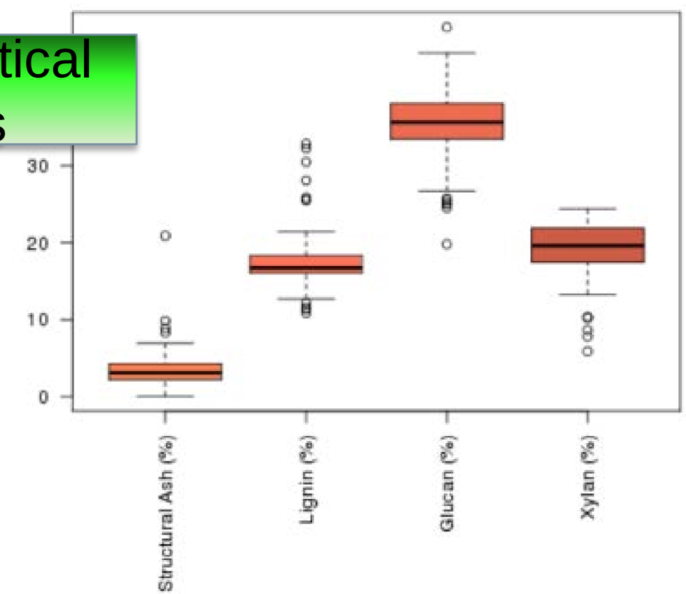
- Publicly and privately available aggregate Information
  - Quality reviewed for applicability
- Targeted search
- Overview and detailed statistics
- Exportable information and data

Attribute	#Entries	Min Value	Max Value	Mean	Standard Deviation	Download Raw Data Set
Compositional Characterization,Wet Chemical (NREL/TP-510-48087),Structural Ash (%)	56	0.05	20.90	3.60	3.09	Structural Ash (%)
Compositional Characterization,Wet Chemical (NREL/TP-510-48087),Lignin (%)	56	10.87	32.86	18.05	4.70	Lignin (%)
Compositional Characterization,Wet Chemical (NREL/TP-510-48087),Glucan (%)	56	19.81	47.99	35.31	5.53	Glucan (%)
Compositional Characterization,W[illegible] Chemical (NREL/TP-510-48087),[illegible] (%)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Xylan (%)

Data Easily Exported



Visual Statistical Analyses



Biomass Reference Material

- 8 Biomass materials in bulk
  - Fully characterized and available for request
- Examples:
  - University of Kentucky – Lignin research
  - University of Cincinnati – Fundamental conversion research
  - Louisiana Tech – Organosolv research
  - University of Delaware – NSF research

Automated Request Process

To request biomass for research purposes fro

Full Name:

E-mail Address:

Phone Number:

Shipping Address:

Institutional Affiliation:

	Crop Type	Amount
Blend:		

Fully Characterized

Switchgrass

Pedigree

Institution: Oklahoma State University
Location: Garvin County, OK
Cultivar: Alamo

Harvested: 2012
Received at INL: 2013
Sample Preparation: Ground to pass through a 1-inch sieve using a Vermeer BG480 grinder

Composition

Table 1. *Chemical composition[a] of Reference Switchgrass*

%Structural Ash	%Extractable Inorganics	%Structural Protein	%Extractable Protein	%Water Extracted Glucan[b]
1.88	2.07	1.51	0.54	2.28
%Water Extracted Xylan[b]	**%Water Extractives Others**	**%EtOH Extractives**	**%Lignin**	**%Glucan**
0.09	6.68	2.68	16.24	33.21
%Xylan	**%Galactan**	**%Arabinan**	**%Acetate**	**%Total**
21.65	1.43	3.27	3.07	96.60

[a]Determined using NREL "Summative Mass Closure" LAP (NREL/TP-510-48087)
[b]Determined by HPLC following an acid hydrolysis of the water extractives

Easily Accessible

Biomass Info

The Bioenergy Feedstock Library hosts characteristic data from

This page highlights a selection of the Library's crop types. Sam characterized at INL for use in research applications. Physical sa

Request Biomass Samples »

Corn Stover

Data Sheet PDF (Revised 02-10-2016)
Corn stover is the most common crop for bioenergy research. Corn stover, an agricultural by-product, consists of the leaves and stalks of corn plants left in a field after

Switchgrass

Data Sheet PDF (Revised 02-10-2016)
Switchgrass is a native warm-season perennial grass that can thrive in a variety of climatic conditions and soil types. It can be grown on land that is not suitable for row crop

Working with Us

Challenge: Biorefineries typically operate at just 50% of design capacity[1]

- Capabilities - INL's core strengths in feedstock supply, logistics, and preprocessing are helping address key industry challenges
- Innovation - Work with DOE program investments to create innovative solutions that avoid challenges and expand the bioenergy market
- New Business Tools - User Facility and other business tools are rapidly progressing to function ***at the speed of business***
- For more information contact Kevin Kenney at Kevin.Kenney@inl.gov

[1]Merrow (1985) Linking R&D problems experienced in solids processing. Chem Eng Prog 14-22;
Bell (2005) Challenges in the scale-up of particulate processes--An industrial perspective. Powder Tech 60-71.

Questions?

The Uniform Commodity Feedstock Vision enables commodity-scale, custom-formulated feedstocks to play a critical role in producing biofuels, biopower, and other bioproducts.

Biomass Preprocessing

Biomass preprocessing, which transforms biomass into feedstock, is key to a commodity bioenergy vision. A preprocessing depot can provide a link between biomass producers and refineries. It also alows flexibility for local communities to produce bioproducts including feedstocks customized for biochemical, thermochemical, and combustion conversion facilities. It also enables production of renewable products, such as livestock feeds, and recycled byproducts, such as soil amendments.

The Preprocessing Depot enables development of commodity biomass feedstock markets by managing diverse biomass, promoting increased resource access, and ensuring quality, on-spec feedstock delivery to conversion facilities.

But a preprocessing depot can do much more. It offers limitless opportunities for innovations to supply entirely new products and markets.