Catchlight Energy Update with the U.S. Department of Energy

Washington, D.C. July 12, 2012

Catchlight Energy™

A Chevron | Weyerhaeuser Joint Venture

Craig Brown
Maro Imirzian
Paul Spindler
Eric Sucre

Catchlight Energy Participants

Paul Spindler – Vice President, Technology

Maro Imirzian – Vice President, Finance

Craig Brown – Manager, Thermochemical

Eric Sucre – Sustainability Scientist, Weyerhaeuser

Andrea Howell – Federal Affairs Manager, Weyerhaeuser

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Agenda

- **Introductions and expectations (Paul)**
- **Share Catchlight Energy's unique focus**
  - Business overview and industry challenges (Maro)
  - Focusing on our commercialization strengths
    - Wrap-arounds, feedstock sourcing & product integration (Paul)
    - Sustainability science (Eric)
    - Conversion technology
      - Solvent Liquefaction (Craig)
      - Sugars platform (Paul)
- **Summary**
- **Q&A**

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Who is Catchlight Energy (CLE)?

- 50/50 Chevron and Weyerhaeuser joint venture
- Our Mission is to commercialize the large scale production of liquid transportation fuels from sustainable forest based resources
- We commercialize the supply chain elements needed to produce 2nd generation biofuels
- We leverage synergies between CLE, Weyerhaeuser, Chevron, and 3rd parties

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Commercializing Forest to Fuels

End-to-End Value Chain Solution Leverages the Strengths of Two Natural Resource Leaders

Feedstocks at Scale

Conversion Technology

Fuel Integration

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When CLE was formed…

- Outlook for biofuels was robust
- Chevron faced a rapidly growing obligation under RFS2
- Weyerhaeuser seeking opportunities to expand biomass business
- Based on this, the Catchlight Energy JV
  - Expected to quickly Build-Own-Operate
  - Established research platforms for forest feedstock scalability and environmental sustainability
  - Developed product integration strategies
  - Embarked on ambitious technology developments

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Industry Challenges

- **Uncertainty in biofuel and RIN market**
- **Feedstocks at scale**
  - Growth and logistics
- **Cost competitive technology**
  - Commercialization in early stage; Gen 2.0 and beyond
- **Tight capital**
  - Overall economic conditions; capital intensive new technology
- **Product integration**
  - Compatibility with present infrastructure

Our Commercialization Strengths

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- Large scale sustainable feedstock from certified timberlands.
- Well-established fuel testing, blending, distribution, refining, and marketing system
- Sustainability science leadership
- Wood and hydrocarbon conversion and handling knowhow
- More than 200 years of energy and forestry industry expertise and resources
- End-to-end solution with just one partner
- Financial wherewithal and improved financing solutions

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CLE has adapted

Focusing on our core strengths:

- Commercialize feedstock supply and product off-take components of the supply chain. Establishing “wrap-around” partnerships
- Continue forest feedstock scalability and sustainability R&D
- Continue to evaluate investment opportunities and 3rd party conversion technology
- Progress internal conversion technology development where:
  - Technology is transformational & based on core expertise
  - Industry and government collaborations can help reduce risk and accelerate commercialization

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“Wrap-around” Partnerships

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Feedstock supply

- Forest sustainability certification
- Conversion plant siting; assured biomass supply at scale
- Biomass pre-processing
- Woodyard design and operation; inventory control

Product off-take / integration

- Consulting on storage and offtake facilities
- Assured offtake and logistics support
- Fuel testing, specification & registration
- Product stewardship

KiOR “Wrap” is our first

FCU, Columbus, MS

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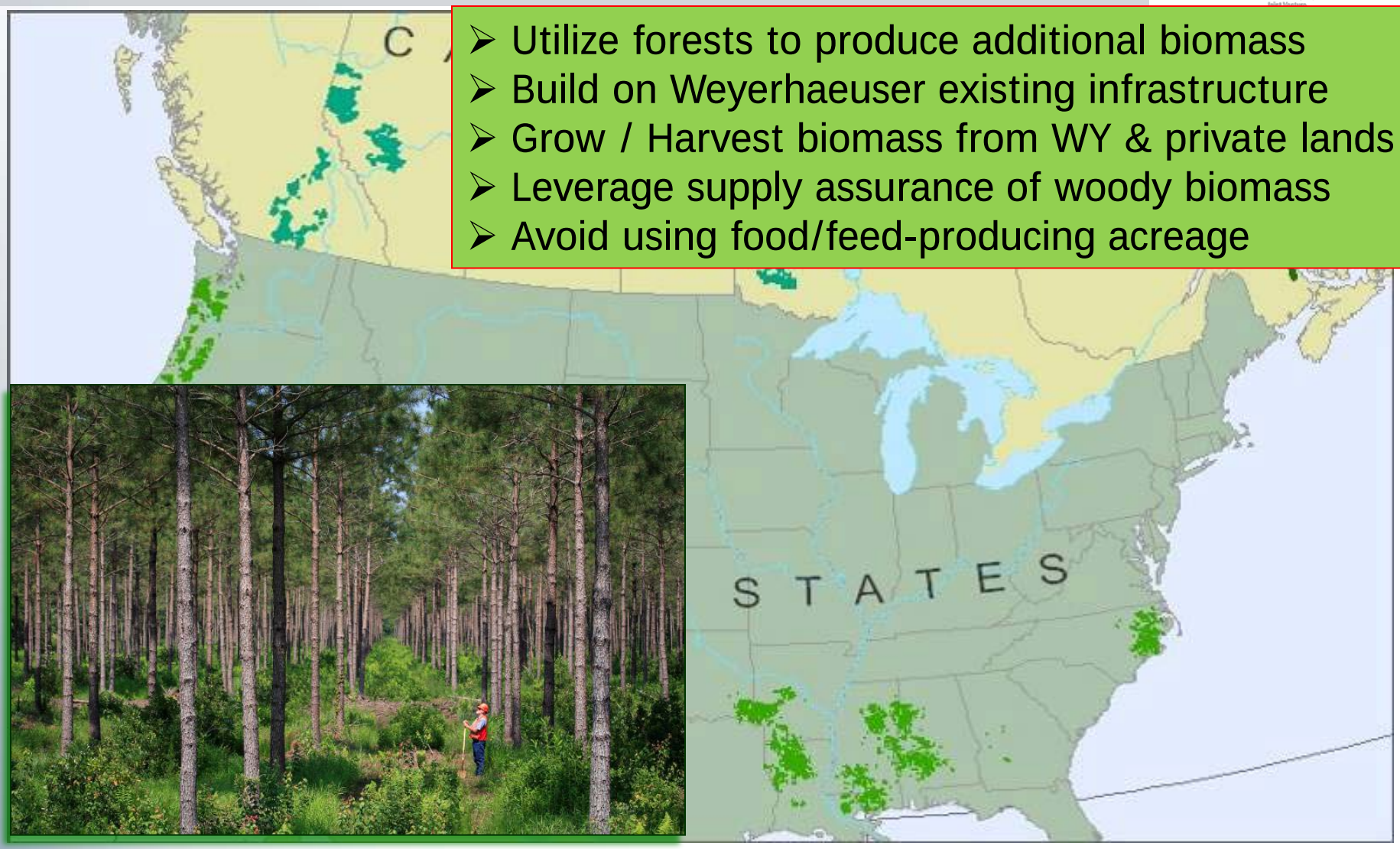
CLE Feedstocks Strategy

- Utilize forests to produce additional biomass
- Build on Weyerhaeuser existing infrastructure
- Grow / Harvest biomass from WY & private lands
- Leverage supply assurance of woody biomass
- Avoid using food/feed-producing acreage



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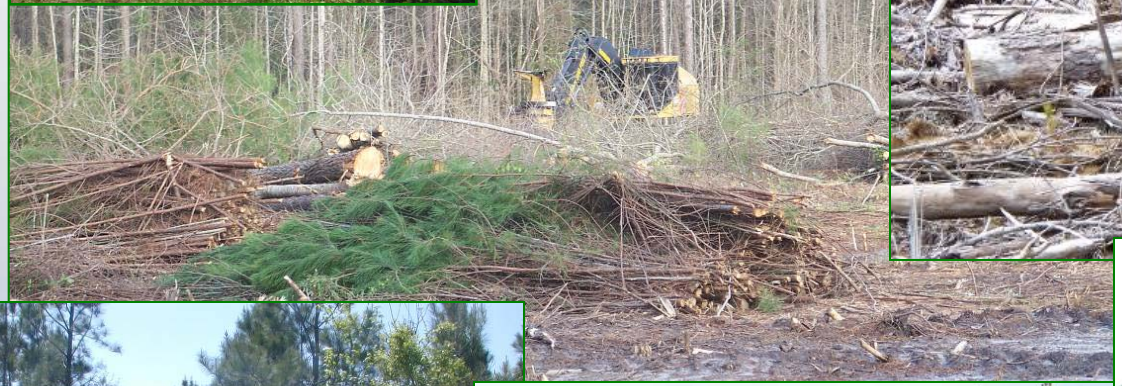
Feedstock Sources



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Why Forest Based?

- **Builds on an large existing infrastructure**
- **Leverages Weyerhaeuser's strengths**
  - Precision, science-based sustainable forestry
  - Extensive and efficient harvest, handling and transport infrastructure
  - Expertise in feedstock procurement from third parties
  - Expertise in genetic improvement
- **Superior assurance of woody biomass supply**
- **Recognition that forestlands can grow more than just sawtimber alone**

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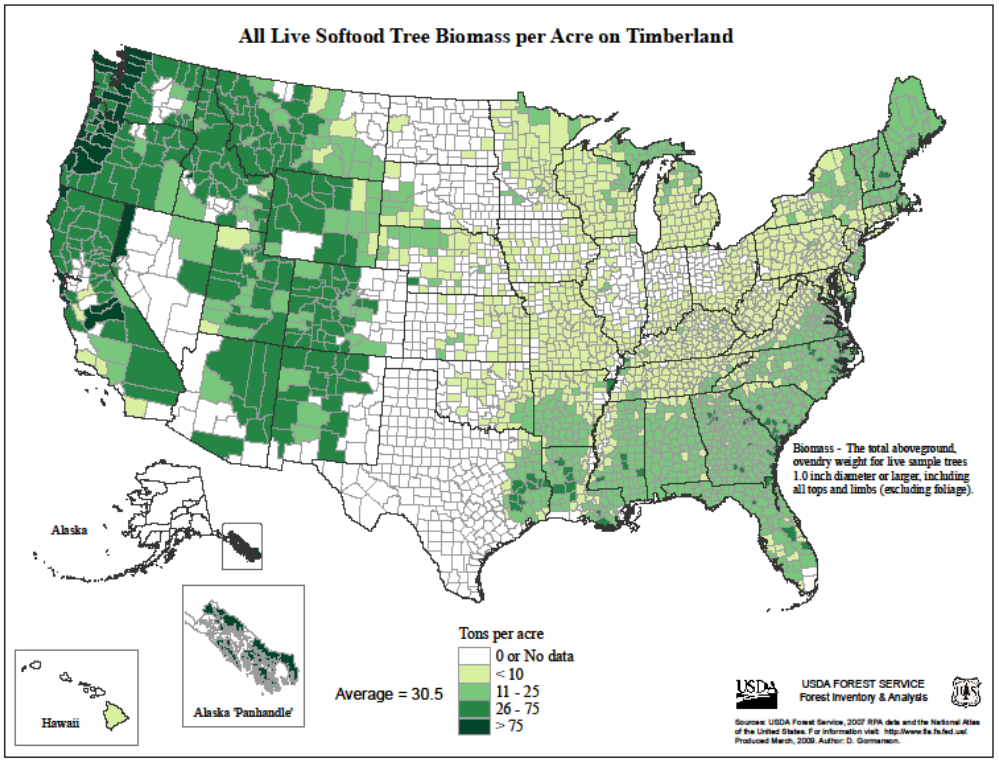
US Softwood is Plentiful



- Twice as much softwood as hardwood
- Many studies show these harvest levels are sustainable
  - annual growth equals or exceeds harvest

- Not much harvest from Federal lands (national forests)
- Softwood more recalcitrant towards hydrolysis than hardwood

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Feedstock Sourcing and Scalability

Catchlight Energy is actively developing forest-based biomass supply systems

- Cost reductions through productivity and logistics improvements
- Forest residuals, understory
- Intercropped switchgrass - 2000 acres planted
- Field processing methods
- Harvesting techniques and equipment
- Transportation and Logistics
- Wood/grass basket size and location

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Downstream Integration

Fuel registration and pathway approval are req'd from the US EPA

- Testing for fuel registration is extensive, including engine emission tests, and may need to be repeated for various blends
- Product Stewardship
- CLE has a process to identify all potential risks
- Frequent product testing to manage risk and assure on-spec product
- Requires MSDS's and information on Pre-Manufacturing Notices (PMN's)

Product Logistics Issues

- Adequate offtake facilities at bio-refinery
- Product handling practices and integration of small volumes
- Product segregation to avoid contamination risk and maintain renewable characterization
- Capital investment for the above

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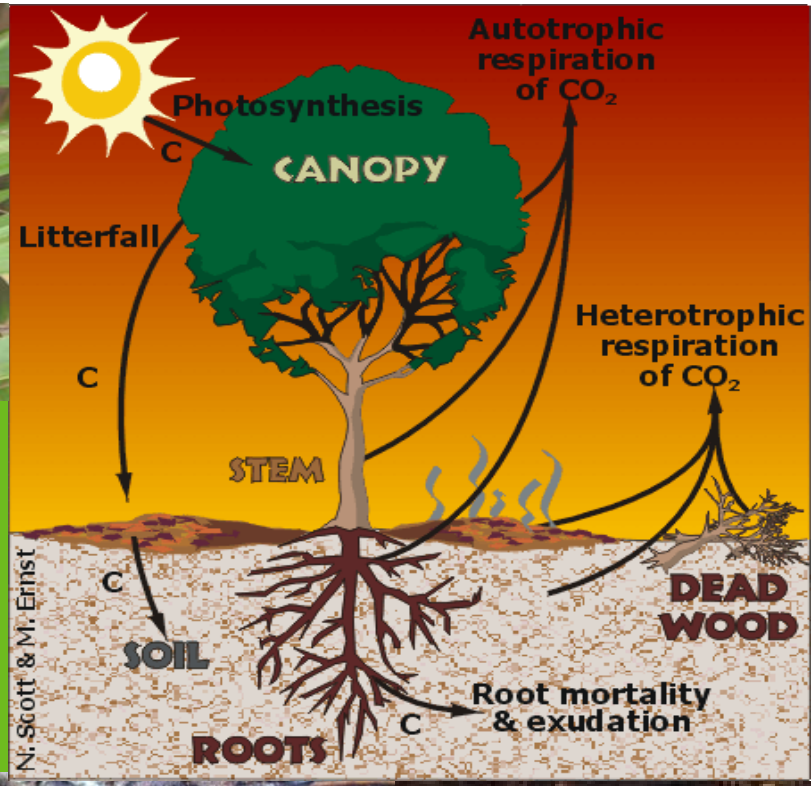
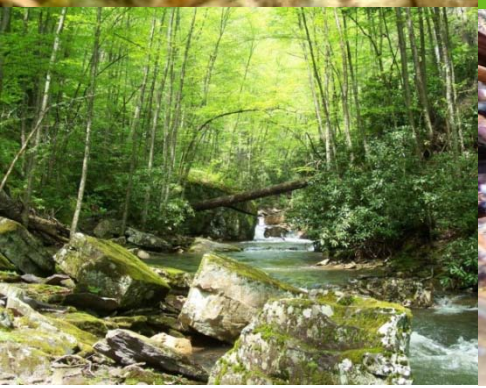
SUSTAINABILITY





Why Conduct Sustainability Research?

- Influence evolving criteria driving biomass production and use
  - Regulatory definitions of qualifying v. non-qualifying biomass
- Make good science available so policy makers will use it – rather than using less objective criteria
- Meeting these goals will require a technically-sound and widely-accepted evaluation of environmental effects

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How do we operate – "Creating a Research Platform"

- Maximize credibility and minimize cost in order to achieve strategic goals
- Establishment of research "platforms"
- Utilize internal resources to implement/establish sites where a complete set of "basic" environmental data are collected
- The availability of the sites and support for collecting base data attracts collaborators
- Collaborators provide:
  - Increased credibility
  - Expertise not available internally
  - Financial support (government grants, student support, etc.)

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Information needs

- **Productivity and Soil Nutrients**
  - Pine productivity relative to intercropping switchgrass
  - Fertilization
  - Soil physical properties (e.g., compaction)

- **Carbon – Life Cycle Analysis (LCA)**
  - Above and below ground carbon stocks
  - Balance of carbon uptake and release including growth, harvest, and transport of biomass

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Information needs

- **Water**
  - Water quality and quantity
  - Sedimentation

- **Biodiversity**
  - Vegetation/habitat response
  - Wildlife community response

- **Ongoing (Nature of the information needs will change over time)**
  - Requires engagement with stakeholders
  - Review of scientific literature and professional discussions (i.e. EPA Workshop, Biomass Council, etc.)

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Catchlight Energy Sustainability R&D Teams

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Soils

Biodiversity

Sustainability

Hydrology

Life Cycle Analysis Model

Comprehensive look at the environmental aspects of biomass management

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Soil Productivity Research

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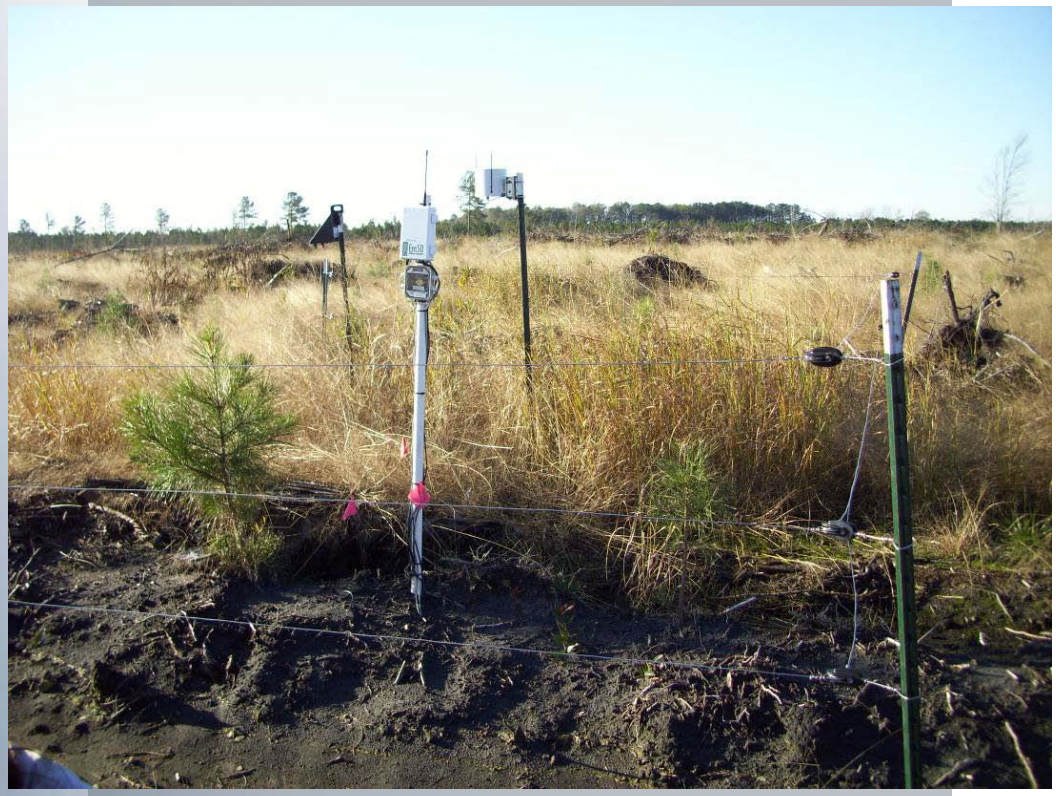

Project Leaders

Dr. Zakiya Leggett
&
Dr. Eric Sucre

Lenoir 1 Sustainability Study

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- Main Objective: Determine the effects of intercropping and/or biomass management on site productivity and sustainability throughout the rotation in a loblolly pine plantation

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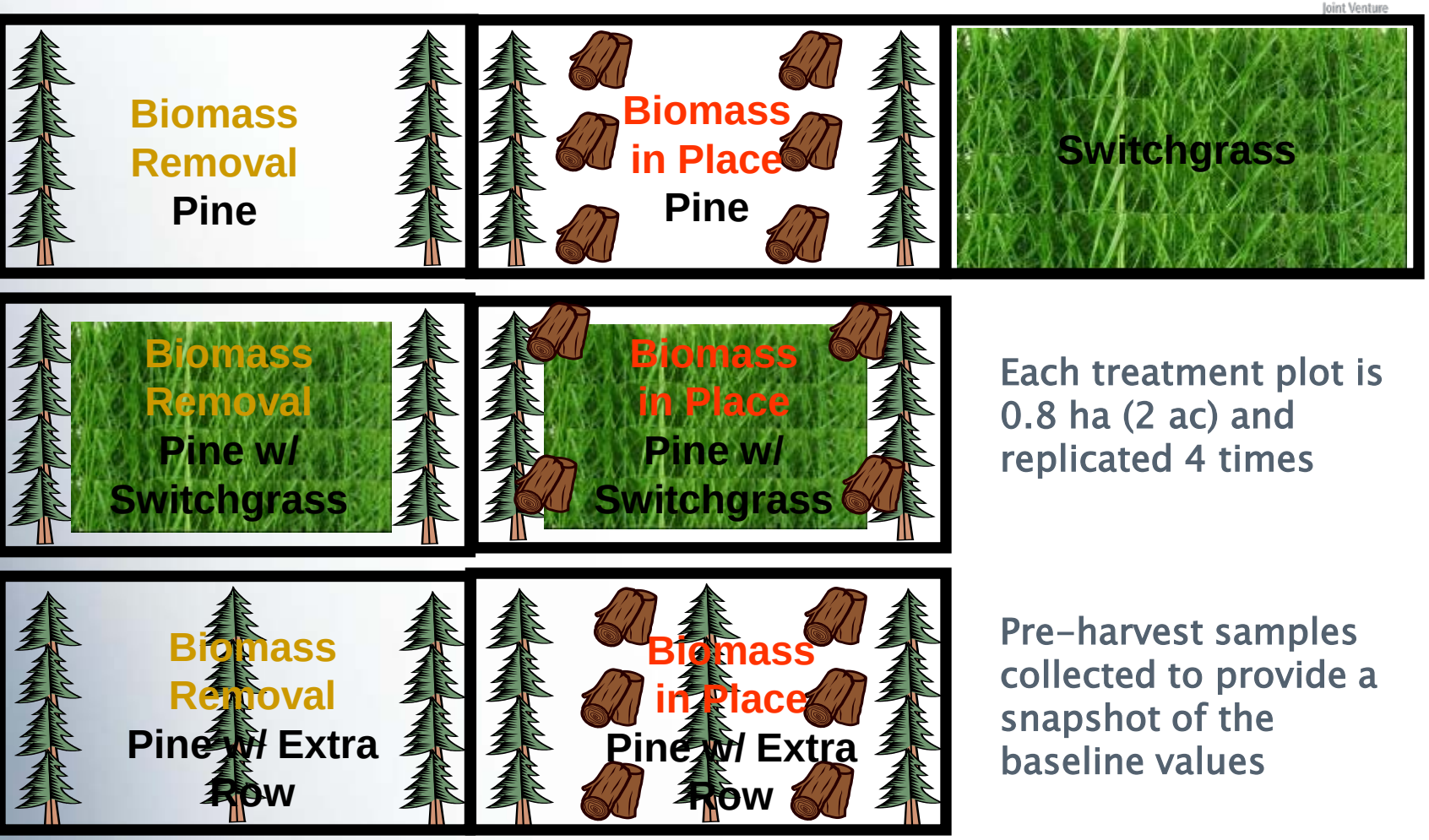
Treatments



Each treatment plot is 0.8 ha (2 ac) and replicated 4 times

Pre-harvest samples collected to provide a snapshot of the baseline values

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Field Instrumentation

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- Onset Weather Station

- Per plot installation:
- Soil Moisture/Temperature probes (2 depths)
- Rain Gauges
- Electric Fences with Solar Panels

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Coarse Woody Debris Assessment

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NICHOLAS SCHOOL OF THE ENVIRONMENT
DUKE UNIVERSITY
forging a sustainable future

Objectives and Methods

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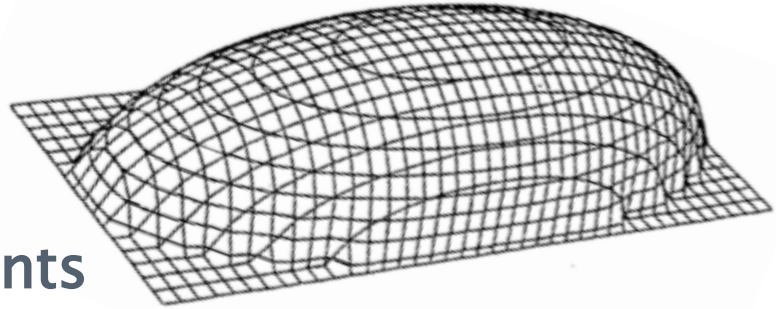
Objective:

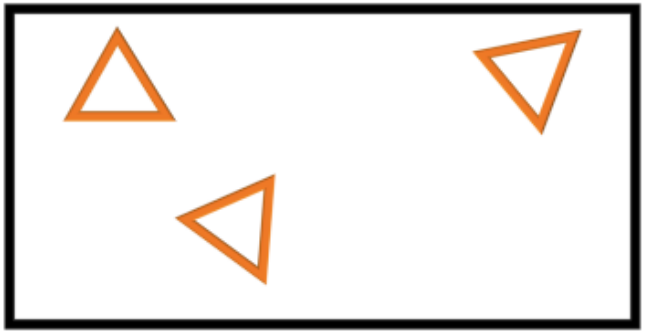
•To estimate the total quantity and carbon and nitrogen contents of CWD for three different debris management techniques:

- Biomass in place (Biomass +)
- Biomass removed (Biomass –)
- Root raked– switchgrass treatments



•Biomass estimate methods:

- Pile estimation and/or
- Line intersect method



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Site Preparation

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Switchgrass Only
- 100% V-shear
- Root Raked
- Machine Planted

Biomass Removed
- V-sheared and bedded
- Excavator used for biomass removal
- 100% V-sheared (switchgrass intercropped treatment)

Biomass in Place
- V-sheared and bedded
- 100% V-sheared (switchgrass intercropped treatment)

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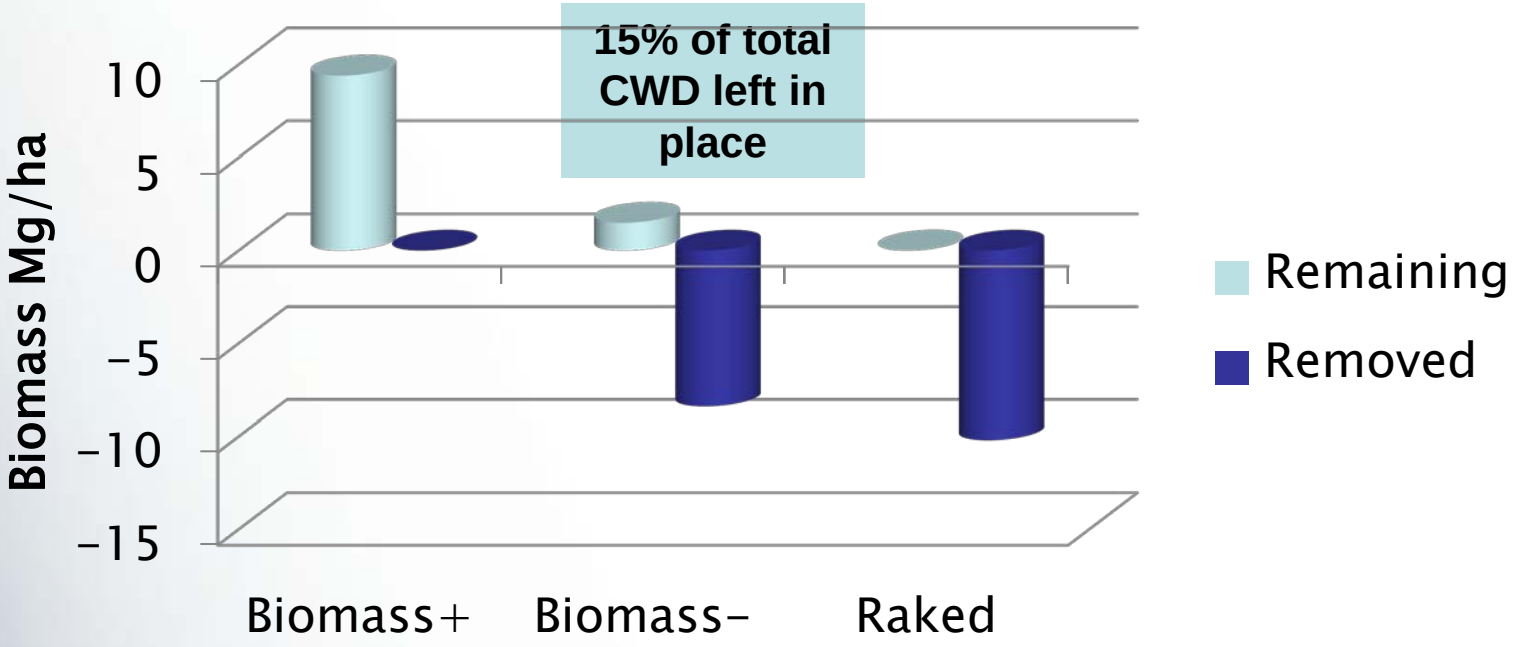
Coarse Woody Debris Estimates



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Soil Compaction Assessment

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Research Question

Has Intensive Site Preparation, Logging Residue Harvesting and Repeated Switchgrass Harvesting Caused Significant Soil Compaction?

Summary of Post Site Prep, Post Treatment Establishment, 1st and 2nd year harvests

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- No significant treatment establishment effects.
- Repeated switchgrass harvesting caused significant soil compaction.
  - switchgrass > pine w/ switchgrass > pine only = pine w/ extra row in top 15cm only.
  - Increase in soil compaction was not reflected in a decrease in pine productivity.
  - Severe wet winter prior to 1st year switchgrass harvest may have resulted in slightly higher soil compaction.
- Soil conditions could improve over time due to switchgrass' prolific rooting system.

Peer-reviewed publication scheduled for submission in 2012

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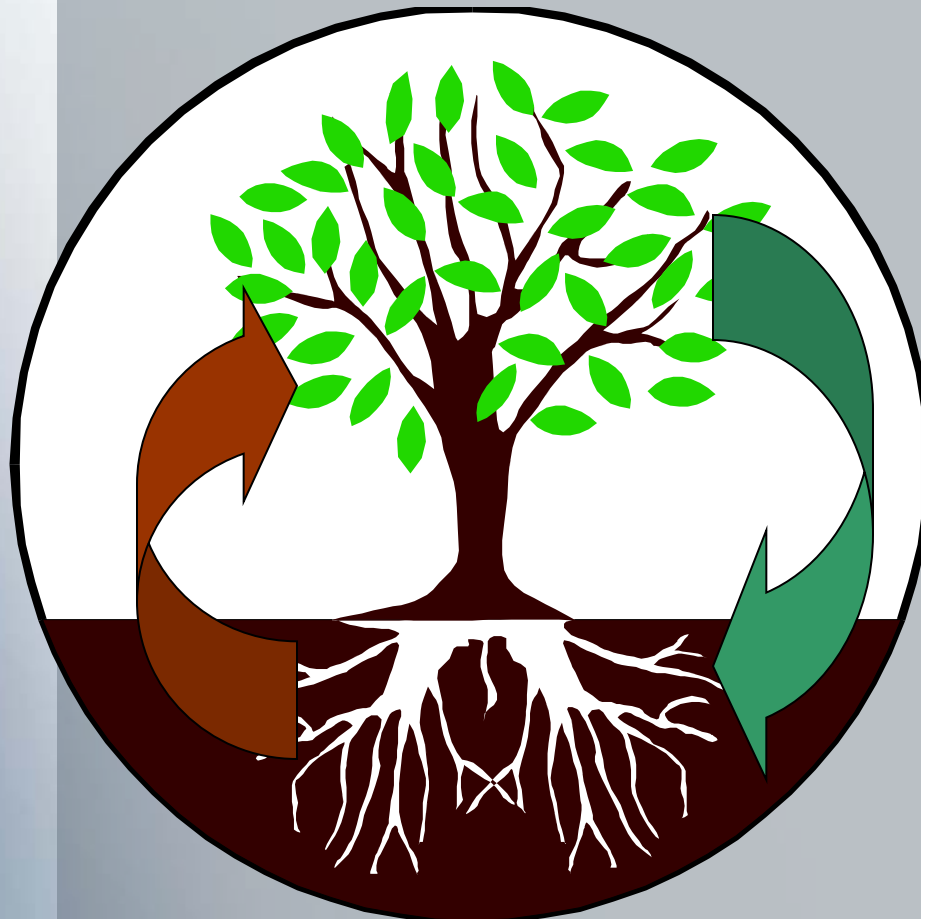
Soil Carbon and Nutrient Cycling



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VirginiaTech

Objective and Methods

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Objective:

- Understand how switchgrass affects soil carbon (C) fractions and cycling of essential nutrients

Methods:

- Quantify the labile and recalcitrant soil carbon pools by sequential density fractionation
- Monitor nutrient availability in the soil using ion exchange membranes

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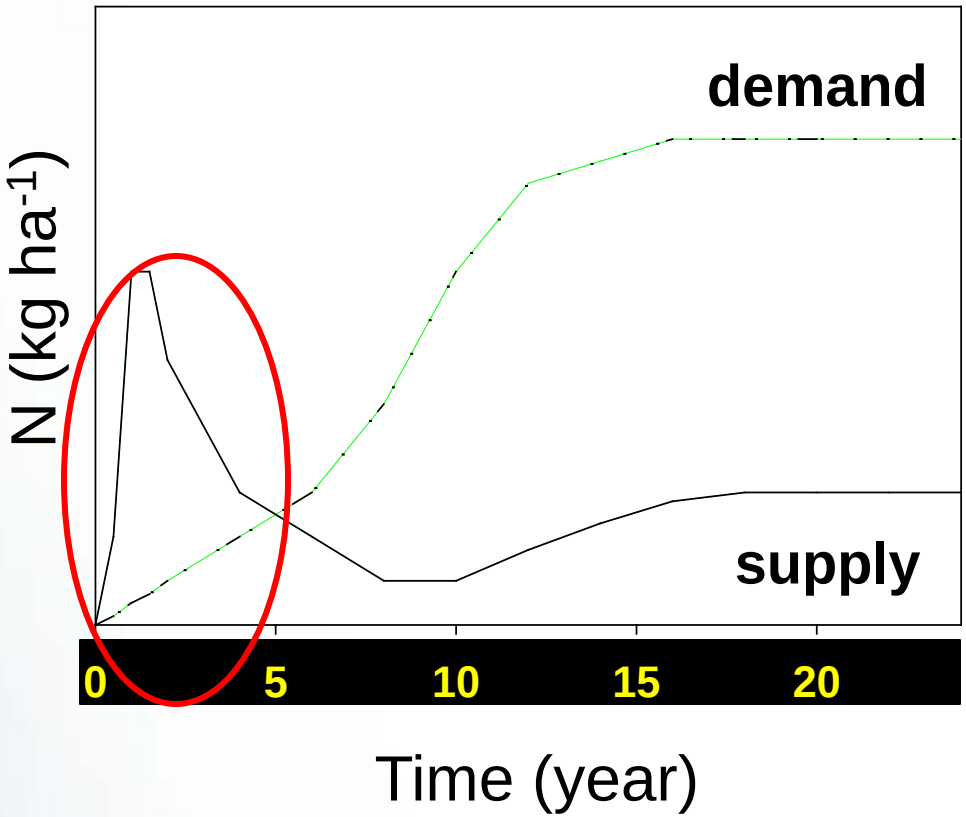
Post-harvest N-dynamics: *Assart Effect*

TRADITIONAL PATTERN



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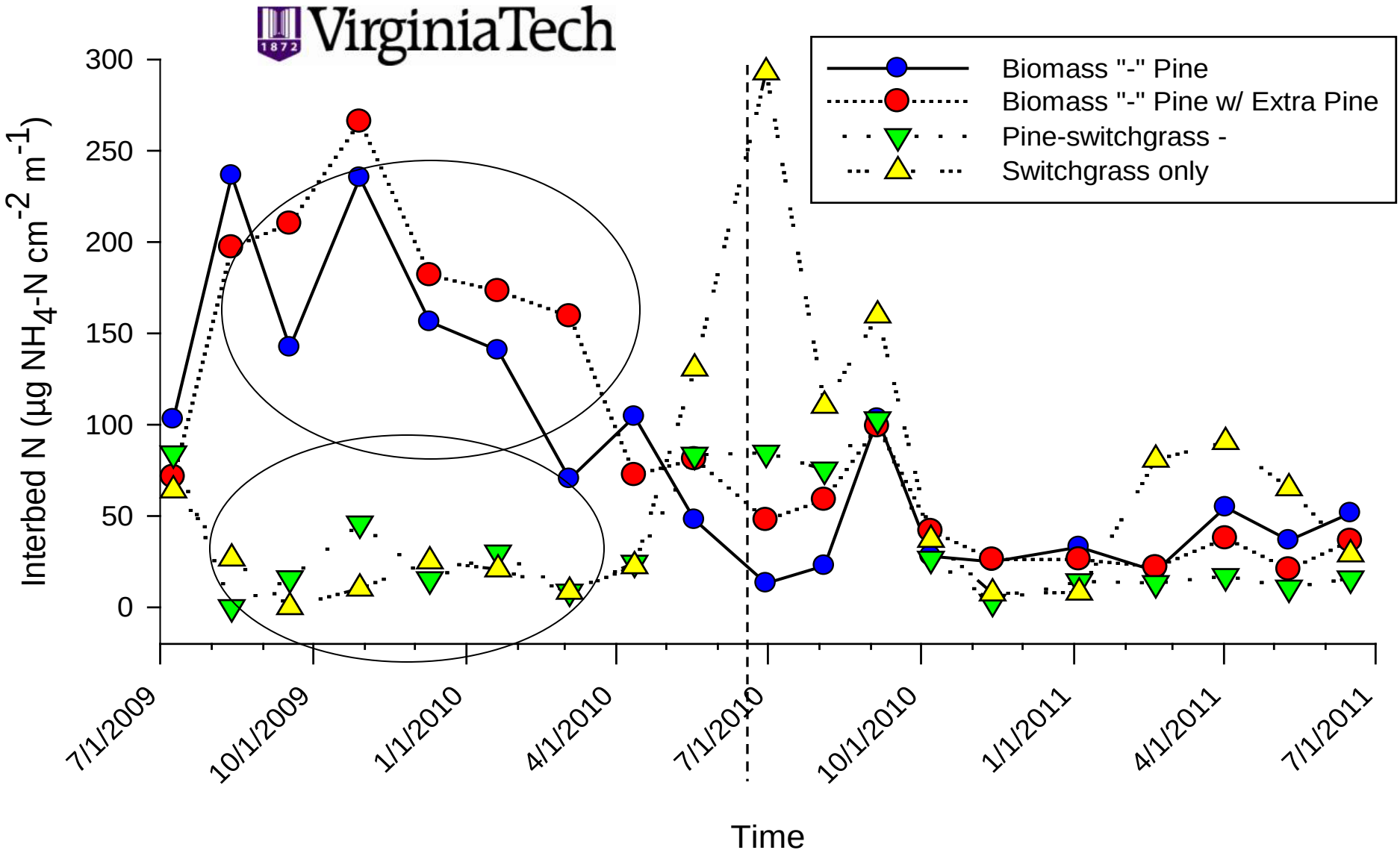

- Clear assart period for non-switchgrass treatments
- Switchgrass reduced soil NH_4^+ and NO_3^- in 2009
- Switchgrass fertilization increased available NH_4^+

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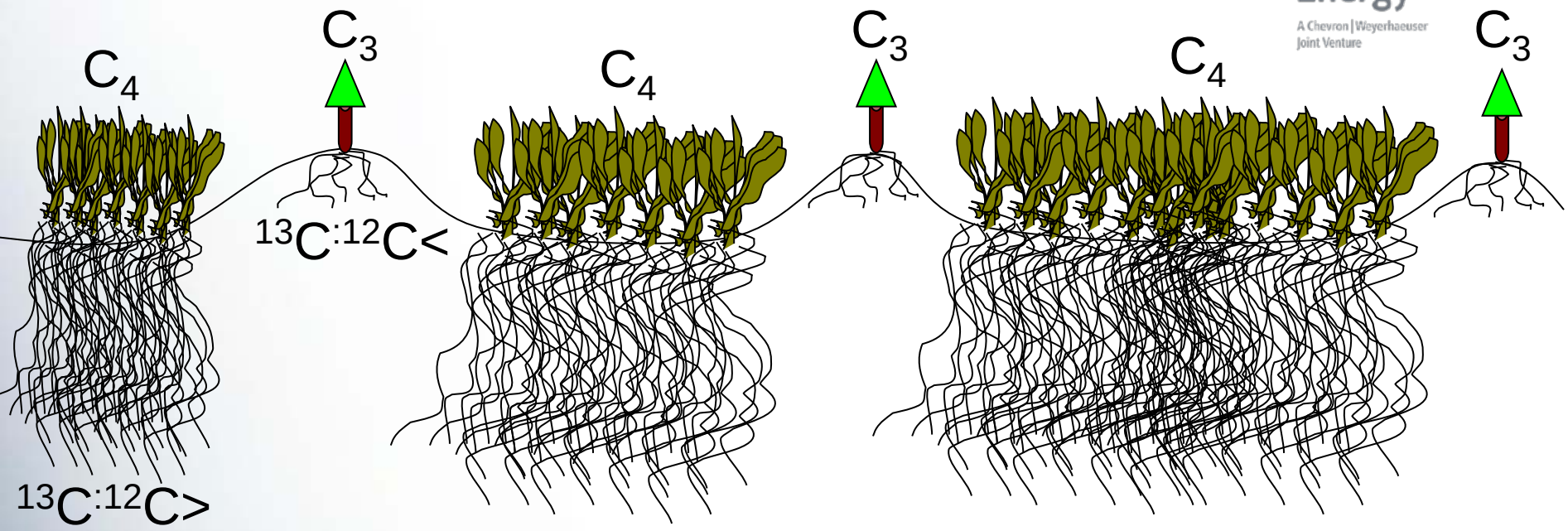
^{13}C Soil Sampling Project



- **This study will assist in determining the contribution of switchgrass to carbon storage on the site.**

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Collaborative Efforts

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- **Duke University**
  - Masters student focused on coarse woody debris assessment
    - Peer-reviewed publication scheduled for submission Fall 2012
- **Virginia Tech**
  - Post-doc focused on analysis of baseline samples for nutrient cycling
  - Doctoral Student focused on soil carbon and nutrient cycling
- **NC State University**
  - Doctoral student focused on hydrology and water quality
  - Post-Doctoral research focused on plant physiology
  - Master student focused on miscanthus intercropping study (student funded by Biofuels Center of NC)
- **Yale University**
  - Post-Doctoral research focused on soil microbial communities

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Collaborative Efforts (cont.)

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- **Roanoke College**
  - Undergraduate student focused on examining microinvertebrate communities
- **University of NC– Greensboro**
  - Masters students (2) focused on small mammal populations and small mammal diets
- **East Carolina University**
  - Undergraduate student focused on reptile and amphibian populations
- **US Forest Service**
  - Biomass Partitioning
- **NCASI**
  - Soil Quality Indicators (Southeastern US)

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Life-cycle Analysis Modeling

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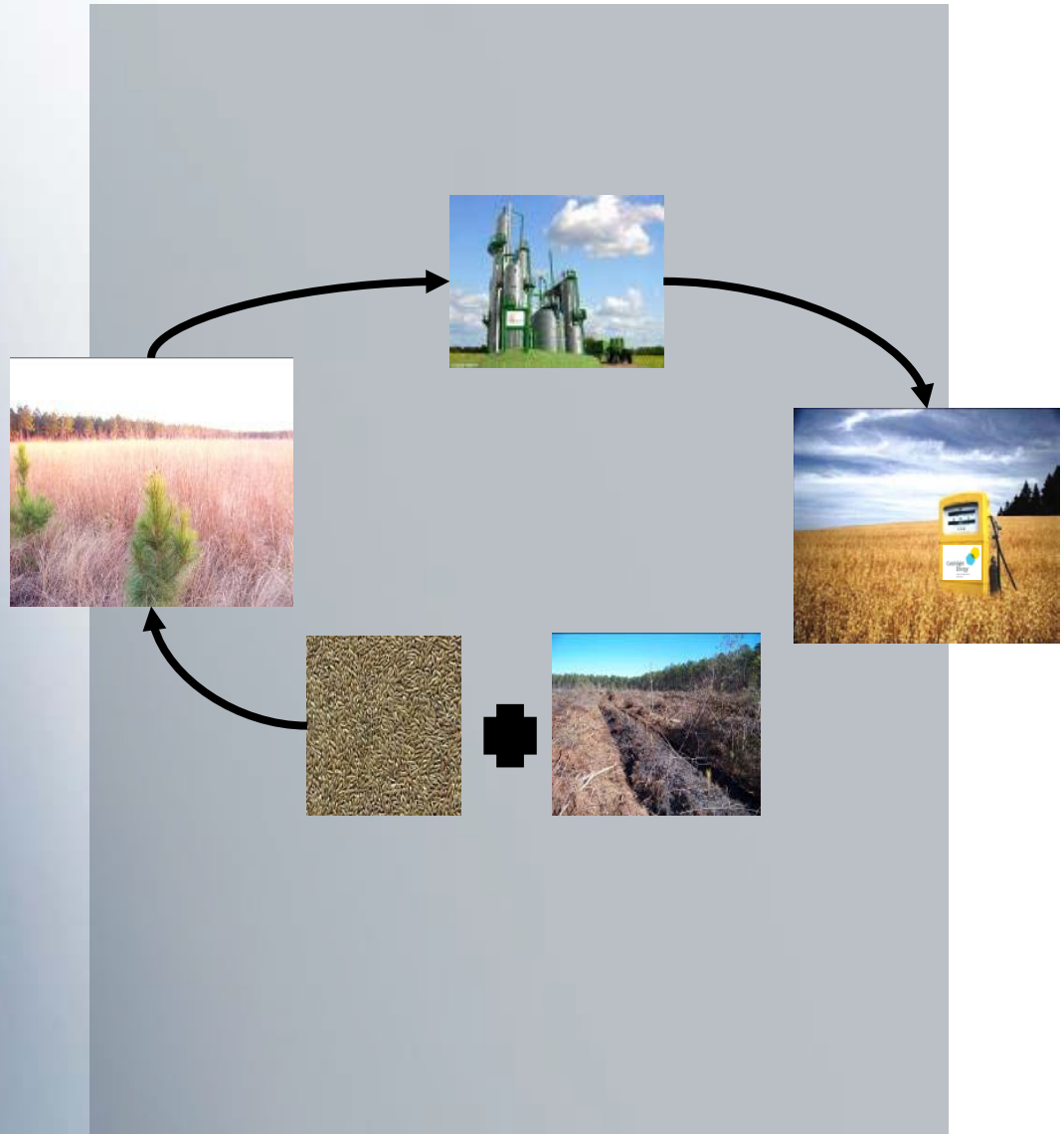

Project Leader

Dr. Eric Sucre

Catchlight Energy's LCA

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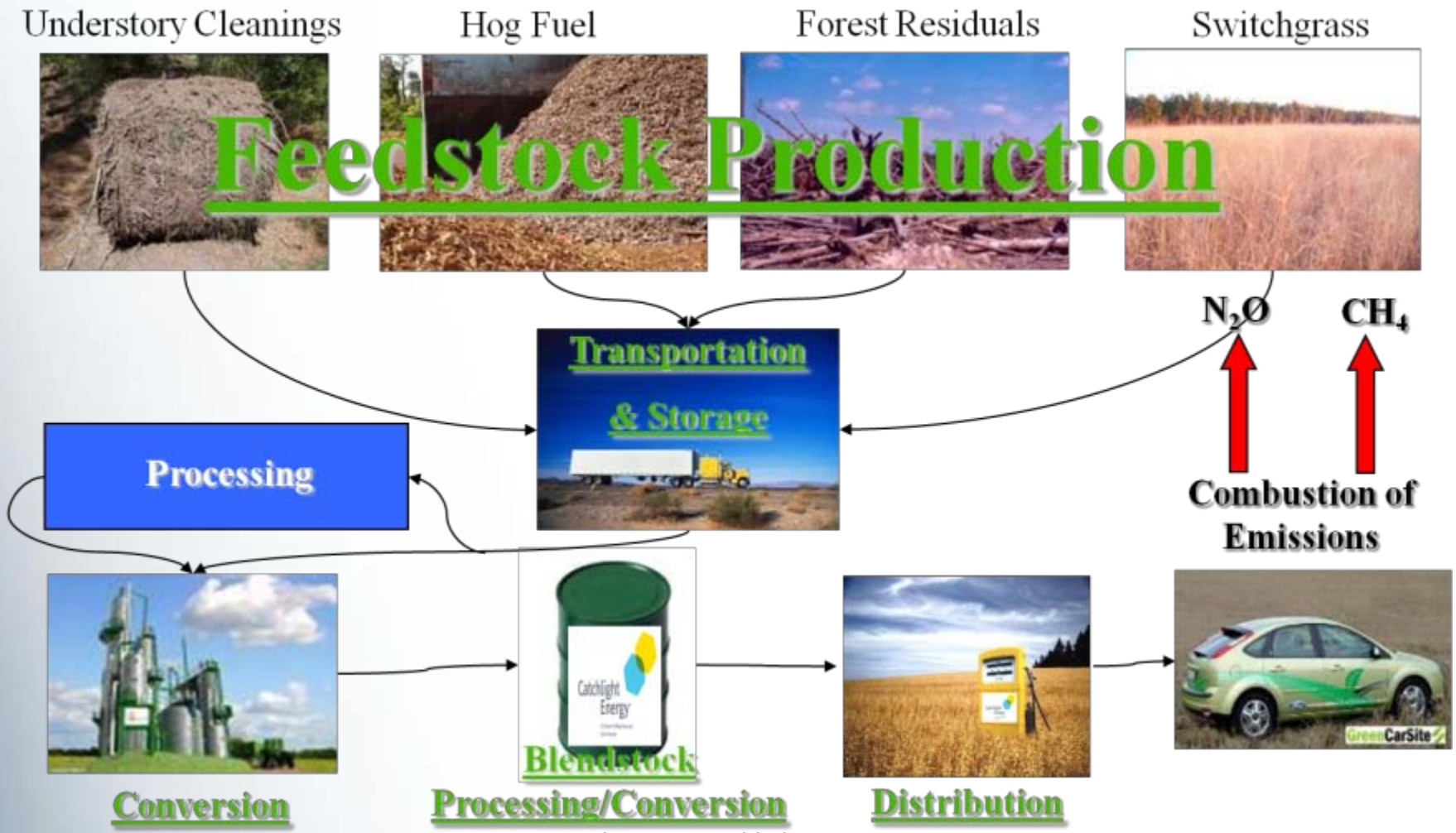

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Hydrology Research

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Project Leader

Dr. Jami Nettles

STRATEGY: SCIENCE

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Objective

Determine the effects of forest biofuel operations on water resources at small (plot-level) and large (watershed-level) scales.

- **Water quality**
  - Sediment
  - Nutrients
- **Water quantity**
  - Stream flow
  - Groundwater
  - Soil moisture
- **Aquatic Life**
  - Biological indices
  - Species of local concern

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Water Quality/Quantity Studies

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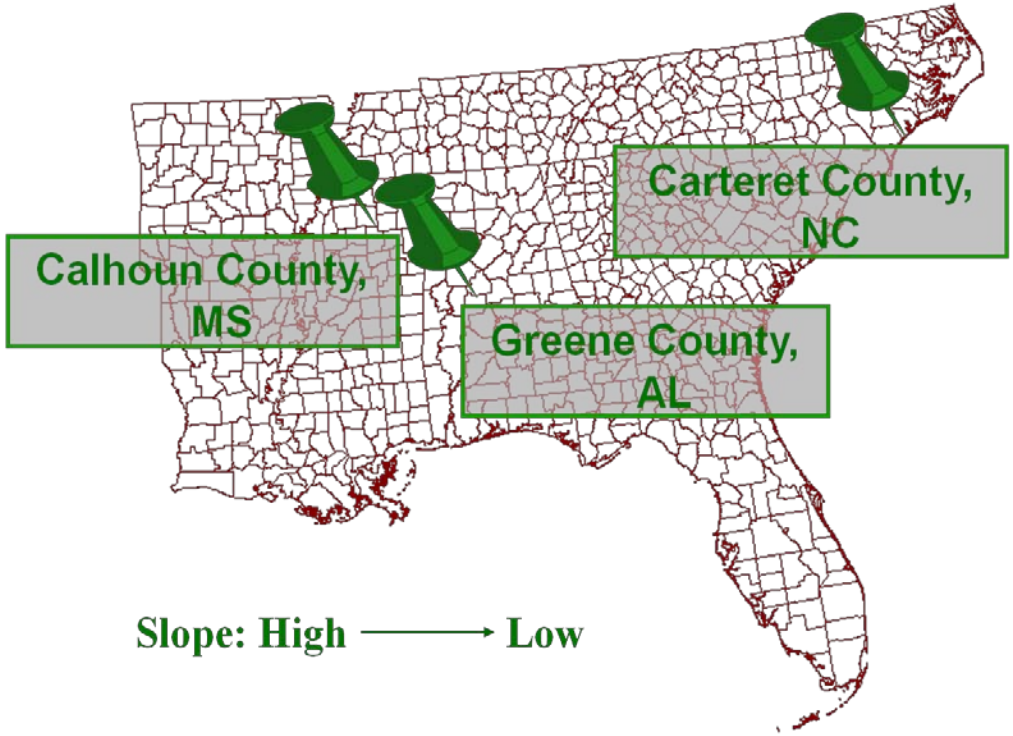

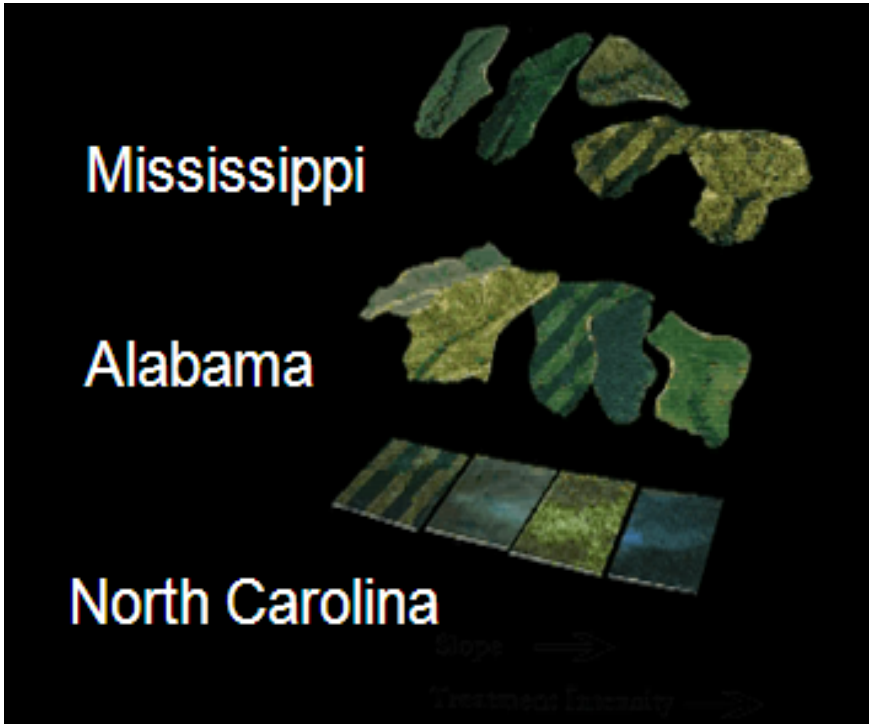

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Water Quality & Quantity

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Soil Moisture Studies

- Switchgrass and bare ground
- Reference sites with existing understory
- Soil moisture readings at multiple depths

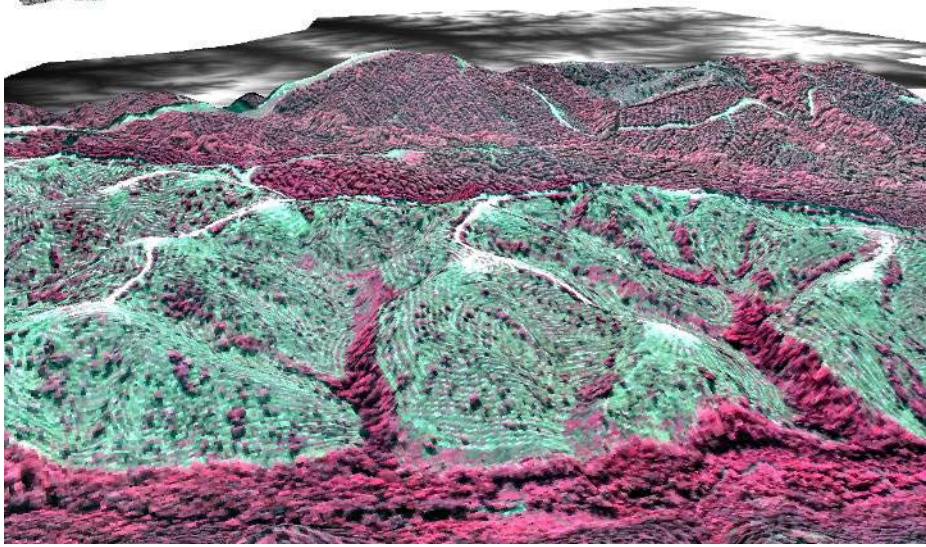
Integrated Watershed-Scale Biofuel Sustainability (DOE-FOA-000314)

Combines existing watershed studies with:

- More instrumentation coverage
- Extended modeling
- Cross-disciplinary sustainability work
- Operations/economic evaluation
- BMP guidance

Sediment Surveys

- Survey of additional sedimentation from biofuel intercropping
- 1/3 of intercropped sites randomly selected from most erodible sites
- Complete survey of last switchgrass row before riparian area



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Plot-level water quality and quantity study

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Hydrology and Water Quality Assessment

$NO_3^- + NO_2^-$-N

MEAN ANNUAL CONCENTRATION (mg/L)
(p = 0.1521)

	2009	2010	2011
Pine	1.23	0.48	0.26
Pine-Switchgrass	1.58	1.34	0.18
Switchgrass	1.52	0.43	0.06
Reference Stand	-	-	0.12

NH_4^+-N

MEAN ANNUAL CONCENTRATION (mg/L)
(p = 0.9228)

	2009	2010	2011
Pine	25.31	10.08	14.65
Pine-Switchgrass	22.15	8.64	12.57
Switchgrass	20.53	8.28	13.23
Reference Stand	-	-	13.44

OPO_4-P

MEAN ANNUAL CONCENTRATION (mg/L)
(p = 0.4991)

	2009	2010	2011
P	0.10	0.09	0.08
P-S	0.10	0.08	0.07
S	0.09	0.07	0.06
R	-	-	0.06

– No significant treatments effects water quality at this point.

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Biodiversity Research

Project Leaders

Dr. Darren Miller
&
Dr. Jessica Homyack

Biomass Production and Biodiversity

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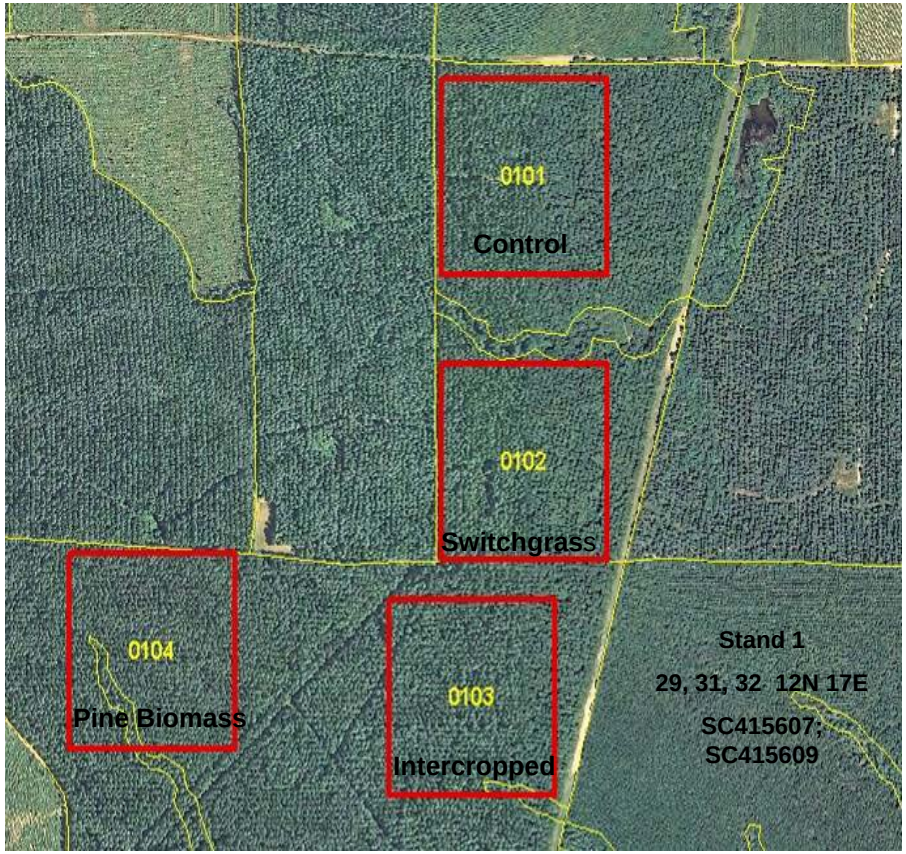
- **Objective:** Understand relationships between biomass production and biodiversity.

- **Examine response of wildlife** and **plant communities** to biomass removal and to establishment of a native biomass crop within intensively managed pine stands in east-central Mississippi.



Example of 4 treatments within each block (N = 6)

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Example:
Rodents and Herpetofauna Research

- **Ecological Characteristics**
  - Taxa associated with down woody debris
  - Rodents and Herpetofauna sensitive to changes in habitat structure and microclimate
  - Important ecological roles in food webs

- **Sampling Considerations**
  - Size and configuration of treatment plots
  - Relatively quick population responses

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Conclusions after two years post treatment

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1. Neither biomass removal nor intercropping influenced rodent community structure.

2. Presence of switchgrass decreased the number of native white-footed mouse and increased the number of non-native common house mouse.

3. Intercropping did not influence the trophic role of white-footed mice .

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Catchlight Energy's Scientific Outreach

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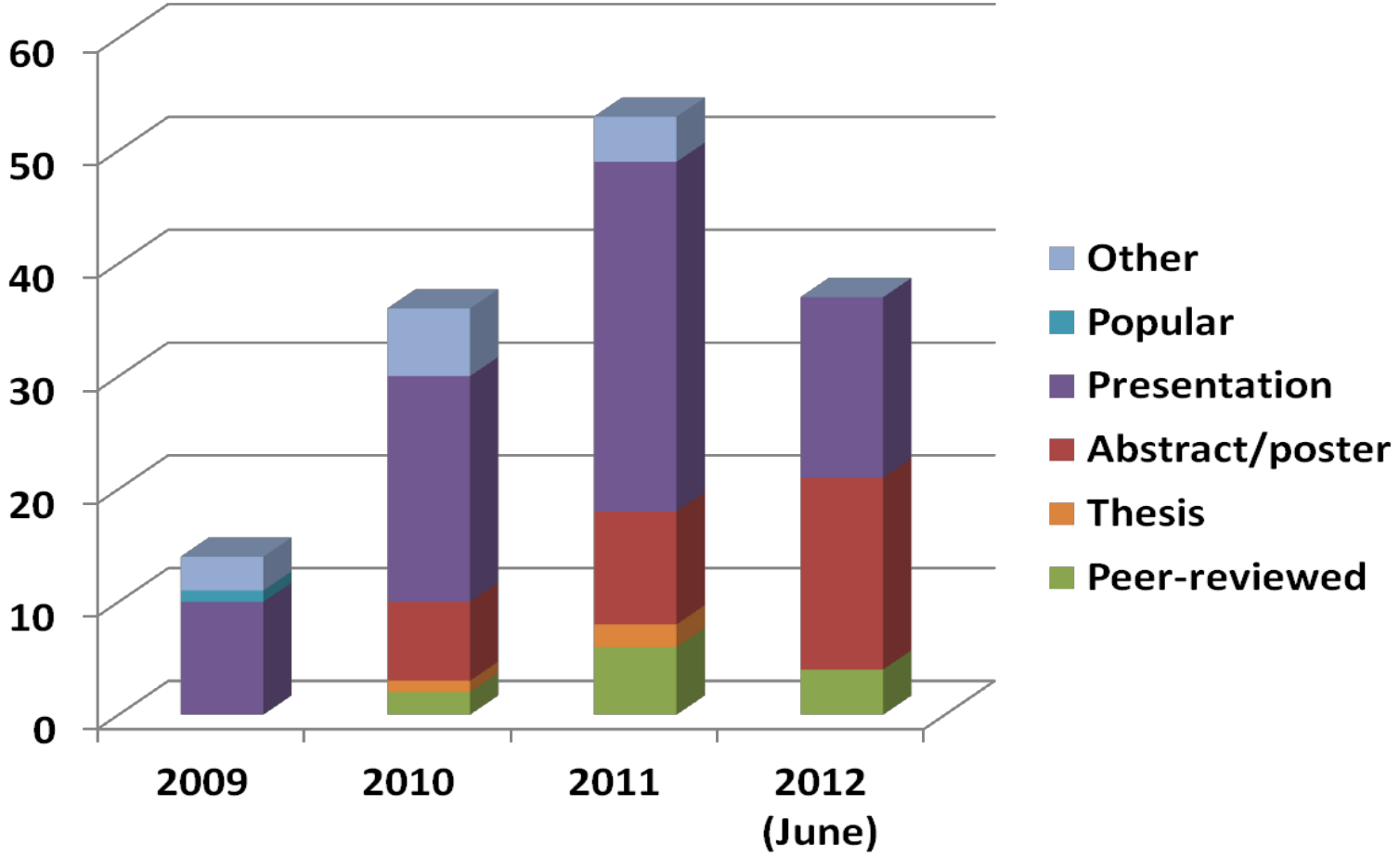
- An indicator of scientific integrity through *Cooperative* based research



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Conversion Technology R&D

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CLE pretreatment process enables cellulosic sugar from softwood

CLE Solvent Liquefaction technology produces refinery compatible bio-oil at high yield and low cost

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Catchlight Energy's Solvent-based Technology to Produce "Drop-in" Hydrocarbon Fuels

U.S. Department of Energy
Office of Biomass Program
Washington DC
July 12, 2012

Craig Brown
Manager,
Thermochemical Conversion

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Overall Agenda

- Overview of Catchlight Energy's biomass solvent liquefaction technology development
  - What is CLE solvent liquefaction (SL)?
  - Overview CLE's R&D program & outcomes
  - Technology competitive assessment
- Research & demonstration needs for commercialization

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What is Solvent Liquefaction ?

- Thermal decomposition route
  - Lower temperatures than fast pyrolysis
  - Lower pressure than hydrothermal liquefaction
  - Solvent helps stabilize wood-oil products
    - Providing H (Hydrogen-donor solvent)
    - Solvate intermediate products
    - Solvent dilutes concentration of heavy oil products – helps prevent cross-linking
- Coal liquefaction has been studied since the 1970s
  - Coal liquefaction is different than biomass solvent liquefaction
  - Tetralin is the most common solvent
  - Tetralin is an effective biomass solvent but is not commercially viable

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Solvent Liquefaction Development History

- Texaco developed lignin phenol technology in 80's & 90's culminating in a demonstration in 2000 where 500,000 lbs of Lignin was successfully hydrotreated in a semi-commercial reactor.
- CLE Solvent liquefaction developed in bench-scale and larger batch autoclave reactor runs in 2008-2009.
- Chevron and Catchlight Energy created JDA to pursue biomass liquefaction development (2009).
- A once-through solvent liquefaction pilot unit was designed, built and successfully run. Pilot unit corroborated batch results (2010).
- Solvent Enhanced Biomass Liquefaction patent application published Jan 2012
- Next steps in SL development are:
  - the modification of pilot unit to separate the product from the solvent and to recycle the solvent for mixing with biomass
  - to develop hydroprocessing conditions for upgrading the bio oil from solvent liquefaction.

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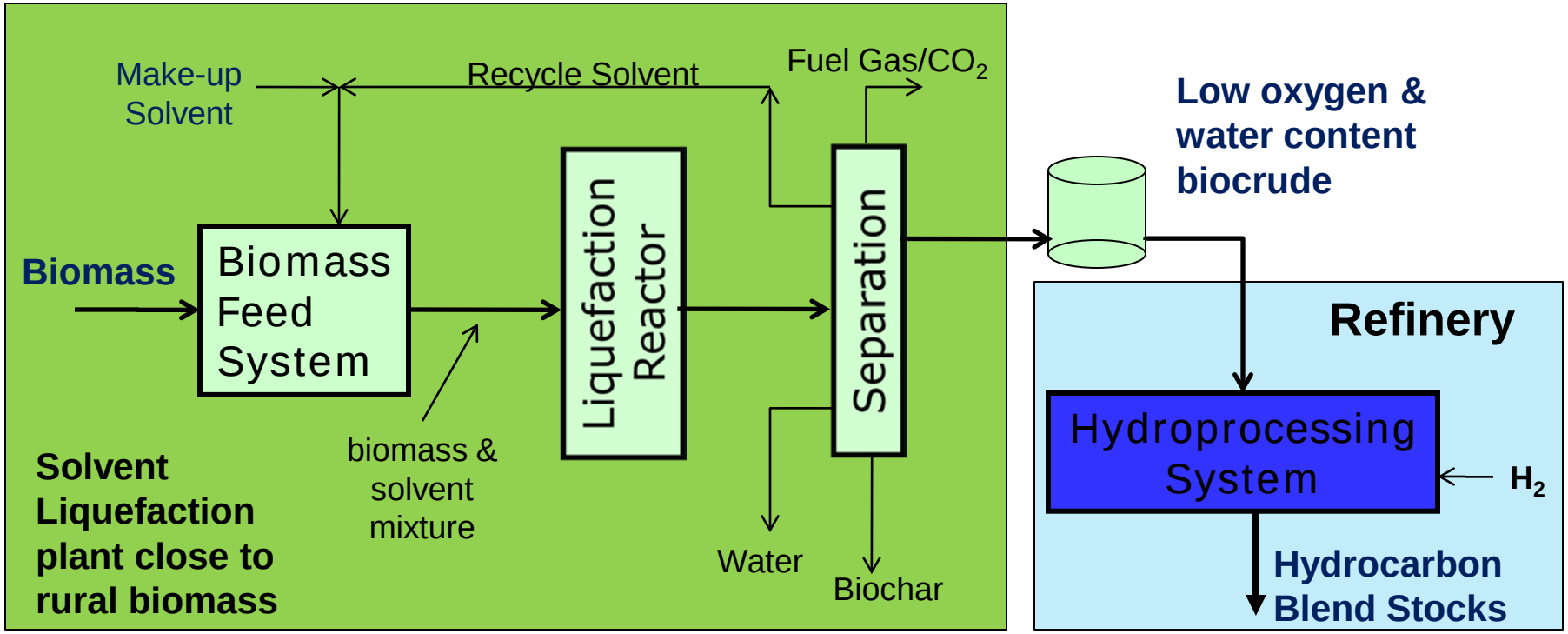
CLE Solvent Liquefaction (SL) Process

Main Process Steps

- Biomass Feed System (raise biomass pressure & temperature for reaction)
- Convert biomass in the presence of organic solvent & partially remove oxygen
- Hydroprocess liquefied-biomass to remove remaining oxygen in refinery



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CLE Solvent Liquefaction Process

- In our batch and continuous test program, CLE has demonstrated the following process advantages:
  - High yields (>100 gal of finished HC products/BDT)
  - High carbon conversion to product biocrude (ca. 70 wt%)
  - Low char (<8%) and aqueous phase (<3%) carbon loss
  - Lower oxygen content biocrude (15-30 wt%)
  - Moderate pressure operation (<600 psi)
  - A commercially practical solvent system
  - Can process a wide variety of biomass
- Attractive Economics – based on our current level of development:
  - Internal analysis shows CLE liquefaction economics are better than competitive technologies

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Comparison with other bio-oil pathways

	Solvent Enhanced Liquefaction (SEL)	Hydrothermal Liquefaction (HTL)	Catalytic Fast Pyrolysis (CFP)	Fast Pyrolysis (FP)
Process Conditions	400-600 psi 350-380°C <10 min No catalyst	3000 psi 300-350°C 10-20 min Alkali catalyst +Reducing gas	Atmospheric ~500°C <2 sec FCC/Zeolite catalyst	Atmospheric ~500°C <2 sec No catalyst
Feedstock constraints	Up to 2" chips Up to 55% MC	Pumpable slurry Up to 90% MC	Sawdust <10% MC	<1/8" <10% MC
Carbon Conversion **- to organic phase** **- to aqueous phase** **- to char** **- to gas**	 **70%** <3% 2-8% 20%	 **51%** 36% 3% 10%	 **<40%*** >25%* >25%*	 **45%** 30% 15% 10%
Bio-oil properties	15-30% Oxygen <1% water**	10-20% oxygen <1% water**	11-17% oxygen	35-45% oxygen 15-30% water
Final hydrocarbon yield (0% oxygen)	90-120gal/BDT	70-105 gal/BDT	55-90 gal/BDT	70-105 gal/BDT

*Limited published data
**Water in organic phase after gravity separation. Water in fast py-oil does not gravity separate.
*** Comparison accuracy varies with available information & the maturity of each technology

SEL maximizes carbon conversion to the organic phase

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CLE's Solvent Liquefaction R&D Program

CLE invested significantly in a comprehensive solvent liquefaction research and development program

- Process synthesis study
- Experimental program
  - Extensive batch autoclave and pencil reactor testing
  - Design, construction & operation of a continuous pilot plant
- Commercialization
  - Development and modeling of a commercial PFD
  - Development of commercially scalable feed system
  - Technical economic analysis

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Batch Testing – Autoclave and Pencil Reactors

- Focused on developing an effective and commercially viable solvent system
- Investigated key process variables:
  - Residence time
  - Feed moisture content
  - Feedstock size
  - Feedstock type
  - Impact of adding catalysts

Pencil Reactors

Autoclave Pressure Reactor and Control Tower

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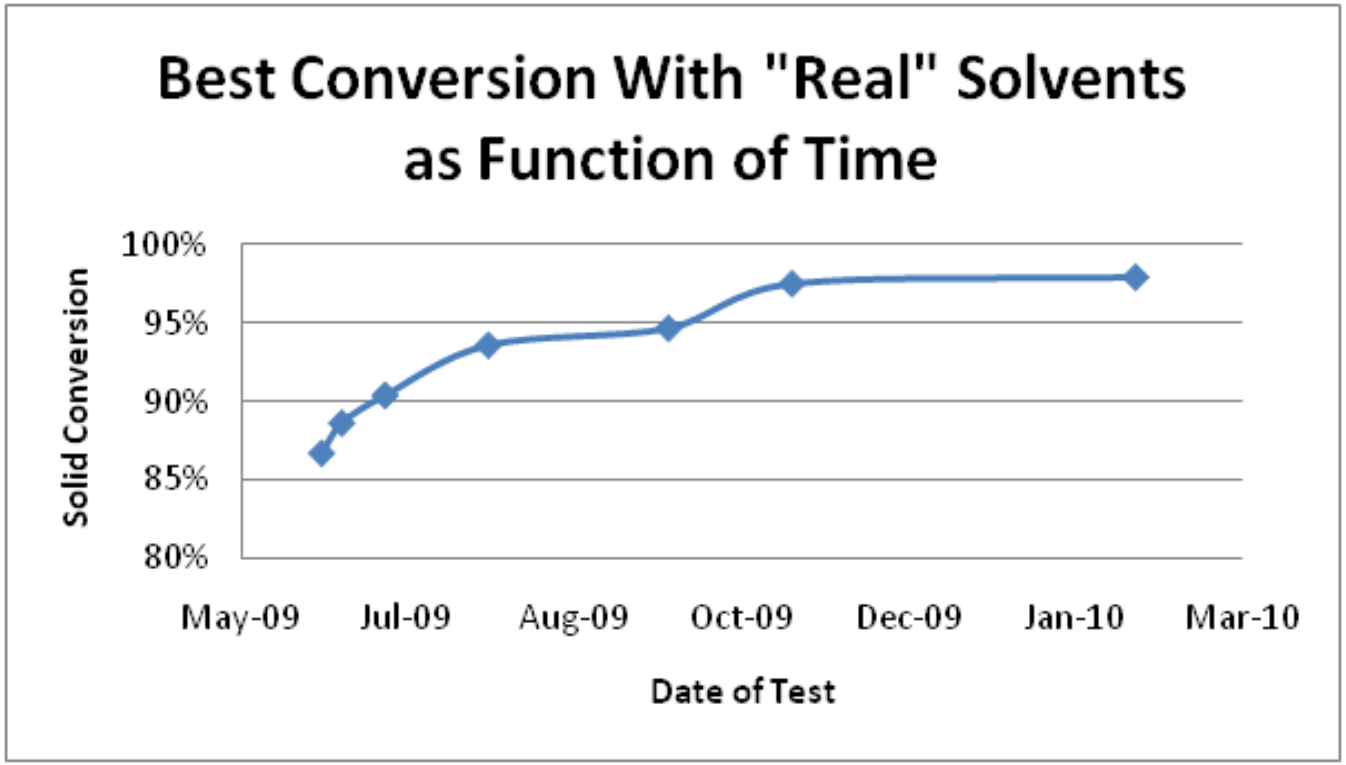
Batch Testing – Key Results



Understanding of key solvent characteristics lead to improvements in conversion and development of an effective solvent system.

The secret is in the "sauce"

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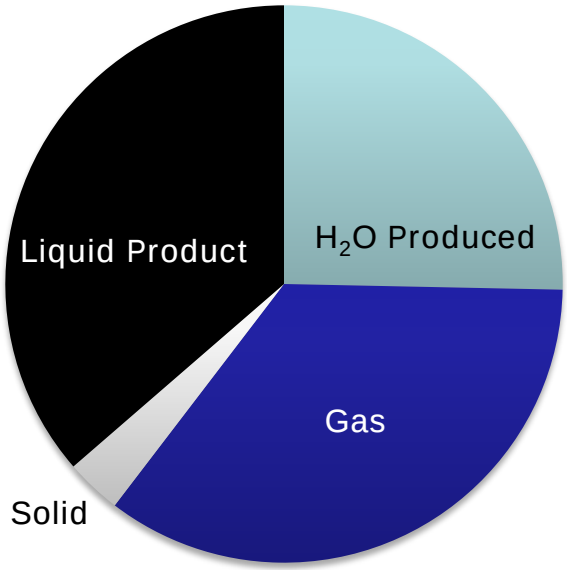
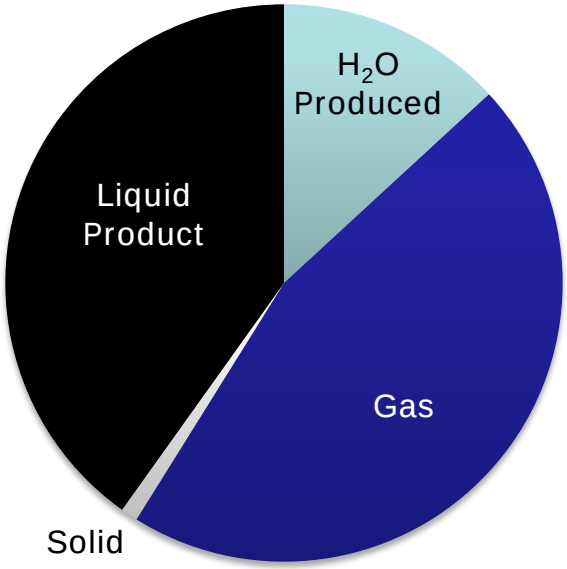
Oxygen Distribution

Solvent A



Solvent B



- Oxygen distribution is a function of solvent and operating conditions

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Continuous Liquefaction Pilot Plant

Based on promising batch test results a continuous pilot test facility was designed and constructed at Chevron's Briarpark research lab

Design Conditions:

- 2 lb/h at 50% mc
- Up to 600 psi

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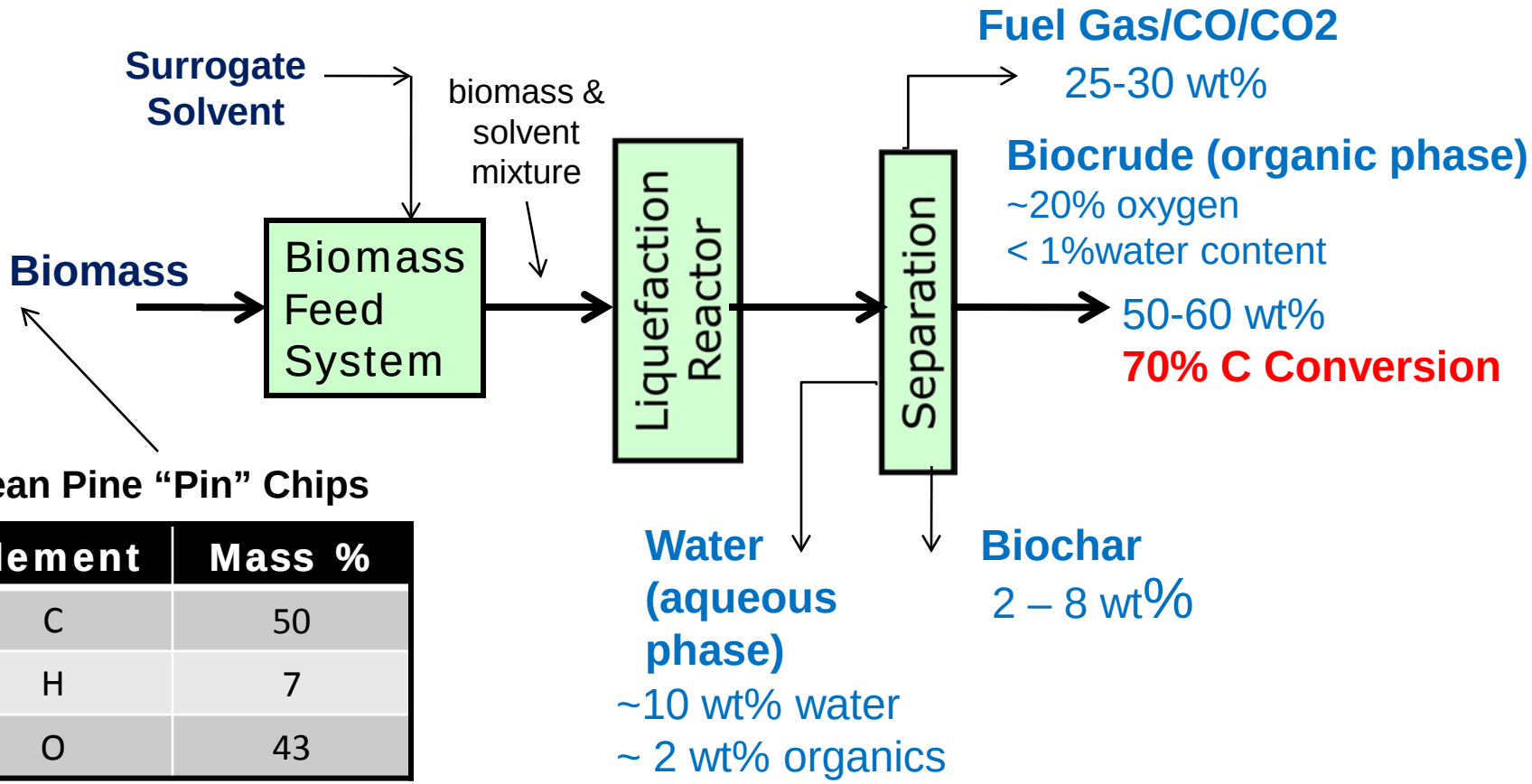
Continuous Pilot Testing – Key Results

Representative mass balance (wt% of dry biomass)



Element	Mass %
C	50
H	7
O	43

Excellent overall mass balance closure (98-102%)
Validated batch yield structure results

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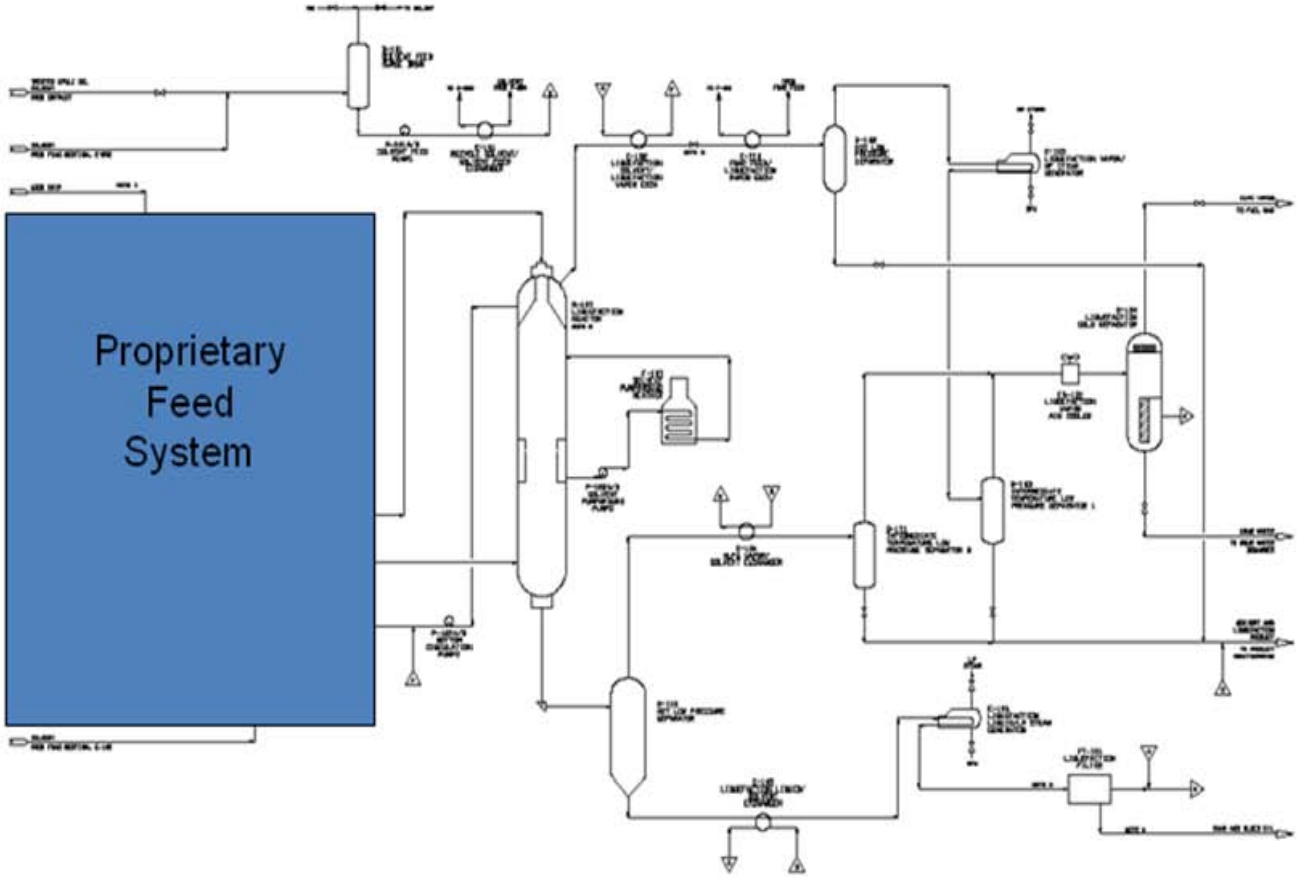
Commercial scale PFD and modeling



2650 BDT/d => ~100 MMgpy finished gasoline & diesel blend stock

Proprietary feed system is a key factor in reducing capex

Test results provided the basis for commercial concept design and economic analysis

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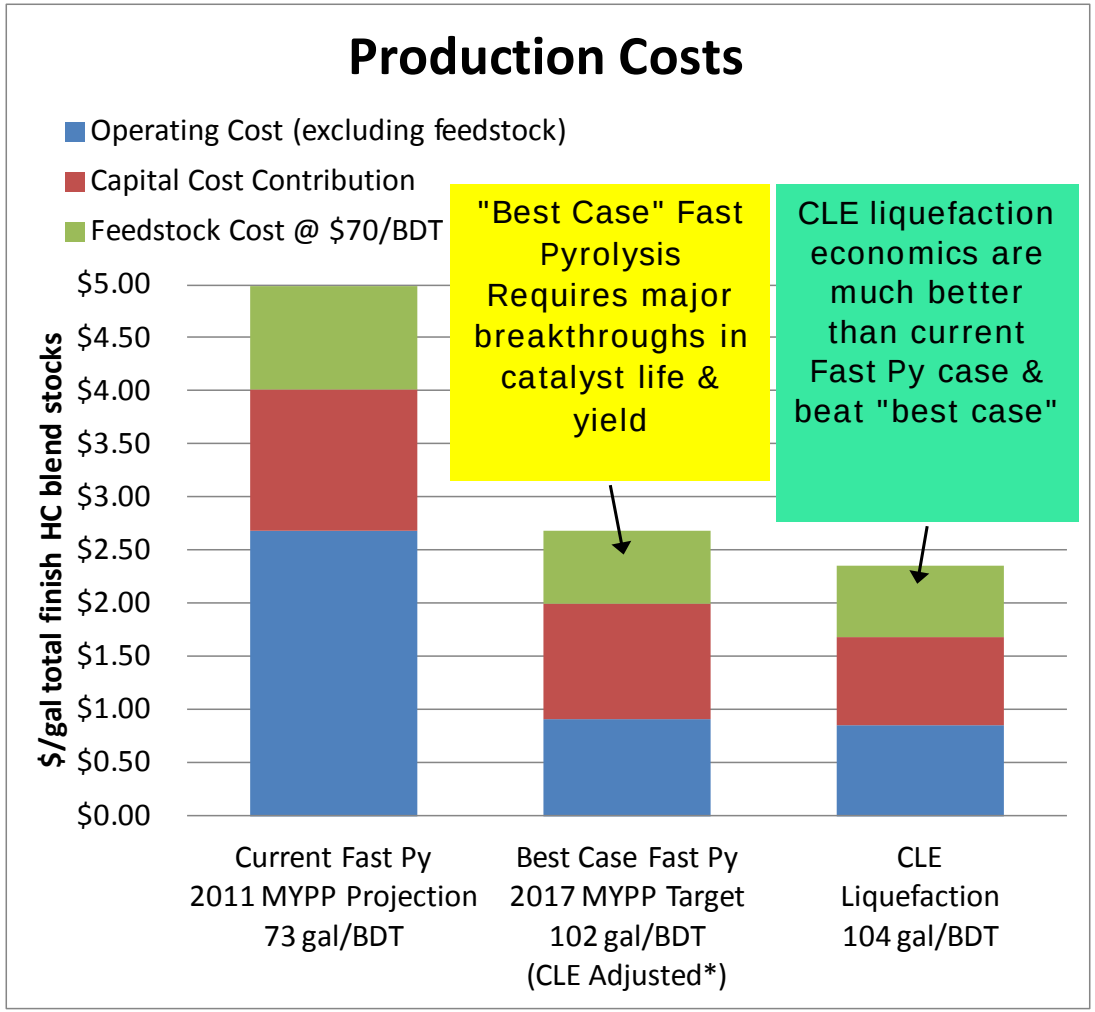
Production Cost Comparison



CLE TEA indicates SL production cost is >$2/gal less than current Fast Py case and >$0.3/gal less than best case

Fast Py Best Case based on PNNL 2017 design case with CLE adjustments for capex and opex. $70/BDT biomass, 12.5% capital recovery factor

Initiating work with NABC team on common basis TEA

CLE TEA indicates economics better than fast pyrolysis

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Process proof-of-concept established

- Over 100 bench-scale tests
  - Validated solvent chemistry, mass balance & yield structure
  - Defined key attributes of an effective solvent system.
  - Tested a variety of feedstocks
- Successfully scaled-up and operated 50 lb/d continuous pilot
  - Once-through with surrogate solvent systems & clean pine feed
  - Validated product yield structure
- Developed commercial design concept with favorable economics
  - Developed proprietary, commercially scalable feed system
  - >$0.30 lower production cost than best future case fast-pyrolysis scenario
  - >$2.00 lower production cost than current fast-pyrolysis scenario

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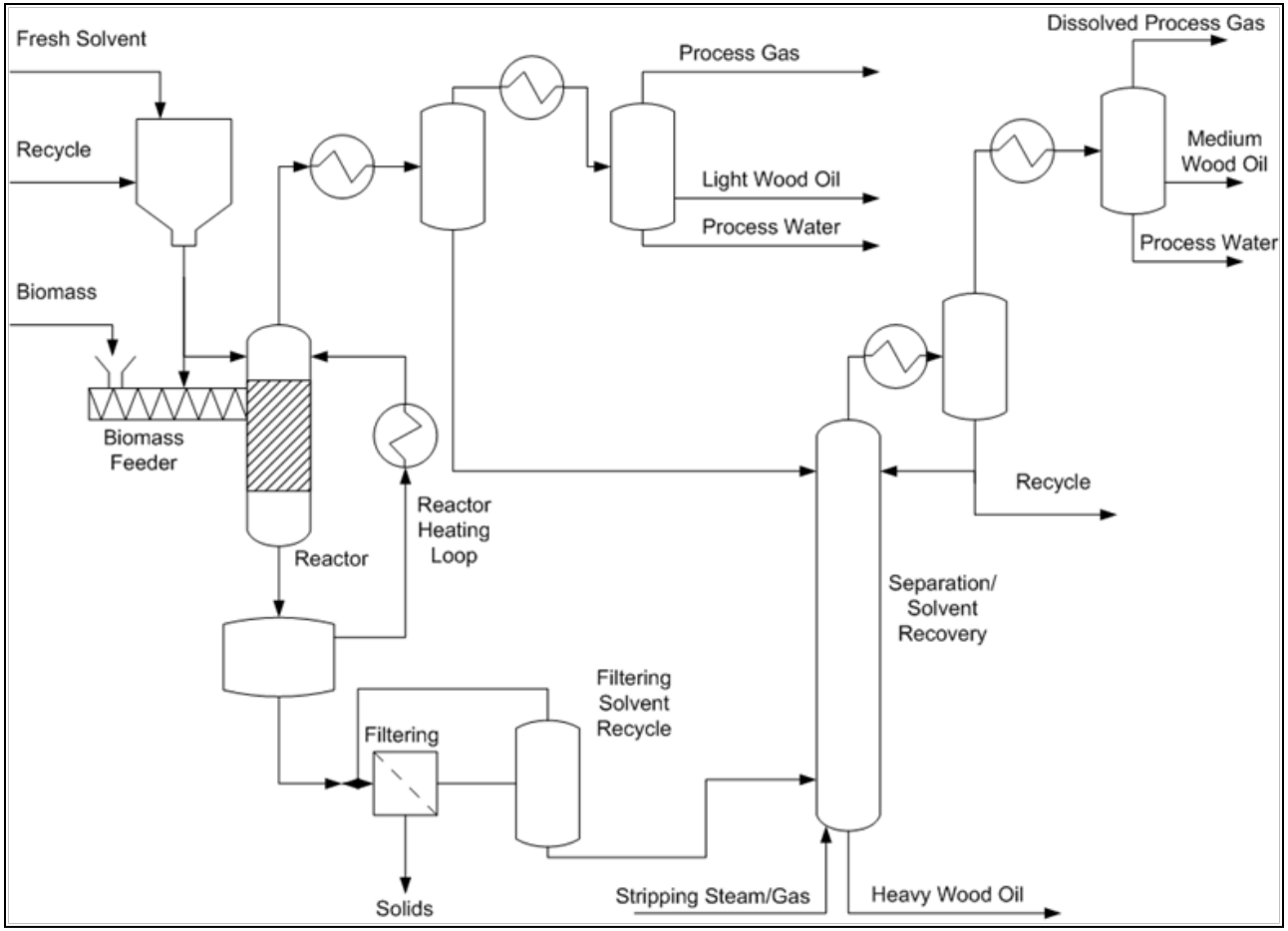
Critical Next Step



Process validation with solvent recycle is required prior to demonstration

Only practical means to achieve this is in a continuous pilot plant

Several process options are being considered

Continuous pilot with solvent recycle is critical next step

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R&D barriers to scale-up and commercialization

- Demonstrate continuous recovery and recycle of process solvent
  - Avoid thermal degradation over time
  - Establish optimal recycle cut & char separation
  - Characterize bio-oil product composition & properties
- Determine hydroprocessing conditions required to upgrade the bio-oil
- Demonstrate technology robustness with other feedstocks
- Demonstrate novel feed system
- Establish engineering scale-up parameters
- Expand fundamental knowledge of solvolysis mechanisms
- Refine process economics

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Summary

- CLE has developed a unique biomass liquefaction process
  - based on a unique solvent system (i.e. a new reaction media)
  - produces a high yield of low oxygen and water content bio-oil
  - does not require a catalyst or on-site hydrogen production
  - operates at moderate reaction pressures and temperatures
  - does not require special feed pretreatment
- These advantages enable production of drop-in fuels at significantly lower cost than competing pathways.
  - CLE TEA shows >$2/gal lower production cost compared with current state of fast pyrolysis
- Proof-of-concept established in extensive test program.
  - Culminated in successful scale-up and operation of a 50 lb/d continuous pilot
- Further research and demonstration is needed.
  - Demonstration of continuous recovery and recycle of solvent is a necessary next step toward a commercial design
- CLE is pursuing value-added collaborations to:
  - Leverage our technology investment to accelerate commercialization
  - Partner with others that have complementary resources and experience

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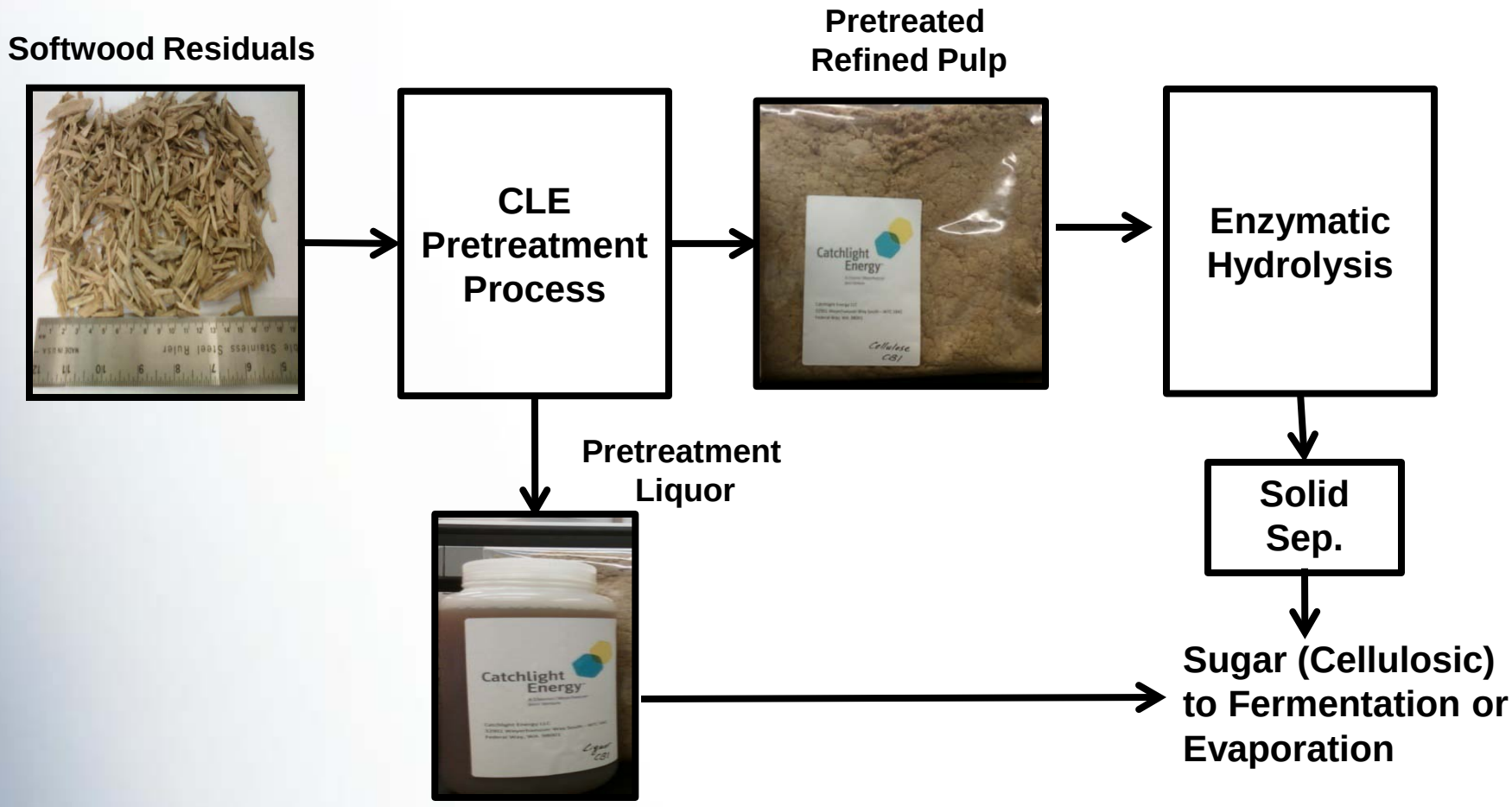
CLE Pretreatment and Sugar Production



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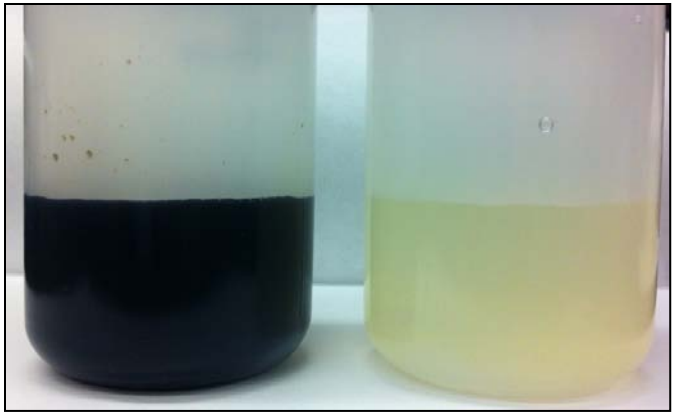
CLE Sugar Process

- Demonstrated effective on softwood and other feedstocks
- Uses scalable processes well-known in the pulp and paper industry
- Currently operate at kg scale
- Sugars are fermentable by yeast even without cleaning, but any necessary level of cleanliness can be achieved



Unpurified and purified softwood sugars: Both are fermentable!

Douglas-fir Syrup

Pine Sugar

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Softwood – Southern Pine Chips

Pilot Pretreatment Results

Pilot Pretreatment Size: 3 kg OD chips/1 cu ft digester	
Overall Sugar Yield on Wood Sugar (after hydrolysis)	87%
Furan Formation on Wood	<1.5%
Acetic Acid on Wood	~1.0%

CLE pretreatment produces high yield of sugar at low impurity levels and reasonable enzyme loading

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In Summary…

- **Catchlight Energy (CLE) has commercialized the feedstock and product integration elements of the biofuels supply chain**
- **CLE's strategy has adapted to a changing view of technology and markets**
  - Implementing wrap-around partnerships
  - Cost competitive technology is still on the horizon
  - Seek industrial and government collaborations to accelerate development of transformational Gen2.5 technology.
- **We are committed to a sustainable solution**
- **We are uniquely positioned to commercialize biofuels through scientific collaborations and strategic partnerships**

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Questions?

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