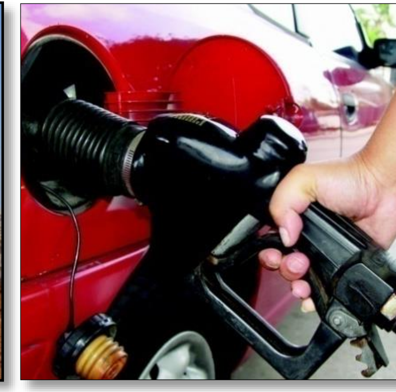






DOE Bioenergy Technologies Office (BETO) 2015 Project Peer Review

High Tonnage Forest Biomass Production Systems from Southern Pine Energy Plantations

Date: 03.25.2015
Technology Area Review: Terrestrial Feedstocks

Principal Investigator: Steve Taylor
Organization: Auburn University

AUBURN UNIVERSITY
Center for Bioenergy and Bioproducts

Project Goals

- Design and deploy machines and systems that can reduce delivered cost of woody biomass.
  - Design and fabricate a harvesting, pre-processing and transportation system for southern pine biomass; and
  - Demonstrate and document performance of the system at full industrial scale to show possible reductions in feedstock cost.

AUBURN UNIVERSITY
Center for Bioenergy and Bioproducts

Quad Chart Overview

Timeline

- Project start: 10.01.2010
- Project end: 06.30.2014
- 100% complete

Budget

	Total Costs FY10 –FY12	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15-Project End Date
DOE Funded	$ 4.129 m	$ 0.784 m	$85k	$0
Project Cost Share (Comp.)*	$ 4.129 m	$ 0.869 m	$0	$0

Barriers

- Barriers addressed
  - Ft-D Sustainable Harvesting
  - Ft-L Material Handling and Transportation
  - Ft-M Integration and Scale-Up

Partners

- Auburn University, USDA Forest Service, Corley Land Services, Tigercat
- Project management by Auburn University

1 – Project Overview

- Program goal was to demonstrate feedstock delivery system that could be used to produce 100 million dt/yr of selected feedstock
  - Target feedstock: southern pine energy plantations
  - Proposed final harvest at age 10 – 15 yrs
  - 15 million acres of southern pine plantations could produce 100 million dt/yr (at growth rates of 7 dt/acre-yr)
  - Using a 10 year rotation, harvesting 1.5 million acres each year will yield 105 million dt/yr
- Objectives:
  - Develop design improvements in tree-length harvesting machines for southern pine energy plantations;
  - Demonstrate and document performance of the system at full industrial scale to show possible reductions in feedstock cost.
- System overview:
  - Track feller buncher with high speed shear felling head
  - High capacity wheeled grapple skidder
  - Track loader and disk chipper
  - Chip vans for transport

AUBURN UNIVERSITY
Center for Bioenergy and Bioproducts

2 – Approach (Technical)

Phase I - R&D

- Design new machines and systems
- Develop benchmarks for existing system productivity, cost, feedstock quality

Stage Gate Review

Phase 2 - Commercial-Scale Test and Demonstration

- Test new machines
- Test transpirational drying to determine if field drying can reduce transportation costs
- Test extended shifts to determine if double shifting can be an effective method of improving economic feasibility
- Develop and demonstrate information systems for monitoring machine productivity and biomass quality
- Quantify industry and landowner acceptance of biomass production and harvest systems

2 – Approach (Management)

Auburn University

- Project management
- Assisted with conceptual design of felling and skidding machines
- Machine and system productivity and cost characterization and modeling
- Sensor development
- Biomass quality measurement
- Project reporting

Corley Land Services

- Field test and demonstration of new machines

USDA Forest Service

- Field productivity measurement
- Cost and productivity analysis
- Quantify remaining residue on harvest sites

Tigercat

- Design and fabrication of new feller buncher and skidder

Additional vendors

- Precision Husky fabricated disk chipper
- Peerless fabricated chip vans

Woody Biomass Logistics Systems

Traditional Longwood System

Felling → Skidding → Delimbing → Loading → Transport → Log Storage and Handling → Debarking → Size Reduction (Chipping) → Drying → Conversion

In-woods Chipping System

Felling → Skidding → Delimbing Debarking → In-woods Chipping → Transport → Chip Storage and Handling → Size Reduction → Drying → Conversion

High Tonnage System Studied

Chip-at-Stump Systems

Chip-at-Stump → In-woods Chip Transport → Loading → Transport → Chip Storage → Size Reduction → Drying → Conversion

Harvest System

New Tigercat 845D track-type feller buncher

- High-speed shear felling head designed for 6 in. DBH (max 18 in.)
- Initial target productivity of ~70 gt/PMH
- Tier 4i emissions system
- Energy recovery swing system
- ER Boom for easy operation and energy efficiency
- Lower site impacts due to low ground pressure and swing-to-tree operation

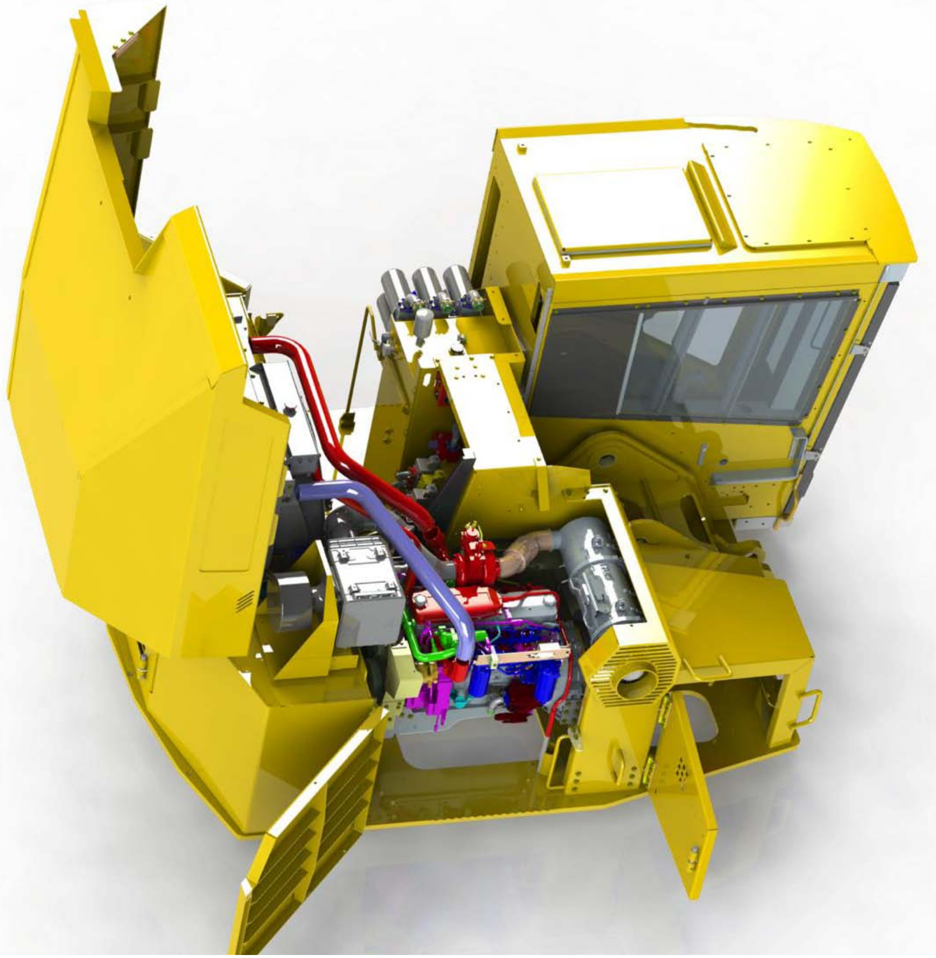
Tigercat 630D wheeled skidder

- Industry's largest grapple (25 ft^2) for skidding small-diameter trees
- Initial target productivity of ~80 gt/PMH
- Ergonomic/productivity improvements

AUBURN UNIVERSITY
Center for Bioenergy and Bioproducts

PMH = Productive Machine Hour

AUBURN
UNIVERSITY
Center for Bioenergy
and Bioproducts




845D

AUBURN
UNIVERSITY
Center for Bioenergy
and Bioproducts


Tigercat
630D

Field Drying

"Transpirational drying"

- After felling, bunches of full trees remain at site for 6 to 10 weeks to reduce moisture content to near 30%
- Reduces transport costs
- Reduces conversion costs

AUBURN UNIVERSITY

CENTER FOR BIOENERGY AND BIOPRODUCTS

Processing and Transport

In-woods chipping with Precision WTC2675 whole tree disk chipper

- 4 or 8 knives
- Pulp chips or micro chips
- Clean chips or whole tree chips
- Debarking for clean chips

Truck transport

- High capacity chip trailers
- Volume increases up to 20%
- Designed for field dried wood

2 - Technical Accomplishments/ Progress/Results

- Industrial scale tests of the high tonnage harvest and transport system show higher productivity, and lower delivered cost for biomass.

- Transpirational drying tests show wood moisture content can be reduced to ~35%, allowing for reduced transport and conversion costs.

- Tests of extended shifts showed no change in feller buncher productivity when working at night, which provides opportunity to further reduce feedstock costs by increasing machine utilization rates.

- Information systems measure productivity and provide useful feedback to machine operators (e.g. sensors to quantify mass flow and moisture content of chips produced).

- Focus groups show that landowners and loggers are willing to accept short rotation systems if market demand exists.

AUBURN UNIVERSITY
Center for Bioenergy and Bioproducts

Felling and skidding cost and productivity

"Conventional" system

Timberking 340 (wheeled machine w/saw)

Caterpillar 525 (2 skidders)

- 80 green tons/PMH
- $3.72 per green ton

845D Tigercat

630D Tigercat

- 114 green tons/PMH
- $2.31 per green ton
- Lower site impacts

- Side-by-side tests of machines in the same timber stand
- PMH = productive machine hours
- Data for 6 in. mean dbh loblolly pine
- Costs are based on "machine rate" calculations – average cost of ownership; does not include profit, overhead, after-tax effects

AUBURN UNIVERSITY
Center for Bioenergy and Bioproducts

Chipping cost and productivity

Precision Husky 2675
4/8 knife disk chipper

Chip Size	Knives	Productivity	Fuel Consumption	Cost
Conventional (pulp)	4	79.5 gt/PMH	0.24 gal/gt	$3.08 / gt
Microchip	8	70.7 gt/PMH	0.28 gal/gt	$3.82 / gt

- PMH = productive machine hours
- Microchips have been tested by biopower producers and pellet producers
- Costs are based on “machine rate” calculations – average cost of ownership; does not include profit, overhead, after-tax effects

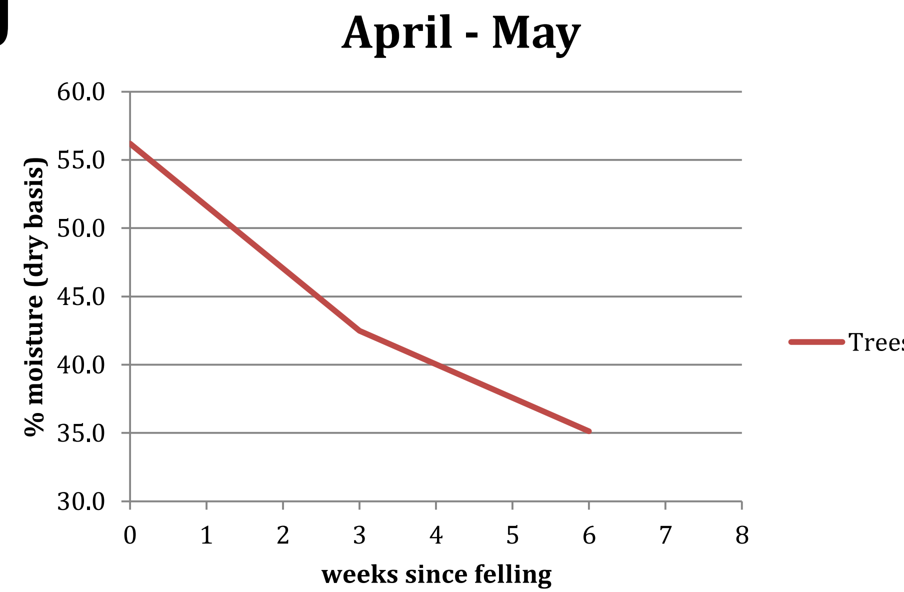
AUBURN UNIVERSITY
Center for Bioenergy and Bioproducts

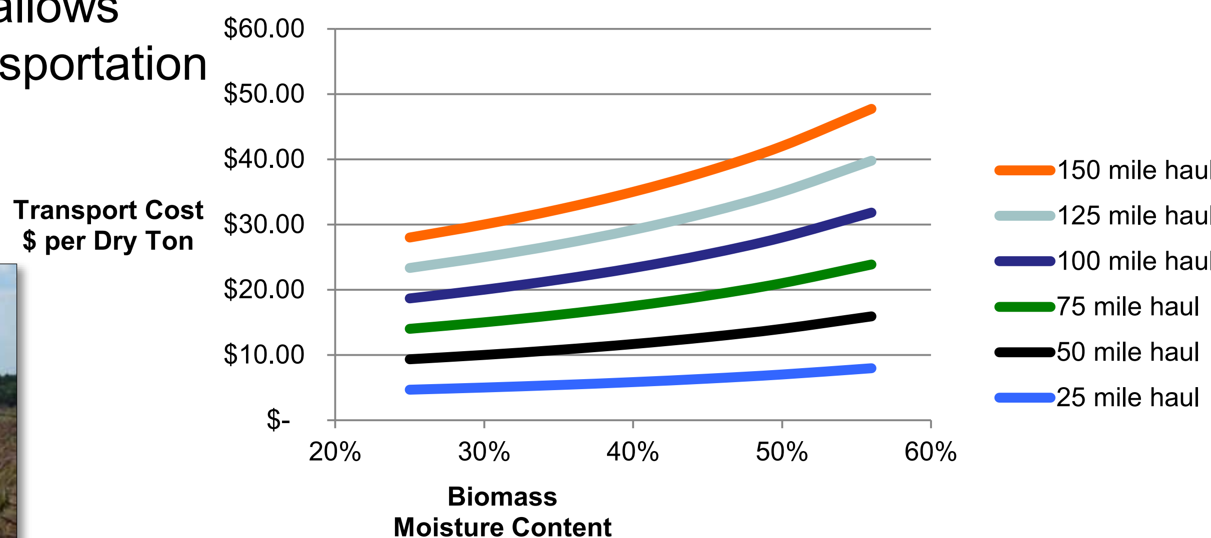
Field drying

Transpirational drying of bunches showed reductions in moisture content from 56% to as low as 25% in summer tests.

Winter drying tests, in piles, achieved moisture contents as low as 32% (with pile average of 40%).

Reducing moisture content allows significant reductions in transportation costs.





3 - Relevance

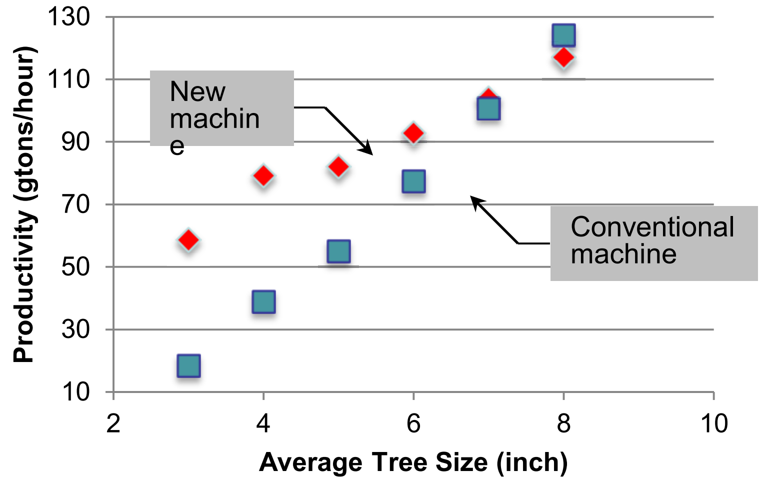
- New machines have demonstrated:
  - Cost and productivity of new systems are relatively insensitive to tree size
  - Cost effective harvesting systems can be developed for smaller diameter trees

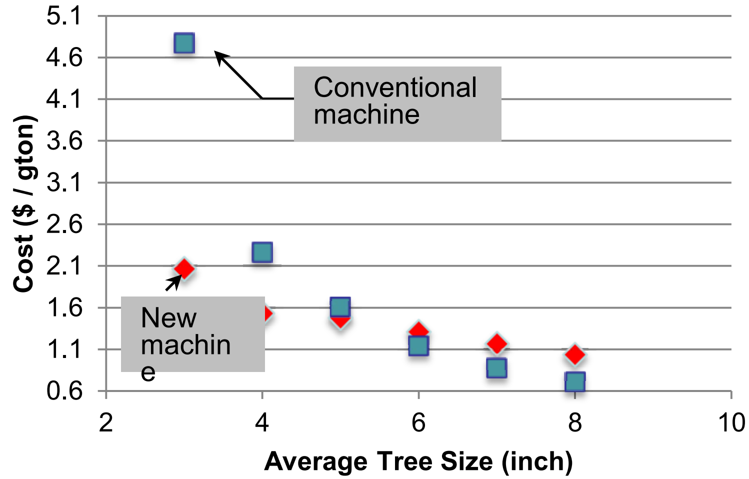
- Transpirational drying demonstrates:
  - Significant reductions in transport costs
  - Effective increases in procurement radius for a given biorefinery
  - Possible savings in drying costs at the biorefinery

4 - Critical Success Factors

- Productivity and cost of new felling machine relatively insensitive to tree size

- Short rotation, smaller diameter trees can be harvested without significant increases in cost.





New machin e

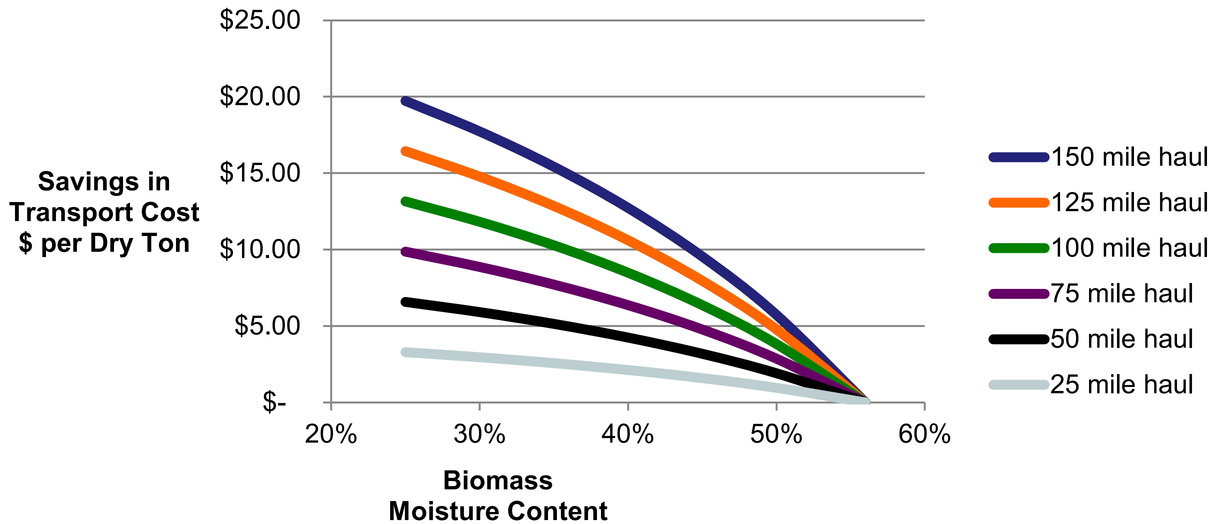
Conventional machine

AUBURN UNIVERSITY

Center for Bioenergy and Bioproducts

4 - Critical Success Factors

- Reducing moisture content can result in significant savings in transportation costs or increases in feasible transport distances



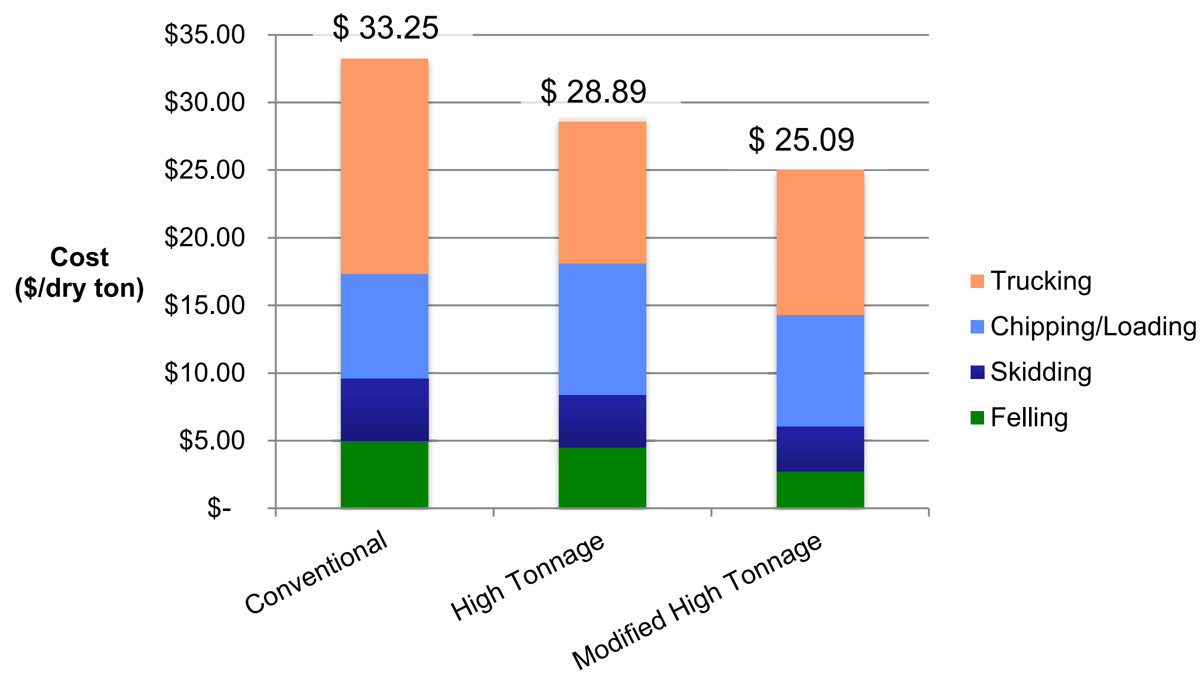
AUBURN UNIVERSITY
Center for Bioenergy and Bioproducts

4 - Critical Success Factors

- System balance is critical to achieving cost targets
  - Feller buncher and skidder are very high productivity machines (~ 115 gt/hr)
  - Chipper had lower productivity (~80 gt/hr) and therefore limited the system productivity
  - An alternative system was proposed where the feller buncher worked longer hours per week and was shared by two other skidding/chipping crews to achieve a “balanced” system with lowest delivered cost

4 - Critical Success Factors

Harvest, process, and transport costs for various scenarios



- Machine rate costs for felling, skidding, chipping and loading are based on average cost of ownership; data do not include profit, overhead, after-tax effects.
- High Tonnage and Modified High Tonnage incorporate transpirational drying.
- Transport costs based on 50-mile one-way transport distance, $0.14/ton-mile.
- Costs do not include landowner payment.

AUBURN UNIVERSITY
Center for Bioenergy and Bioproducts

4 - Critical Success Factors

- Feller buncher and skidder are commercially available
  - *Tigercat 845D track feller buncher, Tier 4, is now available with sawhead (shear available as market develops)*
    - *$425,000 MSRP*
  - *Tigercat 630D, Tier 4, is now available with high capacity grapple available as special order*
    - *$320,000 MSRP*


845D/L845D FELLER BUNCHER

Tigercat

The 845D series feller bunchers are quick, agile and well suited to plantations, natural stands and small diameter/high cycle applications. The 845D also has the power and stability to handle larger timber. The L845D is equipped with a super-duty FH400 leveling undercarriage for high performance and stability on slopes.

BENEFITS AND ADVANTAGES:

Powerful, efficient Tigercat FPT Tier 4f engine
- Extremely quiet and fuel efficient
- Simple, reliable SCR emission control technology

Efficient high-capacity cooling system
- Automatic variable fan speed for improved fuel efficiency
- Automatic reversing cycle to clean the heat exchangers
- Rear cooling air intake is well away from saw discharge

ER boom technology unique to Tigercat
- Increases productivity, performance and fuel efficiency
- Smooth planar boom motion reduces operator fatigue
- ER control switch provides a boost for extra stick force
- Structural parts are well proven in high cycle applications

Quiet, climate controlled operator's station
- Full length front window for a clear view of the tracks
- High output heater/air conditioner with multiple vents
- Extreme duty air-ride suspension seat
- Generous storage space behind the seat

Tigercat-built forest duty undercarriages
- F8 non-leveling or FH400 leveling
- Long track frames for excellent stability on slopes

Super-duty leveling system
- Large pins, roller bearings eliminate wear in pivot joints
- Frames are built with thick steel sections to minimize flex
- Field-proven in over 1,000,000 hours of operation

Highly durable design and construction
- Solid steel one-piece turntable and smooth, impact resistant engine enclosure

Excellent service and component access
- Clamshell style retracting roof for excellent access to the engine, major components and service points
- The pumps and filters are housed in a separate, easily accessed compartment
- Large clean-outs underneath

635D

TIGERCAT 630D SKIDDER

AUBURN UNIVERSITY

Center for Bioenergy and Bioproducts

5 - Future Work

- If we target biomass from traditional forest harvests (first or second pine plantation thinnings), how can we reduce costs of biomass products?
  - Current harvests leave most residue (limbs, tops)
  - Residue is generally poor quality with high ash content, high processing and transport costs
  - Is it possible to minimize harvest costs and transport full tree to centralized processing and merchandizing facility to improve biomass quality and reduce cost / add value?

AUBURN
UNIVERSITY
Center for Bioenergy
and Bioproducts

Summary

New machines and systems can reduce delivered cost of southern pine biomass:

1) Higher productivity = Lower cost
2) Productivity and cost of new felling machine relatively insensitive to tree size
3) Short rotation, smaller diameter trees can be harvested without significant increases in cost
    a) When system is balanced, felling and skidding costs are reduced by ~$2.80/dt or more
4) Transpirational drying can reduce moisture content significantly
    a) Summer drying reached 25%
    b) Winter drying reached 40%
5) Transpirational drying can reduce transportation and conversion costs significantly
    a) savings of ~$5/dry ton for 50 mile haul
    b) procurement radius can effectively be increased
6) Overall machine rate cost reductions (in felling, skidding, chipping, trucking) from high tonnage system can be as much as 24% of the conventional system cost

AUBURN UNIVERSITY
CENTER FOR BIOENERGY AND BIOPRODUCTS

Publications, Presentations, and Commercialization

Theses and Dissertations

- Pan, Pengmin. 2014. Monitoring Moisture Content and Mass Flow of Wood Chips Using Electrical Capacitance Tomography. Ph.D. dissertation, Biosystems Engineering, Auburn University, Auburn, AL.
- Oginni, O. 2014. Contribution of Particle Size and Moisture Content to Flowability of Fractionated Ground Loblolly Pine. MS Thesis, Biosystems Engineering, Auburn University, Auburn, AL.
- Dhiman, J. 2014. Prediction of Heating and Ignition Properties of Biomass Dusts Using Near Infrared Spectroscopy. MS Thesis, Biosystems Engineering, Auburn University, Auburn, AL.
- Hehar, G. 2013. Physicochemical and Ignition Properties of Dust from Loblolly Pine Wood. MS Thesis, Biosystems Engineering, Auburn University, Auburn, AL.
- Jernigan, P. 2012. High tonnage harvesting and skidding for loblolly pine energy plantations. M.S. Thesis, Forestry and Wildlife Sciences, Auburn University, Auburn, AL.

Journal Articles and Proceedings Papers

- Jernigan, P., T. Gallagher, D. Mitchell, L. Teeter. 2011. High Tonnage Forest Biomass Production Systems From Southern Pine Energy Plantations. In: Proceedings of the 34th annual meeting of the Council on Forest Engineering. COFE, Morgantown, WV.
- Klepac, J., B. Rummer and J. Thompson. 2011. Harvesting Small Trees for Bio-Energy. In: Proceedings of the 34th annual meeting of the Council on Forest Engineering. COFE, Morgantown, WV.
- Mitchell, D. 2011. Air Quality on Biomass Harvesting Operations. In Proceedings of 34th International Meeting of the Council on Forest Engineering. Council on Forest Engineering, Morgantown, WV.
- McDonald, T., J. Fulton; P. Pan. 2012. Mapping machine productivity and tree size of a feller-buncher harvesting biomass in pine plantations. In Proceedings of 35th International Meeting of the Council on Forest Engineering. Council on Forest Engineering, Morgantown, WV.
- Mitchell, D. 2012. Ups and Downs Associated with Implementing Shift Schedules on a Southern Harvesting Operation. In Engineering New Solutions for Energy Supply and Demand. In Proceedings of 35th International Meeting of the Council on Forest Engineering Annual Meeting. Council on Forest Engineering. Morgantown, WV.

Publications, Presentations, and Commercialization

<u>Journal Articles and Proceedings Papers</u>

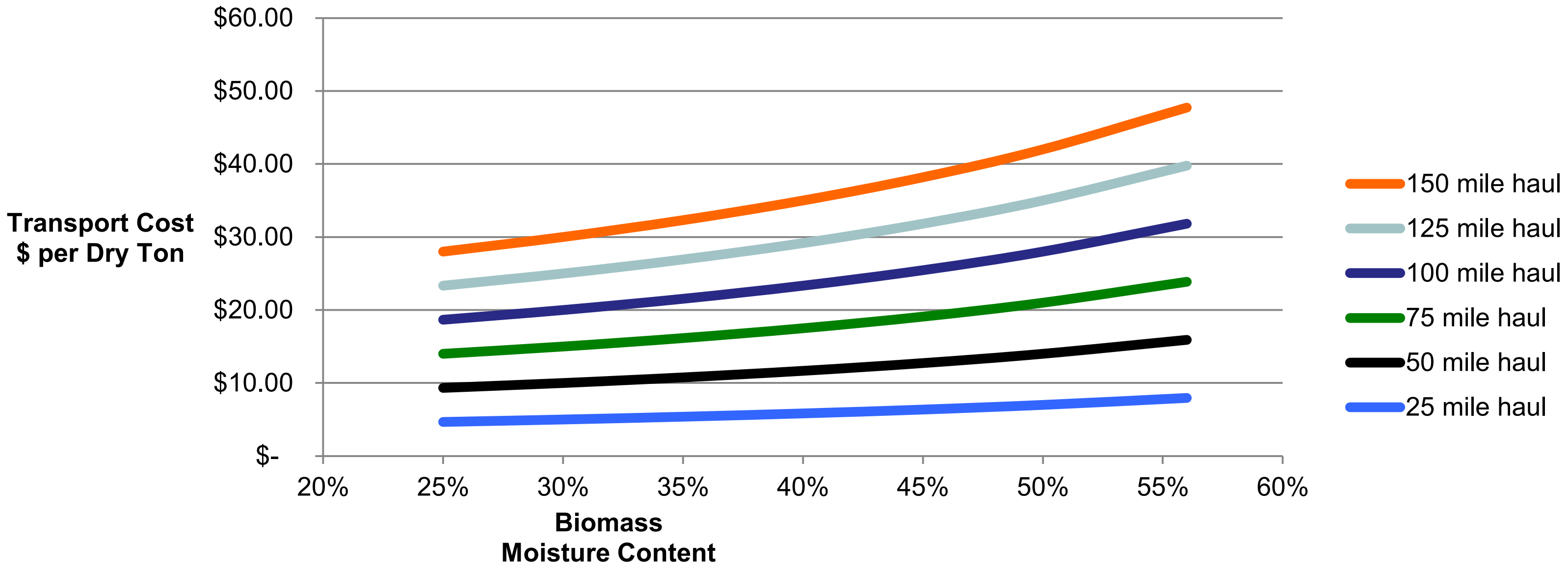
- Pan, P., T. McDonald, S. Taylor, J. Fulton. 2012. Real-time monitoring mass-flow of wood chips based on force sensor. In Proceedings of 35th International Meeting of the Council on Forest Engineering. Council on Forest Engineering, Morgantown, WV.
- Klepac, J. 2013. Performance of a tracked feller-buncher with a shear head operating in small-diameter pine. In: Proceedings of the 36th annual meeting of the Council on Forest Engineering. July 7-10, 2013. Missoula, Montana: University of Montana. 9p.
- Thompson, J., and W. Sprinkle. 2013. Production, Cost and Chip Characteristics of In-Woods Microchipping. In Proceedings of 36th International Meeting of the Council on Forest Engineering. COFE, Morgantown, WV.
- Maza, C, F. Seixas, T. McDonald. 2013. Comparação entre métedos de estudo de tempo: uma aplicação a operacao de arraste florestal com uso de “Skidder”. Submitted to: Revista Scientia Forestalis.
- McDonald, T, F. Corley, N. Hindman. 2013. Performance of a prototype eLoad Sheet for monitoring timber hauling operations. In Proceedings of 36th International Meeting of the Council on Forest Engineering. Council on Forest Engineering, Morgantown, WV
- Wadkins, J.; A. Shrestha, O. Fasina, S. Adhikari, and S. Taylor. 2013. Frictional properties of ground loblolly pine chips. Auburn University Journal of Undergraduate Research (AUJUS), 2: 26-31.
- Klepac, J., D. Mitchell and J. Thompson. 2014. The effect of pile size on the moisture content of loblolly pine while field drying. In: Proceedings of the 37th annual meeting of the Council on Forest Engineering. June 15-18, 2014. COFE. Morgantown, WV.
- McDonald, T., J. Fulton, T. Gallagher, M. Smidt. 2014. Correlation between tree size and disc saw speed during felling using a wheel-mounted feller-buncher. In Proceedings of 37th International Meeting of the Council on Forest Engineering. Council on Forest Engineering, Morgantown, WV.
- Hehar*, G., O. Fasina, S. Adhikari, and J. Fulton. 2014. Heating and volatilization behavior of dusts from loblolly pine wood. Fuel Processing Technology 127: 117-123.
- Jernigan, P., T. Gallagher, M. Smidt, L. Teeter and D. Mitchell. 2015. High tonnage harvesting and skidding for Loblolly Pine energy plantations. Forest Products Journal. (accepted for publication).
- Owen, K., O. Fasina, S. Taylor, S. Adhikari. 2015. Thermal decomposition behavior of loblolly pine stemwood, bark and limbs/foliage using TGA and DSC techniques. Trans. ASABE. Accepted.

AUBURN UNIVERSITY

CENTER FOR BIOENERGY AND BIOPRODUCTS

Field drying and transportation costs

% Moisture	Net Tons per Load	Dry Tons per Load	Cost per Dry Ton
56%	28.5	12.5	$15.91
50%	28.5	14.3	$14.00
45%	28.5	15.7	$12.73
40%	28.5	17.1	$11.67
35%	28.5	18.5	$10.78
30%	28.5	20.0	$10.00



AUBURN UNIVERSITY
Center for Bioenergy and Bioproducts