Appendix C

Workshop Agenda and Survey

Transforming Biomass into High-Quality, On-Spec, High-Density Feedstocks

WORKSHOP
AUGUST 23–24, 2011

WEBINAR
AUGUST 30, 2011

BIOMASS WORKSHOP

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BIOMASS PROGRAM

WELCOME

Welcome to the Biomass Workshop—**"Transforming Biomass into High-Quality, On-Spec, High-Density Feedstocks"**—sponsored by the U.S. Department of Energy Biomass Program (OBP), the Office of Science (SC), and the Advanced Research Projects Agency – Energy (ARPA-E).

The DOE Biomass Program has shaped the vision of a national, commodity-scale feedstock supply system. Much progress has been made in developing and reaching this vision through optimizing biomass logistics—and defining commodity attributes compatible with existing commodity-scale, solids-handling infrastructure. Now, this commodity vision is expanding to include the development of next-generation, customized feedstocks that are optimized for conversion performance. This vision enables commodity-scale, custom-formulated feedstocks to play a critical role in producing biofuels, biopower and other bioproducts.

Presentations and demonstrations in this workshop will cover densification and mechanical, thermal, chemical, and biotechnical preconversion technologies for transforming biomass into high-quality, on-spec, densified feedstocks. The impacts of these technologies on supply chain logistics and feedstock performance for biofuels and biopower applications will be discussed.

Workshop Objectives

- Generate a report for Secretary Chu that includes bioenergy industry feedback
- Broaden the view of biomass densification to include preconversion and formulation concepts
- Demonstrate the Feedstock Process Demonstration Unit (PDU)
- Integrate plant genetics that improve biomass productivity/energy density and ease of conversion
- Solicit industry opinions on the concepts of preconversion, formulation, and densification
- Encourage partnership opportunities for use of the feedstock PDU.

Your participation in this workshop is valued and your input will help shape an S1-level workshop report to be provided to Secretary Chu's office and a biomass feedstock R&D roadmap to be drafted in the coming months.

We are pleased that you have chosen to join us at Idaho National Laboratory (INL) for this workshop. We hope the following information will help make your registration, badging, and participation comfortable and enjoyable.

Badges

Badges are valid August 22 through 25, 2011, and should be worn at all workshop functions. For security purposes while on INL facilities, workshop participants will be escorted by INL personnel. Break-out groups will be accompanied by multiple escorts.

Photographs

The use of cameras and recorders is prohibited during the tours and technology demonstrations. Photographs taken by INL staff will be provided after the conference.

Meals, Refreshments, & Special Accommodations

Meals are provided as indicated in the agenda. If you have special dietary needs, please inform one of your INL hosts.

Similarly, if you are in need of any special accommodations, your INL hosts can assist you.

TUESDAY, AUGUST 23 – WORKSHOP DAY 1	
7:00 TO 8:00 AM	***BREAKFAST AND REGISTRATION*** *Location: Shilo Inn, Lobby*
8:00 TO 9:45 AM	***WELCOMING REMARKS AND COMMODITY FEEDSTOCK VISION*** *Location: Shilo Inn, Twin Falls / Boise Meeting Room*
8:00 AM	**INL Welcome** *David Hill, Deputy for Science and Technology*
8:15 AM	**DOE Welcome and Workshop Introduction** *John Ferrell, Feedstocks Team Lead, DOE Biomass Program* **Transforming Raw Biomass to Feedstock** *Sam Tagore, Technology Manager, Feedstock Logistics, DOE Biomass Program*
8:45 AM	**DOE Integrated Biorefineries and Related Biomass Program Investments** *Melissa Klembara, Technology Manager, Integrated Biorefineries, DOE Biomass Program*
9:05 AM	**Advancements in Feedstock Logistics and Preconversion** *J. Richard Hess, Department Manager, Biofuels and Renewable Energy Technologies, Idaho National Laboratory*
9:45 TO 10:00 AM	***BREAK***
10:00 TO 12:00 PM	***OPENING TECHNICAL SESSION –BIOTECHNOLOGY*** *Location: Shilo Inn, Twin Falls/Boise Meeting Room* *Moderator: John Ferrell, DOE-OBP*
OFFICE OF SCIENCE 10:00 AM	**Engineering of Biomass Density and Cell Wall Composition for Improved Biofuels Production** *Henrik Vibe Scheller, LBNL, Joint Bioenergy Institute*
10:30 AM	**Value Prior to Pelletization** *Troy Runge, University of Wisconsin, Great Lakes BioEnergy Center*
ARPA-E 11:00 AM	**Eliminating the Recalcitrance of Lignocellulosic Biomass: Expressing Enzymes in Plants** *David Agneta, Agrivida*
11:30 AM	**High Biomass Energy Crops from Enhancing Nitrogen Use Efficiency** *Jisheng Li, Ceres*
12:00 TO 12:45 PM	***LUNCH AND REVIEW / INSTRUCTIONS*** *Location: Shilo Inn, Yellowstone / Grand Teton Meeting Room* *Moderator: J. Richard Hess, INL*
12:45 TO 1:00 PM	***DEPART FOR TECHNICAL BREAKOUTS*** *Location: Board buses from Shilo Inn, Convention Center Lobby*

1:00 TO 5:00 PM	***AFTERNOON TECHNICAL BREAKOUT TRACKS*** *Location: INL Conference Rooms and Laboratories* ***(Attend track as indicated by colored stripe along bottom of your name badge)***

TRACK 1 - MECHANICAL PRECONVERSION

Location: BCTC Lab 4/5
Moderator: Chris Wright (INL)

Size Reduction Technologies
Tyler Westover (INL)

Size Reduction with Selective Material Orientation
Jim Dooley (Forest Concepts)

Demo: Woody Crumbles Feedstock
Tyler Westover, INL

Facilitated Discussion

TRACK 2 - THERMAL PRECONVERSION AND DENSIFICATION (LIQUID)

Location: IEDF
Moderator: Richard Boardman (INL)

Demo: Biomass Torrefaction
Michael Clark, (INL)

Thermal Pretreatment
Jum Phanphanic (INL)

Pyrolysis, Liquid Format Densification
Jonathan Male (PNNL)

Facilitated Discussion

TRACK 3 - CHEMICAL PRECONVERSION

Location: IRC 120
Moderator: Garold Gresham (INL)

Leaching
Luis Cerezo, EPRI

AFEX
Tim Campbell (MBI)

Demo: AFEX Material Preconversion Properties
Tim Campbell (MBI) and Erin Searcy (INL)

Facilitated Discussion

TRACK 4 - MECHANICAL DENSIFICATION (SOLID)

Location: BCTC Bay 7
Moderator: David Muth (INL)

Pretreatability of Densified Feedstocks
Allison Ray (INL)

Formulation of Biomass Feedstocks
Henrik Ribe Scheller (SNL/JBEI)

Demo: Densification
Jaya Shankar Tumuluru (INL)

Facilitated Discussion

	TRACK 1	TRACK 2	TRACK 3	TRACK 4
1:00 PM	Yellow	Green	Red	Purple
2:00 PM	Green	Red	Purple	Yellow
3:00 PM	Red	Purple	Yellow	Green
4:00 PM	Purple	Yellow	Green	Red

5:00 TO 5:15 PM	***DEPART FOR FACILITATED REPORT OUT DISCUSSIONS*** *Location: Board buses from BCTC*
5:15 TO 9:00 PM	***EVENING SESSION***
5:15 PM	***Facilitated Report Out – Workshop Day 1*** *Location: Shilo Inn, Twin Falls / Boise Room* *Moderators: Technical Breakout Session Moderators*
6:00 PM	**Social (No-host bar)** *Location: Shilo Inn, Yellowstone / Grand Teton Room*
7:00 PM	**Dinner**
7:40 PM	**Plenary Presentation: *Replace the Whole Barrel, Supply the Whole Market: The New Horzons of Bioenergy*** *Paul Bryan, Biomass Program Manager, DOE*
9:00 PM	***ADJOURN***

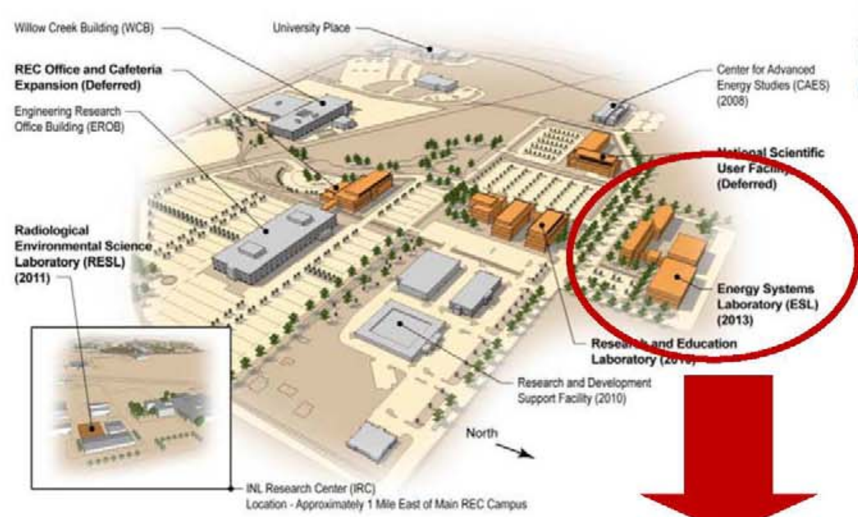
WEDNESDAY, AUGUST 24 – WORKSHOP DAY 2

7:00 TO 8:00 AM	***BREAKFAST*** *Location: Shilo Inn, Convention Center Lobby*
8:00 AM	**Plan of the Day and Safety Brief** *Location: Shilo Inn, Yellowstone/Grand Teton Room* *Patrick Laney, INL*
8:15 to 8:30 AM	***DEPART FOR PDU DEMONSTRATION AND INFORMATION SESSIONS*** *Location: Board buses from Shilo Inn, Convention Center Lobby*
8:30 TO 10:45 AM	***FEEDSTOCK PDU DEMONSTRATION AND INFORMATION SESSIONS*** *Location: INL NBA* *Moderator: Colleen Shelton Davis, INL*
8:30 AM	**Feedstock PDU Demonstration**
9:00 AM	**PDU Instrumentation and Data Collection** *Rod Shurtliff and Garold Gresham, INL* **PDU Safety Systems** *Matt Anderson, INL* **PDU Deployment** *Colleen Shelton Davis, INL* **PDU Partnerships** *David Anderson and Eric M. Barzee, INL* **Biomass Harvest, Collection, and Storage** *Bill Smith, Mark Delwich, and Ian Bonner, INL*
10:15 TO 10:30 AM	***DEPART FOR FOCUS GROUP DISCUSSIONS AND CLOSING REMARKS*** *Location: Board buses from INL NBA*
10:30 TO 12:20 PM	***FACILITATED FOCUS GROUP DISCUSSIONS, REPORT OUT, AND CLOSING REMARKS*** *Location: Shilo Inn, Yellowstone /Grand Teton Room* ***(Group topics to be assigned)***

	Biotechnology	Preconversion	Formulation	Densification
11:00 AM	*Moderator: Tom Ulrich, INL*	*Moderator: Chris Wright, INL*	*Moderator: Garold Gresham, INL*	*Moderator: David Muth, INL*

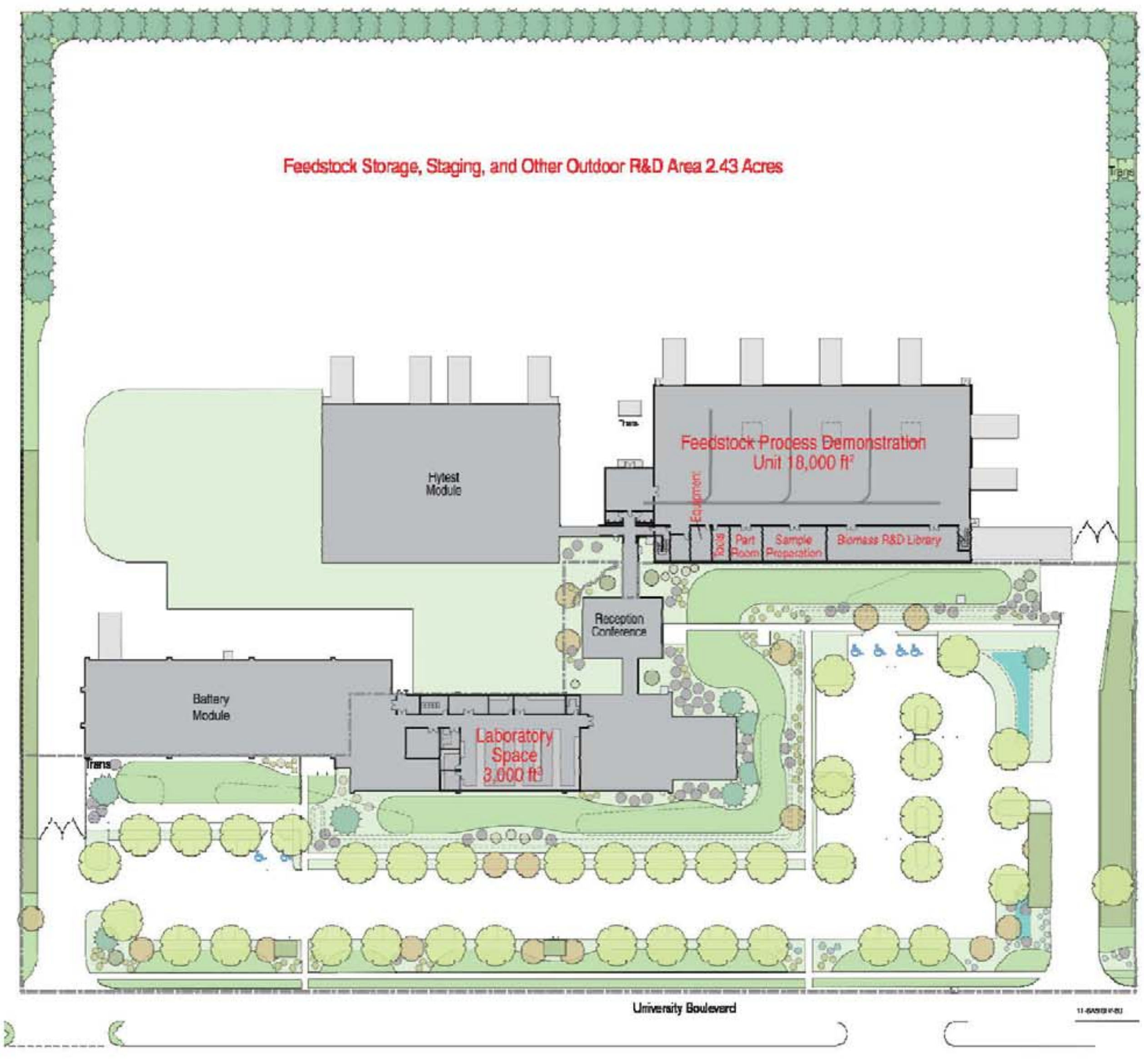
12:20 PM	**Closeout Remarks** *Melissa Klembara, DOE-OBP*
12:30 PM	***ADJOURN*** *(Grab-N-Go lunch provided)*

ENERGY SYSTEMS LABORATORY (ESL) UNDER CONSTRUCTION



New to the INL Research and Education Campus, the ESL includes state-of-the-art bioenergy development capabilities:

- ~2.5 ac of outdoor storage, staging, and other R&D area
- 18,000 ft^2 high-bay Feedstock Process Demonstration Unit (PDU) facility with adjoining sample preparation and Biomass R&D Library areas
- 3,000 ft^2 feedstock development laboratory
- Scheduled for occupancy in FY 2013.



Mechanical Preconversion

Includes:

- Size reduction
- Fractional Deconstruction
- Separations
- Other:__________________

Constraints:

- Cost
- Energy Balance
- Carbon Balance
- Other:_____________________________

Assumptions (Indicate the position that best represents your reaction to each assumption)	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	N/A
10. In comparison with raw, unprocessed biomass, mechanical preconversion will increase performance of the feedstock in **thermochemical conversion processes**.						
11. In comparison with raw, unprocessed biomass, mechanical preconversion will increase performance of the feedstock in **biochemical conversion processes**.						
12. In comparison with raw, unprocessed biomass, mechanical preconversion will increase performance of the feedstock in **biopower processes.**						
13. Mechanical preconversion will increase bulk density of raw biomass.						
14. Fractional deconstruction is a viable mechanical preconversion process.						
15. Mechanical preconversion can provide value for bioenergy production today.						
16. Locating mechanical preconversion systems at distributed biomass preprocessing depots is essential for these technologies to have their greatest impact.						

(Indicate timeframe that best represents your opinion)	**Near Term (<2 yr)**	**Mid Term (2–10 yr)**	**Long Term (>10 Yr)**	**Never**
17. Fractional deconstruction has been shown to optimize biomass utilization by producing fractions for different uses and applications. Fractional deconstruction will be viable when?				
18. Mechanical preconversion can transform bioenergy production.				

Comments:

Thermal Preconversion and Densification (Liquid)

Includes:

- Drying
- Deep Drying
- Torrefaction
- Pyrolysis
- Other:_________________

Constraints:

- Cost
- Energy Balance
- Carbon Balance
- Other:___________________________

Assumptions (Indicate the position that best represents your reaction to each assumption)	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	N/A
Thermal Preconversion						
19. In comparison with raw biomass, thermal preconversion will increase performance of the feedstock in **thermochemical conversion processes**.						
20. In comparison with raw biomass, thermal preconversion will increase performance of the feedstock in **biochemical conversion processes**.						
21. In comparison with raw biomass, thermal preconversion will increase performance of the feedstock in **biopower processes**.						
22. Thermal preconversion can increase stability of raw biomass and enable feedstock storage greater than 1 year.						
23. Torrefaction has limited application unless it is performed prior to densification.						
24. Thermal preconversion can provide value for bioenergy production today.						
25. Locating thermal preconversion systems at distributed biomass preprocessing depots is essential for these technologies to have their greatest impact.						
Thermal Densification (Liquid)						
26. In comparison with raw biomass, thermal densification processes that produce liquid intermediates (e.g., pyrolysis) offer significant supply system advantages.						
27. In comparison with raw biomass, liquid densification using enzymatic/chemical processes (e.g., sugar liquors, syrups) offers significant supply system advantages.						
28. Locating thermal densification systems at distributed biomass preprocessing depots is essential for these technologies to have their greatest impact.						

(Continued on reverse)

(Indicate timeframe that best represents your opinion)	**Near Term (<2 yr)**	**Mid Term (2–10 yr)**	**Long Term (>10 Yr)**	**Never**
Thermal Preconversion				
29. Deep drying, a non-reactive thermal preconversion step, has been shown to improve feedstock logistics through improved handling and stability. Deep drying be viable when?				
30. Considering current challenges associated with mass loss during torrefaction (up to 20%), this thermal preconversion process will be viable when?				
31. Thermal preconversion in general can transform bioenergy production.				

Comments:

Chemical Preconversion

Includes:

- Leaching
- Ammonia Treatment
- Dilute-Acid Treatment
- Other:__________________

Constraints:

- Cost
- Energy Balance
- Carbon Balance
- Other:_____________________________

Assumptions (Indicate the position that best represents your reaction to each assumption)	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	N/A
32. In comparison with raw biomass, chemical preconversion will increase performance of the feedstock in **thermochemical conversion processes**.						
33. In comparison with raw biomass, chemical preconversion will increase performance of the feedstock in **biochemical conversion processes**.						
34. In comparison with raw biomass, chemical preconversion will increase performance of the feedstock in **biopower processes**.						
35. Chemical preconversion can increase stability of raw biomass and enable feedstock storage greater than 1 year.						
36. Chemical preconversion can provide value for bioenergy production today.						
37. Locating chemical preconversion systems at distributed biomass preprocessing depots is essential for these technologies to have their greatest impact.						
38. Some forms of chemical preconversion are similar to pretreatments in that currently occur in biochemical conversion processes. The ability to deploy these processes to distributed preprocessing centers will add value through the production of a pretreated solid feedstock intermediate.						

(Indicate timeframe that best represents your opinion)	Near Term (<2 yr)	Mid Term (2–10 yr)	Long Term (>10 Yr)	Never
39. Chemical preconversion can transform bioenergy production.				

Comments:

Formulation

Includes:

- Blending
- Agglomeration
- Other:_________________

Constraints:

- Cost
- Energy Balance
- Carbon Balance
- Other:___________________________

Assumptions (Indicate the position that best represents your reaction to each assumption)	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	N/A
40. In comparison with raw biomass, formulation will increase performance of the feedstock in **thermochemical conversion processes**.						
41. In comparison with raw biomass, formulation will increase performance of the feedstock in **biochemical conversion processes**.						
42. In comparison with raw biomass, formulation will increase performance of the feedstock in **biopower processes**.						
43. Formulation can increase stability of raw biomass and enable feedstock storage greater than 1 year.						
44. Formulation can provide value for bioenergy production today.						
45. Locating formulation systems at distributed biomass preprocessing depots is essential for these technologies to have their greatest impact.						
46. A commodity-based biomass feedstock supply system is necessary for formulation to be viable.						

(Indicate timeframe that best represents your opinion)	**Near Term (<2 yr)**	**Mid Term (2–10 yr)**	**Long Term (>10 Yr)**	**Never**
47. Formulation can transform bioenergy production.				

Comments:

Mechanical Densification (Solid)

Includes:

- Extrusion
- Forging
- Agglomeration
- Other:_________________

Constraints:

- Cost
- Energy Balance
- Carbon Balance
- Other:___________________________

Assumptions (Indicate the position that best represents your reaction to each assumption)	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	N/A
48. Densified feedstocks perform as well or better than undensified feedstocks in **thermochemical conversion processes**.						
49. Densified feedstocks perform as well or better than undensified feedstocks in **biochemical conversion processes**.						
50. Densified feedstocks perform as well or better than undensified feedstocks in **biopower processes**.						
51. Densification can increase stability of raw biomass and enable feedstock storage greater than 1 year.						
52. Densification is essential for making raw biomass compatible with existing solids handling infrastructures.						
53. Densification can provide value for bioenergy production today.						
54. Locating densification systems at distributed biomass preprocessing depots is essential for these technologies to have their greatest impact.						

(Indicate timeframe that best represents your opinion)	**Near Term (<2 yr)**	**Mid Term (2–10 yr)**	**Long Term (>10 Yr)**	**Never**
55. Densification can transform bioenergy production.				

Comments:

Appendix D

Biomass Library and Characterization Capabilities

On the second day of the Densification Workshop, a demonstration of the Feedstock Process Demonstration Unit (PDU) data collection and sample characterization capabilities was provided. The demonstration area was set up near the PDU, and provided attendees the opportunity to see the mechanism of how PDU operational data and characterization data are linked and retained to develop performance-based relationships between feedstock specifications and conversion performance. In general, this is achieved by characterizing the positive and negative impacts of feedstock characteristics and specifications on conversion performance. One example presented was the effect of mitigating ash in switchgrass through best harvesting practices and harvest timing.

The cornerstone of the performance-based relationship effort is the INL Biomass Resource Library. The Library and database was described to the attendees and includes specification-performance data to enable better understanding of the relationship of how specific supply chain process-to-intermediate-to-specifications pathways influence the downstream conversion processes, for a variety of feedstocks and processed intermediates. The Library database can be retrospectively analyzed to establish specification-performance relationships and identify those feedstock materials (characteristic and specifications) that may have positive and/or negative effects on conversion processes. Figure 1 shows the attendees listening to a presentation on the capabilities of the Library and how the PDU data is linked to the Library database.

The Biomass Resource Library was initially developed as a straightforward library system to systematically track, house, and retrieve feedstock materials created from the DOE Regional Partnership Programs. The strength of a more comprehensive data system was envisioned, and the Library was transformed from a simple systematic tracking and storage system of feedstock materials into an *integrated knowledge management system* that assimilates feedstock pedigree information, harvest information, storage information, unit operational data from the PDU and field demonstrations, physiochemical data generated in the laboratory, lab-based biological data, lab-scale conversion data, and full-scale conversion data from the conversion platforms in to a single data system, along with physical storage and tracking of each of the feedstock materials and process intermediates used in the overall research. The Library along with the physiochemical characterization capabilities at the INL provide a significant resource for evaluation and investigation of feedstock characteristics and conversion performance, and will directly impact the overall understanding of tradeoffs between the feedstock attributes/specifications relative to conversion operations, identifying and mitigating negative impacts on feedstock materials, and enhancing the biomass-feedstock supply system.

Figure 1. Attendees of the Densification Workshop listening to presentation on capabilities of the Biomass Feedstock Library.

<u>Biomass Resource Library.</u> The Biomass Resource Library, developed within Idaho National Laboratory's (INL's) Biomass Feedstock Program, provides a robust mechanism to store, track, and retrieve biomass feedstock materials for research and demonstration purposes. The Library is comprised of two primary components: the physical storage of feedstock materials and the archival Database System. The physical storage component of the Library includes inside and outside storage in various container types as appropriate for the species, format, and volume of the sample feedstock. The physical control, in conjunction with the archival Database System, has been established to meet the project needs of maintaining, storing, tracking, and retrieving biomass feedstock samples, sample information, and characterization/physiochemical results in a secure and practical manner.

Feedstock materials, process intermediates, and samples in the Biomass Library are stored in a number of different configurations and containers. A variety of storage containers are used for storing sample materials. These containers range from zippered bags and small jars to 1000 lb super sacks and 55 gal barrels. For each sample, a unique barcode is generated on a label and affixed to the exterior of sample container. **Error! Reference source not found.** demonstrates the secured storage containers and the various methods for storing biomass feedstock samples of multiple formats and volumes.

Figure 1. Secured storage containers used for biomass feedstock sample storage

The data management system of the Biomass Library provides a mechanism to track samples through various operations (e.g., grinding, fractionation, formulation, etc.), store sample historical and physiochemical data, and retrieve and export this data through query and filter functionality. The general and flexible nature of the data management system enables users from across the county and even the world to interact and manage with their samples. In addition to providing these tools, the Biomass Library also includes necessary security measures for handling sensitive samples, sample data and project limited information. A novel method for tracking samples through sample hierarchies, a physiochemical analysis queuing system, and a literature database is also incorporated into the system. These tools within the Biomass Library data management system enable and facilitate characterization of biomass feedstocks.

The Biomass Library enables users to interact and extract historical and physiochemical data from various feedstock materials. Each sample in the Biomass Library is given a global unique identifier (GUID) where all information associated to that sample is linked and retrievable by the GUID. Samples stored at the INL receive a label containing basic information and the GUID barcode to assist in storing and retrieving the samples from storage. Figure 3 shows an example of a bale of reed canary grass stored near the PDU with accompanying GUID and 2-deminsioinal barcode.

Figure 2. Sample label consisting of barcodes and relevant sample information for quick identification.

The sample interface (**Error! Reference source not found.**) allows users to perform queries on multiple parameters such as project, feedstock, operations, analysis, and specific analysis parameters. Returned sample records provide high level information about the sample that further allows the user to organize and filter the records by feedstock, location, date, amount, etc. Additional information provided to the user is whether the sample is part of a hierarchy of samples and whether there is any physiochemical data associated with the sample. Users can view historical or "pedigree" information about the sample by clicking the Edit link next to the GUID. This provides background information about the sample such as where it originated from, how it was created, when it was created, etc. Users can also select a sample or multiple samples and export their associated data.

The Operation link allows users to create a child sample(s) from the existing sample. The Biomass Library uses a sample hierarchy schema shown in **Error! Reference source not found.** to determine the operations that require creation of a new sample. Basically, if a sample experiences a physical format change or a splitting/separation of material, the feedstock is assigned a new GUID. This generates a hierarchy of samples that creates a history or lineage of the sample so users can understand and be informed of the various operations a given sample has gone through to reach its current format and characteristics. Each GUID in the hierarchy has operational details associated with it to describe how the sample was created as well as any physiochemical data that may be associated to the GUID. The sample hierarchy enables an understanding of how operations impact feedstock characteristics and performance and enables users to identify the operations required to meet a feedstock specification. Samples containing the  icon, identifies the sample as part of a hierarchy and selection of the icon displays the sample within a hierarchy tree where users can navigate up and down to view additional samples that are part of the samples history and their relationship.

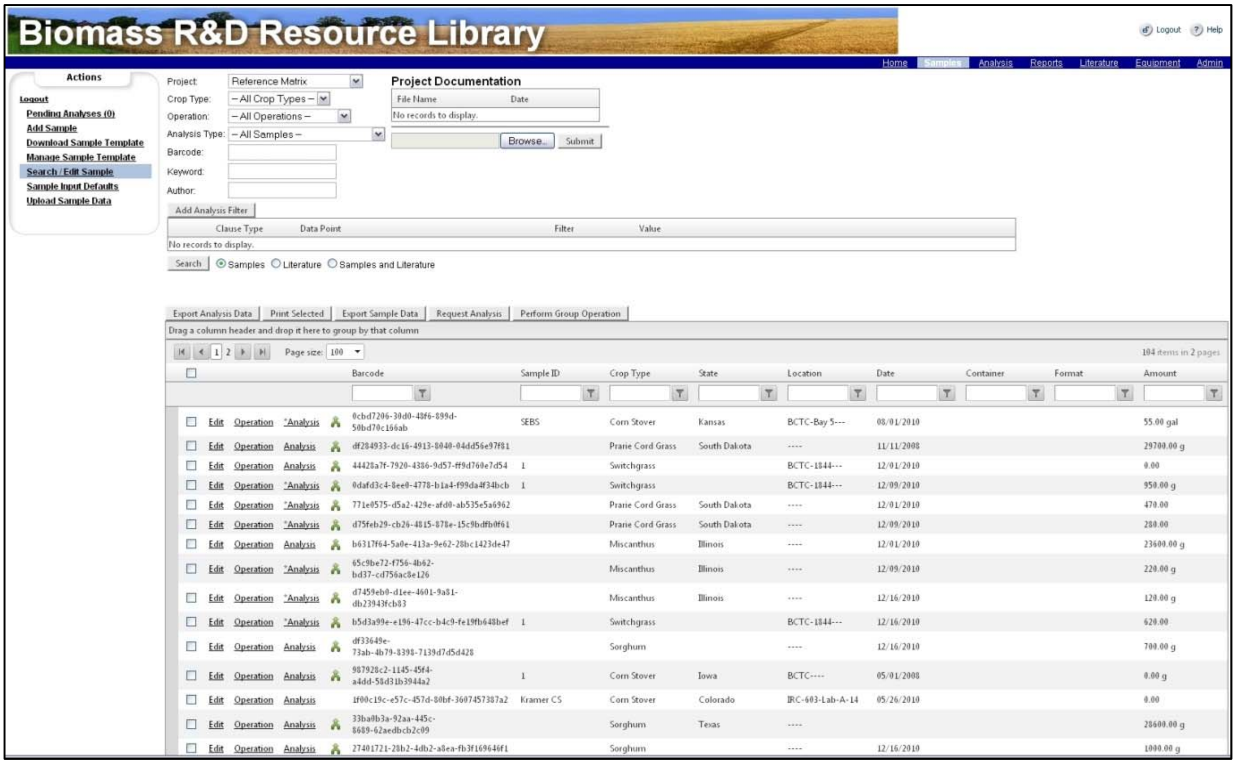


Figure 3. Feedstock sample interface displaying returned records where users can interact with the samples.

Figure 4. Sample hierarchy schema for creating new samples.

The Analysis link next to each GUID navigates the user to the analysis page for that sample (**Error! Reference source not found.**). On the analysis page a user can upload and download physiochemical data files, view specific physiochemical parameters, and view an analysis representation of the sample hierarchy. Users can associate physiochemical data files of any format to a sample by uploading them through the analysis interface. Once the files are uploaded, users are informed of the type of analysis contained in the file, who uploaded it, and when it was uploaded. The files are also then available for download. Also found on the analysis page is a list of analysis types with specific analysis parameters. Again, an asterisk denotes if an analysis type has populated physiochemical data parameters. These populated analysis parameters are used in performing queries. For example, samples containing ash or moisture less than a certain percentage can be included in queries and return samples with those parameters that meet the query criteria. Lastly, the analysis page contains an analysis representation of the sample hierarchy. In this hierarchy, the analysis performed on each sample of the hierarchy is displayed. This informs the user of current and past analyses performed on the sample and the sample's ancestry. Samples that have an asterisk located next to the Analysis link means there is some form of physiochemical data associated with the sample.

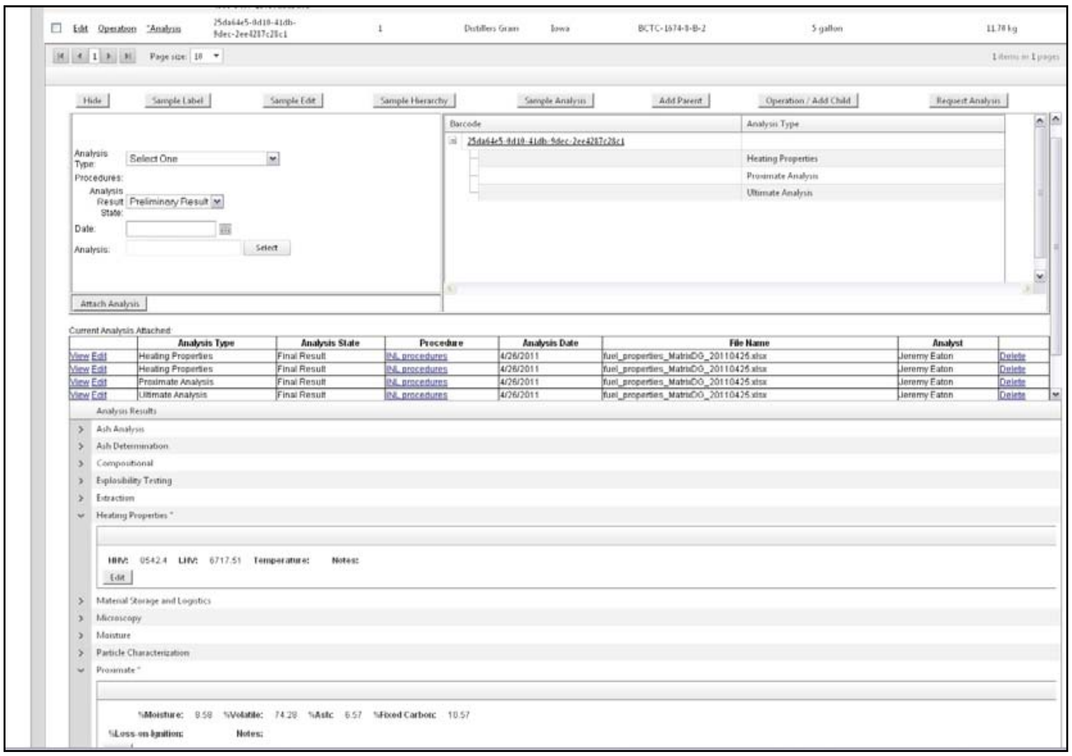


Figure 5. Analysis page containing various forms and representations of the sample's physiochemical data.

Another component contained in the Biomass Library is the Analysis Queuing System. The Analysis Queuing System enables users to request and manage analysis on their samples. Users can select a set a samples, select the type or types of physical, chemical or biological analysis to be performed on the sample set, choose a desired completion date, and provide any additional comments to the analyst for completion of the analysis. Once the request is submitted, they are entered into the queue where analysis can be reprioritized as needed. The user can manage/edit their request and can view where their samples reside in the queue on their own Analysis Status page. An automated system is used to notify users of the status of their samples and upon completion, sends out the results to the requester via email where they can either accept or decline the results. Acceptance of the results automatically uploads the file to the sample and populates the specific analysis parameters. Declining the results allows the user to provide comments as to why the results were declined; comments are sent to the analyst that performed the analysis. All samples requiring analysis are entered into the queuing system.

Another component of the Biomass Library is the literature database. The literature database contains information and results of biomass experiments found in the open literature. A majority of the experimental results overlap with the specific analysis parameters found in the sample database allowing simultaneous querying of physical sample results found in the sample database and experiment results found in literature. This allows users to compare experiments and physiochemical results to published material and reconcile or identify any discrepancies that may exist. The literature database is accessible to all users of the Biomass Library.

The ability to interact with the above mentioned functionality is determined by a user's role within the Biomass Library. Within the data management system, user roles have been established to permit and limit access to information based on the user's defined role. Currently, five user roles have been established: General, Member, Analysis, Literature and Administrator.

- *General* – Users with this role have read-only access to public information in the database. This is information released to the public with permission from institutions and project managers responsible for the samples and their associated data.
- *Member* – Users with this role have the same privileges as General users with the addition of read-write access to the samples and data within their projects. This role is meant for project managers and people within the project scope, designated by the project manager to interact with samples in the database. Member users will be able to add and modify data and analysis within their respective projects as well as request analysis on their samples.
- *Analysis* – Users with this role are analysts who have access to the analysis queuing system. Analysis users not only perform analysis on the samples, but they also prioritize analysis and inform the analysis requestor of the status of their analysis request.
- *Literature* – Users with this role have the ability to add literature information and data to the literature database. Literature users have access to a separate interface for entering in the information that is made public through the search page.
- *Administrators* – Users with this role have read-write access to systems within the database. Administrative privileges will be restricted to a limited number of personnel at INL who will be maintaining the database and interacting with project managers to properly establish accounts and initiate projects.

Database users can take on multiple user roles based on the level of interaction required by and permitted to the user. A user is given an all-purpose user role for the Biomass Library but may have another user role within a specified project. For example, a user may have a General user role within a collaborative project but a Member user role within the user's own project. Or a user with a Member role may be able to make analysis requests within the user's project and also have an Analysis role that allows the user to perform analysis on samples in any project. As the database system evolves and grows, it is likely that the number of user roles will grow as more people begin using the database and specific needs arise.

Once an account is created, users can download documentation and instructions for the Biomass Library. They also have the ability to set up user preferences that will enhance their use of the system. In addition to this, a mobile application for the sample database portion of the Biomass Library has been developed enabling users to access sample information from mobile devices including handheld scanners. This enables users retrieving samples from a storage location or working in the field to identify and retrieve samples and sample data instantly.

Characterization of Biomass. The demonstration area also provided attendees the opportunity to speak with individual analyst and scientist as to how feedstock materials and process intermediates are characterized. The impact of supply system operations such as harvesting, transportation, storage, grinding, fractionation, preconditioning, and densification can significantly impact or modify the physical/chemical/biological attributes and uniformity of these feedstocks and ultimately the viability of the biomass delivered to conversion refineries. To more clearly understand the impact of these various processes on feedstocks, several posters were presented outlining the physical, chemical and biological attributes of biomass feedstock materials at various stages throughout the supply chain. As seen in Figure 7, attendees are speaking with scientists about measuring particle size distribution and morphology and how this impacts the flow characteristics of feedstock materials.

Figure 7. Attendees of the Densification Workshop speak with individual analysts and scientist about particle characteristics and their impact on feedstock flow characteristics.

The INL uses ASTM, NREL laboratory analytical procedures (LAP), standard analytical procedures and laboratory specific methods for the characterization of biomass feedstock materials and their process intermediates. Researchers utilize thermochemical feedstock properties analysis to evaluate the rate and efficiency with which given feedstocks will combust. Proximate analysis, as the name implies, is the determination of categorical characteristics, while ultimate analysis is an exact determination of elemental composition (carbon, nitrogen, hydrogen, sulfur, and oxygen content) composition. Partial chemical fractionation provides insight into the solubility of specific elements. Multiple analytical capabilities are use to determine the percent constituency of moisture, volatiles, ash, fixed carbon, and loss-on-ignition material content, as well as calorific content or high heating values. Several of these processes contribute to compositional analysis as well. For example, moisture and ash content are used extensively in compositional analysis calculations, but traditional methods require more far longer analysis times; nitrogen determinations can also be used to approximate total protein content within a sample. All of these dynamic analyses are based on long-established procedures for coal and biomass and are executed using a semi-automated system of instrumentation designed for macro-scale, high-throughput operation. Attendees were able to review the analytical methods and analytical results of a field demonstration that focused on the impact of harvest timing on switchgrass and big bluestem grass feedstock quality. The data indicated, as seen in Figure 8, that the spring harvested switchgrass has improved feedstock quality attributes over the fall harvested switchgrass; the increase in %nitrogen and %sulfur in the switchgrass is likely a result from incomplete senescence of the plant. These increases are not only is problematic due to the nutrient removal from the soil, but it also negatively impacts on the biochemical and thermochemical conversion processes. Fall harvested big bluestem has favorable quality attributes over the spring harvested big bluestem grass; the decrease in %moisture of the fall harvested thru natural senescence favorably impacts biochemical conversions processes and increases the HHV and %carbon per unit volume. Low moisture content provides opportunities for more efficient transportation and storage options.

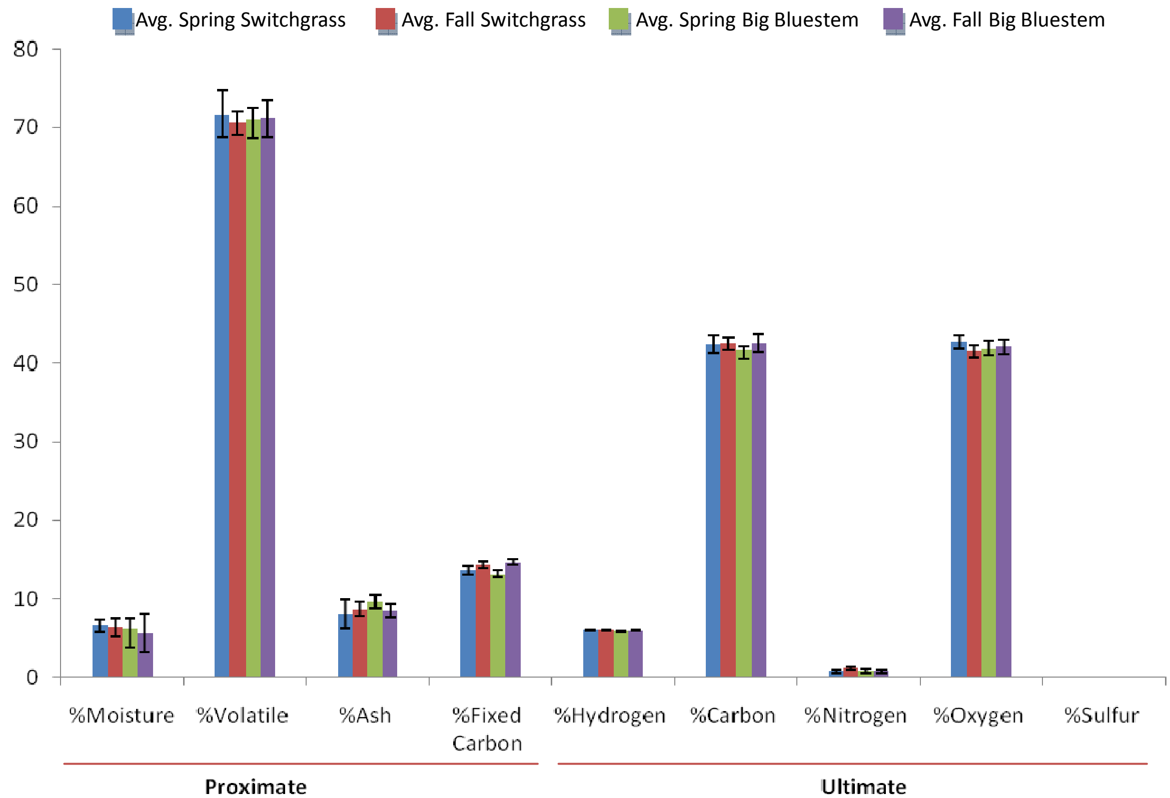


Figure 8. Proximate and Ultimate Analysis results for the 2 grasses from fall and spring harvests. The error bars show the standard deviation of the 4 year harvests. Sulfur content was only 0.07-0.1% in all samples (not visible on the current scale).

Compositional analysis is a wet-chemical analysis method used to determine the chemical constituents of a biomass sample that sum to 100% by weight. Compositional characterization includes sequential water and ethanol extractions using a Dionex automated solvent extraction system; acid hydrolysis of polymeric carbohydrates into soluble monosaccharides followed by filtration; ultraviolet-visible spectroscopy to determine acid-soluble lignin concentration and high performance liquid chromatography (HPLC) to determine carbohydrate and organic acid concentrations. As seen in Figure 9, attendees are able to review posters that show that the *Miscanthus* sample may produce greater ethanol yields than the switchgrass sample, due its higher carbohydrate content; however, *Miscanthus* also has a higher lignin content

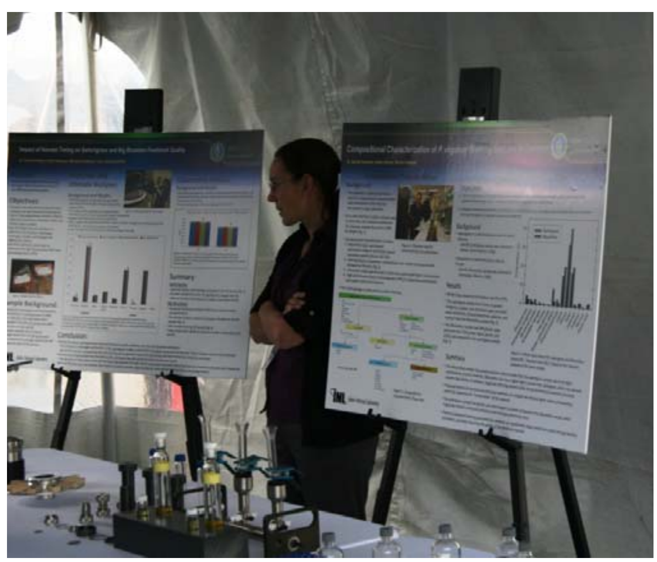


Figure 9. Attendees of the Densification Workshop are able to review the compositional analysis process and gain a better understanding of the compositional differences of feedstock materials.

than switchgrass, which may decrease enzyme digestibility of cellulose negatively affecting ethanol yields during biochemical conversion processes. Additionally, the switchgrass sample has greater ash and inorganic contents compared to the *Miscanthus* sample, which negatively impacts conversion processes and increases processing costs.

The wet-chemical compositional analysis process is the gold –standard for composition; however, this methodology is costly and very labor intensive. Alternative cost-effective, rapid-screening techniques are being developed in conjunction with NREL and other collaborators that will allow for the characterization and analysis of feedstock materials; providing results in a matter of minutes instead of days. One method combines multivariate analysis with near-infrared spectroscopy (NIRS) for the determination of chemical composition in feedstock materials. Laser-induced breakdown spectroscopy (LIBS) has been identified as an alternative technique that could allow for rapid elemental analyses of the inorganic content of biomass feedstocks, which would complement the chemical composition data provided by NIRS. As much as one-fifth of herbaceous biomass is composed of inorganic constituents, commonly known as ash. These inorganic components are not converted to energy and create a number of downstream problems in conversion processes, specifically thermochemical processes. The inorganic elements Si, K, Ca, Na, S, P, Cl, Mg, Fe and Al are particularly problematic and are known to influence reaction pathways, contribute to fouling and corrosion, poison catalysts, and impact waste streams. LIBS is a technique that is similar, in principle, to atomic emission spectroscopy. With LIBS, a sufficiently high-energy pulsed laser is focused on to the sample producing a high-temperature (25,000 K) plasma that vaporizes the sample and reduces it to its excited, elemental constituents. As seen in Figure 10, each element has a unique plasma spectra (wavelength) determined by the electronic transitions of its atoms & ions, allowing each element to be identified qualitatively and potentially determined quantitatively.

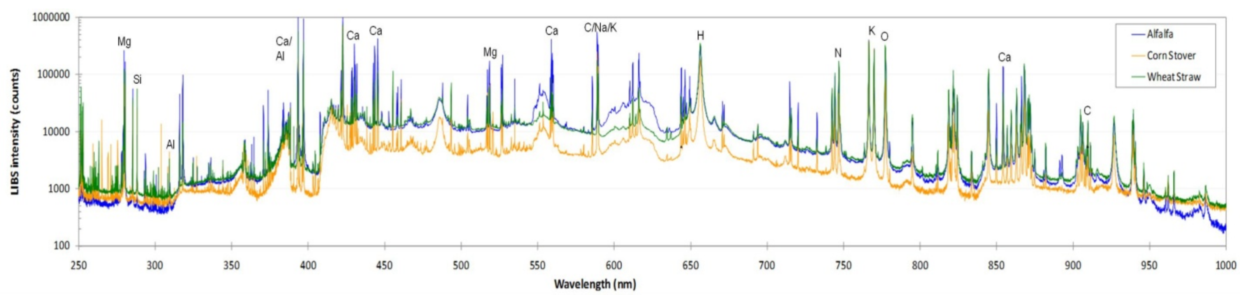


Figure 10. Spectra from poster “Rapid Screening of Feedstock Ash Composition using Laser Induced Breakdown Spectroscopy (LIBS)” demonstrating LIBS capabilities.

Additionally, alternative techniques were discussed to evaluate the recalcitrance of process intermediates. A commercial pH-hardened accelerated solvent extraction (ASE) system is being evaluated as a tool to test the relative reactivity of biomass feedstock to different pretreatment chemistries (i.e., low to high severity; or alkaline to acidic, etc.). This bench-scale technique provides an alternative to the labor-intensive pilot-scale techniques conventionally used.

Particle morphology can specifically impact flowability, feedstock recalcitrance, densification, feed rates, and reaction kinetics. Many different methods and types of instrumentation are used to evaluate particle morphology (particle size distribution, shape, and general characteristics of a particle). Some of these parameters, such as length and width, are basic, well-defined, and determined directly from multiple techniques. One of the most fundamental is conventional sieve analysis. INL has multiple sieve systems for the determination of particle-size distribution, from the small Ro-Tap system to the large-scale forage separator systems that are used to separate large particle materials into respective subsets. Additionally, the automated CAMSIZER instrument can simultaneously measure particle size distribution, particle shape, density, and other parameters of feedstock materials. The Camsizer is a digital image processing-based system capable of performing individual particle size and shape analysis of a wide range of particles (from 30 µm to 30 mm) with extreme accuracy using relatively small sample sets. The Camsizer data can be directly related to standard ASTM sieve sizes, as well as indicate particle shape factors that conventional sieving techniques do not provide. As seen in Figure 11, attendees are speaking with scientists about measuring particle size distribution and particle characteristics using the Camsizer and the advantages of the digital image processing system relative to the conventional sieve systems.

Researchers also provided information on how particles interact with their surroundings, be it gas, liquid, or other solids. Particle characteristics such as surface area, pore size, pore volume, density, and water sorption, impact rates of dissolution and other rate-related phenomena. State-of-the-art gas sorption analyzers for characterization of surface area, pore volume, and pore size distribution of microporous and mesoporous solids, using classical BET helium void volume method and commercial helium-free methods are utilized. To augment the gas sorption analyzer, an automated pore size and pore volume analyzers capable of water intrusion studies on hydrophobic materials are available as well. An automatic gas pycnometer for specific volume and true (skeletal) density measurement of porous solids and powders is also available for characterization of the particle properties of feedstock materials.

Figure 11. Attendees of the Densification Workshop speak with individual scientists about the influence particle characteristics on overall feedstock properties.

Appendix E

Feedstock Process Demonstration Unit (PDU)

On the second day of the Densification Workshop, a demonstration of the full scale Process Demonstration Unit (PDU) was performed. The system is a research tool used to convert loose or baled biomass materials into a ground, dried, and/or pelletized product that meets the specifications of a particular user. For the demonstration, four materials (corn stover, switchgrass, pine, and eucalyptus) were combined in a 1-1-1-1 ratio into a pelletized product. The same formula was demonstrated using lab scale equipment on the previous day. Results from those tests helped to identify initial operating conditions for the larger system. The scale of the PDU (nominally 5 tons/hour) allows larger volumes to be produced in a reasonable time and provides processing data and information about scale up issues from the laboratory and bench scale systems. This particular formulation was developed by a customer who determined that mixture provided optimum results in their conversion process. Figure 1 shows the attendees while the system was operating.

Figure 1. Attendees of the Densification Workshop viewing the PDU while it was operating.

Equipment in the PDU consists primarily of off-the-shelf items with three unique features: it is portable, modular, and designed for research and development purposes. Each major component is either mounted on a skid, is installed or will fit inside a cargo container, or can be disassembled to fit on a standard truck trailer. All mechanical, electrical, and control connections are designed for easy disconnection and subsequent transport.

The PDU is also organized into four modules: grinding, drying, milling, and densifying. Distribution of electrical, instrumentation, and controls for each module are housed in a cargo container (except the dryer which is self contained) that can be moved with the module equipment. The containers are also configured such that various combinations of conveyors or support equipment can be included in the module. Any combination of modules can be operated individually or in combination as needed. Or alternative equipment can be substituted into any module to evaluate new technologies or designs. A control trailer is available that houses the data collection and storage system. Portions of the PDU can be operated from the trailer or at the operating controls at each module.

Other features were added to the system to increase the research and development capabilities. For example, all equipment (including the conveyors) are sealed to minimize material losses, both from a material balance viewpoint, to reduce dust for an environmental control, and for a desire for the product to include all fractions of the feedstock. There are multiple conveyors throughout the system of varying types and sizes, and most are adjustable and mounted on wheels. This increases the flexibility allows for wide range of configurations depending on the requirements of a particular experiment. Most also have sampling ports and flexible joint connections so they can be reconfigured for use in any module and to accommodate a variety of system configurations.

To demonstrate how the PDU can be used to achieve a desired formulation, it was operated for a short time during the Workshop to produce a densified product that meets one customer's specification. Equal parts of corn stover, switchgrass, pine, and eucalyptus were moved to the PDU from a staging location (Figure 3). Alternating bales of corn stover and switchgrass were placed on the in-feed belt to the larger electric grinder (capacity of 15 tons/hour) with a 1 inch screen (Figure 4). Simultaneously, alternating loads of eucalyptus and pine were placed onto the in-feed of a smaller diesel powered grinder with a ¾ inch screen (Figure 4). Weights and moisture content of the feed materials were taken prior to being fed into the PDU. A pneumatic transfer system was also attached to the smaller grinder during the wood material size reduction. This is a unique INL component (with skid mounted blower and bag house) that increases air flow through the grinder increasing capacity and efficiency by about two.

Figure 3. Material staging area showing various bales of herbaceous and stacks/piles of wood feedstock.

Figure 4. Grinder with one bale of corn stover and one bale of switch grass loaded on the in-feed conveyor (left). Eucalyptus chips are placed on the grinder in-feed conveyor (left).

A good quality pellet requires the feed material to be about 12% moisture. The wood materials however, were about 40-50% moisture. Therefore, the eucalyptus and pine were conveyed into a dryer after being ground to reduce the moisture to an optimal value. The dryer is a three pass rotary drum design with a propane or natural gas burner. Drying is controlled by adjusting the outlet temperature, drum speed, and air flow (Figure 5). Some separation of material by density and size is accomplished during the drying process of shorter run times; the lighter materials pass through first with the heavier particles exiting at the end of the run. It is mounted on three skids that separate and can be loaded onto three trucks for transport to another location.

Figure 5. The control screen near the dryer burner (left). Dried wood material is returned to the conveyor that moves the ground herbaceous materials (right).

Once the wood material is ground and dried, it is returned to the conveyor that moves the ground herbaceous material away from the larger grinder. Some initial mixing of the four materials takes place as it is conveyed up to the hammer mill inlet for fine grinding (a 3/16 inch screen was installed). The fine material is collected in a plenum chamber below the hammer mill (Figure 6) where a conveyor in the bottom moves the material out and to the metering bin. A blower and bag house are mounted on top of the plenum chamber to collect the finer material. A pulse of air every 5 seconds in the bag house returns the fines to the chamber to minimize losses and maximize the amount of material in the final densified product.

Figure 6. Hammer mill mounted on top of the plenum chamber (left). View showing the inlet conveyor, hammermill, blower (dark gray), and bag house (white) mounted on a platform above the plenum chamber (right).

The metering bin is an active bin with a moving floor, doffers at the end, and an auger on the top (Figure 7). This keeps the material moving and prevents bridging. Once a sufficient amount of each material is conveyed into the bin (about ¾ full), the conveyors can be reconfigured to cycle the material out the bottom and back in the top, resulting in a well mixed formulation. When mixing is complete (verified by analysis), the conveyors are reconfigured again so the mixture can be fed into the pellet mill.

Figure 7. Metering bin showing material inlet on top (left) and inside showing top augers.

Prior to entering the pellet mill, the mixture is combined with steam to raise the temperature and produce better quality pellets more efficiently. This is done in a conditioning conveyor mounted above the pellet mill and outside the cargo container. The pellet mill is housed in a cargo container and the associated steam generator is mounted in an adjacent cargo container (Figure 8). The sides come off and two containers are connected for a larger, continuous space for the pelletizing system. Fresh pellets are still hot from the extrusion process and are very fragile while in this condition, thus they are gently conveyed to a pellet cooler prior to being loaded into super sacks or a truck.

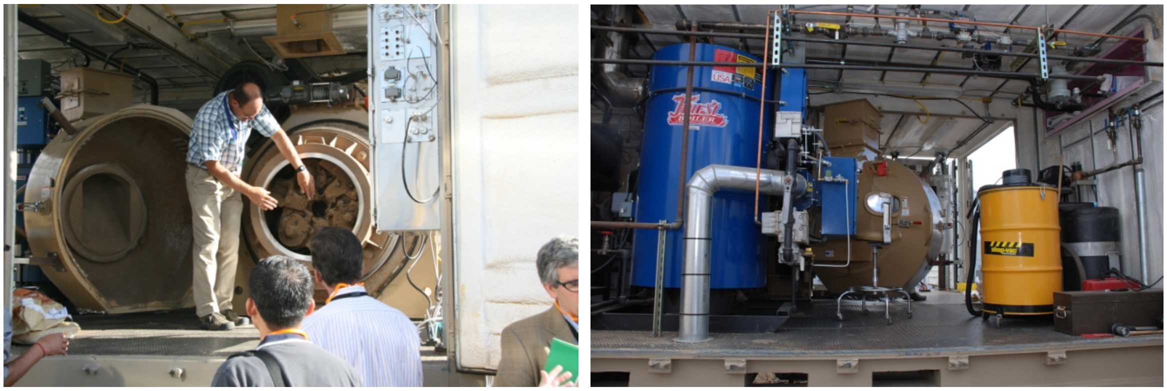


Figure 8. Pellet mill door was opened to show the extrusion process (left). Steam generator is located in an adjacent, connecting cargo container (right).

Material samples can be taken after every process step and can be correlated to data collected on the equipment to help determine the how operating conditions affect product quality. Sample size can be from a small bag to a 55 gallon drum or even a super sack if desired (Figure 9). The samples are labeled with a bar code that relates back to the source feedstock and forward to all analyses that will be performed through the feedstock library and database.

Figure 9. Herbaceous material samples are removed from a conveyor after the initial grinder, then split in a riffle splitter prior to bagging for analyses (left). Other samples of the mixed material are removed from a conveyor just prior to entering the pellet mill (right).

Instrumentation is available with each PDU component that can be expanded to include nearly any sensor that may be required. Currently, data are collected on motor amperage, power, temperature, moisture, and atmospheric conditions. More details on the instrumentation, controls, library, analyses, and database were available at a booth near the PDU during the demonstration (Figure 10).

Figure 10. Covered area highlighting the biomass library, material analysis capabilities, process control, data collection and storage.

After demonstrating the operation of the PDU for about 30 minutes, the system was stopped, put into a safe condition, the barriers were removed, and the Workshop attendees were allowed to move around the equipment and visit with the researchers. Additional booths were available with more detailed information on PDU components, information about deployment opportunities and mechanisms, and harvesting, transportation and storage research (Figure 8). Samples of the material at each stage of the process were also available for close inspection and handling. Small bags were provided for those who wanted to take a sample with them.

Figure 8. Booths with information about deployment (top left) and harvesting, transportation, and storage (top right) were distributed around the area. Buckets were available with samples from each stage of the process for close up inspection (bottom).