U.S. Department of Energy (DOE)
Bioenergy Technologies Office (BETO)
2017 Project Peer Review

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

# Next Generation Logistics Systems for Delivering Optimal Biomass Feedstocks to Biorefining Industries in the Southeastern US

Wednesday, March 8, 2017
Feedstock Supply & Logistics

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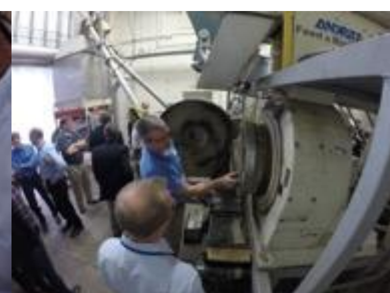
The University of Tennessee

# Goal Statement

The project goal is to develop a state-of-the-art biomass merchandizing and processing system to identify and reduce sources of variation along the supply chain of multiple, high-impact biomass sources, and to develop practices that **manage biomass variability** to deliver a consistent feedstock optimized for performance in specific technology platforms.





# QUAD CHART OVERVIEW

## Timeline

- Start date – 2/1/2016
- End date – 1/31/2019
- Percent Complete – 33%

## Barriers

- FT-A Feedstock availability & cost
- FT-E Feedstock Quality & Monitoring
- FT-G Biomass Material Properties & Variability
- FT-I Biomass Material Handling & Transportation
- Tt-C Relationship between Feedstock Composition & Conversion Process

| | FY 16 Costs | FY 17 Costs | Total Planned Funding (FY 17-Project End Date) |
|---|---|---|---|
| DOE Funded | $294,866 | $80,627 | $3,624,507 |
| Project Cost Share | $73,139 | $191,186 | $2,362,425 |

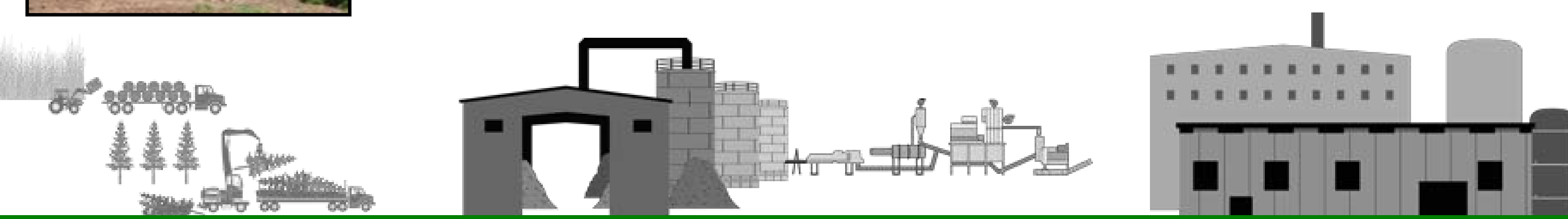
## Partners

- University of Tennessee
- Auburn University
- Genera Energy, Inc.
- Herty Adv. Mat. Dev. Center (GA Southern)
- Idaho National Laboratory (0%)
- John Deere
- North Carolina State University
- Oak Ridge National Laboratory
- PerkinElmer, Inc.

# Project Overview




- New Project with DOE BETO regarding improved logistics (Logistics for Enhanced-Attribute Feedstock - LEAF)
  - Builds on advances in two previous High Tonnage projects:
    - Auburn developed harvest and transport systems to clearcut small-diameter, southern pine dedicated bioenergy plantations (10 to 15 years old)
    - Genera developed advanced harvest and processing systems for switchgrass
- Current opportunities:
  - Advanced merchandizing systems to maximize quality and reduce cost from southern pine biomass residue found in approximately 40 million acres of traditionally managed pine plantations (15 to 30 years old)
  - A more extensive forest product mix will add value to woody biomass and reward landowners across the U.S.
  - Dependence on single sources of biomass significantly constrains the scale of conversion facilities.
  - Information is needed to effectively utilize the inherent variability of biomass characteristics to optimize process behavior.



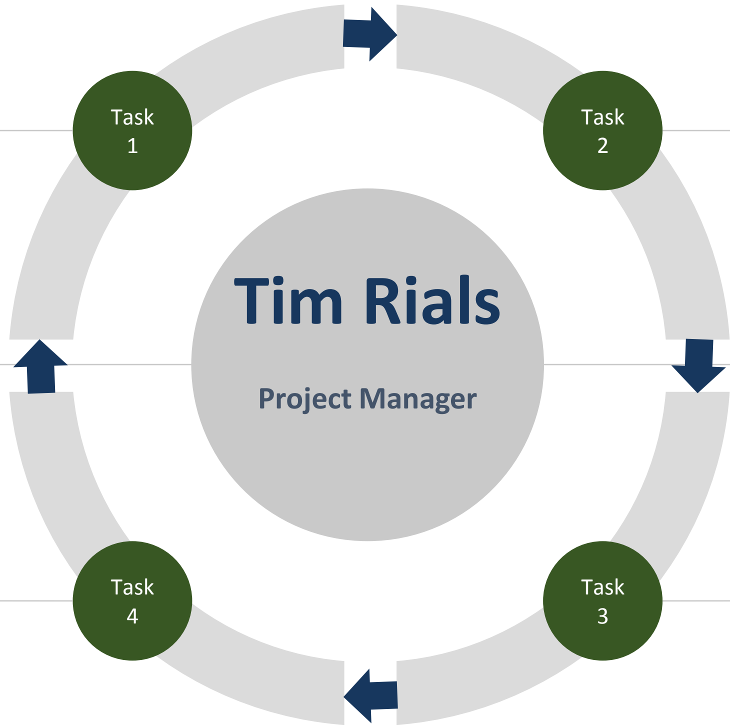
# Management Approach

**Steve Taylor, AU**

Tim McDonald
Tom Gallagher
Burt English

**Niki Labbé, UT**

Peter Muller
Sam Jackson
Sunkyu Park
Sushil Adhikari
Oladiran Fasina
Omar Ali
Tim Young




Burt English
Rich Venditti
Sam Jackson

**Steve Kelley, NCSU**

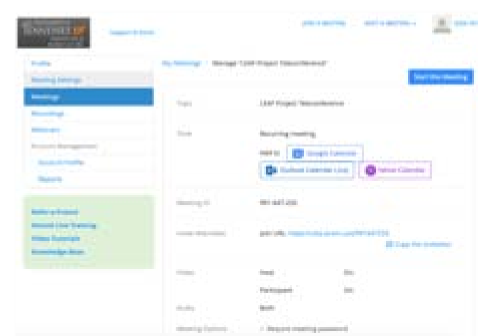
Sam Jackson
Oladiran Fasina
Steve Taylor
Omar Ali

**Jaya Shankar, INL**

Gantt Chart

Project Site


Monthly Calls



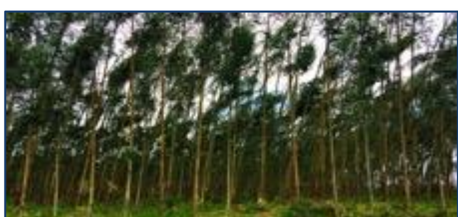
# TECHNICAL APPROACH

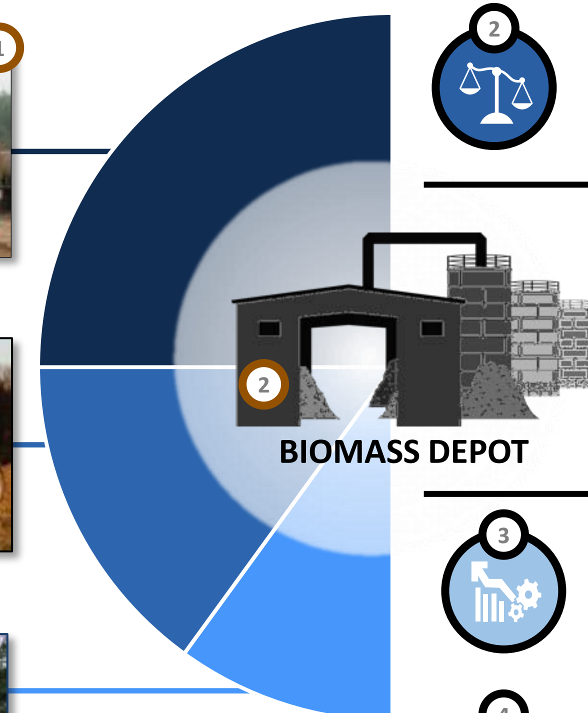
## DIVERSE BIOMASS SOURCES

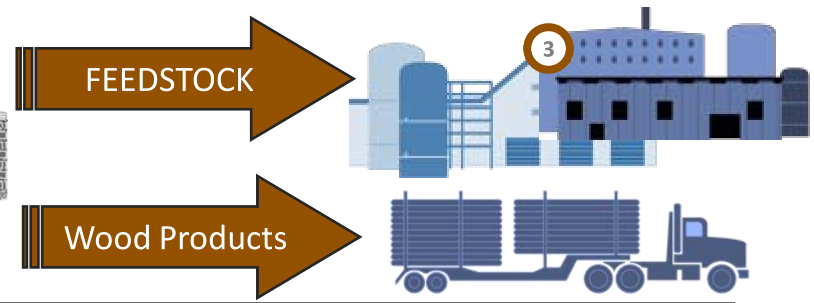
**Pine Residue**

**Herbaceous**

**Woody Crops**






**TASK 1: INTEGRATED MERCHANDISING**
Demonstrate an integrated harvest, transport, and merchandizing system for maximizing value, quantity, and quality of biomass from southern pine forests.

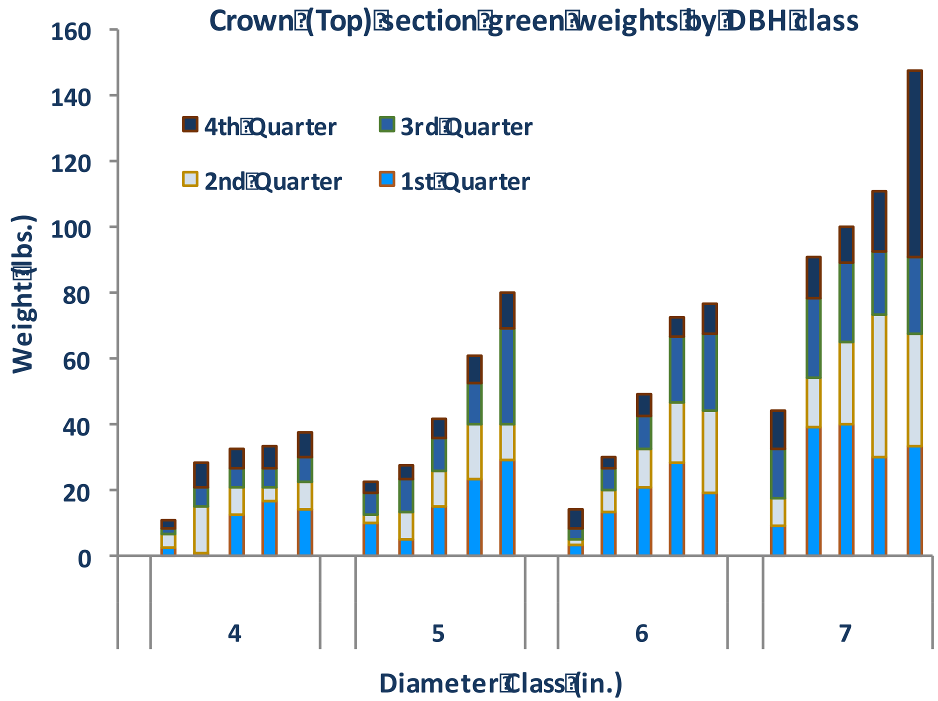
**TASK 2: FORMULATING CONSISTENT QUALITY**
Introduce statistical process control methods that utilize biomass quality metrics obtained from novel, rugged spectroscopic sensor data to reduce feedstock cost, and improve quality.

**TASK 3: ENGINEERED FEEDSTOCK**
Explore the potential to formulate feedstock blends from diverse biomass inputs for improved processing performance at lower costs.

**TASK 4: SYSTEM EVALUATION**
Quantify the spatially specific economic and life-cycle gains afforded by the new system incorporating advanced methods and instrumentation to improve feedstock quality and consistency relative to the current supply system.

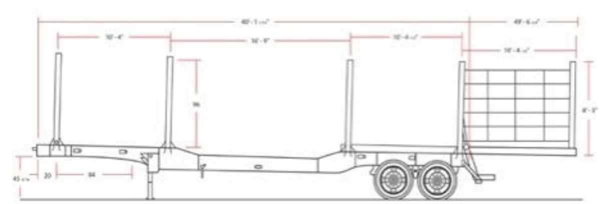
# Technical Accomplishments: Task 1

- Building merchandizing model from biomass residue sampling data (mass and composition)
- Completed the design, fabrication and initial testing of full tree log trailer
  - Payloads (with residue) can be increased by ~20%, which will reduce transport costs
  - With proposed changes in DOT regulations, an additional axle will allow the heavier trailers to meet GVW limits
- Developed simulation models to predict and partition costs of integrated round wood and biomass delivered to a depot




| | Partitioned Pulpwood Harvest & Transport Cost | Partitioned Biomass Harvest, Chipping, & Transport Cost | Net cash flow for the logger |
|---|---|---|---|
| 25-year-old stand, 50 acre harvest, 5.5 in. diameter merchantable top, 50-mile haul distance | $9.10 / green ton | $29.84 / green ton | $7,650 |

Machine rate costs - do not include landowner payments (stumpage), profit, overhead, road building costs



# Technical Accomplishments: Task 2

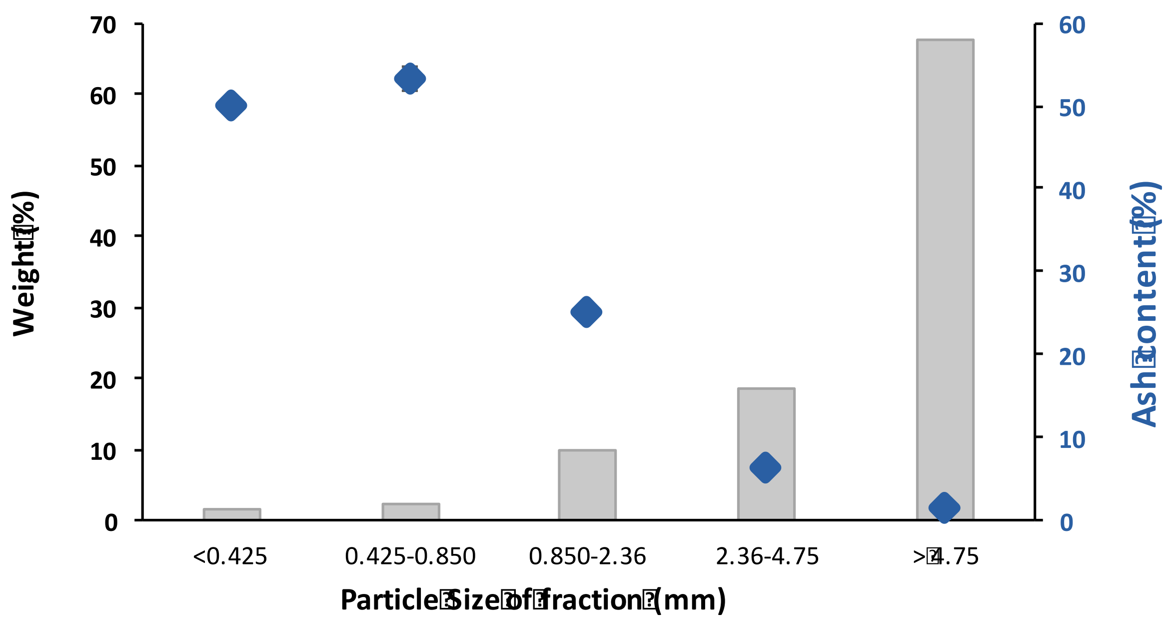
| NIR Models | | Moisture | Ash | Carbon |
|---|---|---|---|---|
| Range | | 8.6 – 42.1 | 0.4 – 6.4 | 40.0 – 49.4 |
| N | | 60 | 223 | 70 |
| Factors | | 6 | 10 | 7 |
| Calibration | $R^2$ | 0.97 | 0.93 | 0.95 |
| | RMSE | 1.4 | 0.4 | 0.5 |
| X-Validation | $R^2$ | 0.96 | 0.92 | 0.94 |
| | RMSE | 1.4 | 0.4 | 0.6 |

## Rapid Assessment of Biomass

- Robust laboratory NIR models to predict moisture, ash, and carbon content are available for transfer to online sensor.

## Increase Biomass Quality

- Removal of low particle size fraction decreases ash content in biomass.
- Alkali and earth metals are detrimental during thermochemical conversion.

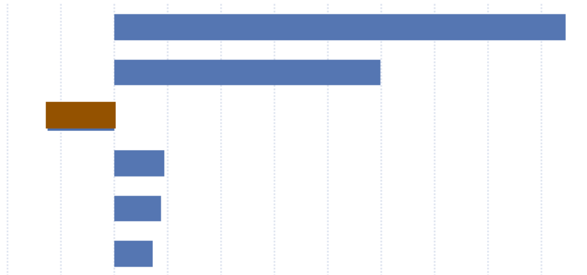


# Technical Accomplishments: Task 2

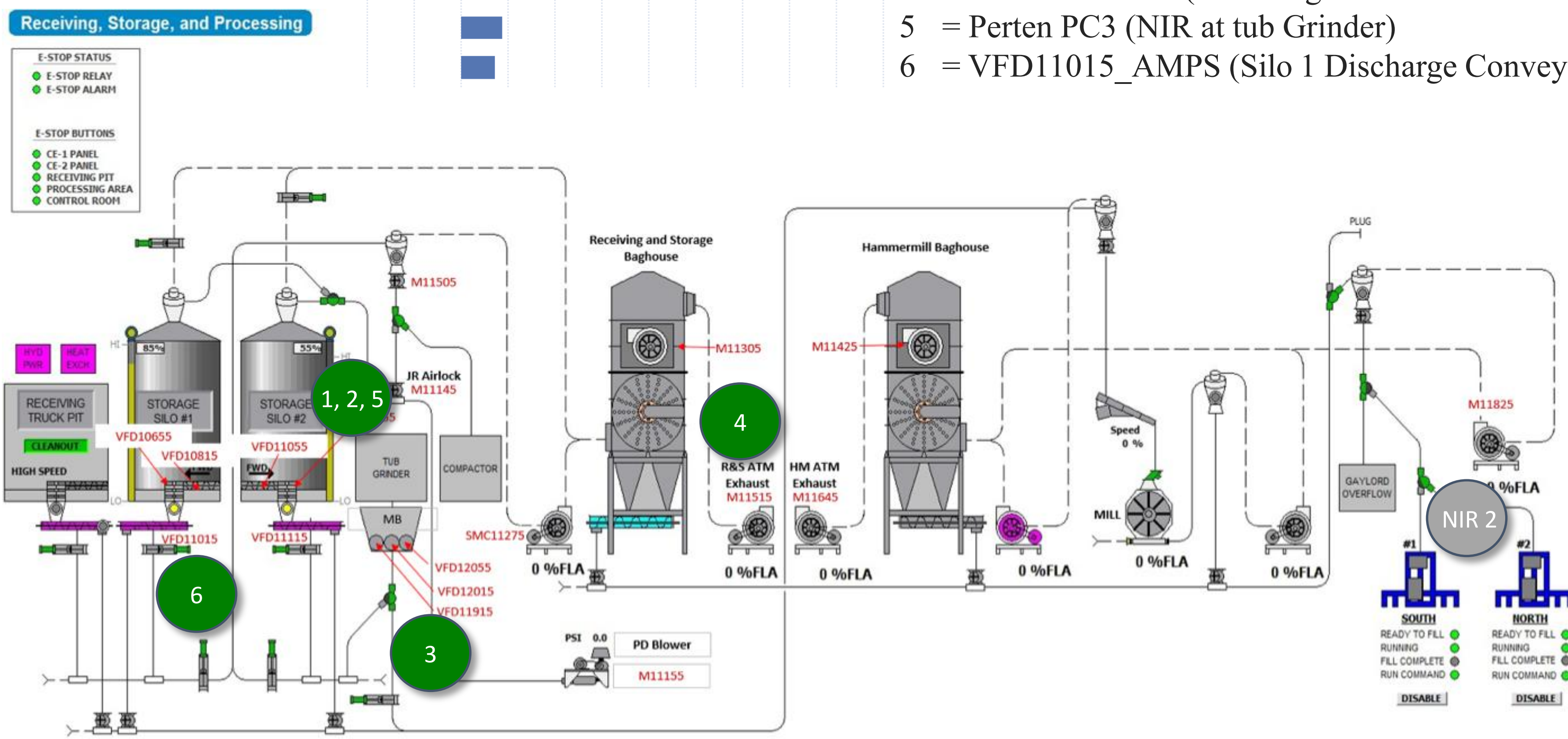
- Access to previous data and systems provided
- Completed test grind of just over 284 tons of switchgrass
  - Tested NIR collection
  - Collected periodic samples for chemical analysis to validate model
  - Determined mounting system for one NIR unit on large grinder
  - Conducted vibration testing on grinder to determine impact on NIR equipment

# Technical Accomplishments: Task 2

Plant Process/NIR sensor data (Switchgrass Moisture Content Model at GEI)

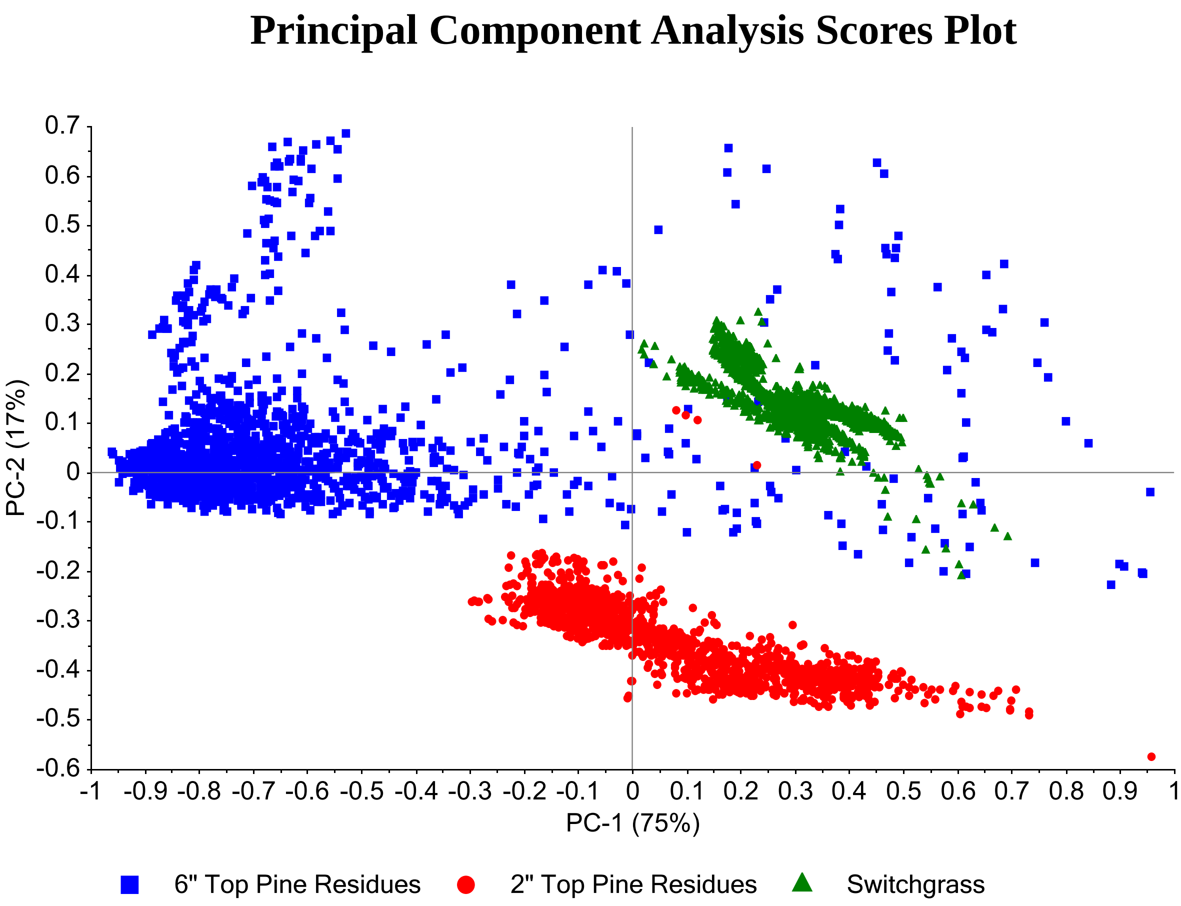


1 = Perten PC1 (NIR at tub Grinder)
2 = Perten PC2 (NIR at tub Grinder)
3 = VFD11915.Amps (Metering Bin Screw 1)
4 = M11515.AMPS (R&S Baghouse Exhaust Fan)
5 = Perten PC3 (NIR at tub Grinder)
6 = VFD11015_AMPS (Silo 1 Discharge Conveyor)



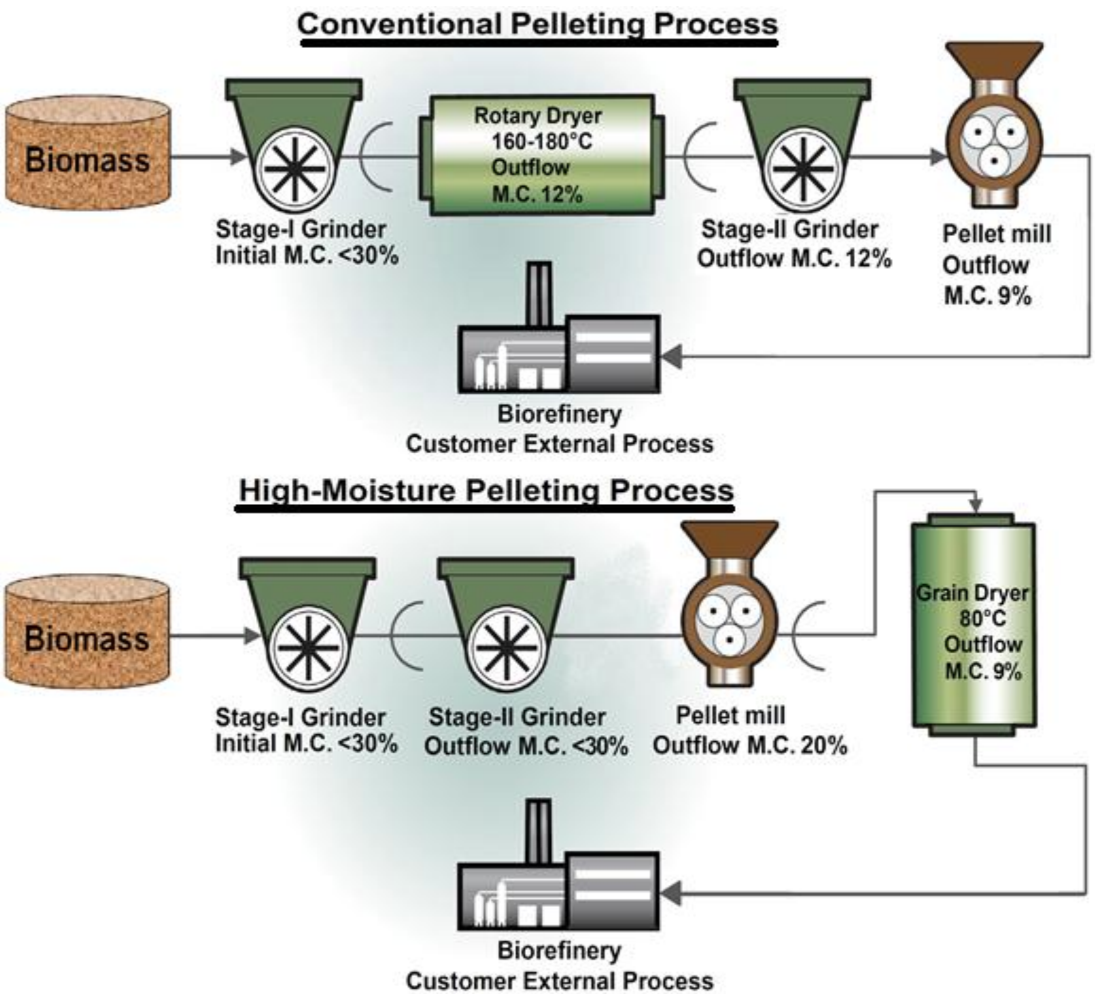
# TECHNICAL ACCOMPLISHMENTS: TASK 2

Plant Process/NIR sensor data (Herty Advanced Material Development Center)



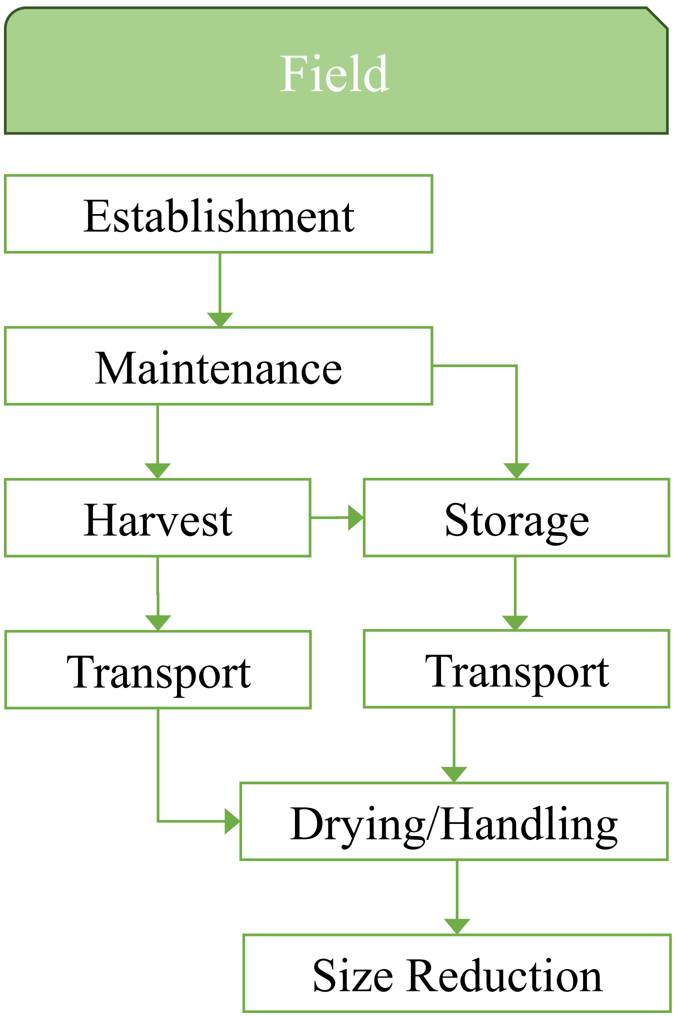

# Technical Accomplishments: Task 3

<u>High Moisture Pelleting Process Developed at INL</u>




- This work is scheduled to begin mid-2017.
- As indicated in previous slide, standard biomass materials are now being distributed to the team.
- This process will develop methods to pelletize pine and switchgrass blends at a high moisture content.
- Studies on techno-economic analysis have indicated that the cost of pelleting reduces by about 40% using this process.
- Another big advantage of high moisture pelleting is the frictional heat developed in the pellet die helps to drive some of the moisture out of the biomass (5-10%).

# TECHNICAL ACCOMPLISHMENTS: TASK 4




| Component | Single-Feedstock System | |
|---|---|---|
| Opportunity cost | $3.69 | 4.45% |
| Establishment | $6.58 | 7.93% |
| Maintenance | $8.33 | 10.04% |
| Harvest | $30.48 | 36.75% |
| Storage | $10.40 | 12.54% |
| Transportation | $9.07 | 10.94% |
| Drying + Handling | $11.61 | 14.00% |
| Size Reduction | $2.79 | 3.36% |
| Supply Chain Cost | $82.95/Mg | 100% |

# TECHNICAL ACCOMPLISHMENTS: TASK 4

| Run (#) | Carbon (%) | Ash (%) | Moisture (%) | Bio-oil (kg/hr) | Hydrocarbons (kg/hr) | $CO_2$ emissions (kg/hr) | Natural gas used for $H_2$ production (kg/hr) | Power generation from Extra heat (MW) |
|---|---|---|---|---|---|---|---|---|
| 1 | **44** | 3 | 35 | 14476.3 | 4761.35 | 10947.2 | 1608.48 | 4.534 |
| 2 | **46** | 3 | 35 | 13619.7 | 4479.60 | 13210.3 | 1513.30 | 4.910 |
| 3 | **48** | 3 | 35 | 12634.1 | 4155.44 | 15693.1 | 1403.79 | 5.151 |
| 4 | **50** | 3 | 35 | 11655.6 | 3833.61 | 18158.0 | 1295.07 | 5.389 |
| 5 | 47 | **1** | 35 | 14276.6 | 4695.68 | 11993.2 | 1586.29 | 3.851 |
| 6 | 47 | **3** | 35 | 13065.2 | 4297.24 | 14554.4 | 1451.69 | 4.961 |
| 7 | 47 | **5** | 35 | 11905.3 | 3915.74 | 17006.8 | 1322.81 | 6.025 |
| 8 | 47 | **7** | 35 | 10889.4 | 3581.61 | 17167.3 | 1209.93 | 6.794 |
| 9 | 47 | 3 | **15** | 13068.2 | 4297.24 | 11046.8 | 1452.02 | 11.462 |
| 10 | 47 | 3 | **25** | 13067.5 | 4297.24 | 13501.7 | 1451.94 | 6.916 |
| 11 | 47 | 3 | **35** | 13067.7 | 4297.24 | 14558.6 | 1451.97 | 4.960 |
| 12 | 47 | 3 | **45** | 13065.8 | 4297.24 | 15996.0 | 1451.76 | 2.294 |

- The updated results are shown in the table above. The energy savings from the drying process are reported as electricity credits.
- The results indicate that lower moisture in biomass feedstock results in more energy savings in the drying process and hence higher electricity credits. The results are easier to interpret and readily used in life cycle analysis.

# PROJECT RELEVANCE

**The strategic goal of Feedstock Supply and Logistics (FSL) is to develop technologies to provide a sustainable, secure, reliable, and affordable biomass feedstock supply for the U.S. bioenergy industry.**

- The team is developing a large-scale, integrated system for recovering an underutilized resource from the harvest of mature pine stands and developing switchgrass production areas in the Southeastern U.S.
- This feedstock system is introducing the ability, through blending of biomass sources to produce engineered bioenergy feedstocks, to:
    1. Reduce the overall cost of the feedstock by removing inefficiencies in the biomass distribution system (≤ $80/dry ton);
    2. Improve the quality of the biomass feedstock by sensing and SPC techniques during processing to reduce the variability in physical and chemical properties; and
    3. Improve the profitability of the biorefineries by demonstrating the use of various biomass sources to produce a least-cost feedstock.
- This least-cost feedstock concept will allow biorefineries to procure larger volumes of biomass, thereby allowing larger scale, and more economically feasible biorefineries to be constructed and operated.

# Future Work

- First field test of the log processing system is scheduled for March 2017.
- Evaluation of the prototype log trailer will continue through mid-2017; fabrication of a second log trailer will be evaluated.
- Simulation models for merchandizing decisions will be refined, and the resulting effects on product value and compositions will be determined.

- Distribute woody biomass and switchgrass to team members to initiate work on pelleting of blended feedstock.
- Conduct large-scale preprocessing campaign of switchgrass/woody biomass to advance SPC framework.
  - Transfer PLS model for biomass properties to online process sensor.
  - Continue chemical analysis of woody biomass to improve model robustness and verify online sensor performance.
- Evaluate feedstock conversion in small-scale pyrolysis reactors for continued process model improvement.
- LCA/TEA assessments scheduled to begin mid-2017.

# SUMMARY

- **<u>Cost</u>:** The envisioned harvest, transport and centralized biomass merchandizing and processing system should be capable of delivering biomass at, or below, cost targets achieved in the previous High Tonnage projects. Those total system costs were found to be about $64 per green ton of biomass.
- **<u>Quality</u>:** We intend to meet processor specifications through formulated blends enabled by online sensing equipment and statistical process control techniques. We also intend to decrease culls of deliveries to roundwood mills by over 50%.
- **<u>Quantity</u>:** The primary factor relating merchandizing system performance with its ability to deliver commercially viable quantities of low-cost, high-quality biomass feedstocks will be the utilization of relatively expensive equipment working at the depot.

# Thank you

UT AgResearch
Institute of Agriculture
The University of Tennessee

HERTY
Advanced Materials Development Center
Georgia Southern University

Oak Ridge
National Laboratory

Auburn
University

Genera Energy

Perten
Instruments
a PerkinElmer company

INL
Idaho National Laboratory

IndusTREE

PerkinElmer
For the Better

NC State University

John Deere

# ADDITIONAL SLIDES

# Responses to Previous Reviewers Comments

***Comment:*** Lots of moving parts to this project that could create issues in reaching objectives. Innovative and forward thinking but must be agile enough to adjust to potential unanticipated system hic-ups. Inclusion of an industrial wood products partner would assist in optimization.

- ***Response:*** The original plan for the project involved a centralized depot where processing occurred, including drying, size reduction, blending, and pelleting. In responding to the reduction in scope, the depot has become more distributed to achieve the goal. Although some efficiency is lost, the initial concept has remained intact and the capacity to demonstrate the value added is available. Without question, though, communication between team members will be that much more important in moving the project forward.
- ***Response:*** We agree that a wood products industry partner could contribute much to the program, and we will work to engage one, or several, of our collaborators. Also, the project team will carefully consider current industry practices in developing and demonstrating the biomass processing system.

***Comment:*** Management is solid. NIR to target needed specs is innovative but project lacks solid industrial partner. New merchandizing approach to whole tree harvest is innovative

- ***Response:*** It is exciting to see NIR spectroscopy moving beyond the laboratory. Our team brings more than 60 years of experience in the development and application of NIR to biomass-related issues, including wood and herbaceous materials. We see the involvement of Perkin-Elmer (an international analytical equipment company), with a long history in spectroscopy instruments as a unique strength of our team. Their commitment to this space is evident by their recent acquisition of Perten (global leader in NIR), which brings even greater versatility and options for the design and development of this important online/at-line sensor. Incorporating information on biomass properties for process control is an attractive approach to consistent production of high-quality feedstock. It is also essential in extending the prospect of efficient use through blended formulations to consistently meet biorefinery specifications. Further, Genera Energy's commitment to improving quality and consistency of their product is genuine, and will also help accelerate introduction into the industry.

# GO/NO-GO REVIEW HIGHLIGHT (SEPT. 2016)

***Comment:*** The reviewers offered thoughtful and constructive comments for for each of the Go/No-go decision criteria. Reviewers were unanimous in their opinion regarding the "Go" decision for criteria #1 through #7 (i.e., Tasks 1 and 2):

1. Completed design for prototype log trailer for transporting full trees
2. Completed economic analyses to document costs associated with re-purposing & multiple handling of wood residues for other mkts
3. Appropriate detection technology platform to provide high quality, accurate characterization of biomass feedstocks selected (the quality of the NIR sensor models (R2> 0.65))
4. Retrieved and integrated biorefinery existing data (air velocity, pressure, etc.) into statistical process control system
5. Completed initial process analysis, defining major sources of variation
6. Robust NIR models to predict biomass quality metrics from laboratory studies made available for process studies
7. Spectral sensor installed in merchandizing depot to monitor biomass

Their opinions were split between "Go" and "Not sure" from criteria 8 and 9. Below are the criteria that the reviewers regarded as the weakest segments of the review:

8. Switchgrass/pine blends prepared and characterized to meet target specifications, and to establish protocols to reduce variability.
9. Please comment on plans, as presented, for LCA. *[This is not a Go/No-go decision criterion.]*

For criterion 8 (Task 3), the main criticism was that reviewers were not able to understand what constitutes "success" for this criterion. Additionally, the goal was not very clearly defined. Nor was it clear how many blends would be explored during this work, or why. What are the desired target specifications for these blends? The strategy for creating blends that reduce variation in the physical and chemical characteristics of the feedstock entering a biorefinery was not convincingly presented. When adding the need for a dynamic capability for producing such blends in a biorefinery environment, this goal becomes even more unclear (though outside the scope of this project).

Criterion 9 (Task 4) was not used as a Go/No-go criterion, but some useful comments were provided by the reviewers: The project team appears very strong, the work is clearly important, and the preliminary work presented seems very encouraging. However, there were signs of inadequate communication and cooperation among all the partners, and the importance of this should be re-emphasized to the project leader in writing, even though it was communicated to him in the closing discussion. Another issue that was raised in the final discussion was a lack of distinction between what had been done in previous grant projects and what was being done in this new project. However, on additional review this is not as serious an issue as originally thought.

# GO/NO-GO REVIEW HIGHLIGHT (SEPT. 2016)

***Comment:*** The comments with regard to criterion 10 (*overall impressions of progress toward overall project goals and objectives, as you understand them*) were also not used for the Go/No-go decision. However, there were issues around communication among the project participants. It seemed clear that at least some of the project participants were not very well connected to the rest of the project activities, even within the same task.

In response, we've been working to improve this issue by:

- Introducing an additional monthly web discussion,
- Additional "specific issue" teleconferences, and
- Face to face conversations were scheduled to more tightly integrate the team.

# Publications, Patents, Presentations, Awards & Commercialization

Refereed Proceedings and Papers:

- Pan, P; McDonald, T; Fulton, J; Via, B; Hung, J. 2017. Simultaneous moisture content and mass flow measurements in wood chip flows using coupled dielectric and impact sensors. Sensors. doi:10.3390/s17010020.

Non-refereed Proceedings and Papers:

- Lancaster, J., T. Gallagher, T. McDonald, and D. Mitchell. 2016. Whole tree transportation system for timber processing depots. In Proceedings of Council on Forest Engineering annual meeting. Council on Forest Engineering. Morgantown, WV.
- Lancaster, J., T. Gallagher, T. McDonald, and D. Mitchell. 2016. Whole tree transportation system for timber processing depots. Short rotation woody crop conference. Ft. Pierce, FL.

Presentations at Professional Meetings:

- Lancaster, J., T. Gallagher, T. McDonald, and D. Mitchell. 2016. Whole tree transportation system for timber processing depots. Council on Forest Engineering Annual Meeting, Vancouver, British Columbia, Quebec, Canada. September 19-22, 2016.
- André, N., W. Edmunds, S. Jackson, N. Labbé, T. Young, and T. Rials. 2016. Reducing the Cost of Consistent, High-Quality Feedstock from Biomass. American Institute of Chemical Engineers Annual Meeting, San Francisco, CA; November 14-17.
- Thomas Loxley, master's student in biosystems engineering, presents his research at Auburn University's Three Minute Thesis competition.

Thesis:

- Maximillian Platzer. 2016. M.S. Thesis. A simulation model of the “bio-depot” concept in the context of components of variance and the “Taguchi Loss Function. The University of Tennessee, Knoxville, TN. 132p.