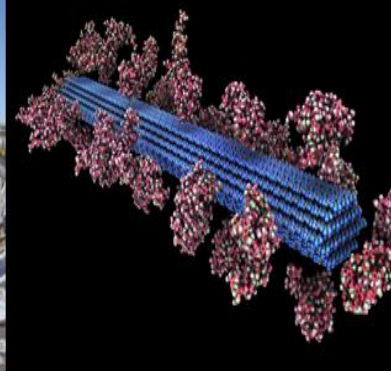




U.S. DEPARTMENT OF
ENERGY

Energy Efficiency &
Renewable Energy



Bioenergy Feedstock Library and Least-Cost Formulation

March 24, 2015

Garold Gresham
Victor Walker (CoPI)
Jeff Lacey (CoPI)

Idaho National Laboratory

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Project Goal

- **Objective**

- Develop innovative knowledge-based management system that enables and supports development of an industry-relevant, commodity-scale feedstock supply system

- **Relevance to BETO and Industry**

- Provides a central interactive repository for quality attribute data to **support BETO's 2017 goal of producing optimized dynamic blendstocks** that meet cost, *quality*, and volume conversion targets
 - Feedstock Quality and Monitoring: Variability presents significant cost and performance risks for bioenergy systems; specifications are not currently mature

- **Outcomes and Relevance**

- Deployable analysis tool sets and least-cost formulation model supported by *robust* feedstock quality attribute data
- Provides the foundation for understanding feedstock variability, quality, and blend options
- Library provides the mechanism or foundation for valorization of feedstocks and understanding of pathways to achieving sustainable energy options through **incorporation of "exchange-point" quality control**

Quad Chart

Timeline

- Project start date: 2008
- Project end date: 2017
- Percent complete: 40%

Partners

- 44 Regional Feedstock Partnership Collaborators
- Oak Ridge National Lab (KDF)
- Washington State University, NARA
- NewBio, USDA-NIFA CAP
- Université Laval, Québec
- DOT, Volpe National Transportation Systems Center

Barriers Addressed

- Ft-G, Feedstock Quality and Monitoring
- Ft-J, Biomass Material Properties
- Bt-B, Biomass Variability
- Tt-K, Thermochem Process Integration

Budget

	Total Costs FY 2010 to 2012	FY 2013 Costs	FY 2014 Costs	Total Planned Funding (FY 2015)
Bioenergy Feedstock Library	\$699K	\$683K	\$716K	\$1,108K
Regional Feedstock Partnership	\$0	\$0	\$0	\$2,000K

1 – Project Overview

- **History**

- Library initially developed as an in-house system to track, house, and retrieve feedstock materials and analysis results created from the DOE Sun Grant Regional Feedstock Partnership (Award #GO85041; WBS 7.6.2.5)
- Recognized as a complex-wide valuable comprehensive knowledge management system
- Deployed in 2010 for internal users and incorporating broader user base in 2012

- **Context**

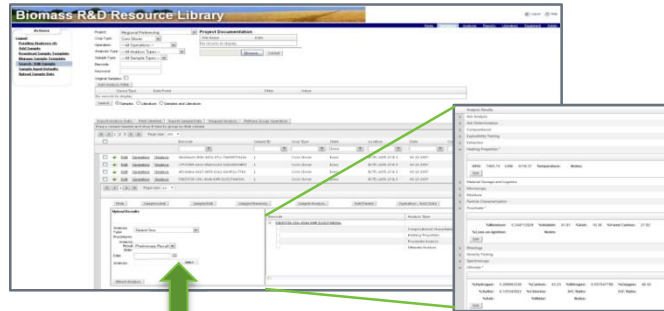
- Library is an integrated physical repository of raw and processed biomass materials, tracking meta-data, quality data, and pedigree information for feedstock materials
- Application also includes built-in advanced analysis tools

- **Objectives**

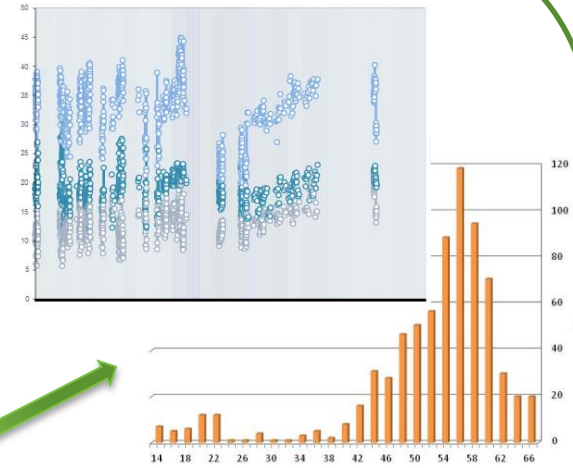
- Support INL, other national laboratories, industry, and universities in achieving BETO goals and objectives to develop a national-scale feedstock supply system
- Provides unique data and data services via internet application

1 - Project Overview

Store and Retrieve
Physical Samples



Store, Retrieve,
Sample Data and
Characterization Data



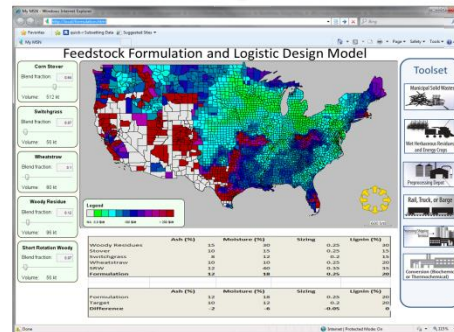
Advanced
Analysis Tools

Regional FS Partner
BETO Projects
External Partners

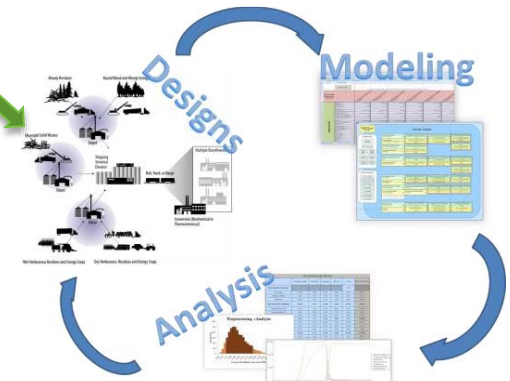
DOE Bioenergy Feedstock Library



KDF Integration



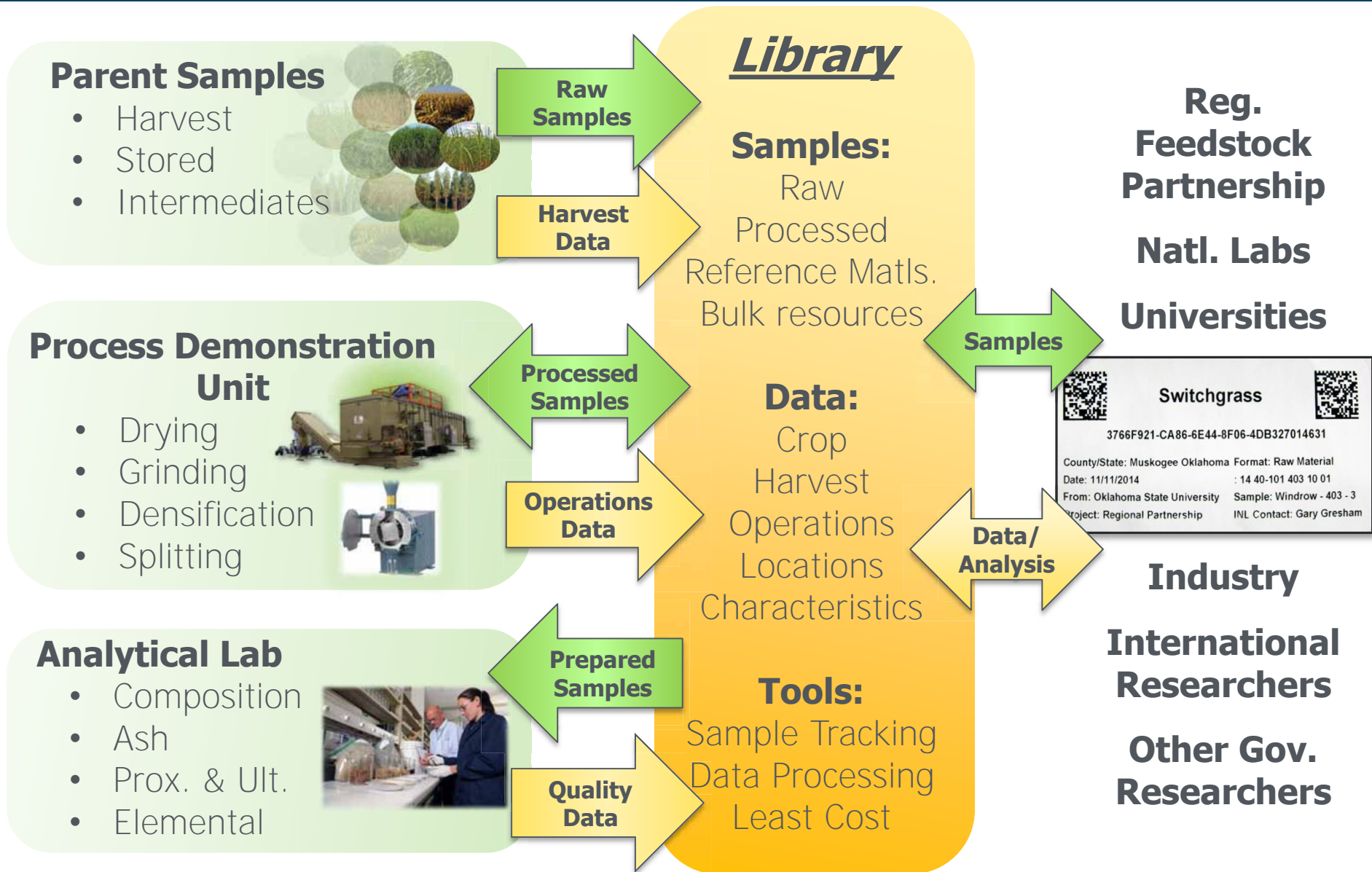
Least – Cost Formulation Model



Biomass Logistics Model

*Results in high impact
analytics that provide
core platforms with insight
and guidance*

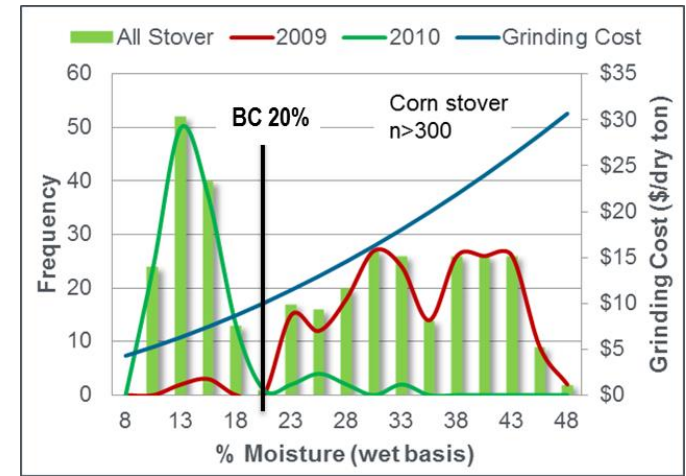
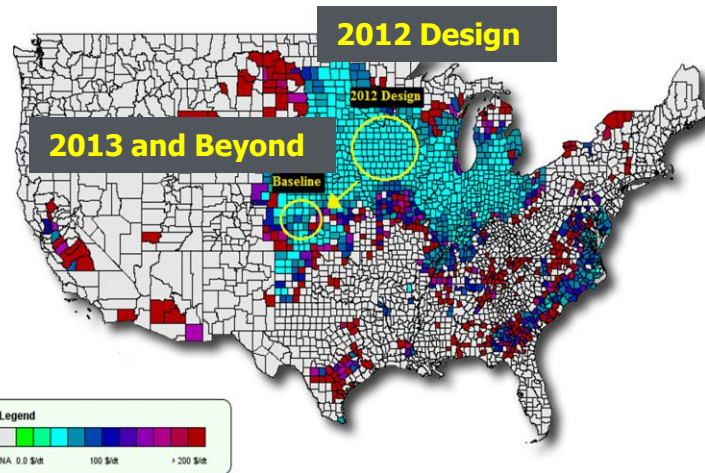
1 - Project Overview



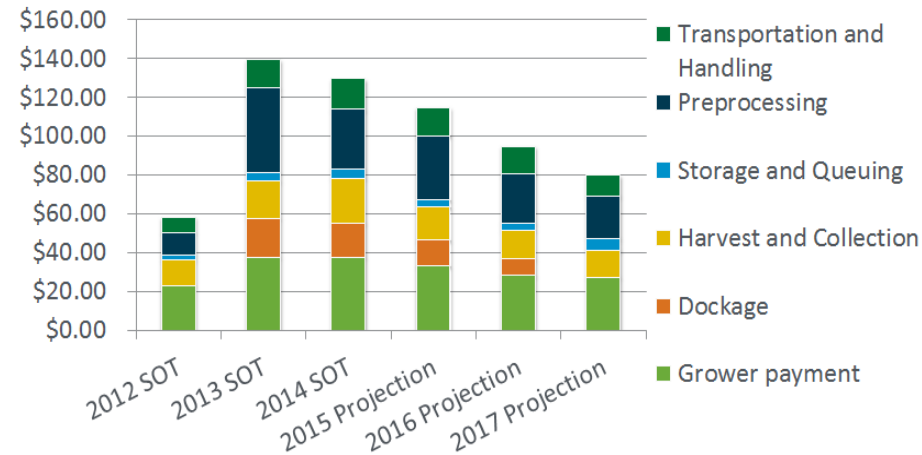
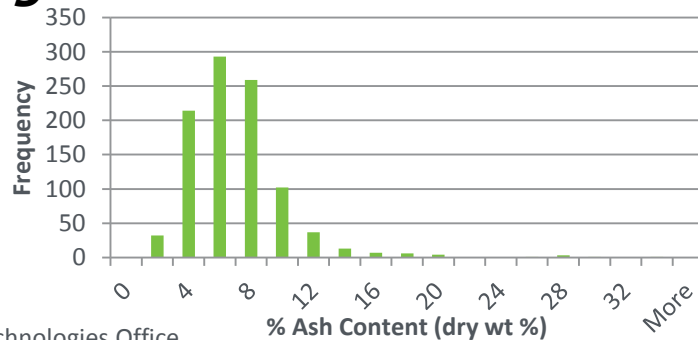
1 – Project Overview

Library quality data informs the design case and SOT reports and drives program decisions

2017 Design Case: Industry Relevant Supply System

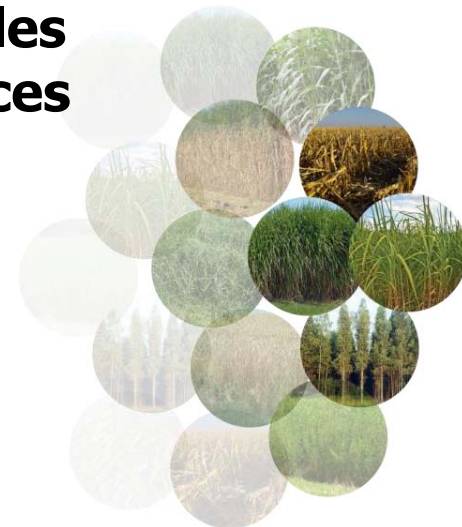


Update to SOTs; Examine 2013 Dockage Estimates



2 – Approach

- **Populate library with relevant feedstock samples and attribute data from a wide variety of sources**
 - Regional Feedstock Partnership
 - Industrial partners and other research projects
- **Provide relevant data in a reliable and usable format via improved toolsets**
 - Imperative that we engage other organizations to help populate the data sets
 - Serve up the library through INL and KDF on the web to increase exposure to potential users
- **Continuously improve the analysis toolsets**
 - Coordinate across research projects at INL and other national labs to define critical needs and leverage expertise
 - Critical that the library show value to users to promote their involvement



2 – Approach

- **Success Factors**

- Market the library to new users
- Enhance data processing and data visualization
- Continue to link data to the core platform programs to guide decisions

- **Challenges**

- Vast variability in data due to different research drivers
- Complexity and quality of data (pedigree)
- Reaching key stakeholders (universities, research institutes, government agencies, and industry)

- **Major Efforts**

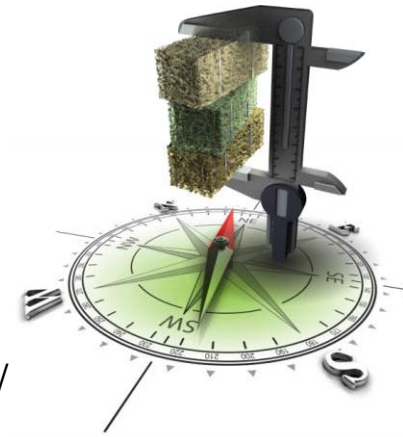
- Inform the Billion Ton Study update by incorporating quality attributes from Regional Feedstock Partnership sample sets
- Assist in demonstrating the performance of "blended" feedstock options, incorporating cost, *quality*, and volume target metrics



Switchgrass

3766F921-CA86-6E44-8F06-4DB327014631

County/State: Muskogee Oklahoma Format: Raw Material
Date: 11/11/2014 : 14 40-101 403 10 01
From: Oklahoma State University Sample: Windrow - 403 - 3
Project: Regional Partnership INL Contact: Gary Gresham

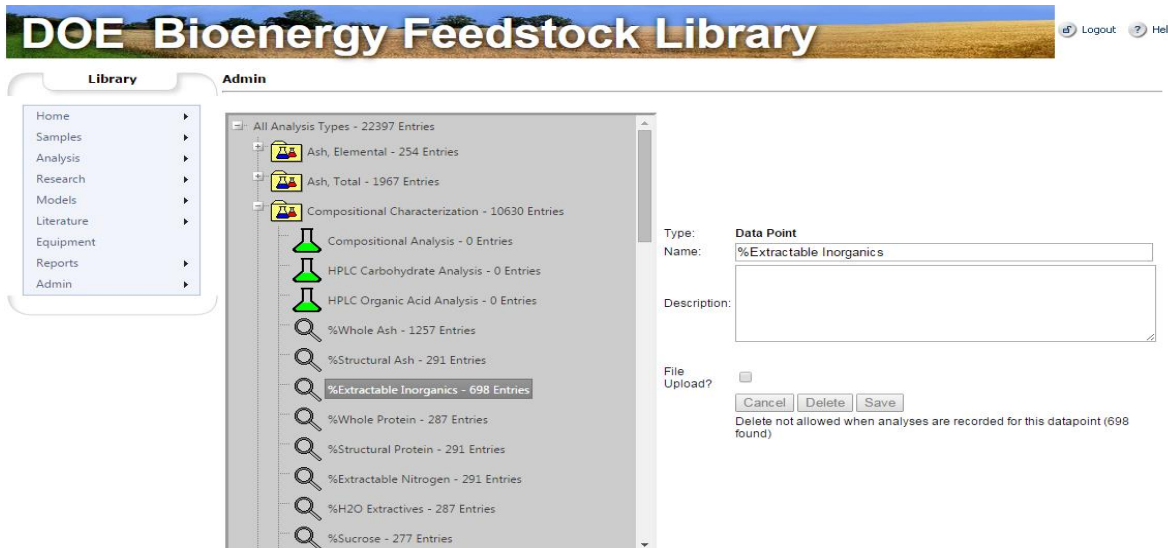
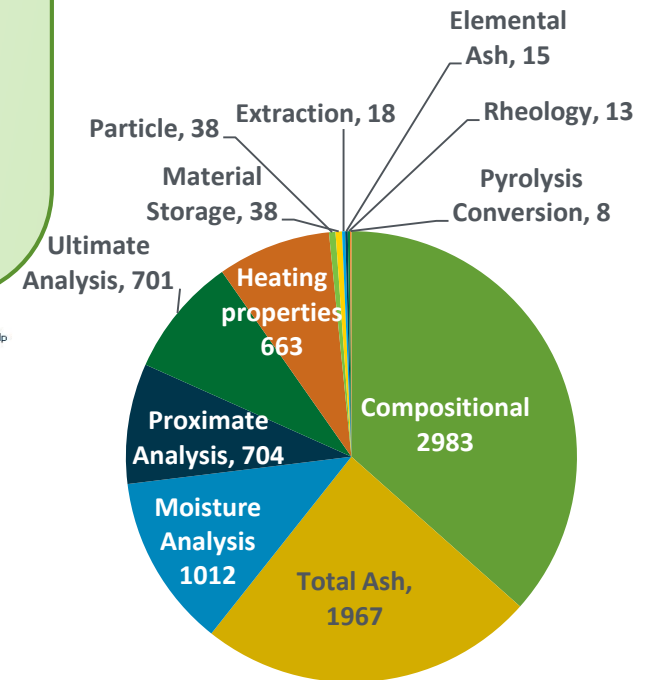


3 – Technical Accomplishments

Data Management

- Meta Data
 - Production location, plant date, and harvest date
 - Harvest method and weather information
- Feedstock Attributes
 - Composition (glucan, xylan, **ash.....**)
 - Property changes
- Preprocessing Information
 - Grinding, pelletizing, leaching, and storage

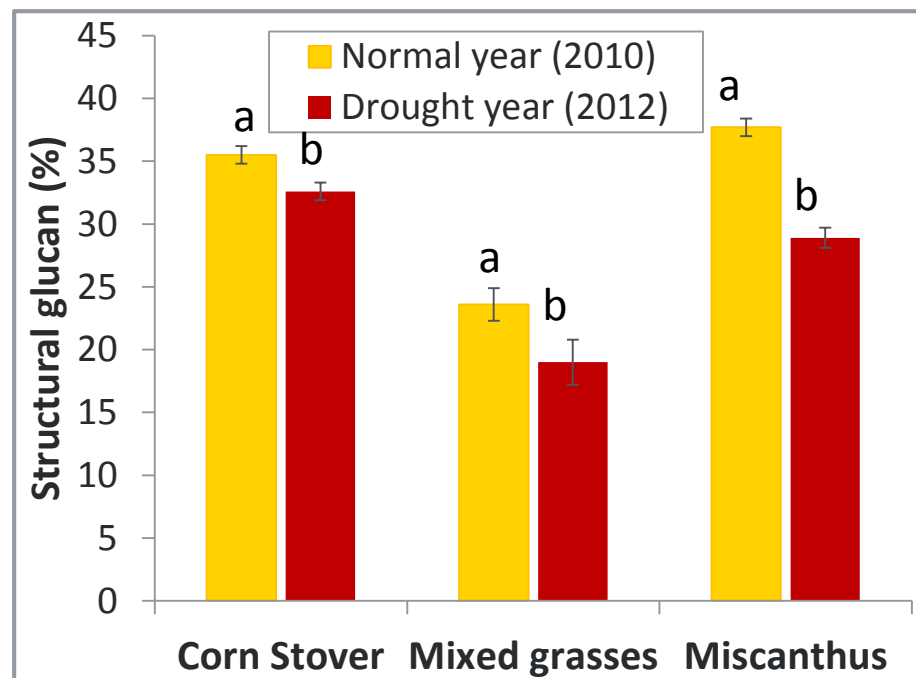
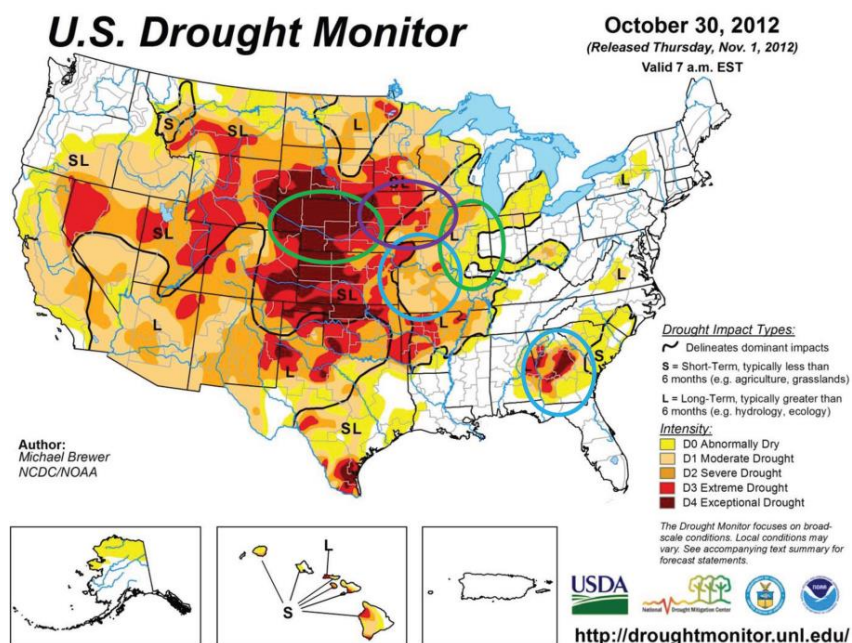
of Analysis by Type



3 – Technical Accomplishments : Reg FS Partnership

Data analysis demonstrates the effects of drought

- Dry biomass yields were lower for mixed grasses and *Miscanthus*
- Feedstock composition was significantly different
- Theoretical ethanol yield decreased by 10 to 15%



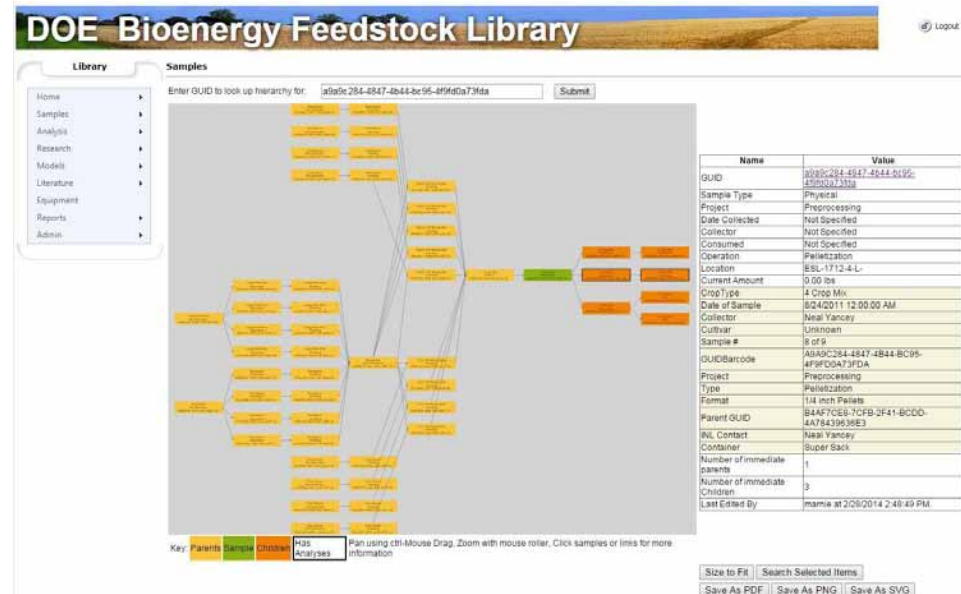
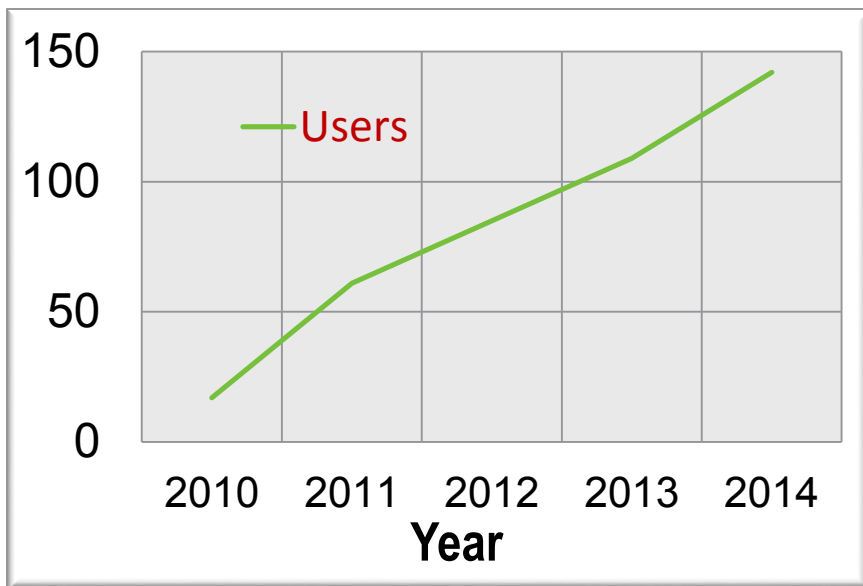
"Drought effects on composition and yield for corn stover, mixed grasses, and *Miscanthus* as **bioenergy feedstocks**," *Biofuels* 5(3): 275-291, 2014.

3 – Technical Accomplishments

User Base

- Extending beyond internal use to external partners and public information
 - Regional Feedstock Partnership Institutions
 - Industry partners
 - Other government agencies
 - Universities

Graphical representation of sample relationships and sample hierarchy



3 – Technical Accomplishments

DOE Bioenergy Feedstock Library

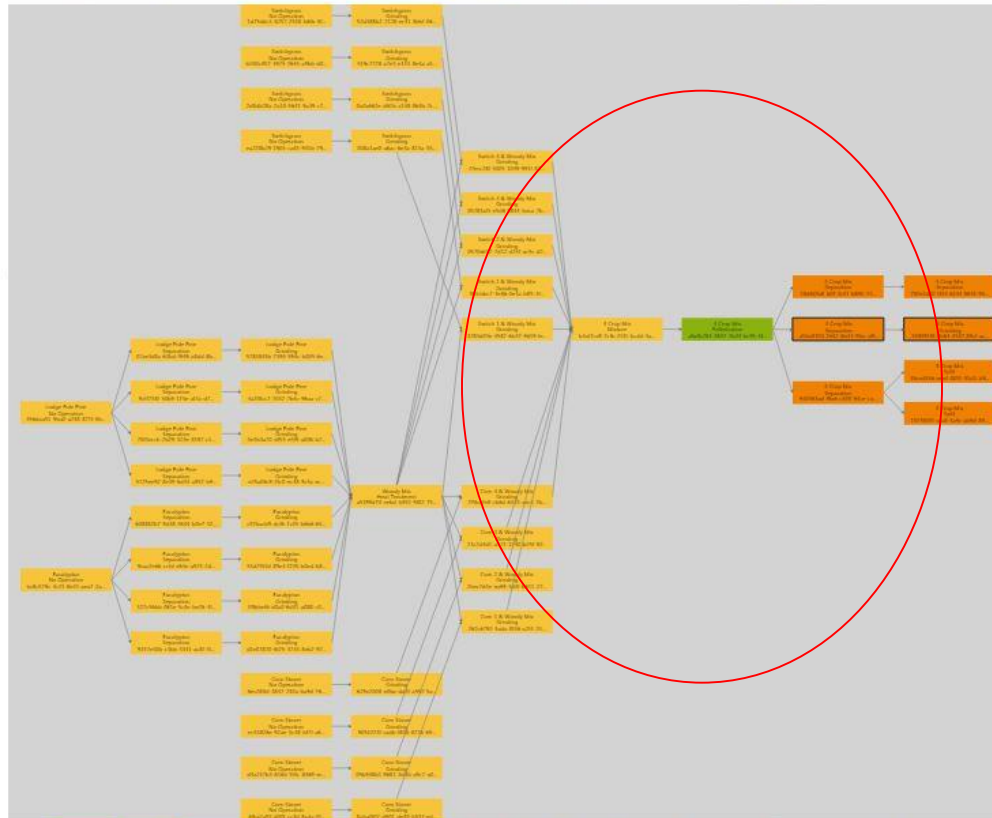
Logout

Library

Samples

- Home ▶
- Samples ▶
- Analysis ▶
- Research ▶
- Models ▶
- Literature ▶
- Equipment ▶
- Reports ▶
- Admin ▶

Enter GUID to look up hierarchy for:



Key: Parents Sample Children Has Analyses Pan using ctrl-Mouse Drag, Zoom with mouse roller, Click samples or links for more information

Name	Value
GUID	a9a9c284-4847-4b44-bc95-4f9fd0a73fda
Sample Type	Physical
Project	Preprocessing
Date Collected	Not Specified
Collector	Not Specified
Consumed	Not Specified
Operation	Pelletization
Location	ESL-1712-4-L-
Current Amount	0.00 lbs
Crop Type	4 Crop Mix
Date of Sample	8/24/2011 12:00:00 AM
Collector	Neal Yancey
Cultivar	Unknown
Sample #	8 of 9
GUIDBarcode	A9A9C284-4847-4B44-BC95-4F9FD0A73FDA
Project	Preprocessing
Type	Pelletization
Format	1/4 inch Pellets
Parent GUID	B4AF7CE8-7CFB-2F41-BCDD-4A78439636E3
INL Contact	Neal Yancey
Container	Super Sack
Number of immediate parents	1
Number of immediate Children	3
Last Edited By	marnie at 2/28/2014 2:48:49 PM.

3 – Technical Accomplishments

DOE Bioenergy Feedstock Library

Logout

Library

- Home
- Samples
- Analysis
- Research
- Models
- Literature
- Equipment
- Reports
- Admin

Samples

Enter GUID to look up hierarchy for:

Name	Value
GUID	a9a9c284-4847-4b44-bc95-4f9fd0a73fda
Sample Type	Physical
Project	Preprocessing
Date Collected	Not Specified
Collector	Not Specified
Consumed	Not Specified
Operation	Pelletization
Location	ESL-1712-4-L-
Current Amount	0.00 lbs
CropType	4 Crop Mix
Date of Sample	8/24/2011 12:00:00 AM
Collector	Neal Yancey
Cultivar	Unknown
Sample #	8 of 9
GUIDBarcode	A9A9C284-4847-4B44-BC95-4F9FD0A73FDA
Project	Preprocessing
Type	Pelletization
Format	1/4 inch Pellets
Parent GUID	B4AF7CE8-7CFB-2F41-BCDD-4A78439636E3
INL Contact	Neal Yancey
Container	Super Sack
Number of immediate parents	1
Number of immediate Children	3
Last Edited By	marnie at 2/28/2014 2:48:49 PM.

Key: Parents Sample Children Has Analyses

Pan using ctrl-Mouse Drag, Zoom with mouse roller. Click samples or links for more information

3 – Technical Accomplishments

DOE Bioenergy Feedstock Library

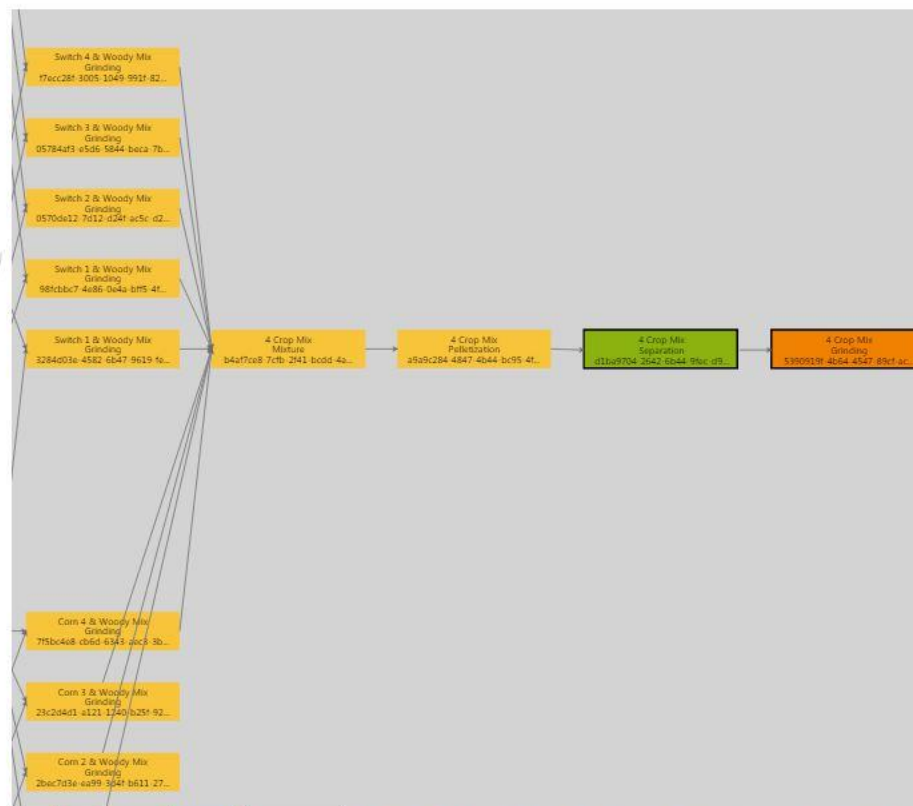
Logout

Library

- Home ▶
- Samples ▶
- Analysis ▶
- Research ▶
- Models ▶
- Literature ▶
- Equipment ▶
- Reports ▶
- Admin ▶

Samples

Enter GUID to look up hierarchy for:



Key: Parents Sample Children Has Analyses Pan using ctrl-Mouse Drag, Zoom with mouse roller, Click samples or links for more information

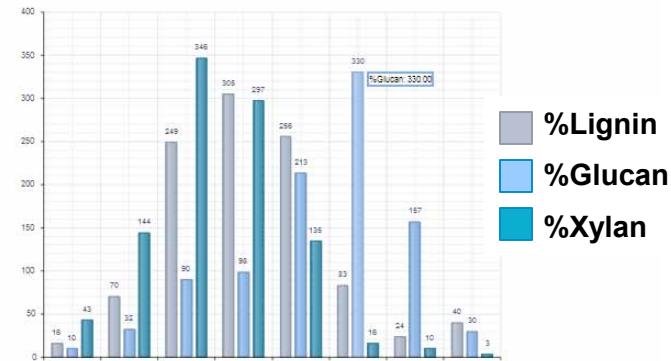
Name	Value
GUID	d1ba9704-2642-6b44-9fec-d926f8b32a9a
Sample Type	Physical
Project	LBNL Formulation Studies
Date Collected	Not Specified
Collector	Not Specified
Consumed	Not Specified
Operation	Separation
Location	----
Current Amount	0.00 lbs
CropType	4 Crop Mix
Date of Sample	10/31/2011 12:00:00 AM
Collector	Neal Yancey
Organization/Institution	INL
Cultivar	Unknown
Sample #	2 of 3
GUIDBarcode	D1BA9704-2642-6B44-9FEC-D926F8B32A9A
Operation	By Hand
Project	LBNL Formulation Studies
Type	Manual
Equipment	By Hand
Container	55 gal Drum
Parent GUID	a9a9c284-4847-4b44-bc95-4f9fd0a73fda
INL Contact	Kevin Kenney
Format	1/4 inch pellets
%Moisture	5.7721
HHV (BTU/lb)	7749.1233
LHV (BTU/lb)	7509.4879
Surface Area	0.2926
Pore Volume	0.0004
Durability	97.5013
Density	729.7879
Number of immediate parents	1
Number of immediate Children	1
Last Edited By	shaybp at 6/14/2012 9:28:46 AM.

Size to Fit Search Selected Items

3 –Technical Accomplishments

Automated Analysis Toolset

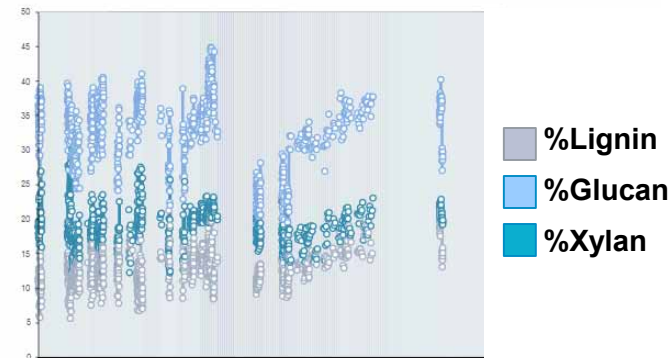
- Statistical Data Analysis
 - Automated statistical tools to screen data sets



Frequency Keys

Key for Frequency Values:

Attribute / Bucket	1	2	3	4	5	6	7	8
%Lignin	6.60-7.66 = 16	7.66-9.66 = 70	9.66-11.53 = 249	11.53-13.91 = 306	13.91-15.48 = 256	15.48-17.46 = 83	17.46-19.43 = 24	19.43-21.41 = 40
%Glucan	13.67-17.47 = 10	17.47-21.58 = 32	21.58-26.29 = 90	26.29-29.20 = 68	29.20-33.11 = 213	33.11-37.02 = 330	37.02-40.93 = 167	40.93-44.84 = 30
%Xylan	12.18-14.41 = 43	14.41-16.64 = 144	16.64-18.86 = 346	18.86-21.09 = 297	21.09-23.32 = 138	23.32-25.55 = 18	25.55-27.77 = 10	27.77-30.00 = 3



Attribute	Entries	Min Value	Max Value	Mean	Standard Deviation
%Lignin	1044	6.60	21.41	12.96	2.74
%Glucan	961	13.67	44.84	32.48	6.60
%Xylan	996	12.18	30.00	19.78	2.52

Saved Filters: Biochemical Conversion V1

Filter Name: Biochemical Conversion V1

Description: Initial assumptions for Biochemical conversions based on 2013 Design Report

Attribute Criteria:

- Compositional Characterization,%Glucan GreaterThan 35.00
- Compositional Characterization,%Xylan GreaterThan 19.50
- Compositional Characterization,%Lignin LessThan 15.80
- Compositional Characterization,%Whole Ash LessThan 5.00

(Compositional Characterization,%Glucan > '35' AND Compositional Characterization,%Xylan > '19.5' AND Compositional Characterization,%Lignin < '15.8' AND Compositional Characterization,%Whole Ash < '5')

Apply

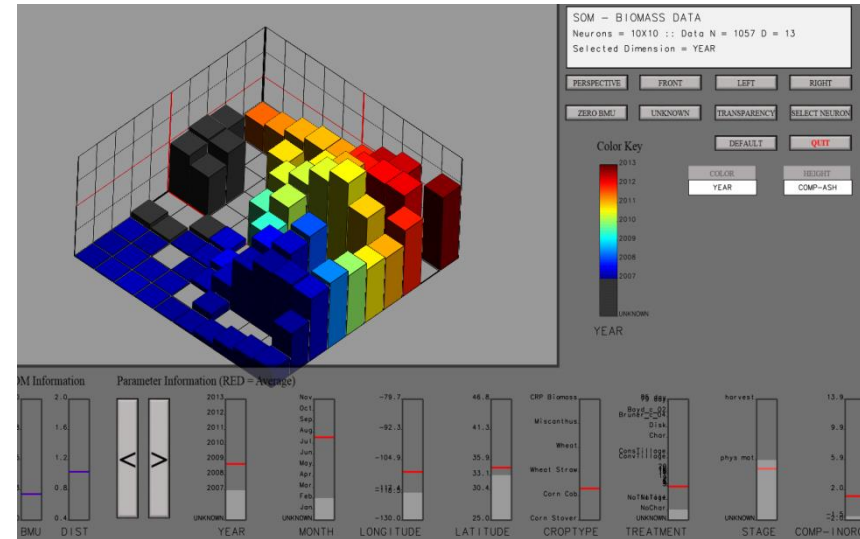
Barcode	Crop Type	%Glucan	%Xylan	%Lignin	%Whole Ash
4785c065-8cb9-4976-ad72-374a5bdceced	Corn Stover	38.3	20.8	12.8	4.2
0312f8ea-dd45-4724-94a8-760a3b0e9d61	Corn Stover	35.1	23.8	7.3	3.5
87845b90-b38e-443e-974e-e407899edd34	Corn Stover	35.9	23.5	8.3	4.6
6d6e4fe2-b498-4c92-839b-80e255de997	Corn Stover	35.4	21.5	5.6	3.4
70e76b32-4a50-4328-a2ef-199023067a1c	Corn Stover	37.3	23.5	8.4	2.8
9fc8a22c-53a2-479a-8f84-c90840b01b7c	Corn Stover	36.1	20.2	14.5	4.1
d12683ab-6aac-4014-b1ef-4a3559f0a333	Corn Stover	37.2	22.8	9.4	2.9

3 – Technical Accomplishments

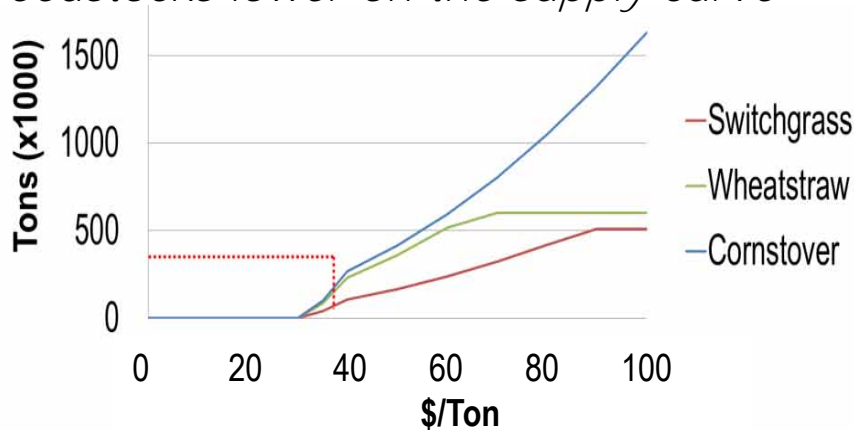
Advanced Data Analysis Tools

Current development:

- Self-organizing maps
 - Data visualization
- Blending design
 - Statistical prediction
- Least-cost formulation

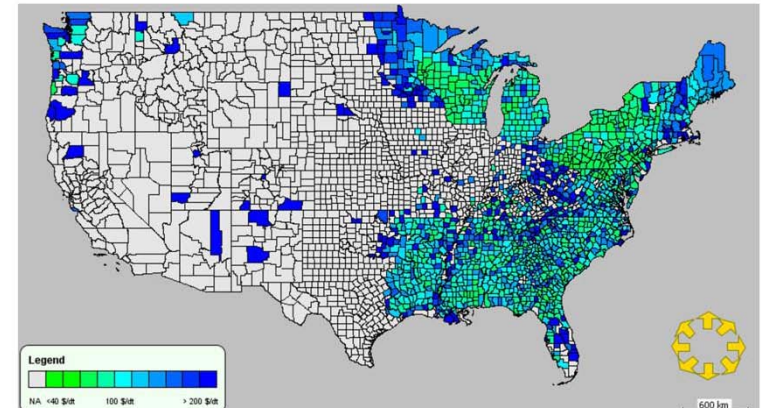


Formulation options enable utilization of feedstocks lower on the supply curve



Biomass supply curve illustrating cost & volume dynamics

A single feedstock limits the ability to meet cost and quality targets



3 – Technical Accomplishments: Least-Cost Formulation

Least-cost formulation effort focused on incorporating cost, volume and *quality* metrics into the formulations/blending options

INL Least Cost Formulation Spatial Tool

Year: 2030 State: County:

Legend: 0.0 kilotons, 150 kilotons, 200.0 kilotons

600 km

1 Select mode:

- cost given volume
- volume given cost
- total cost given blending

2 Select feedstock(s):

- Annlengcrp
- CORN STVR**
- LOGI
- LOGP
- LOGR
- PERNGRASS**
- LOGT

3 Set Target Cost and Radius: (Custom)

draw radius: In-County

target cost (\$/ton): 0 50.0 250

4 Get Volume (kilotons) By County:

Populate Map

Scenario	Year	Production unit
N/A	2030	N/A

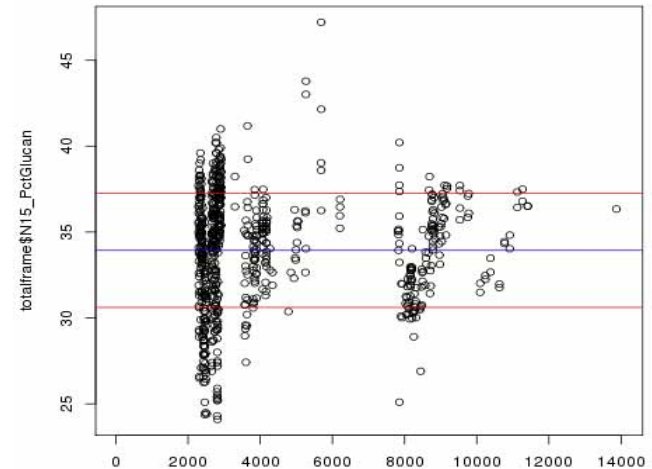
4 – Relevance

- **BETO Design Case and SOT**
 - **Design Case:** Provides quality data for setting technical targets and cost-of-production goals for assessing technology progress and validating processes at increasing scale and integration
 - **SOT:** Provides foundational experimental results relative to technical targets and cost goals from designs to assess progress within and across relevant technology areas
- **Impact**
 - Foundation for feedstock industry implementation of FGIS approach, exchange-point specifications, and valorization
 - Unique database provides detailed data for more flexible analysis
 - Spatial-temporal data from multiple feedstocks
- **Stakeholders**
 - **Researchers:** Provides the foundation for understanding feedstock variability, quality, and blend options
 - **Industry:** Addresses understanding of FS attributes and impacts of logistical processes
 - **Policy Makers:** Clear understanding of pathways to achieving sustainable energy options through incorporation of “exchange-point” quality control

5 – Future Work: DOE Bioenergy Feedstock Library

Initiatives:

- **Improved variability tools**
 - Integrate with KDF for increased number of data points
 - Intelligent prediction of sources of variability
- **Improved usability, user experience, and outreach**
- **Develop data mining tools**
 - Improve visualization of data
 - Look for patterns in results
- **Mobile tools**
 - Improve sample tracking
 - Ease of data upload
 - Image capability
 - Location information
- **Tools to identify impacts of pre-processing on characteristics**



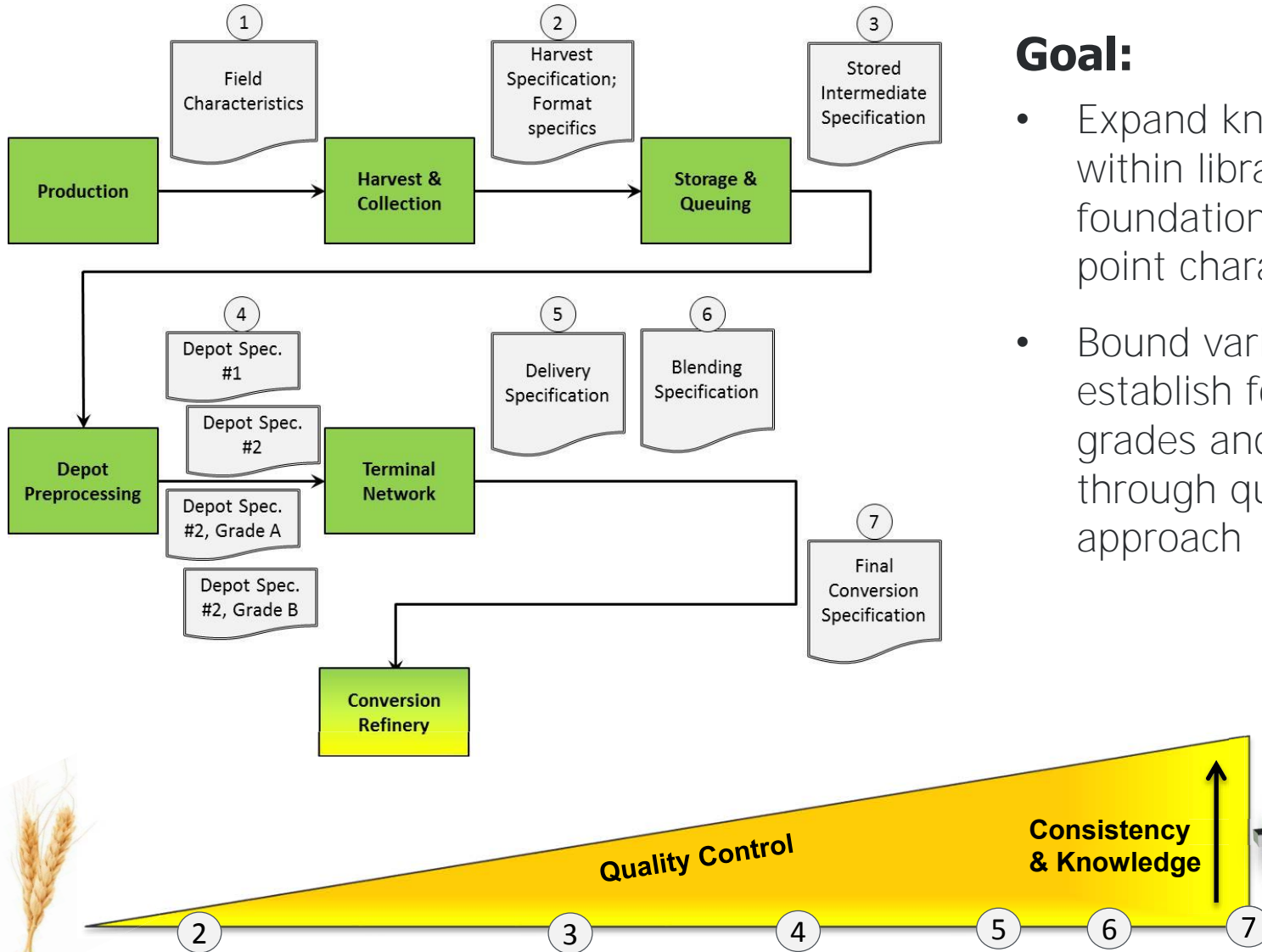
Statistical options for visualizing feedstock attributes (e.g., % Glucan)



Summary

- **Overview**
 - Develop innovative knowledge-based management system that enables and supports development of a commodity-scale feedstock supply system for the nation
- **Approach**
 - Populate library with relevant feedstock samples and attribute data from a wide variety of sources
 - Provide relevant data in a reliable and usable format via improved toolsets
- **Progress and Results**
 - Deployment of automated statistical tools, conversion pathway mapping, blending design, and least-cost formulation
 - Significant collaborative effort with RFP to incorporate high-impact quality data
- **Relevance**
 - Provides a central interactive repository for quality attribute data to support **BETO's 2017 goal of producing optimized dynamic blendstocks** with cost, *quality*, and volume conversion targets
- **Future Work**
 - Improved knowledge extraction from *data*
 - Integrated models for supply-chain feasibility

5 – Future Work: DOE Bioenergy Feedstock Library



Goal:

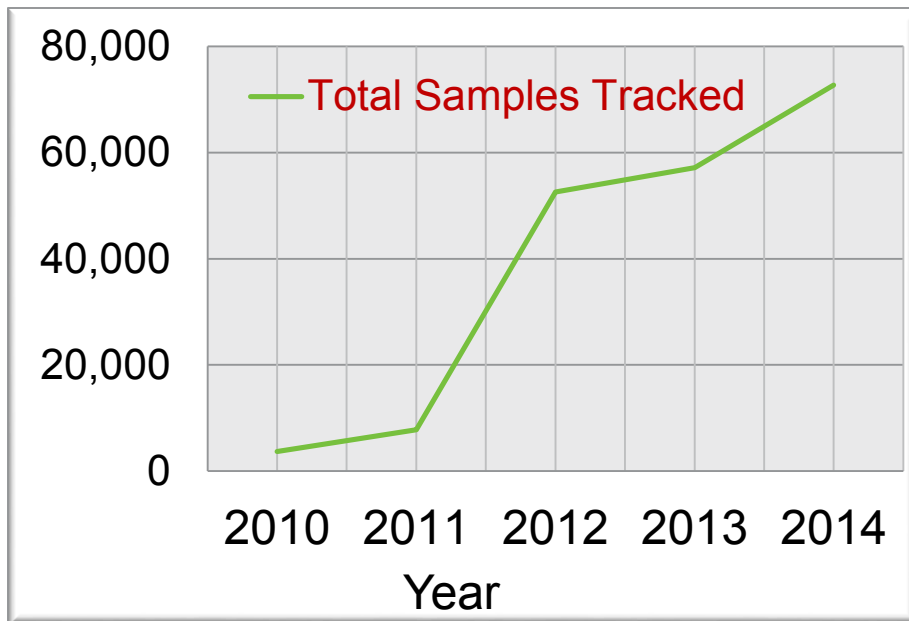
- Expand knowledge base within library to establish foundation for exchange-point characteristics
- Bound variability to establish foundation for grades and specifications through quality by design approach



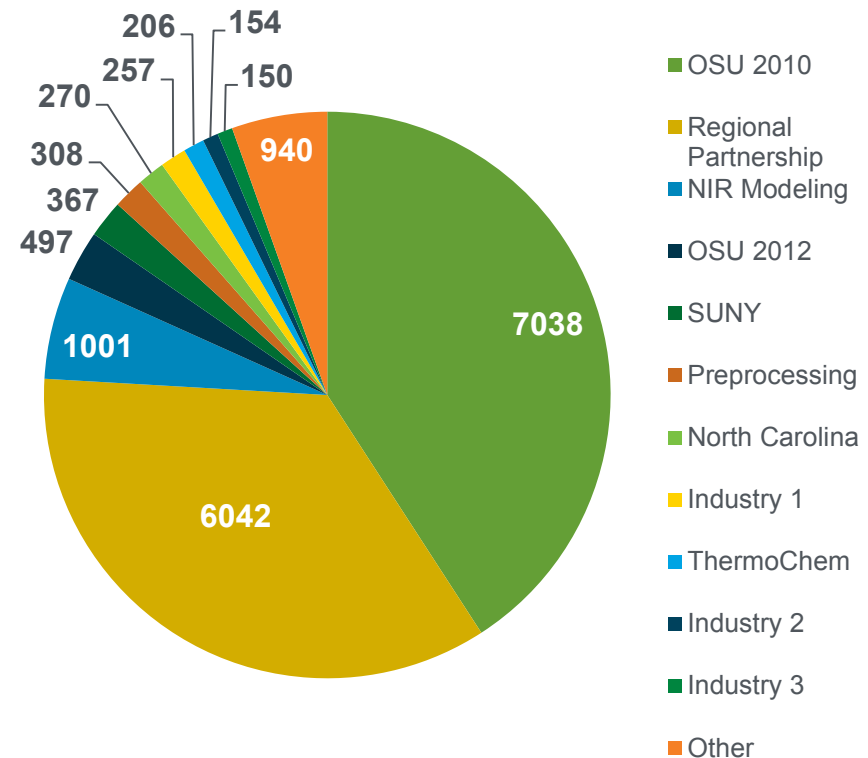
3 – Technical Accomplishments

Database Population

- 79,000 samples tracked
- 1,700,000 sample data points
- 30,000 characterization values
- 60 projects
- 135 crop types (including blends)



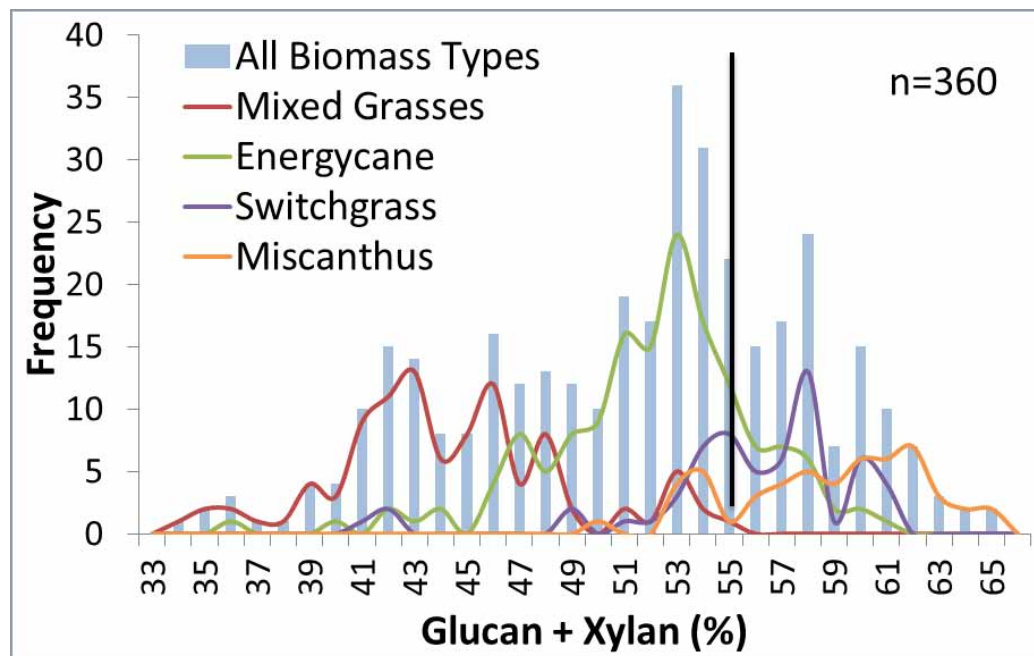
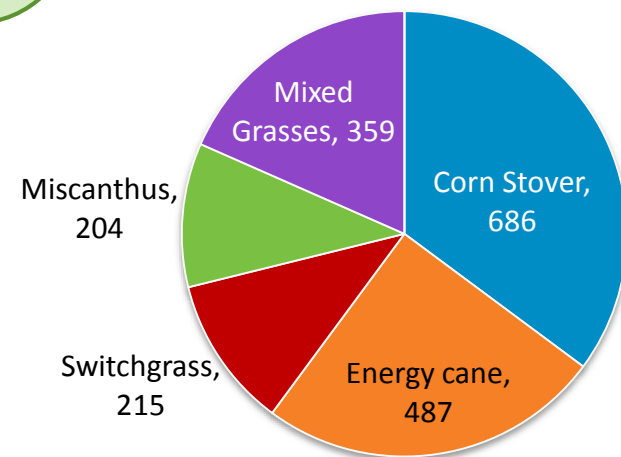
of Original Samples by Project



3 – Technical Accomplishments: Reg FS Partnership

- Sun Grant Regional Partnership provides significant input for feedstock data
- Incorporated in the Bioenergy Feedstock Library
 - 2009 through 2014 sample **sets**; $n \approx 6000$
 - Compile pedigree and analytical data
- **Collect quality data for “high impact” FSs**
- Data supports RFP synth and design case report, SOT, blend options, and analysis

NIR Predicted Composition
n=2037



INL Least Cost Formulation Spatial Tool

Year: 20... State: County: Custer County Blend Region: Midwest Draw Radius: 25 mi (Custom) [Populate Map](#)

Biorefinery Settings

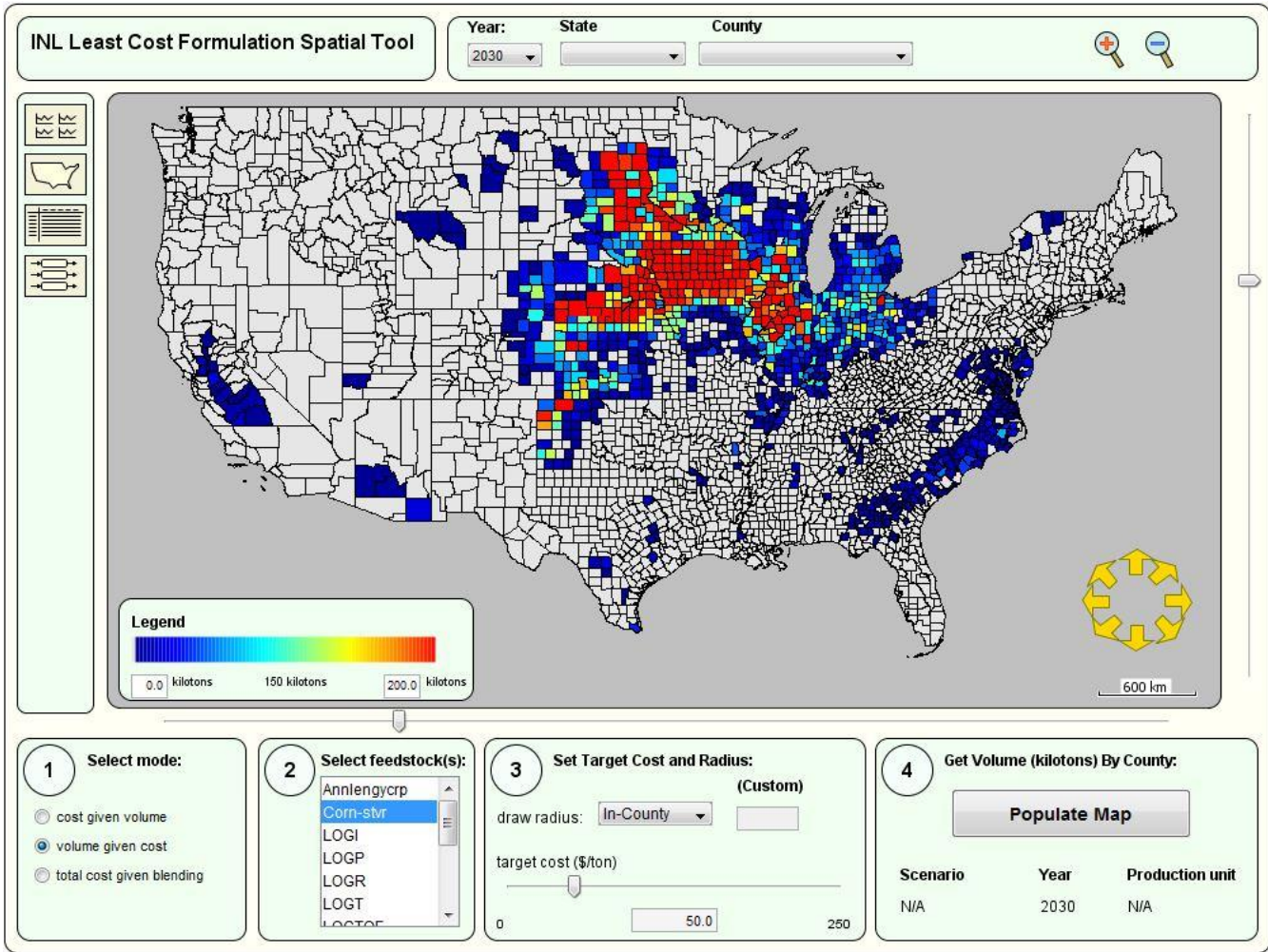
Moisture	Ash	Particle Size (mm)	Volume (kt)
0.15	0.01	6.35	800.0

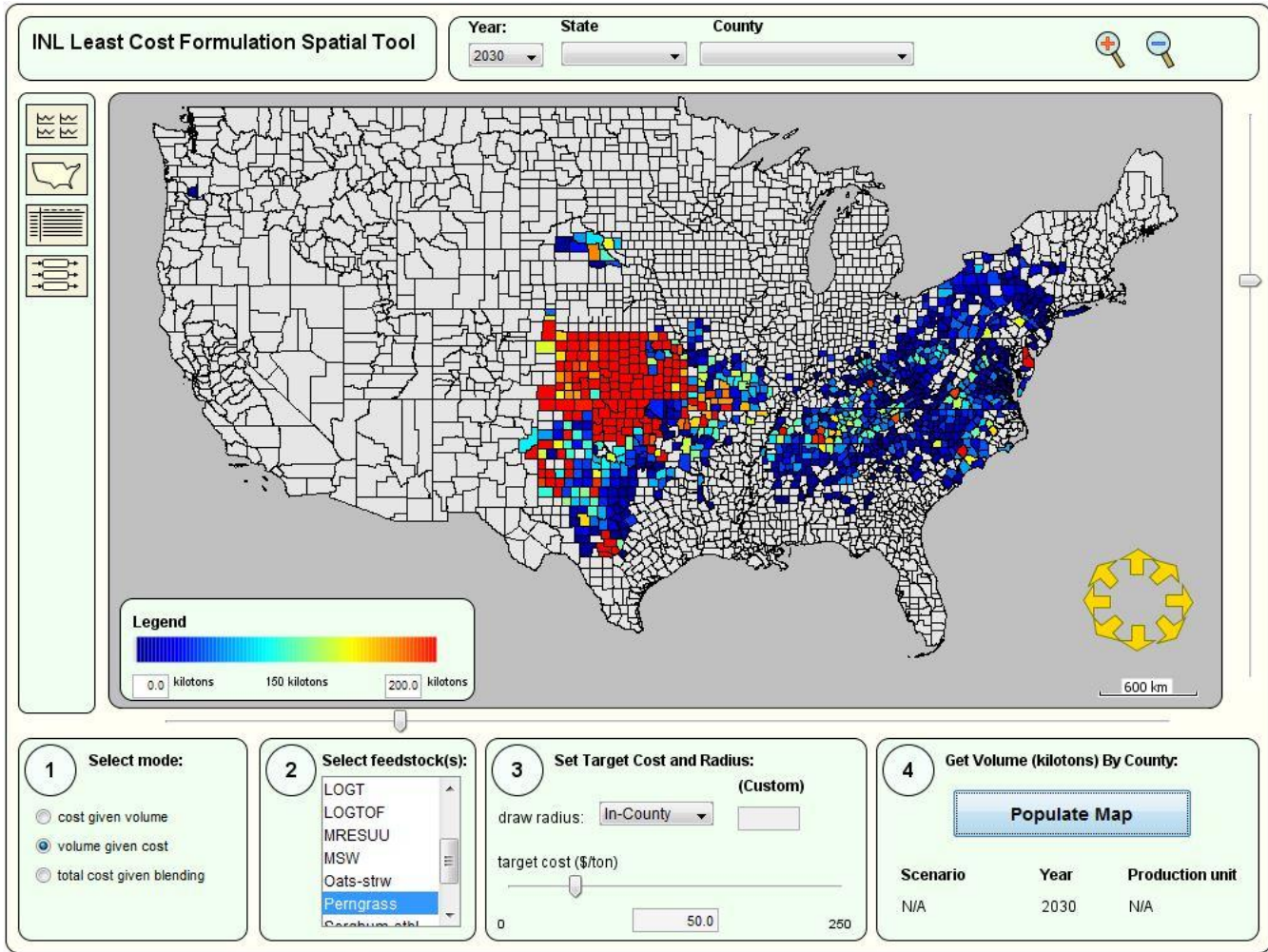
Current Blend: 0.15% Moisture, 0.05% Ash, 0 Particle Size, 690.796kt Volume

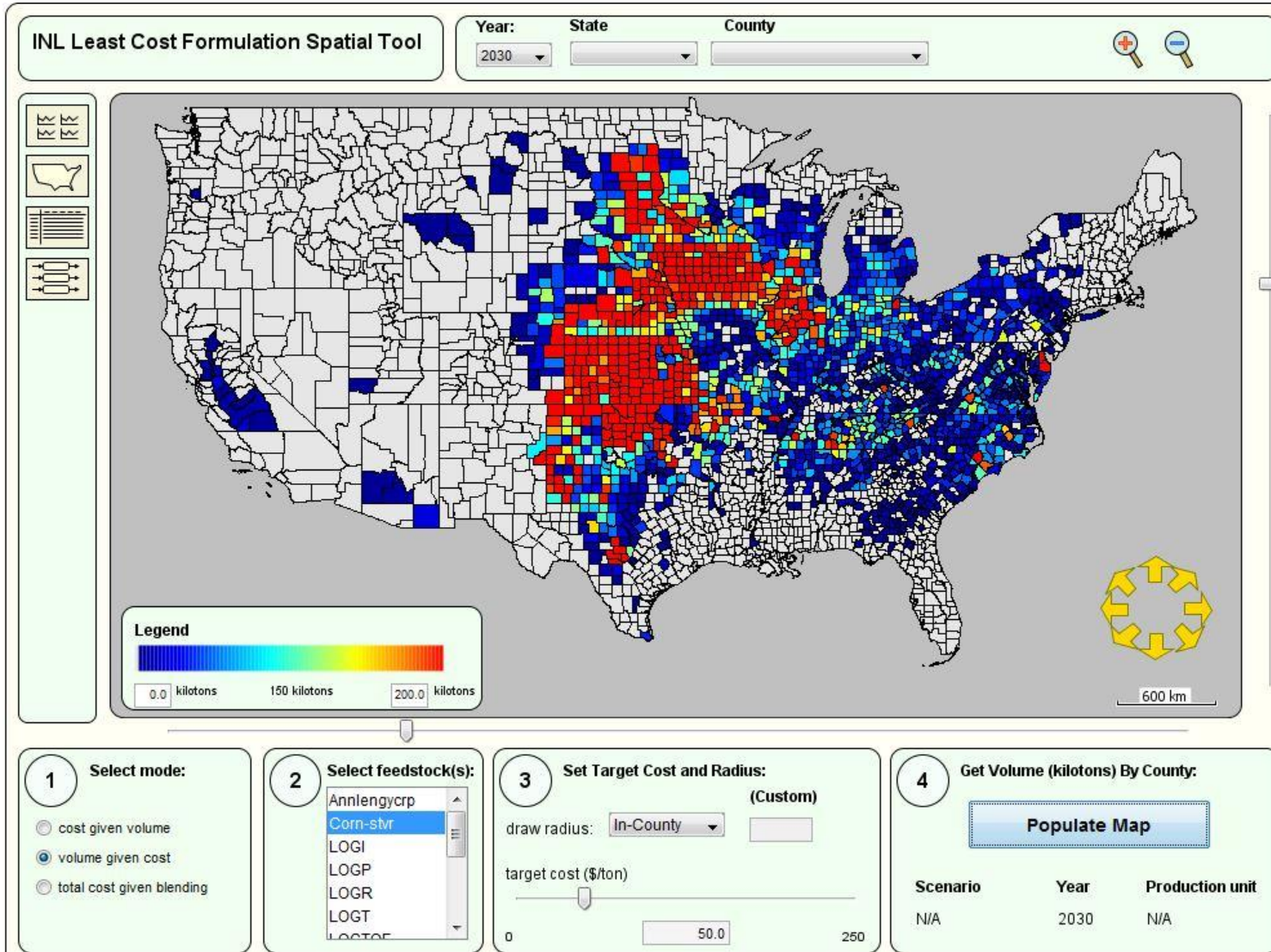
Cost (\$/t)
\$118.178/ton

Custer County Nebraska
[Calculate Formulation](#)

Resource	Resource Cost (\$/ton)	Preprocessing (Landing, Depot, Refinery)	Delivered Cost (\$/ton)	Formulation (Blend fraction, Volume)
Perngrass Moisture: 0.15 Ash: 0.05 Particle Size: 10.0	0 \$/ton	Cost (\$/t): 0.0 (Landing), 0.0 (Depot), 0.0 (Refinery)	0 \$/ton	Blend fraction: 0.1757 Volume: 121,400 dt
Corn-str Moisture: 0.15 Ash: 0.05 Particle Size: 10.0	0 \$/ton	Cost (\$/t): 0.0 (Landing), 0.0 (Depot), 0.0 (Refinery)	0 \$/ton	Blend fraction: 0.8191 Volume: 565,900 dt
Wheat-strw Moisture: 0.15 Ash: 0.05 Particle Size: 10.0	0 \$/ton	Cost (\$/t): 0.0 (Landing), 0.0 (Depot), 0.0 (Refinery)	0 \$/ton	Blend fraction: 0.0 Volume: 0 dt
Annleengycrp Moisture: 0.15 Ash: 0.05 Particle Size: 10.0	0 \$/ton	Cost (\$/t): 0.0 (Landing), 0.0 (Depot), 0.0 (Refinery)	0 \$/ton	Blend fraction: 0.0 Volume: 0 dt
MSW Moisture: 0.3 Ash: 0.1 Particle Size: 10.0	0 \$/ton	Cost (\$/t): 0.0 (Landing), 0.0 (Depot), 0.0 (Refinery)	0 \$/ton	Blend fraction: 0.0050 Volume: 3,496.039 dt







5 – Future Work: DOE Bioenergy Feedstock Library

Goal:

- Increase usability and impact
- Expand use of the library
- Provide data and analysis options not available anywhere else

- Tool shadowing in KDF
- Incorporation of predictive blend tools
- Deployment of least-cost formulation tool

The screenshot shows the KDF website header with the logo and navigation tabs: OVERVIEW, TOOLS & APPS, MAP, and BIOENERGY LIBRARY. Below the header is a search interface with filters for Project, Goal Type, Date of, Analysis Type, and Sample Type. A table of search results is displayed below the filters.

Sample ID	Sample Name	Sample Type	Project	Location	Date	Cost (\$/ton)
582552-0384-01	582552-0384-01	Corn Stover	IL	IL	08/11/2013	0.00
582552-0384-02	582552-0384-02	Corn Stover	IL	IL	08/11/2013	0.00
582552-0384-03	582552-0384-03	Corn Stover	IL	IL	08/11/2013	0.00
582552-0384-04	582552-0384-04	Corn Stover	IL	IL	08/11/2013	0.00
582552-0384-05	582552-0384-05	Corn Stover	IL	IL	08/11/2013	0.00
582552-0384-06	582552-0384-06	Corn Stover	IL	IL	08/11/2013	0.00
582552-0384-07	582552-0384-07	Corn Stover	IL	IL	08/11/2013	0.00
582552-0384-08	582552-0384-08	Corn Stover	IL	IL	08/11/2013	0.00
582552-0384-09	582552-0384-09	Corn Stover	IL	IL	08/11/2013	0.00
582552-0384-10	582552-0384-10	Corn Stover	IL	IL	08/11/2013	0.00

The screenshot shows the INL Least Cost Formulation Spatial Tool interface. It features a map of the United States with a color-coded legend indicating cost per ton (\$/t) by county. The legend ranges from NA (<40 \$/t) in green to >200 \$/t in blue. Below the map are three main sections: 1. Select feedstock(s): A dropdown menu with options LOGI, LOGP, LOGR, LOGT, LOGTOF, MRESUU, and MSW. 2. Set Target Density and Radius: A dropdown for 'draw radius' set to 'immediate county' and a slider for 'target density (ton per mi²)' ranging from 1 to 1,000. 3. Get Cost (\$/ton) By County: A 'Run Calculations' button and a table showing the results for the scenario BLY+EC1_BLT in 2017, with a production unit of 'dt'.

Acronyms

- BC – biochemical
- BETO – Bioenergy Technology Office
- BFNUF – INL Biofuels National User Facility
- CAP – Competitive Grants Program
- CoPI – Co-Principle Investigator
- FGIS – USDA, Federal Grain Inspection Service
- FS – feedstock
- FY – fiscal year
- KDF – Knowledge Discovery Framework (online collaboration toolkit and data resource)
- NARA – Northwest Advanced Renewables Alliance
- NIFA – National Institute of Food and Agriculture
- NIR – near infrared spectroscopy
- RFP – Regional Feedstock Partnership
- SOT – state of technology
- SUNY – University at Albany, State University of New York
- TC – thermochemical
- USDA – U.S. Dept. Agriculture
- WBS – work breakdown structure