2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

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

Renewable Home Heating Oil for the Northeast

May 21, 2013

Principal Investigators: Thomas Butcher, Richard Boardman, Corrie Nichols, James Keiser, Jonathan Male, Corinne Valkenburg, Susanne Jones, Jacob Jacobson

Technology Area Review: Bio-oil

Organization: BNL, INL, ORNL, PNNL

Goal/Objectives Statement

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

The Goal Statement

- Evaluate the options of replacing up to 20 wt% petroleum derived fuel oil in the U.S. Northeast with infrastructure compatible bio-oil by 2022 thereby stabilizing the supply and cost spikes for heating oil

Major Project Objectives

- Displace petroleum used for home heating with bio-oil:
  - Focus on 7 billion gallons of heating oil used in homes, commercial, and educational buildings largely in the Northeast
  - Convert feedstock types abundant in the Northeast to raw bio-oil leveraging R&D on fast pyrolysis and upgrading within the Bioenergy Technologies Office portfolio
  - Identify the extent of upgrading need to formulate renewable Home Heating Oil (HHO) blends by mixing minimally upgraded bio-oils with HHO#2
  - Assemble data that could be start the pathways towards developing standards for renewable heating oil
- To deliver to the EERE Bioenergy Technologies Office the analysis of scenarios of how renewable heating oil blended at up to 20 wt% is beneficial for the NE and the nation

Quad Chart Overview

Timeline

- August, 2012
- September, 2014
- Percent complete 21%

Budget

- Funding for FY11: $0
- Funding for FY12: DOE Share:
  - PNNL $600k (3.2.2.26 E)
  - INL $400k (3.2.5.16)
  - ORNL $150k (3.2.2.16)
  - BNL $350k (3.6.1.5)
- Funding for FY13: $0
- Average DOE funding: $750/yr

Barriers

Barriers Addressed:

- Ft-A. Feedstock Availability and Cost
- Dt-C. Materials Compatibility
- Ct-A. Lack of Acceptance and Awareness
- Tt-E. Pyrolysis of Biomass and Bio-Oil Stabilization

Partners

- PNNL – FP, Upgrading, TEA/LCA
- CanmetENERGY – FP Scale-up
- INL - Feedstock supply and logistics
- ORNL – Corrosion studies
- BNL – Combustion
- National Oilheat Research Alliance – engage industry
- Stony Brook University – elastomer studies
- Mesa Reduction Engineering – feedstock logistics

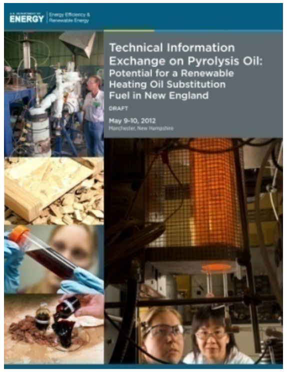
FP = Fast Pyrolysis

Need for Renewable Home Heating Oil in the Northeast

- Northeast is the location of >80% of the 7.2 million U.S. homes that used heating oil in 2009
- Average household consumes 850 gallons of heating oil per season (October – March)
- New York, Maine, Massachusetts, New Jersey, and Vermont have announced state mandates to transition to ultra-low sulfur fuels
- Minimally upgraded bio-oils as a heating oil substitute may present a significant opportunity to reduce heating oil price volatility, and reduce greenhouse gas emissions
- Global wood prices have varied between $65 and $120 per tonne, equivalent to about $4 - $7/million Btu
- Wood prices are typically more stable than crude oil prices

Technical Information Exchange on Pyrolysis Oil: Potential for Renewable Heating Oil Substitution Fuel in New England

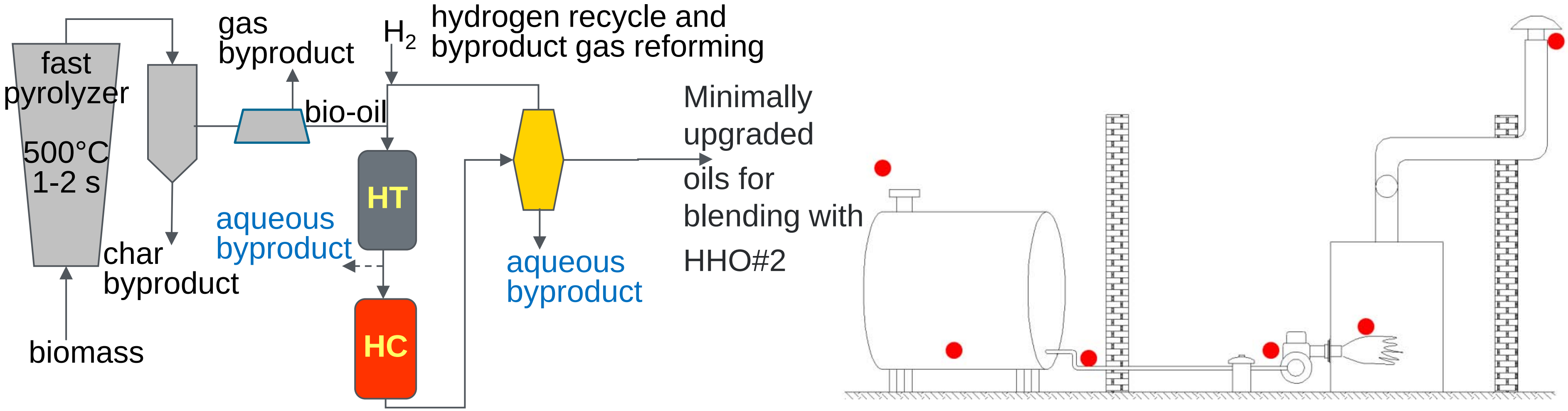
- The Information Exchange on Renewable Heating Oil Substitution Fuel In New England was held May 9-10, 2012
- The following were identified as challenge areas:
  - Feedstock and Production – feedstock availability, homogeneity, process and conditioning enhancements, and specifications
  - Logistics and Compatibility with Existing Infrastructure throughout the supply chain - substitution and replacement issues in transport, storage, and use
  - Operational Issues - what are the most significant barriers to overcome in each market segment?
- The next step identified at the workshop were:
  - Develop a pathway for addressing the key technical and non- technical challenges for delivering an acceptable commodity pyrolysis oil into an existing HHO supply chain
  - Develop an ASTM standard for a blended pyrolysis/HHO—with all the steps leading up to it
  - Understand the cost and performance tradeoffs for deploying a less than perfectly conditioned pyrolysis oil
  - Develop LCA, TEA



http://www1.eere.energy.gov/biomass/pdfs/pyrolysis_workshop_report.pdf

Project Overview

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



- This work is part of a coordinated effort involving PNNL (bio-oils and upgrading); INL (feedstock and logistics), ORNL (materials), BNL (combustion and market entry) - develop this market as a first point of entry for this fuel
- **Focus:** With fuels upgraded to different levels, evaluate all technical aspects in this market sector which affect safe, reliable deployment, and acceptance
- **Focus:** Flow properties, filtration, storage, corrosion, stability, elastomers, atomization and combustion, air pollutant emissions
- **Key Barriers Addressed:** Economic NE feedstocks, economic, minimal upgrading of bio-oil, blending, and infrastructure compatibility

1 – Approach Managerial

- Leverage related Bioenergy Technologies Office work (feedstock interface, pyrolysis, logistics modeling):
  - Work with local biomass suppliers to improve modeling efforts
  - Collect data from available research including BTS Update, INL Biomass Library, Biomass Logistics Model, etc.
  - Share data of feedstock harvesting and supply costs, including costs associated with specific feedstock properties
  - Ready exchange experimental data and new findings
  - Integrate increased understanding of process dynamics and effects of biomass properties into cost models
- Develop and Follow Approved Project Management Plans
  - Statement of work relates to DOE goals
  - Quarterly milestones and deliverables (reports)
  - Coordinate research activities to leverage all biomass research across laboratories
    - Frequent project communications
    - Shared quarterly reports

1 – Technical Approach: 3.2.5.16 INL

- Overall Technical Approach:
  - Analyze cost and quality of available biomass
  - Assess impacts of biomass characteristics versus conversion in-feed specifications and conversion performance
  - Collaborate with local biomass suppliers to validate models and data
  - Model entire biofuel process from logistics through conversion
- Success Metrics:
  - Predictive models for supply, preprocessing, and conversion performance, including determination of local least-cost biomass formulations
  - Reduced costs for feedstocks and delivered fuels
  - Identification of more optimal supply logistics
- Specific Technical Barriers:
  - Model biomass feedstock:
    - Availability, cost, specifications
  - Identify and supply pretreated key feedstocks for heat oil production

1 – Technical Approach: 3.2.2.26 Task E PNNL

- Raw fast pyrolysis derived bio-oil has many undesirable properties, the main technical barriers are: the removal of oxygenated species, cracking of hydrocarbons, and lifetime of upgrading catalysts
- Partner with CanmetENERGY and pyrolyze feedstocks representative of those found in the Northeast, and supplied in a form suitable from INL
- Minimally upgrade bio-oils such that they are miscible with No. 2 heating oil and characterize the species present. Supply sufficient quantities of minimally upgraded bio-oils to ORNL to enable corrosion studies, and BNL to enable combustion studies for residential heating systems
- Establish through available datasets and experimental data models that cover the entire supply chain for the economic viability or renewable heating oil in the U.S. Northeast
- Produce bio-oils and hydrotreat at the bench scale and optimize for continuous flow large hydrotreating

Energy & Fuels **2004** *18*: 590-598

1 - Technical Approach
3.2.2.16 ORNL

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

Activities are scheduled to be started in the third quarter of FY2013

Exposure of corrosion samples in fuel oil tanks or examination of fuel oil tanks taken out of service would provide benchmark or reference data on the corrosion of conventional containment materials in fuel oil

- Future activities include identifying exposure sites and providing corrosion samples for exposures in tanks both immersed in the oil and suspended above the oil
- Deposits in the bottom of fuel oil tanks with many years of service will be collected to provide evidence on the type and extent of corrosion of conventional containment materials in home heating oil

Laboratory corrosion tests provide a means of collecting data on the rate and extent of degradation of containment materials in selected, well controlled environments

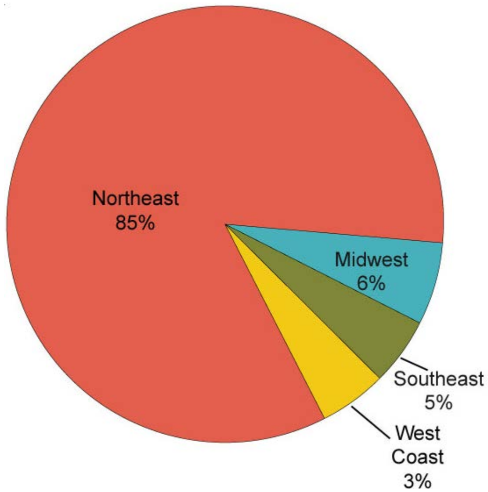
- Laboratory corrosion tests will be used to expose conventional fuel tank materials to four selected liquid environments including home heating oil, hydrotreated biomass-derived oil, and two selected blends of home heating oil and hydrotreated oil

1 – Technical Approach: 3.6.1.5 BNL

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

- Build on prior experience with alternative fuels in this area including biodiesel, SVO, 100% FFA, CTL, GTL, pyrolysis oil
- Utilize a staged approach to establishing upgrading required – eliminate fuels (upgrade level) early that will not meet the needs
- Define fuel (oxygen, TAN, acid composition) properties to support establishing a standard (ASTM)
- For defined fuel, build strong technical case to support acceptance:
  - Basic fuel properties
  - Storage stability – standard protocols
  - Elastomer compatibility – focus on common nitrile shaft seal
  - Combustion and emissions – CO, HC, NO_x, particulates. Performance tests against UL296
  - Technical documentation to ASTM
  - Engage National Oilheat Research Alliance (NORA) as members of diverse industry

U.S. Heat Oil Consumption



Biomass Supply Analysis

The majority of heating oil is consumed in the Northeast, most in New York, Pennsylvania, Massachusetts, and Connecticut

Area Considered

Northeast Home Heating Oil Consumption
(Average 2005-2010)

	Gallons
Annual Consumption	5,466,092,500
Bio-Oil Required - 5%	273,304,625
Bio-Oil Required - 20%	1,093,218,500

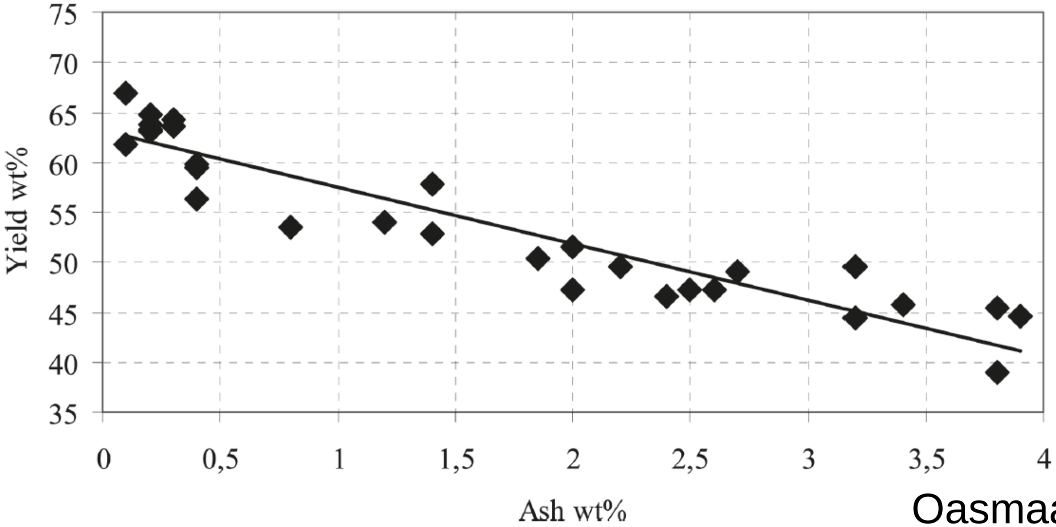
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Pyrolysis production yield tied to feedstock quality
- Feedstock properties tracked in INL Sample Library
- Expected ash content determined

Type:	Source:	Ash %				
		%	St. Dev.	Median	Min	Max
Willow	SL	1.76				
Willow	LDB	1.37				
Poplar	SL	0.78				
Hybrid Poplar	LDB	0.82				
Loblolly Pine	SL	0.87	1.05	0.57	0.27	5.54
Pine	SL	1.32				
Pine	LDB	3.72				
Maple	SL	0.39				
Oak	SL	1.68				
Wheat Straw	SL	11.76	7.10	9.80	0.54	49.46
Wheat Straw	LDB	5.76				
Corn Stover	SL	14.64	10.09	10.81	0.83	59.35
Corn Stover	LDB	7.09				

SL = INL Sample Library
LDB = INL Literature Database

Dry Pyrolysis Oil Yield vs. Feedstock Ash (VTT)



Ash reduction is expensive, and the effect on downstream processes must be understood

Oasmaa, A. *et al* *Energy Fuels* **2010**, *24*, 1380-1388

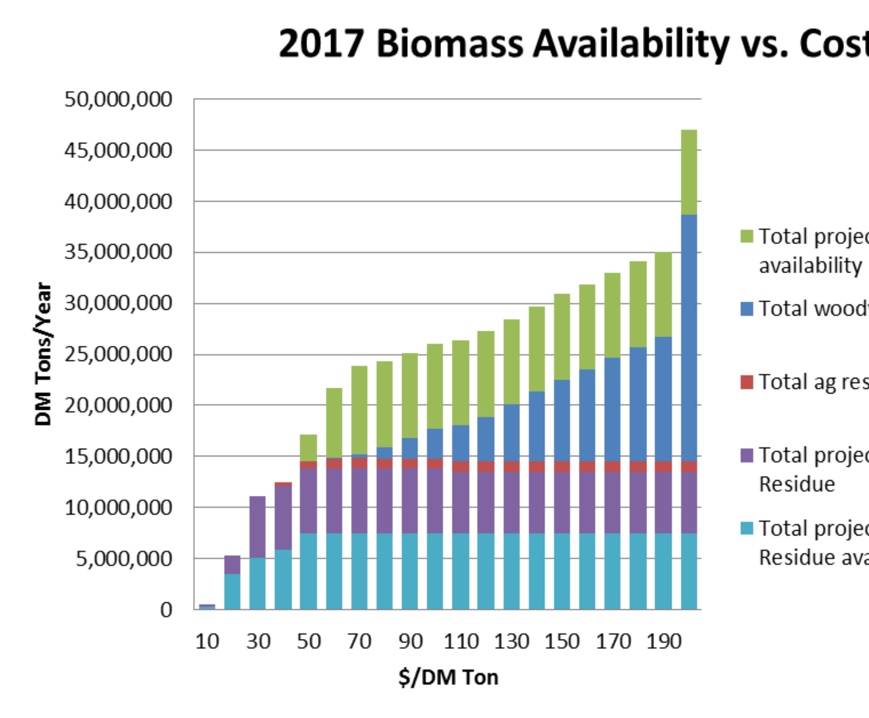
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Pyrolysis and Upgrading Yield	Lbs Biomass Required 5% Case	Lbs Biomass Required 20% Case	Tons Biomass Required 5% Case	Tons Biomass Required 20% Case
30%	8,654,646,458	34,618,585,833	4,327,323	17,309,293
35%*	7,418,268,393	29,673,073,571	3,709,134	14,836,537
40%	6,490,984,844	25,963,939,375	3,245,492	12,981,970
45%	5,769,764,306	23,079,057,222	2,884,882	11,539,529
50%	5,192,787,875	20,771,151,500	2,596,394	10,385,576
55%	4,720,716,250	18,882,865,000	2,360,358	9,441,433
60%	4,327,323,229	17,309,292,917	2,163,662	8,654,646
65%**	3,994,452,212	15,977,808,846	1,997,226	7,988,904

* MYPP 2012 fully upgraded, fully stable bio fuel (2017 Projection).
** MYPP 2012 Pyrolysis oil yield (2017 Projection).

Feedstock Cost Analysis

Biomass Required for Replacement Goals



OAK RIDGE National Laboratory

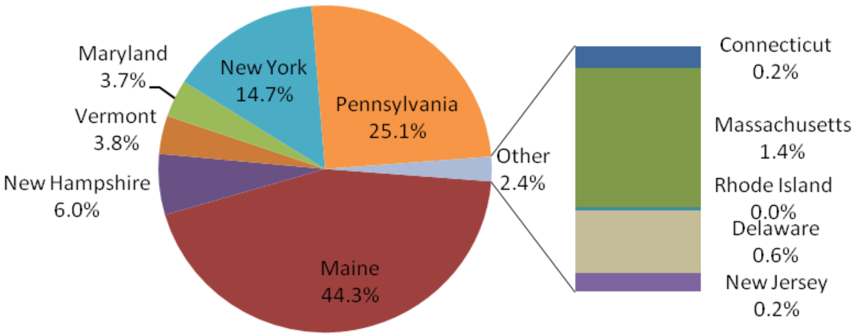
Sufficient low-cost biomass is available to meet demand for even conservative yield estimates for 5% case.

(Primarily Mill and Woody Residues)

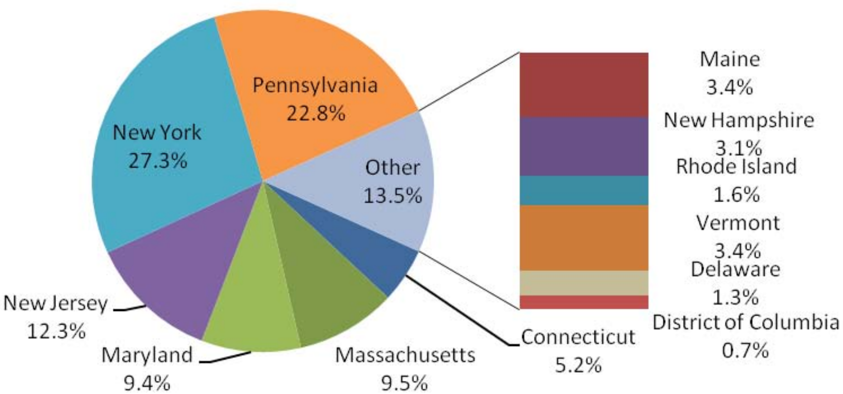
2 - Technical Accomplishments 3.2.5.16 INL

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

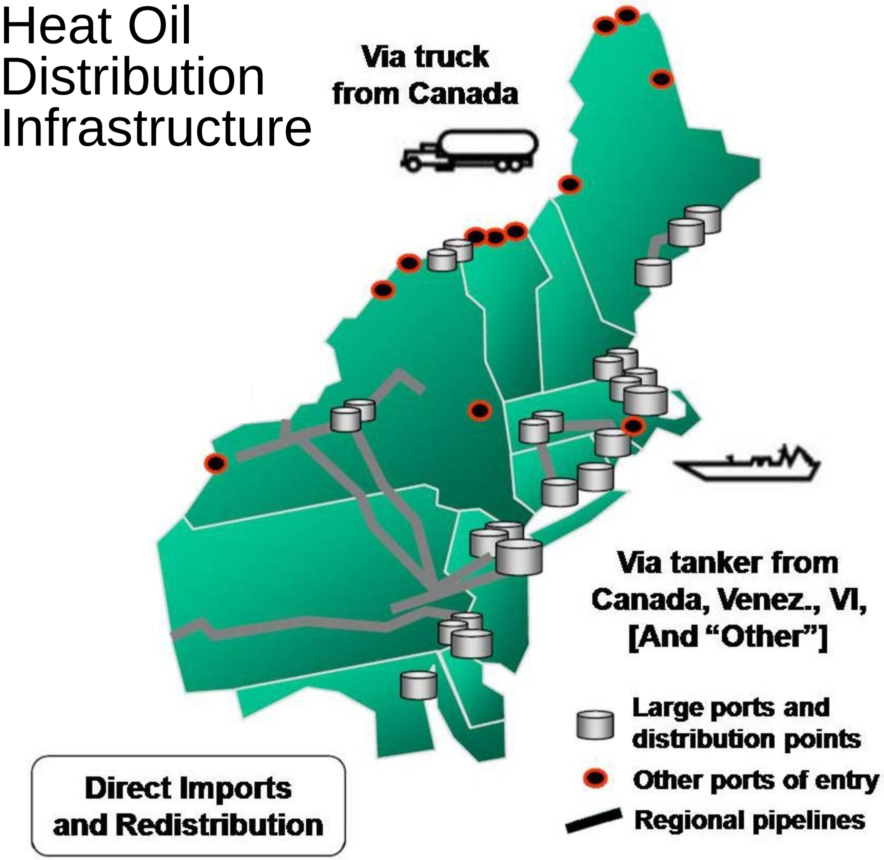
Distribution of Woody Residue Available at $40/DM Ton in 2017



Distribution of Woody Waste Available at $50/DM Ton in 2017



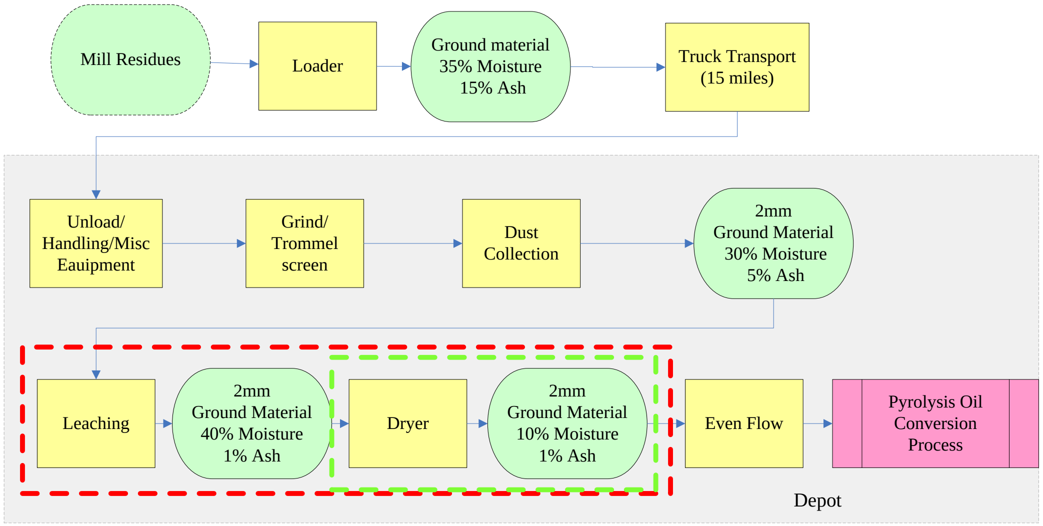
Heat Oil Distribution Infrastructure



Biomass availability aligns well with the heat oil distribution infrastructure for most types of low-cost biomass

2 - Technical Accomplishments 3.2.5.16 INL

- Logistics Models
  - Based on 15 mile transport
  - Optimal pyrolysis plant distribution tied to scalability (economies of scale versus transportation costs)
- Biomass types determine preprocessing operations



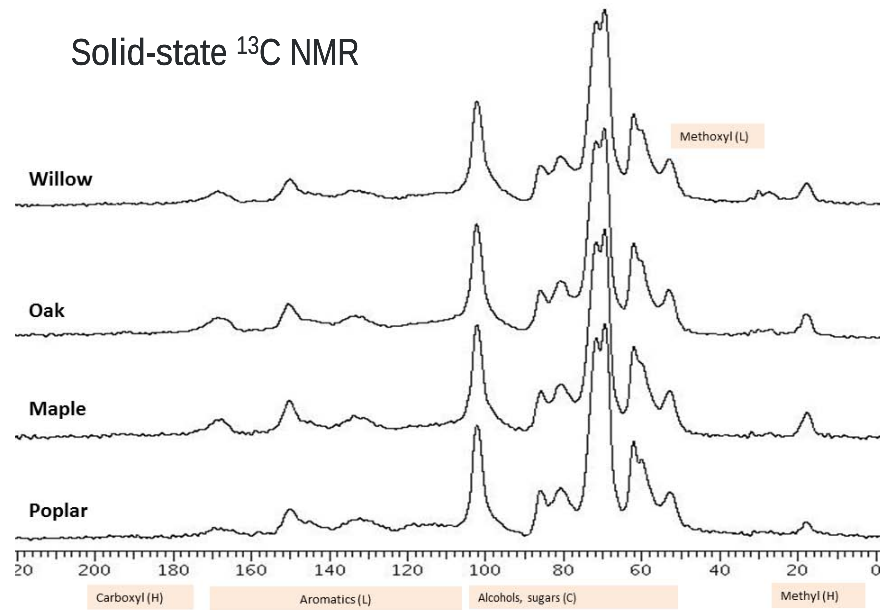
Ash reduction is expensive, overall specification must be explored to deliver optimal biomass condition, and cost

Preprocessing Costs

	Harvesting	Transport	Preprocessing	Storage	Total	Total w/o Harvesting
Stover 1	$57.78	$6.66	$20.71	$7.27	$92.42	**$34.64**
Stover 2	$57.78	$6.66	$29.35	$7.27	$101.03	**$43.28**
Stover 3	$57.78	$6.66	$62.12	$7.27	$133.83	**$76.05**
Thinnings 1	$29.15	$4.42	$47.69	$1.18	$82.44	**$53.29**
Thinnings 2	$29.15	$4.42	$63.51	$1.18	$98.26	**$69.11**
Thinnings 3	$29.15	$4.42	$77.47	$1.18	$112.22	**$83.07**
Mill Residues 1	$0.00	$4.10	$32.89	$0.72	$37.71	**$37.71**
Mill Residues 2	$0.00	$4.10	$45.50	$0.72	$50.32	**$50.32**
Mill Residues 3	$0.00	$4.10	$56.42	$0.72	$61.24	**$61.24**
Willow 1	$16.94	$6.38	$69.17	$0.60	$93.08	**$76.15**
Willow 2	$16.94	$6.38	$100.86	$0.60	$124.77	**$107.84**
Willow 3	$16.94	$6.38	$127.70	$0.60	$151.61	**$134.68**

- INL identified four promising feedstocks that are available in the NE and shipped samples to PNNL
  - Characterization carried out at INL and PNNL
- Solid state ^{13}C NMR carried out to identify various functional groups
  - The peaks are assigned to typical building blocks associated with cellulose (C), lignin (L), and hemicellulose (H) as published.[1]
- Other than the ash content the feedstocks were similar to each other

	% Volatile	% Ash	% Fixed Carbon	HHV (BTU/lb)	LHV (BTU/lb)
Poplar	75.46	1.33	16.69	7,901.5	6,354.8
Maple	79.72	0.39	15.77	8,058.7	6,581.6
Oak	72.07	1.68	17.52	7,823.1	6,240.0
Willow	74.03	1.76	18.18	8,040.2	6,517. 9



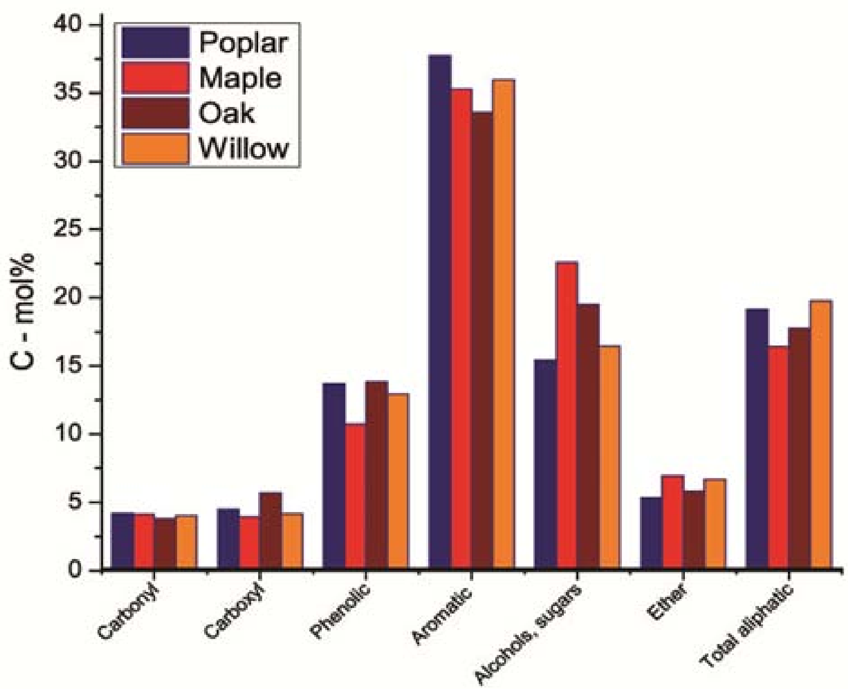
[1]Freitas (Carbon *39*, **2001**, 535-545).

2 - Technical Accomplishments 3.2.2.26 E PNNL

- Lower ash feedstock results in
  - Higher oil yields
  - Lower char content in oils
- Solid state ^{13}C NMR carried out to identify various organic functional groups in oils
  - More pronounced presence of carbonyl moieties such as acids, aldehydes and ketones compared to the feedstock
  - There are small variations in the chemical composition of bio oils
- During thermal depolymerization of the feedstock
  - Different degrees of accessibility to reactions pathways gives rise to variable product distributions
  - Significant amount of acidic and oxygen containing products are formed

Pyrolysis yields

Feed	Feed ash%	wt% Oils	wt% Char	wt% Gases
Poplar	1.1	61%	16%	17%
Maple	0.4	64%	12%	15%
Oak	1.5	55%	18%	14%
Willow	1.6	52%	19%	25%



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

- Inorganic content of the feedstock, oil, and char was studied using ICP - AES
  - High Ca and K levels were found in Poplar, Oak, and Willow
  - Oil based on Maple had the lowest inorganic content
  - Large amounts of Si are present in Willow feedstock
- Majority of the inorganics present in feedstock will be removed as char

	Feedstock				Char				Bio oils			
	Poplar	Maple	Oak	Willow	Poplar	Maple	Oak	Willow	Poplar	Maple	Oak	Willow
Al	73.6	41.7	69.9	121.5	248.1	145.8	326.9	375.7	ND	15.4	13.5	ND
Ca	2,425.0	880.8	4,490.5	3,380.0	13,045.0	7,712.5	30,005.0	19,205.0	230.4	57.4	259.6	214.9
Fe	ND	ND	ND	47.1	378.5	143.0	312.0	415.6	ND	7.4	ND	ND
K	2,037.0	697.6	1,343.5	2,482.0	10,270.0	4,353.0	5,653.5	10,965.0	262.7	53.5	124.6	243.2
Mg	354.4	171.8	259.5	190.0	1,855.0	1,387.5	1,338.5	1,075.5	ND	ND	18.1	ND
Mn	ND	ND	ND	ND	ND	154.7	142.3	77.2	ND	ND	ND	ND
Na	37.1	ND	ND	ND	384.0	364.3	383.9	211.4	116.5	31.8	38.5	105.6
P	51.4	33.3	117.6	211.4	301.4	504.6	698.2	1,275.0	ND	ND	15.4	ND
Zn	ND	ND	ND	ND	63.5	59.8	ND	ND	ND	ND	ND	ND
Si	92.2	ND	47.4	258.9	671.1	221.9	480.0	521.3	63.3	10.5	14.6	32.3
S	173.2	45.9	174.2	153.8	314.7	128.5	136.6	434.1	88.5	38.9	115.8	85.8

2 - Technical Accomplishments 3.2.2.26 E PNNL

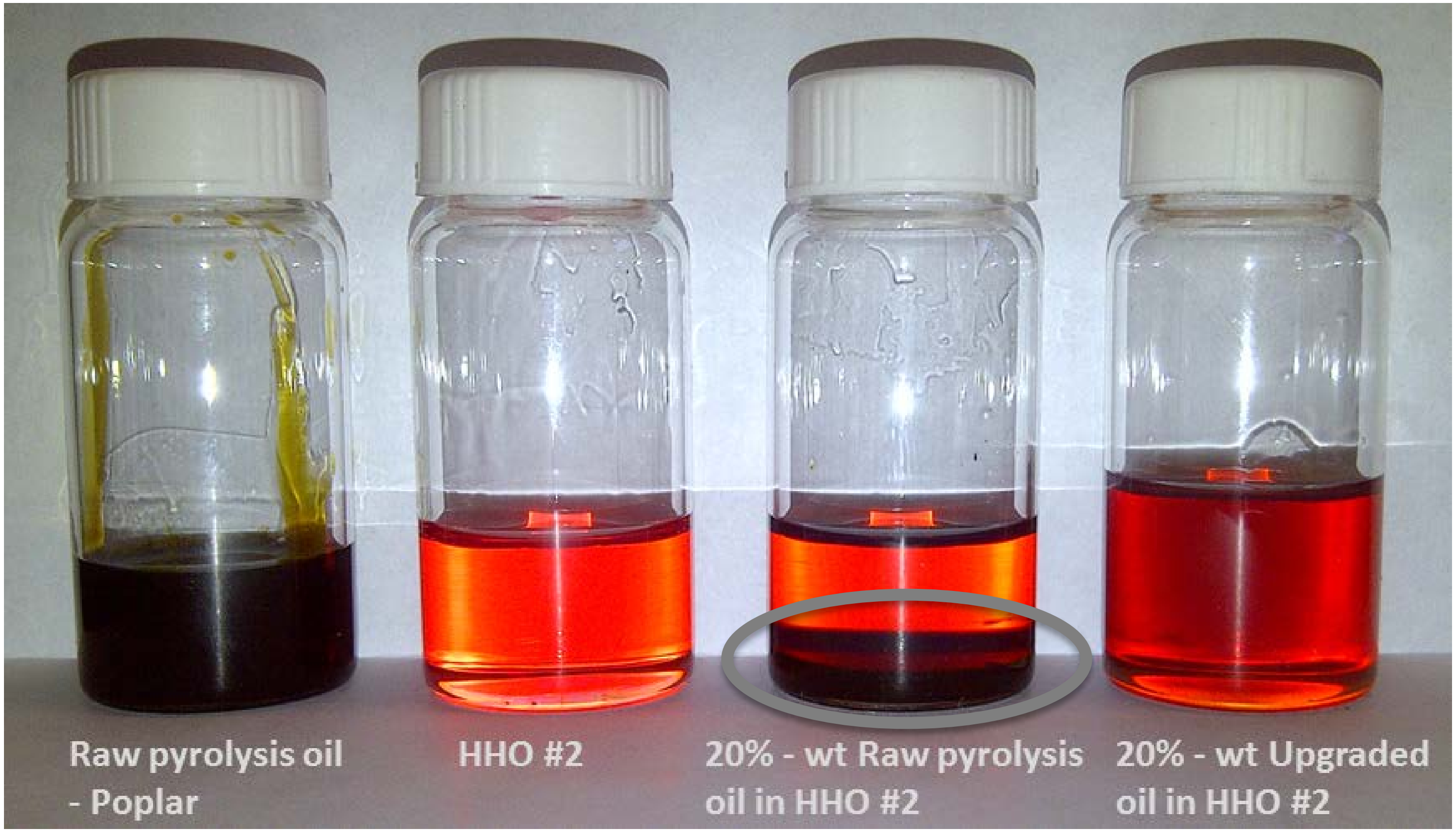
- Standard characterizations of the bio oils were carried out
- Acid, water, and oxygen content higher then what is required for HHO
- Viscosity and the density of the raw oils are higher than that of HHO#2 (2.32 cP, 0.827 g/cm^3)
- To form a perfectly blended renewable home heating oil
  - Acid contents needs to be lowered to account for corrosion issues
  - Water and oxygen containing species must be removed to maintain a high heating value

Feed	Viscosity (cP)	Density (g/mL)	% water	TAN (mg KOH/g)	HHV (MJ/kg)
Poplar	46.86	1.157	15.3	118.3	20.91
Maple	83.51	1.198	12.6	115.8	21.27
Oak	91.32	1.162	13.4	119.7	21.77
Willow	86.16	1.164	15.7	117.0	21.38

2 - Technical Accomplishments 3.2.2.26 E PNNL

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

- Miscibility of Raw pyrolysis oils in HHO No.2 was studied:
  - The raw bio-oil (42.28% wt Oxygen, Density: 1.157g/mL) – not miscible
  - Fully upgraded oil (1.5% wt Oxygen, Density: 0.854g/mL) – miscible



The opportunity is to develop a economic, miscible, minimally upgraded bio-oil

2 - Technical Accomplishments 3.2.2.26 E PNNL

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

- Minimal upgrading of pyrolysis oils based on poplar was carried out
- The objective was to obtain two partially upgraded products
- Upgrading was carried out at 370 ^{o}C then lowered to 350 ^{o}C
  - Lower TAN and density than feed
  - Lower Oxygen content
  - Sulfur < 0.005 wt %
- Medium and low oxygen containing oils were obtained

Temp (^{o}C)	Time	TAN (mg-KOH/g)	Oxygen	% water	Density (g/mL)
Raw Pyrolysis oil		118.3	42.28 %	15.25%	1.157
370	05:07-07:00	1.75	1.80 %	0.16 %	0.895
370	11:00-13:00	1.54	2.95 %	0.16 %	0.918
350	19:00-22:00	2.25	13.75%	2.19 %	0.925
Oxygen measured using ASTM D5373 modified, and values reported without any further manipulation					

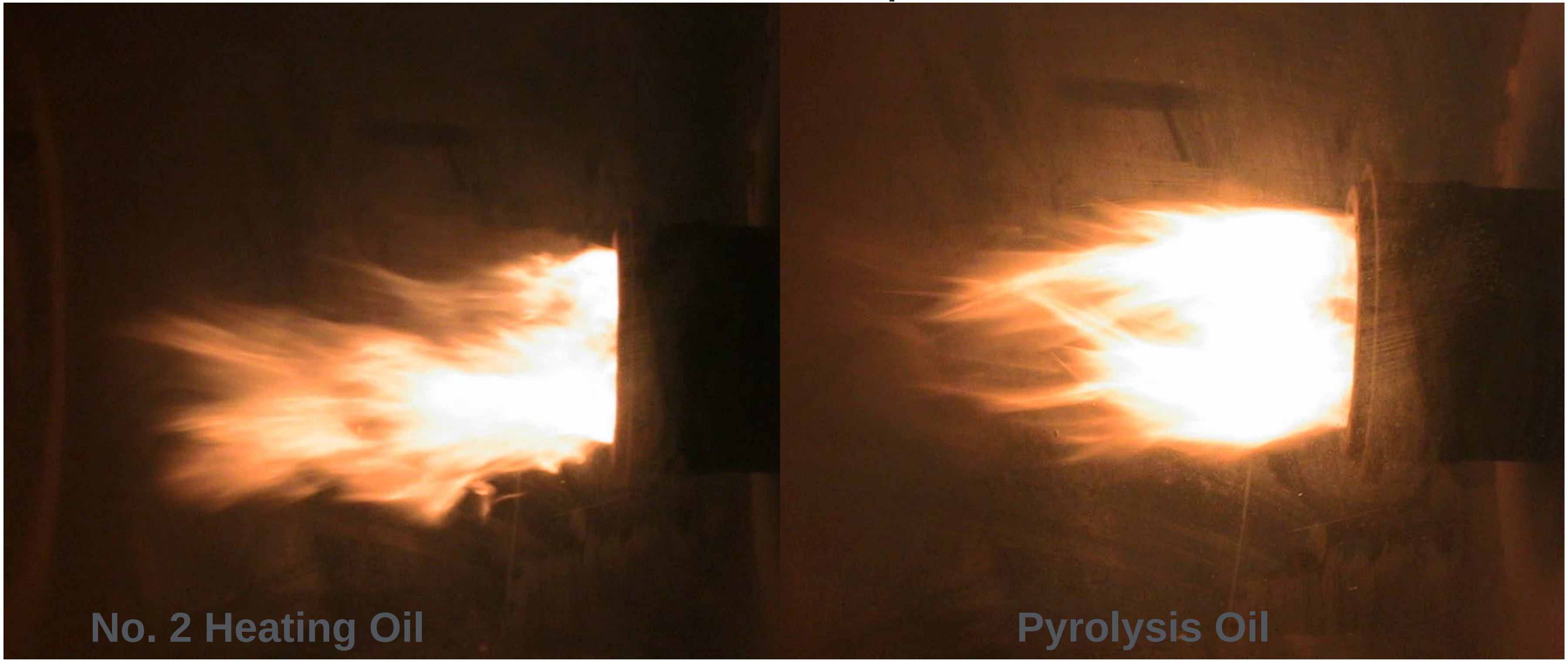
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BNL Heating Systems and Fuels Lab

- Preliminary evaluation of minimally upgraded fuels
  - Elastomer compatibility
  - Basic combustion performance in target equipment
- Collaboration and planning with other labs

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

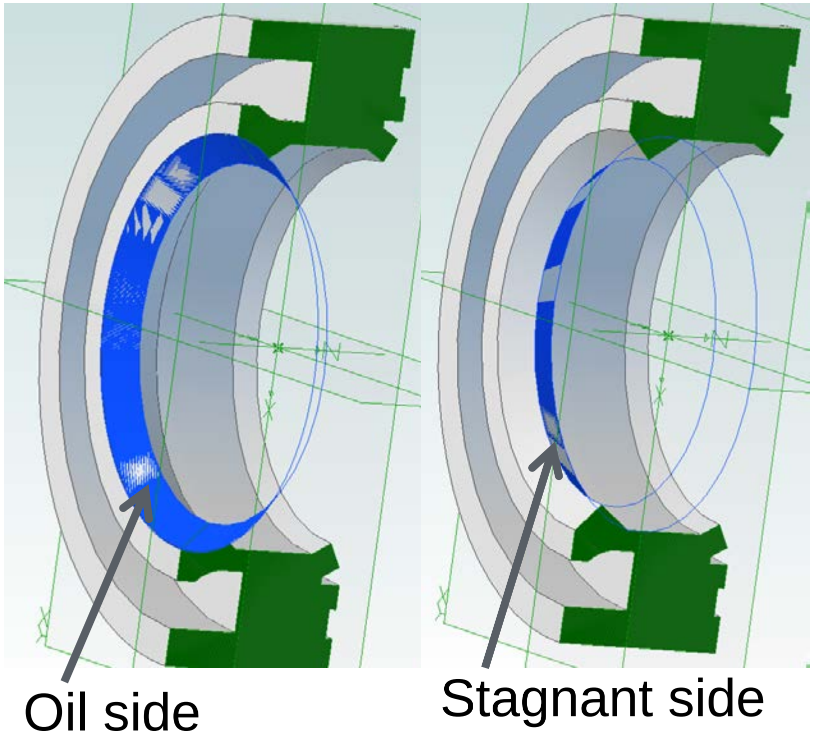
Residential Oil Burner – Flame Comparison



- BNL Quartz Combustion Chamber, Conventional swirl-pressure atomizer and residential burner, fuel at 300 psi, 116 °C - Lower NO_x, higher CO in these preliminary tests
- Raw pyrolysis oil is not suitable for more detailed evaluation in this application

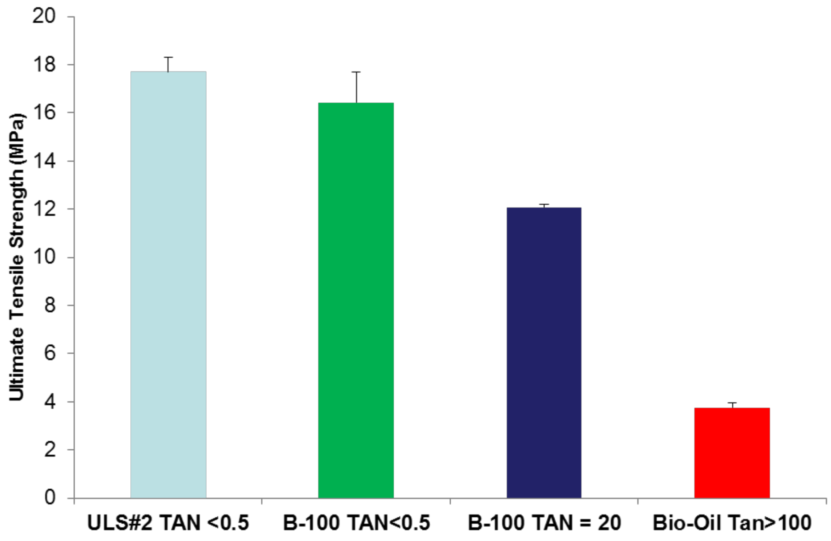
Seal Material Compatibility

- Long-term compatibility with legacy seal material expected to be a key parameter in setting minimum upgrade requirements
- Most legacy burners have the same nitrile seal



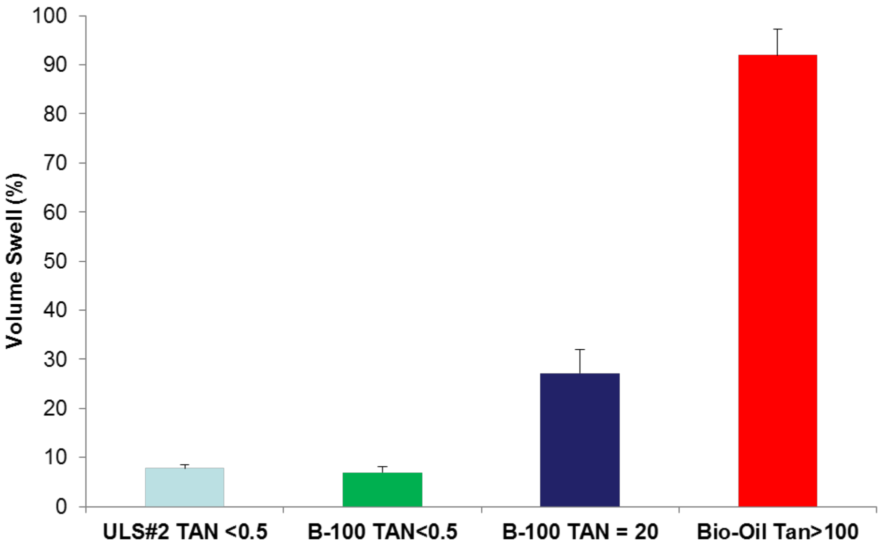
Heating in the seal cavity can lead to fuel degradation, seal damage, and fuel leakage – a strong concern in home heating systems

Tensile Strength – Acid Number Effect



Volume Swell – Acid Number Effect

ASTM D471



Seal performance in burners would be dramatically impacted with raw pyrolysis oil – this serves as a benchmark

2 – Technical Progress - INL

Title	Completion	Status
Obtain, condition and supply 4 representative pedigree northeastern U.S. samples of biomass to PNNL for pyrolysis.	30-Sep-12	✓
Preliminary report on feedstock specification targets and supply logistics for pyrolysis process input for renewable heating oil production	30-Sep-12	✓
Northeast feedstock supply technical and economic analysis (<$65/dry ton, 5% heat oil replacement)	31-Mar-13	✓
Support PNNL in pyrolysis testing by supplying additional feedstock material as required	30-Sep-13	Underway
Preliminary pyrolysis oils supply cost-benefit study (support PNNL)	30-Sep-13	On Schedule

2 – Technical Progress - PNNL

Title	Completion	Status
Report on pyrolysis oil production and supply assumptions	31-Jan-13	✓
Pyrolize 2 New England State materials for bio-oil partial upgrading studies.	31-Jan-13	✓
Partial upgrading and stabilization of the 2 oils.	30-Apr-13	✓
Develop TEA and LCA model of a renewable heating oil plant.	30-Jun-13	Underway
Preliminary pyrolysis oil supply cost benefit analysis report	30-Sep-13	On schedule

Due to rigorous Hazards and Operability studies (HAZOPs) of the large scale hydrotreater and separations system and the need to address additional findings the scheduled supply of gallon quantities of minimally upgraded bio-oils to ORNL and BNL in March has been delayed until July

2 – Technical Progress - BNL

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

Title	Completion	Status
Preliminary Combustion Tests	January 2013	Done
Elastomer effects – minimally upgraded oil	May 2013	Done
Isolate impacts of acid number on nitrile	July 2013	In Progress
Nitrile compatibility tests with PNNL upgraded oil	Sept. 2013	On schedule

Much of the work at BNL is delayed, pending supply of the upgraded bio-oil samples from PNNL. 5% of budget spent to date.

2 – Technical Progress - ORNL

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

Title	Completion	Status
Identify sites for exposure of samples to determine corrosion rates in home heating oil blending, operating and storage systems	June, 2013	Planned
Determine conditions and materials to be used for laboratory corrosion tests	July, 2013	Planned
Fabricate and install corrosion samples in sites identified for studies	September, 2013	Planned
Initiate laboratory corrosion tests in selected environments	October 2013	Planned

3 – Relevance: Multi-Year Program Plan

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

- **Overall BETO Mission**: “Fuels, products, and power from biomass”
- **Milestone, Bio-Oil Pathways R&D**: “By 2013, define requirements for characterizing heating oil from biomass and establish an R&D strategy”
- **Target, Bio-Oils Pathways R&D**: “By 2017, achieve a conversion cost of $1.83 per gallon” (supported by better understanding product minimum requirements)
- **Target, Strategic Communications**: “By 2014, complete outreach efforts focused on new Program technologies, pathways, and directions”.

Text in quotes is from the Bioenergy Technologies Office’s Multi-Year Program Plan, November 2012

3 – Relevance: Bioenergy Industry

- The home heating sector represents a significant entry market with less technical challenges than transportation
  - Technically simpler equipment
  - Better defined storage and use conditions
- Addressing technical, logistical issues, and achieving a pathway to standards, and market impact goals in this adjacent application will facilitate acceptance in the larger transportation market
- With current high fuel costs, and competition from other energy sources (natural gas, wood, electric) this market sector is motivated to engage with biofuels
- Moves to eliminate residual oil and move to Ultra Low Sulfur Diesel for air quality reasons create a market opportunity for renewables

4 – Critical Success Factors

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

- Reduced cost of feedstock, supply & pre-conversion operations (ash reduction, drying)
  - Need low cost pre-conversion operations to bring low-cost feedstocks into specification range with conversion technologies
- Fuel must meet miscibility, stability, corrosion, compatibility, combustion, and emissions requirements as a drop-in fuel. Blend target is 20% by volume
  - Minimal upgrading of bio-oil to meet infrastructure compatibility
- Challenges
  - High cost of ash removal and impact of ash on conversion process efficiency
  - Systemic understanding of the entire supply/conversion chain to reduce the overall cost of producing a cost competitive bio-oil
  - Define minimum upgrading level to enable compatibility economically
  - Fully define what the target fuel must be and develop a pathway to a formal standard for this market
- This project is engaged with the National Oilheat Research Alliance (NORA) to ensure focus on the market needs

5. Future Work - INL

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

Description	FY 13 Q3	FY 13 Q4	FY 14 Q1	FY 14 Q2	FY 14 Q3	FY 14 Q4
Refine northeast projections with information from Mesa Reduction Engineering	■					
Provide material samples as requested for further testing	■	■				
Support PNNL in the development of preliminary cost benefit analysis report	■	■				
Formalized framework to integrate BTS, Biomass Logistics Model, Sample Library, Conversion Process Models		■	■			
Refinement of INL Logistics Model for prediction of biomass cost and optimal preprocessing operations				■		
Include preliminary cost benefit analysis results into optimal biomass formulation					■	
Finalize overall best formulation model for biomass supply for heat oil production						■

5. Future Work - PNNL/CanmetENERGY

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

ML or DL or Go/No Go	Description	FY13 Q3	FY13 Q4	FY14 Q1	FY14 Q2	FY14 Q3	FY14 Q4
E.ML.3	Partial upgrading and stabilization of the 2 oils.						
E.ML.4	Develop TEA and LCA model of a renewable heating oil plant.						
E.DL.1	Preliminary pyrolysis oil supply cost benefit analysis report						
E.ML.5	Scaled-up pyrolysis of 3 NE biomass						
E.ML.6	Scaled-up upgrading of 3 NE bio-oils						
E.GN.1	Demonstration of renewable fuel oil						
E.ML.7	Report capturing the analysis and feasibility of minimally upgraded bio-oils for home heating oil in the NE						

Key Milestones

- Blending studies
- Large scale production of pyrolysis oil and minimal upgrading
- Provide blended HHO oils for further testing by ORNL and BNL

Large Hydrotreater and Separations Equipment

Goal: Construct bio-oil upgrader/distillation unit to produce fuel cuts at scale relevant to industry testing and acceptance

Status:

- Construction and acceptance testing complete
- System delivered and enclosure complete
- Completed HAZOP with internal- and external-consultants, and stakeholders
- Awaiting tie-in, SOP completion, and shakedown testing

5. Future Work - BNL

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

	FY 13					FY 14									
	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	March	April	May	Jun	July
1. Fuel Characterization			■	■											
2. Storage and Stability				■	■	■	■	■	■						
3. Elastomer Compatibility	■	■	■	■	■	■	■	■	■						
4. Combustion and Emissions					■	■	■								
5. Standards Development										■	■	■	■	■	■
6. Industry Information Exchange		■	■	■	■	■	■	■	■	■	■	■	■	■	■

- Receive fuel samples – July 1, 2013
- Complete fuel characterization – Aug 31, 2013
- Complete combustion studies – Nov 30, 2013
- Complete elastomer and storage studies – Jan 31, 2014
- Submit standard proposal package including technical documentation – July 31, 2014

5. Future Work - BNL

- The National Oilheat Research Alliance (NORA) is the national association responsible for the research, educational needs, and consumer education of the industry

NORA tasks will include:

- Works with every level of the industry with petroleum wholesalers, retailers, manufacturers, and researchers serving on its Board
- NORA supported a technical team in the qualification of biodiesel blends, now in widespread use
- In this project, tasks will include focused meetings with industry leaders, preparation of briefing materials – brochures, web info, and trade journal articles, presentations at key industry conferences
- NORA will provide feedback on key concerns and logistical barriers

5. Future Work - ORNL

Description	FY13 Q3	FY13 Q4	FY14 Q1	FY14 Q2	FY14 Q3	FY14 Q4
Identify sample exposure sites	■					
Determine laboratory corrosion test conditions		■				
Fabricate and install corrosion samples		■	■	■	■	
Initiate laboratory corrosion tests			■	■	■	■

- In order to assess the performance of currently used home heating oil containment materials in environments developed when biomass-based oils are blended with home heating oil, sites will be selected and corrosion samples exposed in the selected sites
- Laboratory corrosion tests will be conducted to expose current home heating oil containment materials in four liquids – fuel oil #2, biomass-derived hydrotreated oil, and two blends of oil #2 and hydrotreated oil (currently planned: 5 wt% and 20 wt%)

Summary

Relevance: The heating oil market represents a significant market opportunity for upgraded pyrolysis oil

Approach: A collaborative project of INL, PNNL, BNL, ORNL, and others, and will continue to leverage available research and efforts of other projects to accomplish the goal of identifying more optimal feedstock supply, and the minimum level of upgrading required to achieve a drop-in fuel

Technical accomplishments: Technical scope includes fuel properties, materials issues, storage and stability, and combustion performance. Detailed characterization of feedstocks and bio-oils has begun for renewable heating oil in the Northeast

Future work: A detailed fuel specification and a pathway to a standard is needed for this fuel to be accepted in this market sector

Success factors and challenges: Critical success factors include the integration of data into larger cost models along the entire length of the supply chain in order to maximize beneficial trade-offs

Technology Transfer: The project includes continuous industry engagement through NORA to ensure “voice-of-the-customer” is heard

Additional Slides

Responses to Previous Reviewers' Comments

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

- This was a new project started in late FY2102

Presentations

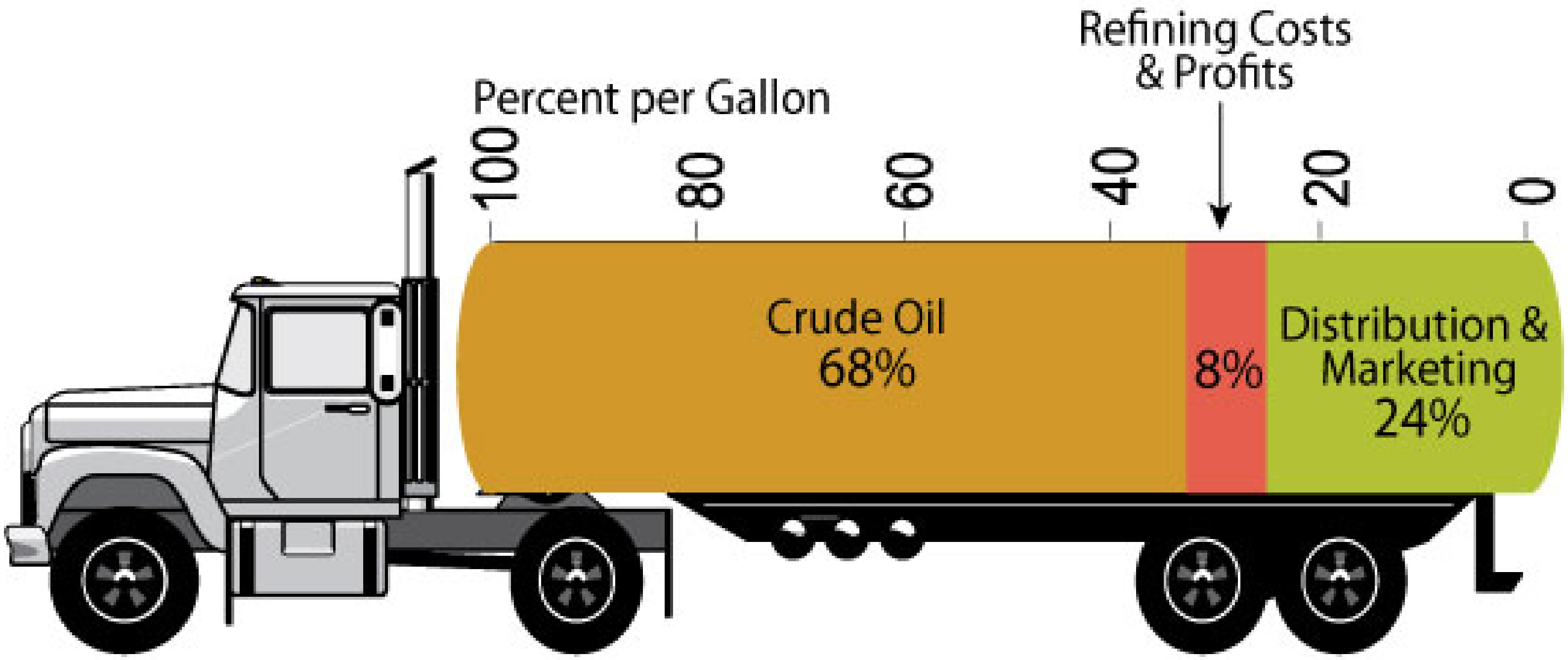
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Renewable Home Heating Oil in the Northeastern U.S., T. Butcher, and E. Levine, U.S. DOE. Advanced Energy Conference, New York City, May 1, 2013.
- Qualification of Alternative Fuels, T. Butcher, J. Huber, DOE Technical Information Exchange on Pyrolysis Oil Workshop, New Hampshire, May 8, 2012.
- Integrated System Sensitivities and Perspective - A qualitative discussion on conversion, stabilization, and upgrading versus infrastructure compatibility and retrofit requirements J. L. Male, DOE Technical Information Exchange on Pyrolysis Oil Workshop, New Hampshire, May 8, 2012.

Breakdown of Heating Oil Price - Background

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

What We Pay for in a Gallon of Heating Oil, 2010

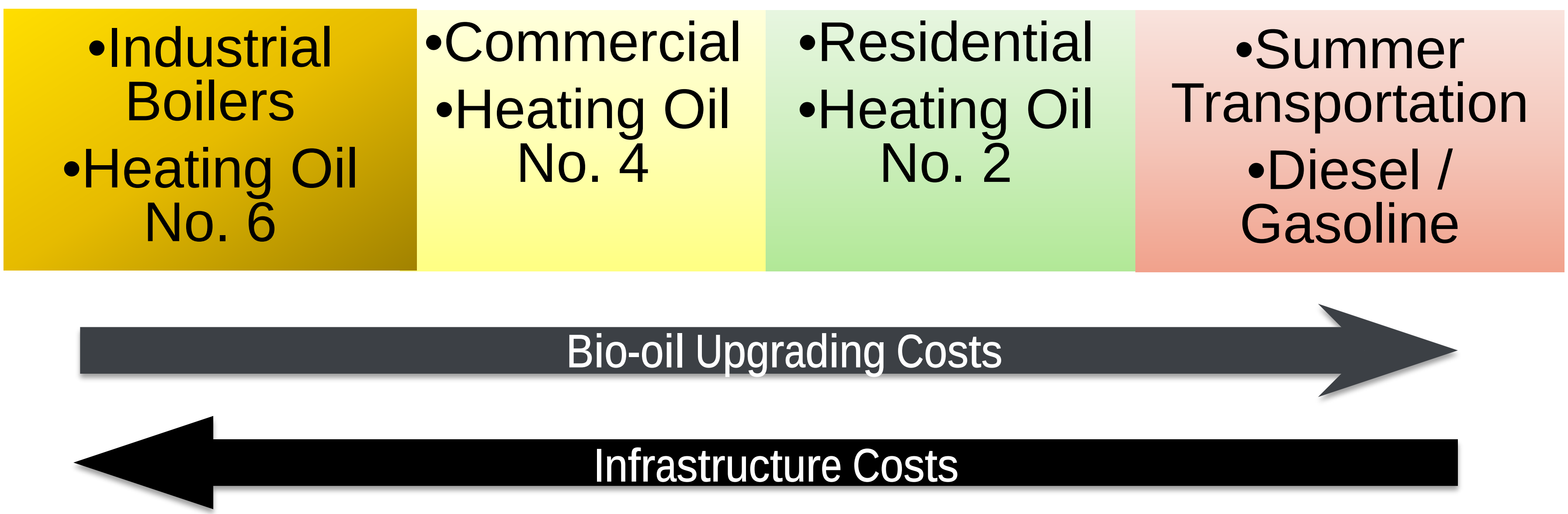


Note: Sum of the components may not equal 100% due to independent rounding.
Source: U.S. Energy Information Administration, *Petroleum Marketing Monthly*, Table 15 (July 2011)

Balancing Upgrading and Infrastructure Modification Costs

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

- Raw bio-oil can be used in a modified commercial application
- A minimally upgraded bio-oil either 100% or blended would be needed for residential application



Potential Bio-oil Market

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

•Bio-Oil Production

Raw Bio-oil

Raw Bio-oil

Upgrading Continuum

Conditioned Bio-oil:
- Char/mineral filtration
- Solvent addition/emulsion
- Oil fractionation

Partially Upgraded Bio-oil:
- Char/mineral filtration
- Moderate hydrotreating
- Decarboxylation

Fully Upgraded Bio-oil:
- Char/mineral filtration
- Severe hydrotreating
- Decarboxylation

Industrial/Commercial

No. 6 fuel oil

No. 6/No. 2 blends

•Technology exists and is about to be deployed

~10% of market*

Home Heating Oil

No. 2 fuel oil

Diesel

•Program efforts focus on technology gaps and readiness

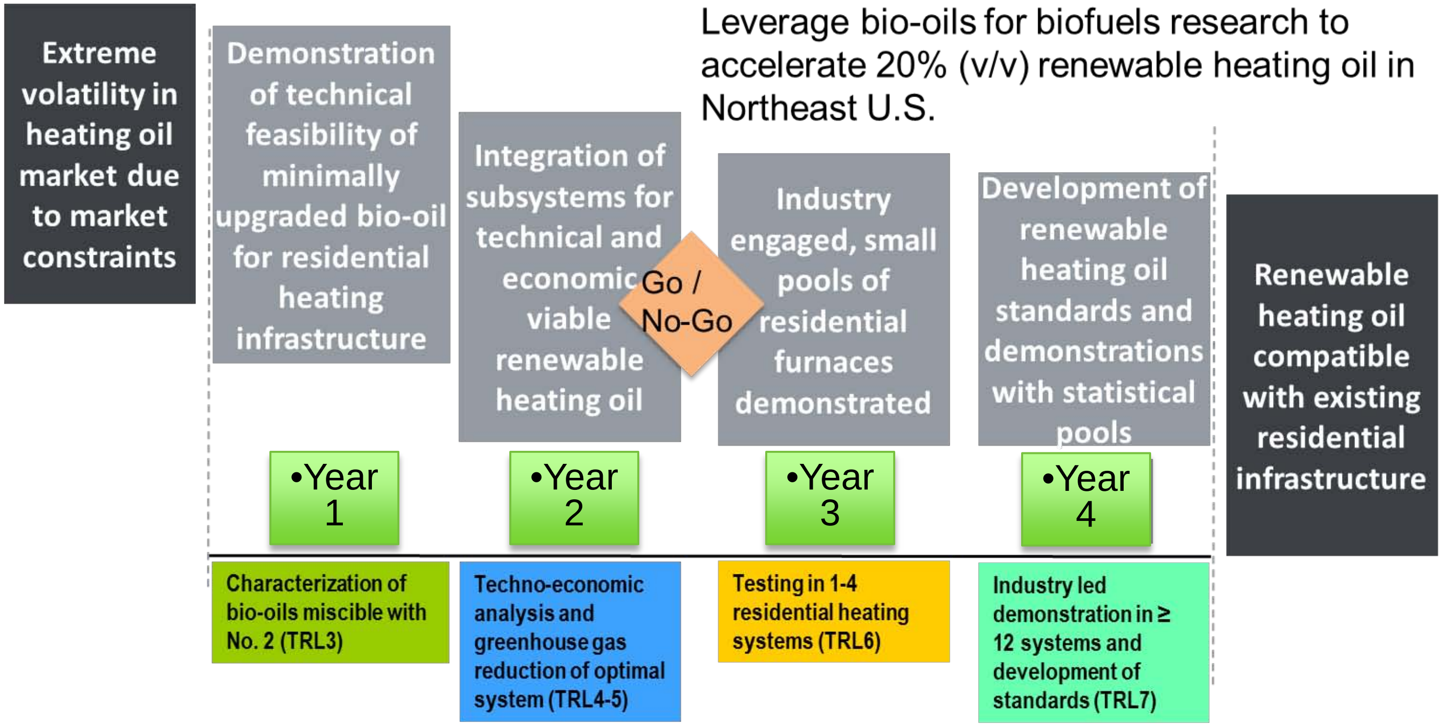
~90% of market

* Data from NORA

Requirements for an Impactful Biomass Based HHO Program

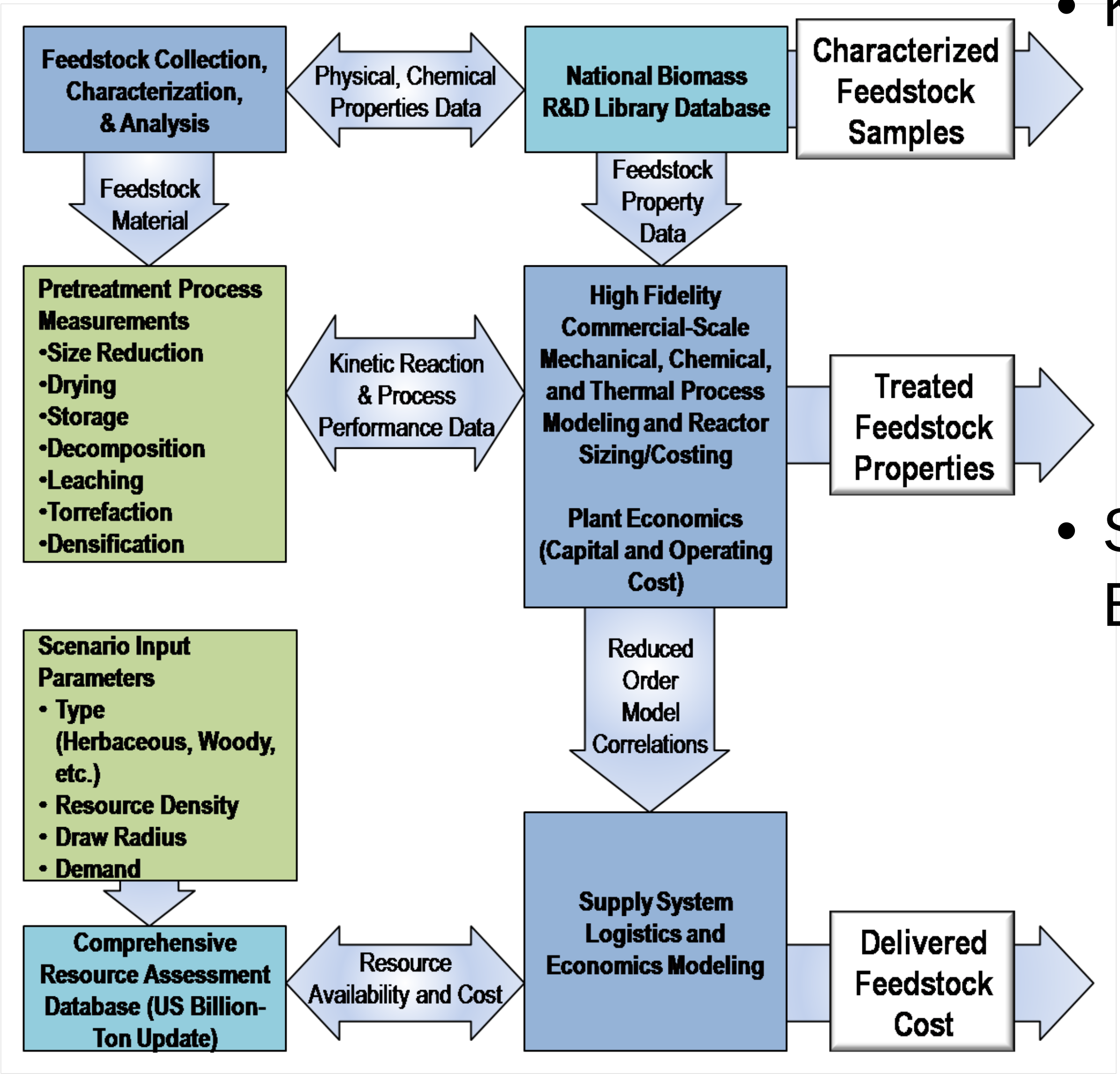
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Need to establish location specific biomass logistics costs (biomass harvest, collection, transportation, handling, storage and processing operations)
- Need to establish target optimum feedstock specifications (may require blending)
- Optimize feedstock based on purchase cost, composition, logistics costs (transportation and processing)
- Optimize direct liquefaction thermal conversion process and upgrading to meet heating oil standards



1 – Technical Approach: 3.2.5.16 INL

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



- Key Unit Operations:
  - Biomass Library Database
  - Pretreatment Process Measurements
  - Commercial Scale Process Modeling
  - Supply System Logistics Modeling
- Specific Technical Barriers:
  - Model biomass feedstock:
    - Availability
    - Cost
    - Specifications
  - Identify key feedstocks for heat oil production

3 – Relevance:

1. *"Enable sustainable… production of advanced biofuels… compatible with today's transportation infrastructure…"*
2. *"Encourage the creation of a new domestic bioenergy industry…"*

Feedstock Supply (FS)

1. Identify sustainable, high-quality feedstock and quantify risk
2. Assess effects across full supply chain
3. Establish baselines and target for improving sustainability
4. Develop best practices

Conversion (C)

1. Lower costs/improve quality of intermediates
2. Enable high performance separations technologies
3. Improve catalyst performance – cleanup/conditioning & fuel synthesis
4. Maximize carbon utilization
5. Develop best practices
6. Optimize reactor performance
7. Define & validate technology
8. Assess progress

- TEA to optimize feed/conversion systems (FS1-2; C1,8)
- Characterize local feedstock materials (FS2-3)
- Assess feedstock preconversion process benefits & costs (FS2-4; C1-7)
- Bench-scale bio-oil production (C6-8)
- Assess impact of feedstock compositional characteristics on liquid yield (FS3-4; C3-7)