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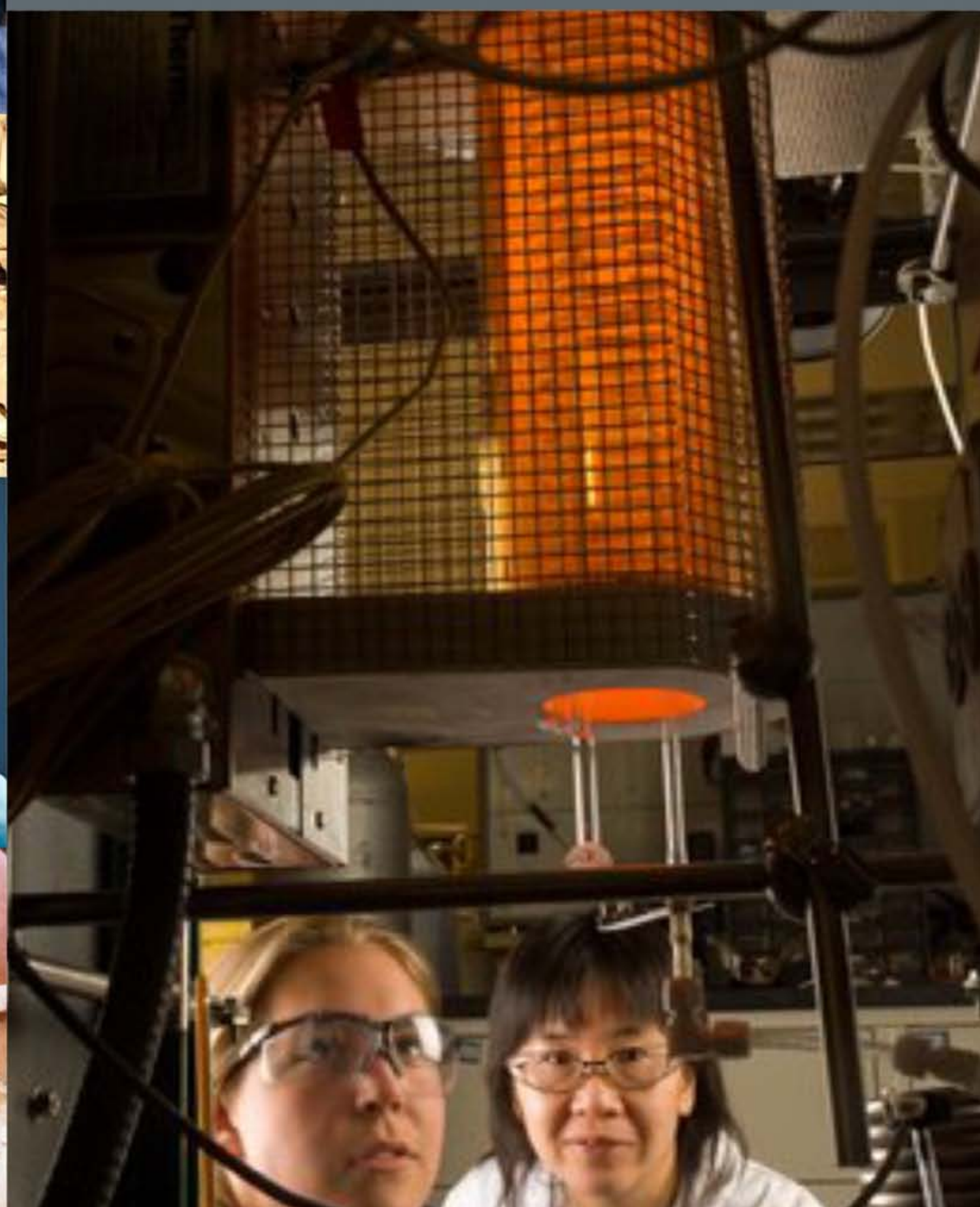
Technical Information Exchange on Pyrolysis Oil:
Potential for a Renewable Heating Oil Substitution Fuel in New England

May 9-10, 2012
Manchester, New Hampshire



PREFACE

The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (DOE/EERE) invests in a diverse portfolio of energy technologies to achieve a stronger economy, a cleaner environment, and a secure energy future for America.

The Bioenergy Technologies Office is an integral component of DOE/EERE's efforts to diversify our energy supply. The office works with industrial partners, national laboratories, and other stakeholders to develop the technologies and systems needed to cost-effectively turn our abundant, domestic biomass resources into clean, affordable bioenergy.

This report summarizes the results of an information exchange sponsored by the DOE/EERE Bioenergy Technologies Office in Manchester, New Hampshire, on May 9-10, 2012. The information exchange was convened to identify and discuss challenges to the expanded use of pyrolysis oil as a replacement for home heating oil in the Northeast region. Discussions addressed feedstocks and production, logistics and compatibility, and operational issues.

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CONTENTS

Executive Summary iii

1 Introduction 1

1.1 Workshop Process 1

2 Pyrolysis Technology and the Potential of Bio-oils as a Home Heating Oil Substitute 3

2.1 Pyrolysis 3

2.2 Northeast Heating Oil Market 4

2.3 Current Bio-Oil Projects 5

2.3.1 VTT Pilot Projects 5

2.3.2 Envergent Technologies 5

3 Feedstocks and Production 6

3.1 Challenges and Constraints 6

3.1.1 Target Markets 7

3.1.2 Biomass Supply 7

3.1.3 Bio-Oil Production 7

3.2 Research, Development, and Demonstration 8

3.2.1 Challenge #1: Establishing acceptable bio-oil blend levels with home heating oil 8

3.2.2 Challenge #2: Moving bio-oils sequentially into the market 9

3.2.3 Challenge #3: Developing feedstock specifications and certifications 9

3.2.4 Challenge #4: Optimizing biomass carbon usage 9

3.2.5 Challenge #5: Uncertainties in best pre-treatment steps essential to certain feedstocks 10

4 Logistics and Compatibility 11

4.1 Challenges and Constraints 11

4.1.1 Storage, Handling, and Compatibility for Transportation 11

4.1.2 Aging and Stability 12

4.1.3 Infrastructure Needs 12

4.2 Research, Development, and Demonstration 12

4.2.1 Challenge #1: Identifying and treating chemical components that lead to corrosion 13

4.2.2 Challenge #2: Unknown effects from different levels of pyrolysis oil upgrading on infrastructure components 13

4.2.3 Challenge #3: Lack of standardized bio-oil analyses and regulatory standards 14

4.2.4 Challenge #4: Uncertainties in acceptable scale for pyrolysis oil production and distribution 14

5 Operational Issues 15

5.1 Challenges and Constraints 15

5.1.1 Stabilization 16

5.1.2 Combustion 16

5.1.3 Corrosion and Neutralization 16

5.1.4 Regulations 16

5.1.5 Market Acceptance 17

5.1.6 Safety *17*
5.2 Research, Development, and Demonstration 17
5.2.1 Challenge #1: Identifying the level of upgrading required to improve stabilization and finding the best upgrading technologies *18*
5.2.2 Challenge #2: Understanding corrosion associated with the combustion of bio-oil *18*
5.2.3 Challenge #3: Better correlating corrosion with percent oxygen content and functional oxygen groups *19*
5.2.4 Challenge #4: Ensuring that bio-oil or oil blends meet stakeholder needs and market expectations *19*
6 Conclusions and Path Forward 20
Appendix A List of Contributors 1
Appendix B Technical Information Exchange Agenda 1
Appendix C Day 2 Worksheets 1
Appendix D References 1

Executive Summary

Of the 7.2 million households in the United States heated by oil in 2009, over 80% are located in the Northeast. This level of reliance on fuel oil for residential heating, coupled with the recent closure of refineries in the Northeast, suggests that an affordable alternative could be particularly beneficial to this region. Bio-oil derived from domestic biomass has been identified as a promising alternative for this market. However, significant challenges must be overcome to reliably produce an ample supply of bio-oil with the characteristics required make it a viable substitute for traditional heating oil.

To explore opportunities for bio-oil in the Northeast, the Bioenergy Technologies Office in the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (DOE/EERE) conducted a *Technical Information Exchange on Pyrolysis Oil* workshop in Manchester, New Hampshire, on May 9-10, 2012. The Technical Information Exchange brought together experts from industry, academia, national laboratories, and government to discuss the technical and economic challenges; research, development, and demonstration priorities; and other topics related to pyrolysis feedstocks, conversion pathways, logistics, infrastructure compatibility, and related operations. The participants identified some significant challenges and actions to address them, as summarized in Table ES-1, below. A number of these priorities were selected for further exploration (see Appendix C) based upon participant expertise.

The Bioenergy Technologies Office will use the workshop results to guide its strategic planning and prioritization of future research, development, and demonstration (RD&D) work on bio-oil as a renewable heating oil blend stock in the Northeast. Based on input from the Technical Information Exchange and a modeling tool developed by the Bioenergy Technologies Office, a cursory assessment of feedstock availability and bio-oil production and upgrading operations indicates that miscible, cost-competitive bio-oil could potentially replace 20% of No. 2 heating oil (by weight) in the Northeast. Achieving this target would likely alleviate some market pressure and heating oil price volatility in the United States while creating American jobs and reducing greenhouse gas emissions. It could replace over 30 million barrels of petroleum-based fuels each year, or approximately 0.5% of all petroleum fuels used in the United States.

The identified priorities for bio-oil RD&D complement the Bioenergy Technologies Office research platforms in feedstock logistics and biomass pyrolysis. At the same time, they specifically focus on improving pyrolysis oil upgrading and testing processes to meet the technical specifications for blending with No. 2 heating oil and for burning it in established home heating furnaces and commercial building boilers in the Northeast.

Table ES 1: Top Challenges and R&D Priorities Identified

Significant Challenges	Priorities for RD&D, Analysis, or Other Actions
Feedstocks and Production	
• Lack of known, acceptable pyrolysis oil blend levels with home heating oil	• Identify blend limits for fully and partially conditioned pyrolysis oil and explore blending limits that could be implemented in the near-term
• Need to move pyrolysis oils sequentially into the market	• Conduct research and development that will evaluate grades of pyrolysis oil and match them to acceptable end uses
• Absence of feedstock specifications and certifications	• Determine materials of concern with conversion, blending, and combustion of pyrolysis oil; work with standards organizations
• Need to optimize biomass carbon usage	• Investigate methods to lower yields of solids and gases during production and explore higher value markets for biochar

Significant Challenges	Priorities for RD&D, Analysis, or Other Actions
• Uncertainties in best pre-treatment steps essential to certain feedstocks	• Conduct research into the removal of alkali from leaching, determine best biomass deconstruction methods, and develop thermal non-pyrolytic drying techniques to increase product value
• Need to understand the life-cycle GHG emissions based on potential market penetration	• Conduct research and development and modeling on emissions from a variety of blends of pyrolysis oil
• Uncertainties related to seasonal demand & storage	• Investigate the issues surrounding product storage and aging
Logistics and Compatibility	
• Lack of standardized pyrolysis oil analyses and regulatory standards	• Develop and refine standardized analyses, identify key physical parameters, and better understand health impacts and toxicity of different grades of pyrolysis oil
• Need to identify and treat chemical components leading to corrosion	• Conduct research to correlate chemical composition and oxygen content to corrosion effects on infrastructure
• Uncertainties in acceptable scale for pyrolysis oil production and distribution	• Determine infrastructure constraints for all aspects of feedstock delivery and oil transport and develop economic models for various sizes of pyrolysis plants
• Unknown effects from levels of pyrolysis oil upgrading on infrastructure components	• Determine the effects of a variety of grades of pyrolysis oil on existing infrastructure to ensure compatibility with materials, equipment, storage components, etc.; research low-cost infrastructure modifications to accommodate pyrolysis oil
• Need point-of-use analytical instruments to measure critical characteristics and specifications of fuel conditions	• Develop cost-effective, rapid analysis instruments that can measure critical specification of the oils in real-time (stability, viscosity, density, volatility, pH, total acid number (TAN), carboxylic acid number (CAN), etc.)
• Lack of information related to distribution requirements	• Develop a cost-effective strategy to address storage, infrastructure, aging, and cost of distribution options (e.g., central stabilization facility with distributed plants)
• Need to determine the compatibility of pyrolysis oil with plastics and ways to coat with cheaper materials	• Evaluate new and existing plastics and polymers for corrosion-resistant pump seals and coatings to retrofit existing infrastructure
Operational Issues	
• Identification of the level of upgrading required to improve stabilization and best upgrading technologies	• Conduct research to determine the needed level of upgrading and identify best technologies to reduce, separate, or modify reactive pyrolysis oil species during production of upgraded pyrolysis oils
• Need to better understand corrosion associated with the combustion of pyrolysis oil	• Conduct lab, pilot, and full-scale tests under varying conditions to identify ways to reduce corrosion of boiler tubes and downstream components
• Need to better correlate corrosion with percent oxygen content and functional oxygen groups	• Conduct a systematic study as a function of composition, temperature, and pressure to better evaluate corrosion in operational components
• Unknown fouling potential when firing pyrolysis oil in the presence of low-melting ash constituents	• Evaluate the fouling potential of existing and potentially new components for burner designs
Market Engagement and Acceptance	
• Need to better inform the public and industry stakeholders on issues related to pyrolysis oil or oil blends	• Establish information exchange with stakeholders early in the process. Initiate lab, pilot, and full-scale tests under varying conditions to illustrate the operational performance of pyrolysis oils or oil blends in existing or new equipment and infrastructure
• Ensure that pyrolysis oil or oil blends meet stakeholder needs and market expectations	• Facilitate market acceptance through the characterization of pyrolysis oils and oil blends, feasibility testing, and industry certification of fuels and listing of equipment

1 Introduction

Approximately 7.2 million households in the United States used heating oil in 2009 to meet their space and water heating needs—and more than 80% of those households are located in the Northeast. In most cases, the use of heating oil is dictated by limited fuel infrastructure options, making fuel substitution difficult. This reliance on fuel oil for residential heating and the recent closures of Northeast refineries indicate that an affordable alternative could be particularly advantageous to this region. Bio-oil derived from domestic biomass has been identified as one of the most promising alternatives for this market. However, significant challenges must be overcome to reliably produce an ample supply of bio-oil that possesses the required characteristics to become a viable substitute for traditional heating oil.

To explore opportunities for biomass-derived, renewable home heating oils (HHO) in the Northeast, the U.S. Department of Energy's (DOE's) Bioenergy Technologies Office (BETO) conducted a "Technical Information Exchange on Pyrolysis Oils" in Manchester, New Hampshire, on May 9-10, 2012. The meeting brought together a broad spectrum of experts from industry, academia, national laboratories, and government to discuss the technical and economic challenges; research, development and demonstration priorities; and other topics related to pyrolysis feedstocks, conversion pathways, logistics, infrastructure compatibility, and operational issues.

The Technical Information Exchange generated a wealth of information and ideas. The Bioenergy Technologies Office will use the results of the meeting to guide its strategic planning and prioritization of future research, development, and demonstration (RD&D) work on bio-oil as a renewable heating oil blend stock in the Northeast.

The results presented here are not comprehensive. This document represents a snapshot of the expert opinions voiced at the Technical Information Exchange and summarizes selected analyses currently available in the public domain.

1.1 Workshop Process

Deputy Assistant Secretary for Renewable Energy Steven Chalk and Bioenergy Technologies Office Technology Manager Elliott Levine opened the Technical Information Exchange with introductory comments and a presentation on the DOE perspective. They encouraged workshop participants to consider the feasibility and path forward for establishing a commercial market for sustainable bio-oil that could alleviate seasonal residential fuel oil shortages and price volatility.

Thomas Butcher of Brookhaven National Laboratory and John Huber of the National Oilheat Research Alliance (NORA) provided valuable context on the unique market conditions for HHO in New England, alternative fuel blending opportunities, and the future of oil heat. Additionally, the following technical presentations provided participants with information pertinent to the technical challenges discussed throughout the meeting:

- Known Challenges Associated with the Production, Transportation, Storage, and Usage of Pyrolysis Oil in Residential and Industrial Settings, by Jani Lehto, VTT Technical Research Centre of Finland

- Integrated System Sensitivities and Perspective—A qualitative discussion on conversion, stabilization, and upgrading versus infrastructure compatibility and retrofit requirements, by Jonathan Male, Pacific Northwest National Laboratory
- Renewable Heating Oil—A Commercial Perspective, by Steve Lupton, Envergent Technologies LLC

Following these stage-setting presentations, participants broke into discussion groups focused on the following three topic areas:

- Feedstocks and Production
- Logistics and Compatibility
- Operational Issues

Within their topic area, each group identified challenges and barriers to the entry of bio-oil into the home heating oil market and subsequently assigned relative priorities to the identified challenges. On the second day of the workshop, the participants formed smaller groups to scope out the technology advancements and R&D efforts needed to address a selected subset of the top-ranked challenges previously identified. The detailed results of this process are shown in Appendix C.

2 Pyrolysis Technology and the Potential of Bio-oils as a Home Heating Oil Substitute

2.1 Pyrolysis

Bio-oil is produced via pyrolysis, a process in which biomass is rapidly heated to 450–500°C in an oxygen-free environment and then quenched, yielding a mix of liquid fuel (pyrolysis oil), gases, and solid char. Variations in the pyrolysis method, biomass characteristics, and reaction specifications will produce varying percentages of these three products. The objective is to maximize the liquid fuel product or bio-oil, which has a viscosity resembling that of No. 4 fuel oil. Several technologies and methodologies can be used for pyrolysis, including circulating fluid beds, entrained flow reactors, multiple hearth reactors, or vortex reactors. The process can be performed with or without a catalyst or reductant.

Pyrolysis oil and wood chips.
Photo from NREL/13194

The original biomass feedstocks and processing conditions affect the chemical properties of the pyrolysis oil, but it typically contains a significant amount of water (15%–30% by weight), has a higher density than conventional fuel oils, and exhibits a lower pH (2–4). The heating value of pyrolysis oil is approximately half that of conventional fuel oils, due in part to its high water and oxygen content—which can make it unstable until it undergoes further processing.

Bio-oil can be hydrotreated to remove the oxygen and produce a liquid feedstock resembling crude oil (in terms of its carbon/hydrogen ratio), which can be further hydrotreated and cracked to create renewable hydrocarbon fuels and chemicals. Hydrotreating stabilizes the bio-oil—preventing molecule-to-molecule and molecule-to-surface reactions—and eventually produces a finished blendstock for fuels. Bio-oil can be deoxygenated from its high initial oxygen content of 35-45 percent by weight (wt%) on a dry basis all the way down to 0.2 wt%. This process, however, consumes energy and hydrogen; it may also overly hydrogenate some hydrocarbons that are beneficial to fuels.

Biomass can be pyrolyzed in a remote or centralized location. Such location decisions must carefully consider logistical and economic ramifications (e.g., feedstock densification requirements and the stability of both feedstocks and intermediates). Remote production of bio-oil will typically require a choice between upgrading the bio-oil at the remote location or making the materials in the transportation infrastructure corrosion resistant.

Raw, unconditioned bio-oil can be used as a heating fuel, but its high oxygen content and corrosiveness would require the replacement of existing heating infrastructure with more robust materials. This approach would appear more feasible for commercial heating rather than residential heating systems, as raw bio-oil is immiscible with hydrocarbon streams—such as No. 2 fuel oil. Using raw bio-oil for home heating would require the use of new or modified home furnaces and delivery infrastructure, and raw bio-oil could not be blended with No. 2 fuel oil without the use of dispersion agents. Partially or fully upgraded bio-oil that is compatible with the existing residential heating oil infrastructure may solve these issues as it would obviate extensive materials replacement and enable blending with No. 2 fuel oil.

Pyrolysis technologies to produce biofuels have been demonstrated at the laboratory scale or are in the early stages of commercialization. DOE analysis indicates that production costs approaching ≤$3 per gallon (in 2007 dollars) are achievable using pyrolysis. This potential for cost-competitiveness and compatibility with existing petroleum distribution infrastructure make the production and upgrading of pyrolysis oil an attractive source of renewable hydrocarbon fuels. Based on the availability of feedstocks in the Northeast, as documented in the 2011 *U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry*, preliminary modeling studies indicate that 20% (by weight) of No. 2 heating oil could be cost-competitively displaced by miscible bio-oil.

2.2 Northeast Heating Oil Market

The Northeast states are the most significant consumers of heating oil in the United States. The average oil-heated home in this region consumes approximately 850 gallons of fuel per heating season (October to March). Regional consumption amounts to about 5 billion gallons of fuel oil annually, or about 120 million barrels per year. This volume represents approximately 3.5% of the 3,300 million barrels of raw crude imported into the United States each year (DOE/EIA-0384, 2010). More importantly, according to the DOE Energy Information Administration, the majority of residential heating oil—approximately 80 million barrels per year—is imported. Consequently, the supply of residential heating oil is subject to disruption by external factors, creating the frequent supply shortages and price spikes that have made fuel oil an increasingly expensive home heating option. In addition, several Northeastern states—including Maine, Massachusetts, New Jersey, New York, and Vermont—have mandated a transition to ultra-low-sulfur home heating oil, effectively increasing price pressures on petroleum-based fuel oil.

Interest in using bio-based blends in stationary applications has been growing since the early 2000s, providing some useful groundwork. Early efforts to introduce biodiesel blends into the Northeast home heating market, for example, were hindered by weak standards and poor quality control. The lack of equipment officially "listed" for use with biodiesel blends created problems for heating equipment manufacturers and building code officials. A formal effort was launched to develop the supporting data and petition ASTM to redefine heating oil to include up to 5% biodiesel. As a result of this effort, B5 is now accepted into ASTM D396, the standard specification for fuel oils, and biodiesel can be used in oil-fired systems.

Entry of biodiesel into the Northeast home heating market may pave the way for a successful introduction of pyrolysis oil into the same market. A DOE analysis indicates that biomass-derived pyrolysis oil and upgraded fuel oil substitute have the potential to become cost-competitive alternatives to home heating oil in the Northeast market. ASTM standards will need to be established and verified through equipment performance testing to qualify 20% bio-oil HHO blends. All aspects of the heating oil market will be touched, including production and intermediate bulk storage; refinery blending; delivery tankers and trucks; and home heating storage tanks, pumps, and furnace burners. In terms of fuel production and processing, pyrolysis oil upgrading will likely require standards and processing steps that differ substantially from those for "drop-in fuels" for the transportation sector.

2.3 Current Bio-Oil Projects

Technical Information Exchange participants heard two presentations regarding the use of bio-oil in industrial and other large-scale applications. While unconditioned bio-oil cannot be used in current home oil heating systems and delivery infrastructure, use of bio-oil in other applications is accelerating the further development of pyrolysis technology and bio-oil logistics. These activities are helping to confirm the financial potential and reduce the implementation risk of pyrolysis oil technologies. These early projects are also helping to convey the broad environmental, economic, and national security benefits of bio-oils.

2.3.1 VTT PILOT PROJECTS

Dr. Jani Lehto of VTT Technical Research Center spoke on the experience and knowledge gained through several pilot projects involving bio-oil production and use in boiler applications. The most significant challenge is to make bio-oil cost competitive with other fuels in combustion applications. To achieve competitiveness, both capital and operating costs must be reduced, while bio-oil yield, energy recovery, and value of by-products need to be maximized. Building the market will require development of standards, specifications, and guidelines for bio-oil. Other important requirements specific to bio-oil production include effectively minimizing incombustible solids and establishing robust quality control throughout the fuel supply chain.

2.3.2 ENVERGENT TECHNOLOGIES

Steve Lupton of Envergent Technologies provided an overview of Envergent’s efforts to produce bio-oil for fuel oil substitution and electricity generation. Envergent is currently working on industrial projects in which the feedstock/product spread favors the economical production and use of bio-oil to replace heavy fuel oil. Bio-oil has already proven to be competitive in this market segment. The company has seven units in operation, and three new projects have been announced. The company is further developing pyrolysis and other technologies for producing and upgrading bio-oil into green gasoline, diesel, and jet fuel.

3 Feedstocks and Production

The Feedstocks and Production group concentrated on identifying the challenges and constraints that must be addressed to establish bio-oil as a viable alternative—both technically and economically—to petroleum-derived fuel oil.

Key challenges for feedstocks and production can be divided into three subcategories:

- Biomass supply
- Bio-oil production
- Target markets

After brainstorming the challenges in each subcategory, the group collectively ranked the most critical barriers to making bio-oil a viable fuel alternative in the home heating oil market. The prioritized challenges are listed below in Section 3.1, Challenges and Constraints.

During the second day of the workshop, the group participants selected a handful of high-priority challenges (in **bold** font below) and split into smaller work groups to map next steps for addressing them. While all challenges were not addressed in detail, the participants chose the challenges they believed they could adequately address given their areas of expertise. For each selected challenge, they defined the current technology status, set performance goals, defined priority key steps to achieve those goals, and indicated an appropriate timeframe for the identified activities. Results from these deliberations are provided in Appendix C and briefly summarized below in Section 3.2, Research, Development, and Demonstration.

3.1 Challenges and Constraints

Feedstocks and production encompass a wide range of issues. As a result, no single theme dominated the discussion of challenges and constraints.

With regard to target markets for bio-oils, participants recognized a need for some fundamental determinations to be made before bio-oils can successfully compete with petroleum-based heating oil. Participants discussed the need for stakeholders to determine a joint strategy for the introduction of bio-oil into the home heating oil market. In addition, acceptable blending levels must be determined, as blends are perhaps the most likely pathway by which bio-oil will enter the market.

In terms of biomass supply, specifications and certifications were identified as priority needs. Participants similarly placed priority on the need to know more about the impacts of feedstock densification on the conversion process. Other challenges relate to the immature commodity market for biomass, policy uncertainty, and lack of detailed biomass production potential information in the Northeast.

In bio-oil production processes, the participants identified critical information gaps, including pretreatment options for different feedstocks, carbon usage, liquefaction technologies, and bio-oil upgrading. Participants also discussed the need for corrosion-resistant materials for production, storage, and transportation of bio-oil. Lack of detailed knowledge about the infrastructure limitations, required capitalization, and other constraints related to scaling up of bio-oil production facilities also poses a significant challenge.

While not intended to be comprehensive, Sections 3.1.1, 3.1.2, and 3.1.3 include full lists of the feedstock and production challenges identified by workshop participants.

3.1.1 TARGET MARKETS

Workshop participants identified and prioritized the following challenges in the area of target markets.

a) **Characterizing and analyzing acceptable levels for blending pyrolysis oil with home heating oil**
b) **Moving pyrolysis oils sequentially into the market**
c) Limited understanding of comparative cost benefits of various grades of delivered bio-oil versus competing fuels
d) Technical and economic uncertainties related to the seasonal demand and storage of bio-oil
e) Lack of air emissions profiles for combustion of different grades of bio-oil in residential and commercial burners
f) Undeveloped supply and product market synergy with other regions
g) Uncertainties regarding incentives for biomass conversion.

3.1.2 BIOMASS SUPPLY

Workshop participants identified and prioritized the following challenges in the area of biomass supply. The challenges are listed in an approximate priority order, as collectively assessed by the participants.

a) **Developing feedstock specifications and certifications**
b) Determining what impact feedstock densification has on the conversion process
c) Limited availability of credit due to immaturity of commodity-type markets for biomass
d) Uncertainty of a biomass policy for pyrolysis and energy sustainability
e) Limited information about biomass production potential in New England

3.1.3 BIO-OIL PRODUCTION

Workshop participants identified and prioritized the following challenges to the economic production of specification-qualified bio-oil for the home heating market.

a) **Limited understanding of the impacts of scaling up pyrolysis plants and product upgrading operations—and the required capitalization** (see Section 4)
b) **Limited understanding of the options and benefits of biomass carbon usage**
c) **Limited understanding of the best pre-treatment steps for specific feedstocks**
d) Limited understanding and analysis of the different biomass liquefaction technologies and pyrolysis oil upgrading steps to produce No. 2 miscible bio-oil
e) Lack of information to adequately characterize and select materials that provide sufficient corrosion resistance for use in the production, storage, and transportation of bio-oil

f) Lack of a robust life-cycle analysis of GHG emissions based on potential market penetration
g) Limited understanding of the issues related to refinery and distribution siting

3.2 Research, Development, and Demonstration

Research, development, and demonstration activities were identified for five of the high-priority challenges, as shown in Tables 3.2.1 through 3.2.5. A sixth high-priority challenge in Feedstocks and Production, "Limited understanding of the impacts of scaling of pyrolysis plants…and the required capitalization," was combined with a similar topic in the "Logistics and Compatibility" session; thus, steps to address this challenge are summarized in Section 4.2.3, "Uncertainties in Acceptable Scale for Bio-Oil Production and Distribution."

As mentioned at the beginning of this section, the participants selected the challenges shown in **bold** (above), and subsequently identified specific steps, metrics, and milestones to address them. Their detailed suggestions are provided in Appendix C.

Note: The suggestions for each priority challenge were generated in a relatively short time period by a small group of workshop participants. Hence, this information should not be considered a final or comprehensive determination of the steps and timeline needed to address the challenges. Rather, this information should be considered a starting point for further deliberation on steps to address the identified challenges.

3.2.1 CHALLENGE #1: ESTABLISHING ACCEPTABLE BIO-OIL BLEND LEVELS WITH HOME HEATING OIL

GOAL: Develop acceptable blends of bio-oils that are compatible with existing infrastructure	
KEY STEPS	TIMEFRAME
• Confirm whether fully conditioned unblended bio-oil is compatible with current infrastructure • Study fuel oil blends for different ranges of upgraded pyrolysis oil to meet an ASTM standard • Explore novel blending methods to develop acceptable blends with partially upgraded bio-oil • Develop ASTM standard for lower-priced blends using less conditioned bio-oil	A new ASTM standard for blends using less conditioned pyrolysis oil could be developed by 2017

3.2.2 CHALLENGE #2: MOVING BIO-OILS SEQUENTIALLY INTO THE MARKET

GOAL: Move pyrolysis oil into the market sequentially, matching different end uses	
KEY STEPS	TIMEFRAME
• Utilize a lab or pilot plant to develop technologies to produce fully upgraded pyrolysis oil at test fuel quantities • Evaluate maximum blend levels of bio-oil • Develop specifications that meet No. 6, No. 4, and No. 2 market needs • Build a demonstration plant	Testing to evaluate blending levels could be completed by 2013-2014; a demonstration plant could be completed by 2014-2015

3.2.3 CHALLENGE #3: DEVELOPING FEEDSTOCK SPECIFICATIONS AND CERTIFICATIONS

GOAL: An agreed-upon feedstock specification that defines allowable levels of materials of concern	
KEY STEPS	TIMEFRAME
• Test available feedstocks and document feedstock properties in a library • Determine materials of concern with conversion, blending, and combustion of bio-oil • Define allowable levels of materials of concern • Develop a feedstock specification, including determination of relevant testing methods	Documentation of feedstock properties could be completed by the end of 2014, identification of materials of concern by the end of 2015, and a specification adopted by 2016

3.2.4 CHALLENGE #4: OPTIMIZING BIOMASS CARBON USAGE

GOAL: Optimization of carbon use in pyrolysis oil production	
KEY STEPS	TIMEFRAME
• Develop techniques, such as hot filtration and membrane separation, to lower the level of carbon solids in pyrolysis oil to less than 0.1 percent by weight (wt%) • Develop biochar as a higher value product, as soil amendment agent, or a product in the chemical industry • Develop techno-economic model and refine integrated production process that maximizes yield of pyrolysis oil and lowers production costs	Carbon-reducing techniques could be developed by 2015; optimized, integrated production process and establishment of a higher-value market for biochar could be achieved by 2020

3.2.5 CHALLENGE #5: UNCERTAINTIES IN BEST PRE-TREATMENT STEPS ESSENTIAL TO CERTAIN FEEDSTOCKS

GOAL: Identification of best methods for pre-treating biomass to produce pyrolysis oil	
KEY STEPS	TIMEFRAME
• Research most effective ways to reduce alkali metal halides (from leaching) in bio-oil • Research biomass deconstruction methods to increase bio-oil yield by 10% while decreasing cost by 10% • Develop thermal non-pyrolytic drying techniques to increase product value by decreasing water content of pyrolysis oil	Research on improved pre-treatment technologies could be completed by 2016-2017

4 Logistics and Compatibility

The challenges identified in the session on Logistics and Compatibility fall within three subcategories:

- Storage, handling, and compatibility for transportation
- Aging and stability
- Product location

After discussing the challenges in each subcategory, the group ranked the challenges to identify those that are most critical to making pyrolysis oil a viable fuel alternative for the home heating oil market. The prioritized lists of challenges are presented below in Section 4.1, Challenges and Constraints.

During the second day of the workshop, the group selected four of the top-ranked challenges (in **bold** font below) and identified research and development efforts to overcome them. While all challenges were not addressed in detail, the participants chose the challenges they believed they could adequately address given their areas of expertise. For each selected challenge area, they identified the technology status, defined performance goals, described priority steps to achieve those goals, and suggested an appropriate timeframe for the needed activities. Results from these deliberations are shown in Appendix C and summarized below in Section 4.2, Priorities for Research, Development, and Demonstration.

4.1 Challenges and Constraints

In the discussion of logistics and compatibility challenges, corrosion emerged as the most significant barrier to more widespread use of bio-oils. There is a need to better understand which chemical components cause corrosion; how different levels of upgrading the bio-oils affect the infrastructure components; and which cost-effective, corrosion-resistant materials should be used. There is also a need to establish regulatory standards and to determine standardized methods for analyzing bio-oil.

Key logistical constraints include the lack of techno-economic analyses and real-world experience in determining the most effective scale of bio-oil production.

While not intended to be all inclusive, Sections 4.1.1, 4.1.2, and 4.1.3 include the full lists of logistics and compatibility challenges identified by workshop participants.

4.1.1 STORAGE, HANDLING, AND COMPATIBILITY FOR TRANSPORTATION

Workshop participants identified the following challenges in the area of storage, handling, and compatibility for transportation; these challenges relate to raw materials, intermediates, and final products. The challenges are listed in an approximate order of priority, as collectively assessed by the participants.

a) **Identifying and treating the chemical components that lead to corrosion**
b) Determining the compatibility of bio-oil with plastics and ways to coat with cheaper materials
c) Lack of standardized pyrolysis oil analyses and regulatory standards

d) **Unknown effects on infrastructure components from different levels of pyrolysis oil upgrading**
e) Determining the critical mass for the logistics system to make the product economical
f) Unknown phase separation properties associated with the mixing of pyrolysis oil and other products, including No. 2 fuel oil
g) Difficulty of gaining consumer confidence and providing homeowners with an incentive to modify home infrastructure, in case the pyrolysis oils do not match No. 2 fuel oil
h) Lack of an economic assessment of the required infrastructure modifications to evaluate the trade-offs for different grades of pyrolysis oil
i) Optimizing post-production blending for drop-in storage and distribution locations, and defining associated standards
j) Uncertainty about requirements for approval to transport the fuels; need to understand the risks associated with potential accidents
k) Unknown impacts from the movement of biomass on local roads and infrastructure
l) Developing an interface model with the existing petroleum distribution system
m) Unknown insurance burden on homeowners

4.1.2 AGING AND STABILITY

Workshop participants identified the following challenges in the area of aging and stability. The challenges are listed in an approximate priority order, as collectively assessed by the session participants.

a) **Lack of standardized pyrolysis oil analyses and regulatory standards**
b) Lack of point-of-use analytical instruments to measure critical characteristics and specifications of fuel conditions
c) Lack of knowledge about the potential for additives to contribute to oil stability

4.1.3 INFRASTRUCTURE NEEDS

Workshop participants identified the following challenges in the area of infrastructure needs. These challenges are listed in an approximate priority order, as collectively assessed by the participants.

a) **Uncertainties in acceptable scale for bio-oil production and distribution**
b) Lack of information related to distribution requirements
c) Need for pyrolysis systems to be self-sufficient in distributed locations

4.2 Research, Development, and Demonstration

Research, development, and demonstration steps were identified for four of the highly ranked challenges.

As mentioned at the beginning of this section, the participants selected the challenges shown in **bold** (above), and subsequently identified specific steps, metrics, and milestones to address them. Their detailed suggestions are provided in Appendix C.

Note: The suggestions for each priority challenge were generated in a relatively short time period by a small group of workshop participants. Hence, this information should not be considered a final or comprehensive determination of steps and timeline needed to address the challenges. Rather, this information should be considered a starting point for further deliberation on steps to address the identified challenges

4.2.1 CHALLENGE #1: IDENTIFYING AND TREATING CHEMICAL COMPONENTS THAT LEAD TO CORROSION

GOAL: Identify chemical components that lead to corrosion and develop technologies to reduce these components in pyrolysis oil	
KEY STEPS	TIMEFRAME
• Conduct research to correlate chemical composition and oxygen content of pyrolysis oil to corrosion effects on infrastructure • Identify key chemical components in bio- oil that cause corrosion • Test identified components to understand their role in corrosion, both alone and with other components • Improve upgrading technologies to target identified key components	Needed research could be conducted by 2016

4.2.2 CHALLENGE #2: UNKNOWN EFFECTS FROM DIFFERENT LEVELS OF PYROLYSIS OIL UPGRADING ON INFRASTRUCTURE COMPONENTS

GOAL: Determine the effects of different bio-oil grades on existing infrastructure and identification of potential low-cost infrastructure modifications	
KEY STEPS	TIMEFRAME
• Test the impact of fully conditioned pyrolysis oil and blends of fully conditioned pyrolysis oil on existing infrastructure • Test the impact of partially upgraded pyrolysis oil and its blends on existing infrastructure • Test the impact of raw pyrolysis oil and its blends on existing infrastructure • Research low-cost infrastructure modifications, such as novel nozzle and burner head concepts, to accommodate pyrolysis oil and its various blends	Required testing and research could be completed by 2016

4.2.3 CHALLENGE #3: LACK OF STANDARDIZED BIO-OIL ANALYSES AND REGULATORY STANDARDS

GOAL: Development of accepted bio-oil analyses and standards	
KEY STEPS	TIMEFRAME
• Development of a suite of analytical techniques to enable characterization of bio-oils • Development of specifications of material compatibility and storage • Development of health and toxicity specifications for different pyrolysis oil grades • Development of specifications for different grades of bio-oils for different applications	Analytical techniques and material compatibility specifications could be developed by 2015; development of all specifications may take until 2020

4.2.4 CHALLENGE #4: UNCERTAINTIES IN ACCEPTABLE SCALE FOR PYROLYSIS OIL PRODUCTION AND DISTRIBUTION

GOAL: Determine what scale of pyrolysis plants are economically viable	
KEY STEPS	TIMEFRAME
• Determine locations, quantities, and locations of available feedstocks • Determine infrastructure constraints for all aspects of operations, including feedstock delivery and pyrolysis oil transportation • Develop economic models for various sizes of pyrolysis plants • Build demonstration plant(s) to confirm economic models	A demonstration facility could be operational by 2016

5 Operational Issues

The challenges identified in the Operational Issues topical area are divided into six subcategories:

- Combustion
- Corrosion and neutralization
- Stabilization
- Regulations
- Market acceptance
- Safety

The participants in this group collectively ranked the challenges to identify those that are most critical to making bio-oil a viable fuel alternative for the home heating oil market. The prioritized lists of challenges are presented below in Section 5.1, Challenges and Constraints.

The group selected four of the top technological challenges (in **bold** font below) and identified priority steps to address those challenges. While all challenges were not addressed in detail, the participants chose those challenges that they believed they could adequately address given their areas of expertise. They described the status of the technology, performance goals, research and development activities needed, and an appropriate timeframe. Results from these deliberations are summarized in Section 5.2, Priorities for Research, Development, and Demonstration.

5.1 Challenges and Constraints

In the discussion of operational issues, corrosion was identified as a major challenge. The participants believe further research is needed to better understand the correlation between corrosiveness and the oxygen content of the bio-oil and to better understand how corrosion affects the combustion of bio-oils. Participants also identified a need to determine the level of upgrading required to adequately stabilize bio-oils.

Market acceptance was identified as a major barrier to bio-oil's entry into the home heating oil market. To facilitate market entry and meet performance expectations, appropriate blending levels and upgrading requirements need to be determined. Further public education on bio-oils is also needed, including a successful demonstration of the use of bio-oil as a heating oil substitute.

On the regulatory side, participants identified the need for comprehensive specifications for bio-oil. In addition, the production and use of bio-oil entail certain safety considerations that do not apply to most other biofuels.

While not intended to be all inclusive, Sections 5.1.1, 5.1.2, and 5.1.3 include the full lists of operational challenges identified by workshop participants.

5.1.1 STABILIZATION

Workshop participants identified the following challenges in the area of stabilization. The challenges are listed in approximate priority order, as collectively assessed by the participants.

a) **Identifying the level of upgrading required to improve stabilization**
b) Inadequate understanding of the effect fractionation on stabilization of pyrolysis oil
c) Evaluating the effect of periodic sonic agitation to avoid phase separation

5.1.2 COMBUSTION

Workshop participants identified the following challenges in the area of combustion. The challenges are listed in approximate priority order, as collectively assessed by the participants.

a) Understanding the corrosion associated with the combustion of bio-oil
b) Unknown fouling potential when firing pyrolysis oil in the presence of low-melting ash constituents
c) Lack of sufficient emissions data
d) Enhanced simulation distillation curves with bio-oil oxygen content and oxygenated hydrocarbons present
e) Lack of flame ignition monitors and controls for home furnaces
f) Lack of knowledge about the potential for blending additives to improve combustion performance

5.1.3 CORROSION AND NEUTRALIZATION

Workshop participants identified the following challenges in the area of corrosion and neutralization. The challenges are listed in approximate priority order, as collectively assessed by the participants.

a) **Better correlating corrosion with percent oxygen content and functional oxygen groups**
b) Lack of knowledge about corrosion of boiler tubes and other parts when firing bio-oil
c) Better understanding production system corrosion as a function of temperature
d) Developing corrosion-resistant materials

5.1.4 REGULATIONS

Workshop participants identified the following challenges in the area of regulations. The challenges are listed in approximate priority order, as collectively assessed by the participants.

a) Lack of specifications that include all aspects of bio-oil, including miscibility, corrosion, odor, and combustibility
b) Developing best practices as a function of end-use and obtaining approval by the appropriate regulatory bodies
c) Lack of emission standards
d) Lack of a Renewable Identification Numbers (RINs) determination for pyrolysis oil

5.1.5 MARKET ACCEPTANCE

Workshop participants identified the following challenges in the area of market acceptance. The challenges are listed in approximate priority order, as collectively assessed by the participants.

a) **Determining the acceptable blend ratios with No. 2 fuel oil and the associated upgrading required to meet performance objectives**
b) Renaming the product to increase acceptance by consumers
c) Better engagement and education of the public and stakeholders
d) Lack of demonstration projects to facilitate market acceptance

5.1.6 SAFETY

Workshop participants identified the following challenges in the area of safety. The challenges are listed in approximate priority order, as collectively assessed by the participants.

a) Developing control and automation systems for safe, unmanned use (for low-grade pyrolysis oil applications)
b) Need to create a Material Safety Data Sheet (MSDS) for each product
c) Procedures for remediating a bio-oil spill

5.2 Research, Development, and Demonstration

Research, development, and demonstration priorities were identified and prioritized for four of the highly ranked challenges.

As mentioned at the beginning of this section, the group selected the challenges shown in **bold** (above), and subsequently identified specific steps, metrics, and milestones to address them. Their detailed suggestions are provided in Appendix C.

Note: The suggestions for each priority challenge were generated in a relatively short time period by a small group of workshop participants. Hence, this information should not be considered a final or comprehensive determination of steps and timeline needed to address the challenges. Rather, this information should be considered a starting point for further deliberation on how the identified challenges should be addressed.

5.2.1 CHALLENGE #1: IDENTIFYING THE LEVEL OF UPGRADING REQUIRED TO IMPROVE STABILIZATION AND FINDING THE BEST UPGRADING TECHNOLOGIES

GOAL: Identify the level of upgrading required to improve stabilization and find appropriate upgrading technologies for bio-oil blends to meet performance and market needs	
KEY STEPS	TIMEFRAME
a. Conduct research to determine the level of upgrading that is required to improve stabilization b. Identify and evaluate technology options to reduce acid components during pyrolysis; demonstrate promising technologies c. Test and evaluate technology alternatives to separate acid species from bio-oil, such as membrane and phase separation; demonstrate promising technologies d. Evaluate various upgrading technologies to modify acid components, including hydrotreating and esterification; demonstrate promising technologies	Needed research and technology demonstrations could be completed by 2017

5.2.2 CHALLENGE #2: UNDERSTANDING CORROSION ASSOCIATED WITH THE COMBUSTION OF BIO-OIL

GOAL: To identify ways to reduce corrosion of boiler tubes and downstream components exposed to condensates when combusting bio-oil	
KEY STEPS	TIMEFRAME
e. Conduct laboratory-scale tests to focus on specific corrosion mechanisms in well-controlled conditions f. Conduct pilot-scale tests to scope out a variety of operating conditions and obtain data under realistic firing scenarios g. Full-scale demonstration tests h. Compile all data to address regulatory questions and other potential issues	Testing could be completed by 2017

5.2.3 CHALLENGE #3: BETTER CORRELATING CORROSION WITH PERCENT OXYGEN CONTENT AND FUNCTIONAL OXYGEN GROUPS

GOAL: Correlate corrosion with concentration of suspect species and other indicators	
KEY STEPS	TIMEFRAME
i. Characterization of corrosive components of pyrolysis oil (acidic species and other species that may contribute) j. Evaluate impact of various methods of neutralization on oil properties and characteristics k. Conduct corrosion studies to relate resistance of various materials to levels of suspect species and corrosion indicators l. Provide recommendations for material compatibility for various grades of bio-oil	A three-year study would be needed to conduct needed analysis

5.2.4 CHALLENGE #4: ENSURING THAT BIO-OIL OR OIL BLENDS MEET STAKEHOLDER NEEDS AND MARKET EXPECTATIONS

GOAL: Improve qualities of 10% percent pyrolysis oil blend to meet combustion certification requirements and to achieve market acceptance	
KEY STEPS	TIMEFRAME
m. Achieve complete miscibility at blend level of at least 10% n. Reduce odor to a level that is acceptable to consumers o. Gain approval/certification to burn 10% bio-oil blend in combustion equipment p. Techno-economic analysis and market analysis to determine optimum upgrading levels for market acceptance and market penetration	Miscibility and odor reduction goals could be reached by 2015; combustion certification could be achieved by 2017

6 Conclusions and Path Forward

Based on discussions at the "Technical Information Exchange on Pyrolysis Oil" workshop, it is clear that significant challenges must be overcome to reliably produce an ample supply of pyrolysis oil that can be used as a viable substitute for traditional heating oil.

Discussions of the most significant challenges were structured to address three topic areas: 1) Feedstock and Production, 2) Logistics and Compatibility, and 3) Operational Issues. The brainstorming and discussion sessions elucidated significant overlap among these three areas, and the participants identified a number of crosscutting issues and challenges that impact the potential viability of pyrolysis oil production systems and end use consumption. Participants also identified challenges that did not clearly fall within one of the three topic areas, including issues related to market engagement and market acceptance.

Thematically, the workshop participants focused their discussions on major challenges in the following three categories:

- **Addressing corrosion:** While numerous technical challenges are involved in introducing pyrolysis oil into the home heating oil market, the corrosiveness of pyrolysis oil appears to present the most significant barrier. There is a need to pursue the following objectives:
  - Better understand how different levels of upgrading and blending the pyrolysis oil with fuel oil will affect this corrosiveness.
  - Develop production processes that minimize corrosiveness.
  - Explore cost-effective means to make production, transportation, and end-use infrastructure resistant to corrosion.
- **Specifications and standards:** To make it possible for pyrolysis oil to enter the home heating oil market, work must be undertaken to develop appropriate specifications and standards for the feedstocks, the pyrolysis oil, blends, and end-use equipment.
- **Successful market penetration strategy:** Stakeholders need to agree on a strategy for effectively introducing pyrolysis oil into to the home heating oil market and then work together to implement the strategy. This cooperation entails reaching agreement on the type of pyrolysis oil product that can be successfully introduced to the market and exploring/identifying the most viable techno-economic models for production and transport of pyrolysis oil.

The Bioenergy Technologies Office expects that next steps to address the technical challenges for this use of pyrolysis oil include: 1) Closer examination of feedstock availability in the Northeast states, and 2) A techno-economic analysis and lifecycle emissions assessment over the entire pyrolysis oil supply chain.

The Bioenergy Technologies Office will use the workshop results to inform its strategic planning and prioritization of future RD&D on pyrolysis oil. Taking into account continuing relevant technology and market developments, BETO expects to work with key stakeholders to refine the strategy for potentially accelerating the introduction of domestic pyrolysis oil into the Northeast home heating oil market.

Appendix A List of Contributors

Technical Information Exchange on Pyrolysis Oil
May 9-10, 2012 Manchester, NH

Name	Organization
Suresh Babu	Brookhaven National Labs
Dennis S. Banasiak	Avello Bioenergy, Inc
Richard Boardman	INL
Alex Brown	Sandia National Labs
Thomas Butcher	Brookhaven National Labs
John Carpenter	RTI
Steve Chalk	DOE
Chris Clark	Energetics Incorporated
Eric Eddings	University of Utah
Sue Ellerbusch	BP
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Richard Hess	INL
John Huber	National Oil Heat Research Alliance (NORA).
Kristina Lisa	NREL
James Keiser	ORNL
George Kervitsky	BCS
Jani Lehto	VTT Technical Research Centre of Finland
Elliot Levine	DOE
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Brenda Maday	Biomass Resource Center
Tommi Makila	Energetics Incorporated
Jonathan Male	PNNL
Matthew McArdle	Mesa Reduction Engineering & Processing
Elliott Moorhead	Tolero Energy
Terry Myer	Iowa State University
Fernando Preto	CanMetENERGY
Don Stevens	Cascade Research
Corinne Valkenburg	PNNL

Appendix B Technical Information Exchange Agenda

Conference Agenda Time	Technical Information Exchange on Pyrolysis Oil: Potential for a renewable heating oil substitution fuel in New England May 9-10, 2012 Manchester New Hampshire
7:30 – 8:30 a.m.	**Registration and Continental Breakfast**
8:30 – 8:40 a.m.	**Welcome and Introduction** **Steve Chalk**, Deputy Assistant Secretary for Renewable Energy, DOE
8:40 – 8:55 a.m.	**The Department of Energy Perspective** **Elliott Levine**, Technology Manager, DOE
8:55 – 9:45 a.m.	**Plenary Presentations – Background and Context** ● **Presentation:** "Known Challenges Associated with the Production, Transportation, Storage and Usage of Pyrolysis Oil in Residential and Industrial Settings" **Dr. Jani Lehto**, Principal Scientist, VTT Technical Research Centre of Finland ● **Presentation:** Integrated System Sensitivities and Perspective "A qualitative discussion on conversion, stabilization, and upgrading versus infrastructure compatibility and retrofit requirements**"** **Jonathan Male,** Pacific Northwest National Laboratory
9:45 – 9:50 a.m.	**Framing and Instructions for Information Exchange** *(Chris Clark, Energetics)* ● Meeting Guidelines – **Chris Clark**, Energetics Incorporated
9:50 – 10:00 a.m.	**Break**

10:00 a.m. – 12:00 p.m.	**Facilitated Discussion on Challenge # 1 – *Feedstock and Production—feedstock availability, homogeneity, process and conditioning enhancements and specifications.* During the discussion each participant will quantitatively rank each aspect of the challenge.**
	• **Introductions, Ground Rules and Agenda**
	• **Facilitated Brainstorming – Group Consensus and Discussion**
	  • *Feedstock availability – physical and chemical composition (not logistics)*
	  • *Process enhancements and optimization – Increase oil yields, reactor design and technological challenges – modeling, reactor bed issue, etc.*
	  • *Emissions changes and impacts from production*

12:00 – 12:45 p.m.	**Lunch** • **Presentation:** "Renewable Heating Fuel – A Commercial Perspective **Steve Lupton**, Envergent Technologies LLC

<table>
<tr><td>12:45 – 2:45 p.m.</td><td>Facilitated Discussion on Challenge # 2 – Logistics and Compatibility with Existing Infrastructure throughout supply chain—substitution and replacement issues in transport, storage and use. During the discussion each participant will quantitatively rank each aspect of the challenge.</td></tr>
<tr><td></td><td>• Facilitated Brainstorming – Group Consensus and Discussion
◦ Location of production
◦ Transporting feedstocks and fuel
◦ Oil storage issues
◦ Infrastructure compatible fuels
◦ Aging of oil
◦ Are there low-cost options?</td></tr>
<tr><td>2:45 – 4:45 p.m.</td><td>Facilitated Discussion on Challenge # 3 – Operational Issues—what are the most significant barriers to overcome in each market segment. During the discussion each participant will quantitatively rank each aspect of the challenge.</td></tr>
<tr><td></td><td>• Facilitated Brainstorming – Group Consensus and Discussion
◦ Pyrolysis oil conditioning: removal of organic oxygen, minimize coke formation, etc.: deoxygenated pyrolysis, catalytic pyrolysis, final product composition, etc.
To effectively address:
▪ Compatibility
▪ Combustion
▪ Corrosivity
▪ Plugging
▪ Fouling
▪ Emissions and ash
◦ Fundamental application issues:
▪ Fuel and burner requirements – certification and specification
▪ CHP
▪ Market penetration</td></tr>
<tr><td>4:45 – 5:00 p.m.</td><td>Day Wrap-up and Discussion of Next Steps Exercise for Day Two</td></tr>
<tr><td colspan="2">DAY TWO</td></tr>
<tr><td>8:00 – 8:30 a.m.</td><td>Continental Breakfast</td></tr>
<tr><td>8:30 – 8:45 a.m.</td><td>Instructions for Small Group Work</td></tr>
<tr><td>8:45 – 11:45 a.m.</td><td>Worksheet Exercise -_Technology Advancement Breakdown</td></tr>
<tr><td></td><td>• Small Group Work – Worksheet Completion on significant challenges—Where are we now in comparison to where we need to be to deploy pyrolysis oil? Break out into smaller groups (2-3 people) by technology need and/or area to fill in worksheets establishing indicators of success and performance goals, as well as expected outcomes tied to the advancement of each technology advancement/solution.</td></tr>
<tr><td>11:45 a.m. – 12:00 p.m.</td><td>Wrap up</td></tr>
<tr><td></td><td>• Group Discussion on Missed Challenges other Concerns from Stakeholders
• Wrap-up and Next Steps</td></tr>
</table>

Appendix C Day 2 Worksheets

Feedstocks & Production: Steps to meet Challenge #1

Challenge Name: Establishing acceptable bio-oil blends with home heating oil

Description of Challenge:

Describe how you perceive the nature of the challenge (logistical, compatibility, process and conditioning enhancement, operational)

Develop acceptable blends fully compatible with existing infrastructure. Explore novel blending techniques.

Is this a new technology, a technology improvement, or something else?

Addressing the Challenge, Specifications and Metrics:

Identify the 1-4 critical advancements that are needed to address the challenge and provide metrics information for each advancement with respect to the current status the desired end state or metric goal and the year at which this advancement can reasonable be achieved.

	Technology Advancement Description	Indicator of Success (How will you know you're done/)	Metric Values			Comments
			2011 Status	Target	By what year?	
A	Identify blend limits for fully conditioned pyrolysis oil	Fully compatible, no blend limit	Believed compatible, confirmation needed	Technical package for standard ASTM	2015	
B	Study fuel oil blends at ranges of upgraded oil (combustion performance, miscibility, materials)	Identify pyrolysis oil suitable for next ASTM standard		Lower priced, ASTM approved blend fuel	2016	
C	Explore novel blending methods	Fully miscible at defined blend levels	None	Acceptable blend with partially upgraded blends	2014-2016	
D	Develop ASTM standard for lower priced blend (using less conditioned pyrolysis oil)	New ASTM standard	-	Lower price than #2 oil	2016-2017	

Additional Information:

Key Assumptions:

Other Guidance:

FEEDSTOCKS & PRODUCTION: MILESTONES FOR CHALLENGE #1

Challenge Name: Acceptable pyrolysis oil blends with home heating oil

Technology Advancement Specifications and Metrics:

Identify the 1-5 critical steps required to complete each of the advancements related to the technology and place them along the timeline.

Technology Advancement (*short description of advancement from the Metrics Worksheet, include current and target metrics*)		Major Steps	Time Line (*Place approximate completion dates for the major steps along the time line*)
Identify blend limits for fully conditioned pyrolysis oil	1	Select and characterize	*Separation, corrosion, burner performance, fuel standard analyses. Will include confirming acceptable combustion in typical burn systems. **Prepare a draft ASTM detailed standard based on input from industry & researchers as best compromise regarding properties, performance and cost. Submit 2014 — Standard 2016
	2	Lab tests - UL296*	
	3	Engage ASRM (other standards groups)	
	4	Draft ASTM for blend stock**	
	5		
Study fuel oil blends at ranges of upgraded oil	1	Select & characterize partially upgraded samples	2016
	2	Explore blending with oils	
	3	Define level of miscibility with partially upgraded blends	
	4		
	5		
Explore novel blending methods***	1	Improve levels of miscibility leading to higher blend levels	***Include consideration of economically viable emulsions and co-solvents (such as alcohol) among others. 2014-2016
	2		
	3		
	4		
	5		
New ASTM standard	1	100 homes demonstrated successfully	2017
	2	ASTM standard defined	
	3	Submit ASTM package	
	4		

Additional Information:

Other:	**Other:**

Other Guidance:

FEEDSTOCKS & PRODUCTION: STEPS TO MEET CHALLENGE #2

Challenge Name: Need to move bio-oils sequentially into markets

Description of Challenge:

Describe how you perceive the nature of the challenge (logistical, compatibility, process and conditioning enhancement, operational)

All of above. From siting and co-locating plants to produce raw oil/#4-6 and moving to a #2 blend with a central plant.

Is this a new technology, a technology improvement, or something else?

Addressing the Challenge, Specifications and Metrics:

Identify the 1-4 critical advancements that are needed to address the challenge and provide metrics information for each advancement with respect to the current status the desired end state or metric goal and the year at which this advancement can reasonable be achieved.

	Technology Advancement Description	Indicator of Success (How will you know you're done!)	Metric Values: 2011 Status	Metric Values: Target	Metric Values: By what year?	Comments
A	Demonstration plant to produce #4-6	Build a plant/ sited & offtake	Small Canada plant	A 15 million gallon plant in NE	2013	Independent qualification of commercial production is needed to reduce the commercial risk of investments in biomass supply and bio-oil delivery
B	From raw #6 technology platform to move to #2 equivalent	At lab/pilot plant develop upgrade technology	R&D product development	Drop-in #2 at test fuel quantities	2015	This is the target fuel for residential HO substitution; #4 and #6 will open the commercial/industrial markets, which will prepare the political support and commercial incentive for residential HO substitution
C	Does this #2 equivalent meet needs of heating oil and at what maximum levels	Blendable works as a drop-in fuel	Preliminary test (Fernando/Tom) 2013	Evaluating maximum blend levels	2014/2015	Proof of blending will increase the market size and flexibility of bio-oil substitution fuel
D	Develop specifications that meet #6, #4, and #2 (blend) markets	Industry accepted specs, user/producer	-	Test fuel quantities evaluated & refined	2016	Target specs, Tasks A, B, C needed to enable Task D

Additional Information:

Key Assumptions: Oil prices remain high and natural gas prices recover, leading to opportunities to lower production costs.

Other Guidance: Develop specs, prototype plants

FEEDSTOCKS & PRODUCTION: MILESTONES FOR CHALLENGE #2

Challenge Name: Moving pyrolysis oils sequentially into markets

Technology Advancement Specifications and Metrics:

Identify the 1-5 critical steps required to complete each of the advancements related to the technology and place them along the timeline.

Technology Advancement (*short description of advancement from the Metrics Worksheet, include current and target metrics*)		Major Steps	Time Line (*Place approximate completion dates for the major steps along the time line*)
Demonstration plant to produce #6	1	Size of plant	Preliminary design 2012; Contract, permit, engineer 2013; Build 2014/2015
	2	Appropriate feedstock	
	3	Design & build	
	4	Offtake/customer	
	5	Recommendations for commercial scale	
Moving raw/#6 into a #2 equivalent	1	Source raw #6, variable feedstocks	Requisition & get source liquids (#6) 2012; Identify reprocessors 2014
	2	Supply #2 developers/reprocessors	
	3	Technology/processes to move from #6/raw to #2 processes	
	4	Evaluating #2 process fuel	
	5		
#2/processed qualified for heating oil use	1	Develop test protocol	2013 - 2014
	2	Key stakeholders/OEMs/auxiliary components	
	3	Conduct trials; identify issues/countermeasures/field test	
	4	Blend level issues	
	5		
Develop appropriate specs for #6/#4/#2 equivalents	1	Stakeholders	Parallel path 2014 - 2016
	2	Appropriate standard setting	
	3	Draft specifications	
	4		

Additional Information:

Other:	**Other:**
Other Guidance:	

FEEDSTOCKS & PRODUCTION: STEPS TO MEET CHALLENGE #3

Challenge Name: Develop feedstock specifications and certifications

Description of Challenge:

Describe how you perceive the nature of the challenge (logistical, compatibility, process and conditioning enhancement, operational)

Is this a new technology, a technology improvement, or something else?

Addressing the Challenge, Specifications and Metrics:

Identify the 1-4 critical advancements that are needed to address the challenge and provide metrics information for each advancement with respect to the current status the desired end state or metric goal and the year at which this advancement can reasonable be achieved.

	Technology Advancement Description	Indicator of Success (How will you know you're done!)	Metric Values			Comments
			2011 Status	Target	By what year?	
A	Understand grades of resources available	Library of feedstocks with testing and analysis results (ultimate analysis)	Library backbone is built	Library needs to be populated by performing testing and documentation	2014	Need a supplier to collect several representative samples and have tested (regional partnership program)
B	Determine materials that are a concern with the process of making, blending and combusting pyrolysis oil	List of materials of concern and the impact concern	Some industry experience but no home heating knowledge base	Comprehensive specification & database	2016	Use of bio-oil is critical input to establish relationship of impact concern
C	Define allowable levels of materials of concern	Defined allowable levels of all deleterious materials	Current regulations on emissions, but nothing for material corrosion (etc.) concerns	Populated database & specification with maximum/minimum allowable for all components.	2015	
D	Determine testing methods and frequency	Determine if online (in process) testing and required, frequency and how often sampling based on risk. Documented in specification	No specification exists	Methods, procedures, equipment documented in a specification	2016	For specifications and eventual library ownership NIST, IEA and ASTM need to be involved

Additional Information:

Key Assumptions:

Other Guidance:

FEEDSTOCKS & PRODUCTION: MILESTONES FOR CHALLENGE #3

Challenge Name: Develop feedstock specifications

Technology Advancement Specifications and Metrics:

Identify the 1-5 critical steps required to complete each of the advancements related to the technology and place them along the timeline.

Technology Advancement (*short description of advancement from the Metrics Worksheet, include current and target metrics*)		Major Steps	Time Line (*Place approximate completion dates for the major steps along the time line*)
Understand grades of resources available	1	Develop feedstock matrix (type, locations)	Step 1 1/2012 — Step 2 1/2013 — Step 3 — Step 4 1/2014
	2	Collect samples	
	3	Test samples (save material of each type)	
	4	Document results	
	5		
Determine materials that are a concern with the process of making, blending and combusting bio-oil	1	Determine failure mechanisms	1/2012 — 1/2013 — Steps 1&2 — Step 3 1/2014 — Step 4 1/2015
	2	Determine elements in fuel that will continue through pyrolysis oil production	
	3	Determine materials that impact pyrolysis oil quality	
	4	Deploy demonstration plant to confirm results	
	5		
Define allowable levels of materials of concern	1	Define how easy it is to remove material of concern	1/2014 — Step 1 — Step 2 1/2015 — Step 3 →----- →-----→ 1/2016 -----→-----→-----→ 1/2017
	2	Define limits	
	3	Run pilot demonstration plant for an extended period	
	4		
	5		
Determine testing methods and frequency	1	Define testing and calibration method	1/2013 — Step 1 — 1/2014 — Step 2 Step 3 1/2015 — Step 4 1/2016 — 1/2017
	2	Install on pilot demonstration unit	
	3	Document results	
	4	Approve specifications	

Additional Information:

Other:

Other:

Other Guidance:

FEEDSTOCKS & PRODUCTION: STEPS TO MEET CHALLENGE #4

Challenge Name: Optimization of biomass carbon usage

Description of Challenge:

Describe how you perceive the nature of the challenge (logistical, compatibility, process and conditioning enhancement, operational)

Process and conditioning enhancement

Is this a new technology, a technology improvement, or something else? Technology improvement

Addressing the Challenge, Specifications and Metrics:

Identify the 1-4 critical advancements that are needed to address the challenge and provide metrics information for each advancement with respect to the current status the desired end state or metric goal and the year at which this advancement can reasonable be achieved.

	Technology Advancement Description	Indicator of Success (How will you know you're done!)	Metric Values: 2011 Status	Metric Values: Target	Metric Values: By what year?	Comments
A	Lower level of carbon solids in oil	Solids free oil; <0.1 wt% in bio-oil	1.0-0.3 wt% solids in bio-oil	<0.1 wt% solids in bio-oil	2015	wt% numbers are ash + carbon
B	In-situ carbon usage to optimize yield of primary product (bio-oil)	Cost producing liquid product (taking side products as a credit):	($300-$100)/$50= 4.0	8.0	2020	Indicator of success: (total value of products-engineering costs)/unit cost of feedstocks - Based on feedstock cost $50/dry ton. Highlights importance of feedstock cost.
C	Develop biochar as a higher value product (soil amendment agent or activated carbon)	Higher value than using char for energy (≥$300/ton)	Burning char is best option	Viable market for biochar	2020	-Establish value of biochar to agriculture - Establish production criteria/specs for biochar
D						

Key Assumptions: Access to reasonable cost feedstock, assumed biochar as viable option, assumed low solids economically viable, volatiles can be used for energy or reactants. Assume no carbon credits.

Other Guidance: DOE should work with industry, other agencies and internationally

FEEDSTOCKS & PRODUCTION: MILESTONES FOR CHALLENGE #4

Challenge Name: Optimization of biomass carbon usage

Technology Advancement Specifications and Metrics:

Identify the 1-5 critical steps required to complete each of the advancements related to the technology and place them along the timeline.

Technology Advancement *(short description of advancement from the Metrics Worksheet, include current and target metrics)*		Major Steps	Time Line *Place approximate completion dates for the major steps along the time line*
Lower level of carbon solids in oil (Task A)	1	Improve measurement precision of small particles in bio-oil	2012; Step 1; Step 2, Step 3 – 2013; Step 4 – 2014; Step 5 – 2015
	2	Technical feasibility of hot filtration	
	3	Technical feasibility of membrane separation	
	4	Practical demonstration ≥150 hrs on bio-oil, on 1L/hr	
	5	Demonstrated integrated system ≥500 hrs	
In-situ carbon usage to optimize yield of primary product (bio-oil) (Task B)	1	Develop techno-economic model & carbon balances & identify opportunities - TEA	2012; Step 1 – 2013; Step 2 – 2014; Step 3 – 2015 (Task A feeds in); 2016; 2017; Step 4 – 2018 (Task C feeds in); 2019; Task 5 – 2020 (Task C in)
	2	Refine process integration to reduce energy consumption	
	3	Examine trade-offs for volatiles to make reductant to upgrade bio-oil.	
	4	Bring in higher value of char (next task)	
	5	Demonstration of integrated carbon efficient system.	
Develop biochar as a higher value product (soil amendment agent or activated carbon) (Task C)	1	Establish value for char for energy (combustion)	Step 1 – 2012; 2013; 2014; Step 2 – 2015; Step 3 – 2016; 2017; Step 4 – 2018; 2019; Step 5 – 2020
	2	Establish processing parameter biochar property correlation	
	3	Screen chars for levels of toxicity, health issues	
	4	Establish agricultural testing of different chars & value	
	5	Establish char as a chemical product/sorbent in chemical industry	

Additional Information:

Other:

Other:

Other Guidance:

FEEDSTOCKS & PRODUCTION: STEPS TO MEET CHALLENGE #5

Challenge Name: Uncertainties in best pre-treatment steps essential to certain feedstocks

Description of Challenge:

Describe how you perceive the nature of the challenge (logistical, compatibility, process and conditioning enhancement, operational)

Essential pretreatment steps

Is this a new technology, a technology improvement, or something else? New technology

Addressing the Challenge, Specifications and Metrics:

Identify the 1-4 critical advancements that are needed to address the challenge and provide metrics information for each advancement with respect to the current status the desired end state or metric goal and the year at which this advancement can reasonable be achieved.

	Technology Advancement Description	Indicator of Success (How will you know you're done!)	Metric Values			Comments
			2011 Status	Target	By what year?	
A	Leaching for alkali metal halide removal	Alkali metal halide content in bio-oil	? – Baseline: no pretreatment	Meet fuel specs for metal halides in bio-oil	2016	Specs will be defined by fuel specification requirements. Need bio-oils to combustion products correlation
B	Biomass deconstruction methods	Bio-oil yield Downstream process cost	Baseline fast pyrolysis values	10% increase in yield	2017	Assumes reductions in oxygen and acid content and increased bio-oil yield will result in lower downstream cost. 10% increase in yield would help attain the HHO substitution goal of 20 wt% with bio-oil
C	Thermal non-pyrolytic (drying)	Pyrolysis product value	Baseline product value assuming low grade heat is used for drying	10% increase in product value	2017	Assumes decreasing water content in oil creates a higher value product. Needs to be examined to see if the additional cost of the pretreatment can be recouped in the total process

Key Assumptions: Access to reasonable cost feedstock, assumed biochar as viable option, assumed low solids economically viable, volatiles can be used for energy or reactants. Assume no carbon credits.

Other Guidance: DOE should work with industry, other agencies, and internationally

FEEDSTOCKS & PRODUCTION: MILESTONES FOR CHALLENGE #5

Challenge Name: Uncertainties in best pre-treatment steps essential to certain feedstocks

Technology Advancement Specifications and Metrics:

Identify the 1-5 critical steps required to complete each of the advancements related to the technology and place them along the timeline.

Technology Advancement *(short description of advancement from the Metrics Worksheet, include current and target metrics)*		Major Steps	Time Line *Place approximate completion dates for the major steps along the time line*
Leaching for alkali metal halide removal	1A	Characterization of baseline levels from various feedstocks	Step 1 2013; Step 2 2014; Step 3 2015; Step 4 2016
	2A	Evaluate effectiveness of technology on feedstock properties	
	3A	Correlate pyrolysis yields/specification with leaching level/technology	
	4A	Techno-economic analysis of pretreatment	
	5		
Biomass deconstruction methods	1B	Lab-scale demonstration & measurements of feedstock pretreatment	Step 1 2013-2014; Step 2 2014-2015; Step 3 2015; Step 4 2015-2016; Step 5 2016-2017
	2B	Lab-scale pyrolysis performance feedback.	
	3B	Down-select evaluation/Go-No-Go decision.	
	4B	Scale-up of deconstruction methods – collect design data	
	5B	Scale-up integration with pyrolysis technology	
	1		
	2		
	3		
	4		
	5		
	1		
	2		
	3		
	4		

Additional Information:

Other:	**Other:**
Other Guidance:	

Logistics & Compatibility: Steps to Meet Challenge #1

Challenge Name: Identification and treatment of chemical components ("bad actors") leading to corrosion

Description of Challenge:

Describe how you perceive the nature of the challenge (logistical, compatibility, process and conditioning enhancement, operational)

Materials of construction and process stream compatibility issues.

Is this a new technology, a technology improvement, or something else? Improving the quality of the oil and establishing materials compatibility

Addressing the Challenge, Specifications and Metrics:

Identify the 1-4 critical advancements that are needed to address the challenge and provide metrics information for each advancement with respect to the current status the desired end state or metric goal and the year at which this advancement can reasonable be achieved.

	Technology Advancement Description	Indicator of Success	Metric Values			Comments
			2011 Status	Target	By what year?	
A	- Correlate O content w/ corrosion. Measure corrosion at 12 O different contents. - Measure corrosion related to char & specific minerals content	Completion of the test matrix. Determination of minimum O content resulting in corrosion	0.5 wt% O = no corrosion (2 done, 10 to go)	Completion of 12 tests; determination of max acceptable char content as of f(minerals) as well	2014	Needs to be correlated with Task B since within the total oxygen atom content is the relative ratios of the oxygenates species present. Need to test corrosion at different temperatures to reflect different point of the supply change
B	GC^2 x MS, LC, 13C NMR, IR etc. analysis to identify components in the low-O content, but corrosivity exhibiting oils	Identification of approximately 10 key chemical components	Zero have been identified	Complete the identification	2014	Some functionalities have been identified, but not components necessarily
C	Testing of model compounds to understand role of each component alone & w/ the other components identified	Documentation of corrosion rates from test matrix	Not started	Completed testing of 10 key components	2015	Targets & metrics should be identified after preliminary work is completed. Need to cross reactions between the species
D	Improve upgrading methods to target key components identified	Reduced H_2 demand (or other process intensity) by treating target components	Not started	Reduced process intensity or H_2 requirements by X%	2017	Targets & metrics should be identified after preliminary work is completed

Additional Information:

Key Assumptions: Sufficient quantities of upgraded oils will be available for testing. Corrosion tests are ~500 hrs. We have to achieve bio-oil that is not corrosive to carbon steel or yellow metals (those typically used in home heating).

Other Guidance: Work with existing bio-oil industry to ensure testing is relevant to their needs.

LOGISTICS & COMPATIBILITY: MILESTONES FOR CHALLENGE #1

Challenge Name: Identification and treatment of chemical components ("bad actors") leading to corrosion

Technology Advancement Specifications and Metrics:

Identify the 1-5 critical steps required to complete each of the advancements related to the technology and place them along the timeline.

Technology Advancement *(short description of advancement from the Metrics Worksheet, include current and target metrics)*	#	Major Steps	Time Line *Place approximate completion dates for the major steps along the time line*
Correlate O_2 content and char content/minerals w/ corrosion & erosion, respectively, by completing 12 tests.	1	Oil production at 12 O levels	Steps 1, 2 & 3: 2014
	2	Material transfer to corrosion lab	
	3	Corrosion & erosion tests	
	4		
	5		
Identification of 10 key chemical components exhibiting corrosion in low-O content oils	1	Chemical specification	Steps 1, 2 & 3: 2014
	2	Quantification of data	
	3	Selection of model compounds	
	4		
	5		
Understanding of corrosion causing species and the effects of combination of species	1	Procurement of model compounds	Steps 1, 2 & 3: 2015
	2	Corrosion test matrix	
	3	Quantification of data	
	4		
	5		
Reduced process intensity (e.g., reduced H_2 consumption) using improved upgrading methods to target key components	1	Evaluation of treatment options	Steps 1&2: 2015; Step 3: 2017
	2	Testing of selected methods	
	3	Analysis of process intensity	
	4		

Additional Information:

Other:

Other:

Other Guidance:

Logistics & Compatibility: Steps to Meet Challenge #2

Challenge Name: Ensure reliable operation while minimizing changes to current combustion infrastructure

Description of Challenge:

Describe how you perceive the nature of the challenge (logistical, compatibility, process and conditioning enhancement, operational)

Compatibility and enhancement depending on feedstock. Links intimately with blending challenge.

Is this a new technology, a technology improvement, or something else?

Addressing the Challenge, Specifications and Metrics:

Identify the 1-4 critical advancements that are needed to address the challenge and provide metrics information for each advancement with respect to the current status the desired end state or metric goal and the year at which this advancement can reasonable be achieved.

	Technology Advancement Description	Indicator of Success (How will you know you're done/)	Metric Values			Comments
			2011 Status	Target	By what year?	
A	Fully conditioned bio-oil and blends	Meet standards list	None		2013	Concurrent with blending
B	Fuel blends with partially upgraded bio-oils	Meet standards list	None		2015	Concurrent with blending
C	Bio-oils (not upgraded) and novel concepts in existing equipment (alcohols)	Meet standards list	None		2015	Concurrent with blending, blending of alcohols with raw bio-oil is known and may not be cost competitive
D	Novel nozzle and burner head concepts (low infrastructure modifications)	Meet standards list	None		2015	Concurrent with blending, leverage work at CanmetENERGY, SNL and others with raw bio-oil

Additional Information:

Key Assumptions:

Other Guidance: Demonstrate as good as or better than existing standards. Standards already exist: Pressure, fouling (efficiency & lifetime), heat transfer, ignition, stability, emissions, flame detector, cold start

LOGISTICS & COMPATIBILITY: MILESTONES FOR CHALLENGE #2

Challenge Name: Ensure reliable operation while minimizing changes to current combustion infrastructure

Technology Advancement Specifications and Metrics:

Identify the 1-5 critical steps required to complete each of the advancements related to the technology and place them along the timeline.

Technology Advancement *(short description of advancement from the Metrics Worksheet, include current and target metrics)*		Major Steps	Time Line *Place approximate completion dates for the major steps along the time line*
Fully conditioned pyrolysis oil and blends	1	Acquire and test materials to listed standards	Linked to blended fuel timeline; 2013
	2		
	3		
	4		
	5		
Fuel blends with partially upgraded pyrolysis oils	1	Acquire and test materials to listed standards	2015
	2		
	3		
	4		
	5		
Pyrolysis oils (not upgraded) and novel concepts in existing equipment (alcohols)	1	Acquire and test materials to listed standards	2015
	2		
	3		
	4		
	5		
Novel nozzle and burner head concepts (low infrastructure modifications)	1	Acquire and test materials to listed standards	2015
	2		
	3		
	4		

Additional Information:

Other:

Other:

Other Guidance:

Logistics & Compatibility: Steps to Meet Challenge #3

Challenge Name: Development of accepted bio-oil analyses and standards

Description of Challenge:

Describe how you perceive the nature of the challenge (logistical, compatibility, process and conditioning enhancement, operational) Compatibility

Is this a new technology, a technology improvement, or something else? New technology and building consensus

Addressing the Challenge, Specifications and Metrics:

Identify the 1-4 critical advancements that are needed to address the challenge and provide metrics information for each advancement with respect to the current status the desired end state or metric goal and the year at which this advancement can reasonable be achieved.

	Technology Advancement Description	Indicator of Success (How will you know you're done/)	Metric Values			Comments
			2011 Status	Target	By what year?	
A	Development and refinement of standardized analyses for the complex matrix of bio-oil.	IEA Bioenergy, ASTM, NIST certified methods of analysis; scientifically proven & internationally accepted	Round robin testing underway internationally, IEA Task 34	A suite of analytical techniques to enable characterization of bio-oil & enable mass balance	2015	On critical path for developing infrastructure for bio-oils
B	Development of consensus on key physical parameters of different grades of bio-oils for different applications (develop specifications).	ASTM standards for the grades of bio-oils	ASTM D744X-10 replacement for heavy oil, CAS No. for bio-oil	ASTM standards for at least 4 grades of oils (raw oil, refinery ready, LFO, HFO, engine, turbine, MFO)	2020	On critical path for developing infrastructure for bio-oils
C	Development of understanding of bio-oil grades health & toxicity specifications to enable handling and market acceptance	Department of Transportation & EPA approved health & toxicity standards	Bio-tox study IEA in 1980's	Approved norms for safe use & handling of oil	2017	On critical path for developing infrastructure for bio-oils
D	Development of specifications of material compatibility and storage	Approved/certified materials for grades of bio-oil usage	Preliminary corrosion work done by ORNL, UOP, VTT & others	Identified & accepted best practices for handling & optimal materials compatibility	2015	On critical path for developing infrastructure for bio-oils

Additional Information:

Key Assumptions: These are done with international collaboration & accepted by industry; this is critical path for market acceptance

Other Guidance: Across agencies & experimentalist variability is essential to capture – need round robin.

Logistics & Compatibility: Milestones for Challenge #3

Challenge Name: Development of accepted bio-oil analyses and standards

Technology Advancement Specifications and Metrics:

Identify the 1-5 critical steps required to complete each of the advancements related to the technology and place them along the timeline.

Technology Advancement		Major Steps	Time Line *Place approximate completion dates for the major steps along the time line*
A-Development and refinement of standardized analyses for the complex matrix of bio-oil (Task A)	1A	State of the art report of analytical techniques for bio-oils	Step 1 Step 2 Step 3 Step 4 Step 5 2012 2013 2014 2015
	2A	Round robin of key analytical techniques with standard oil	
	3A	Round robin of key analytical techniques on different grades of oil	
	4A	Present proposed robust analytical techniques & as for validation	
	5A	Common acceptance of standard techniques	
B-Development of consensus on key physical parameters of different grades of bio-oils for different applications (develop specifications) (Task B)	1B	Measure parameters typical for the petroleum industry for the bio-oil grades	Task A & D feed in Task C feeds in Step 1 Step 2 Step 3 Step 4 Step 5 2012 2013 2014 2015 2016 2017 2018 2019 2020
	2B	Correlate physical parameters to performance of bio-oils (round robin) domestic and international	
	3B	Start writing standards for first 2 grades	
	4B	Start writing standards for other grades	
	5B	Iteration of standards & attain voting at ASTM	
C-Development of understanding of bio-oil grades health & toxicity specifications to enable handling and market acceptance (Task C)	1C	Develop definition of bio-oils & distinction between grades both domestic and international	Step 1 Step 2 Step 3 Step 4 Step 5 2012 2013 2014 2015 2016 2017
	2C	Screening short-term health & toxicity with different grades of oils both domestic and international	
	3C	Develop correlation to key species in the bio-oil grades & tie to toxicity, health issues	
	4C	Develop guide to long-term exposure to grades of oils (biodegradable as well)	
	5C	Publish results & recommendations & regulatory approval	
D-Development of specifications of material compatibility and storage (Task D)	1D	Screen materials for different grades of oils (50 hrs 50 °C, oils & vapors and higher temperatures)	Step 1 Step 2 Step 3 Step 4 2012 2013 2014 2015
	2D	Examine species of oxygenates in oils before & after & on surface. ID species reacting.	
	3D	Develop & use accelerated aging based on Task 2	
	4D	Publish results & recommendations & feed to Task B	

Additional Information:

Other Guidance: Task B steps 3 & 4 are iterative with the ASTM committee to address negative votes

LOGISTICS & COMPATIBILITY: STEPS TO MEET CHALLENGE #4

Challenge Name: Determine acceptable scale for distributed bio-oil generation

Description of Challenge:

Describe how you perceive the nature of the challenge (logistical, compatibility, process and conditioning enhancement, operational)

Logistical, optimal economic scaling

Is this a new technology, a technology improvement, or something else? Technology improvement and scrutinizing trade-offs

Addressing the Challenge, Specifications and Metrics:

Identify the 1-4 critical advancements that are needed to address the challenge and provide metrics information for each advancement with respect to the current status the desired end state or metric goal and the year at which this advancement can reasonable be achieved.

	Technology Advancement Description	Indicator of Success (How will you know you're done/)	Metric Values: 2011 Status	Metric Values: Target	Metric Values: By what year?	Comments
A	Determine quantities, locations of feedstocks	Feedstock map w/ quantities & qualities of feedstock	Some available; need to refine to include quality of available feedstock	See indicator	2013	
B	Determine infrastructure constraints for all aspects: Feedstock delivery, oil transport	List of transportation constraints: Feedstock miles/quantity; Oil: miles/truck, materials/quantities	Commercial suppliers for biopower applications can be leveraged	List of constraints, costs of incorporating needs, i.e., Proximity to feedstock at cost that supports proforma	2014	Examine optimal location for hydrotreating
C	Develop economic model/proforma for various sizes	Spreadsheet based proforma that can be easily modified for changing inputs	Unknown if there is work	Proforma with real #s for given infrastructure constraints	2016	
D	Build/locate demonstration unit to confirm numbers	Demonstration facility minimum of 1/5 scale to operate 2+ yrs	Nothing available now	Locate and build at site that is comparable to minimum of 40 sites in Northeast	2017	

Additional Information:

Key Assumptions:

Other Guidance:

LOGISTICS & COMPATIBILITY: MILESTONES FOR CHALLENGE #4

Challenge Name: Determine acceptable scale for distributed pyrolysis oil generation

Technology Advancement Specifications and Metrics:

Identify the 1-5 critical steps required to complete each of the advancements related to the technology and place them along the timeline.

Technology Advancement (*short description of advancement from the Metrics Worksheet, include current and target metrics*)		Major Steps	Time Line (*Place approximate completion dates for the major steps along the time line*)
Determine quantities, locations of feedstocks	1	Start with feedstock maps/oil markets	Step 1, Step 2, Step 3; 1/2012 – 1/2013 – 1/2014
	2	Determine $/T needed to fit model proforma	
	3	Provide map of quantities of fuel available at various cost points	
	4		
	5		
Determine infrastructure constraints for all aspects: Feedstock delivery, oil transport	1	Need plant size - determine feedstock transportation constraints	Step 1, Step 2, Step 3; 1/2013 – 1/2014 – 1/2015
	2	Determine proximity to market	
	3	Determine means of transporting end product	
	4		
	5		
Develop economic model/proforma for various sizes	1	Utilize feedstock map & proposal locations for inputs	Step 1, Step 2; 1/2014 – 1/2015 – 1/2016
	2	Input various CAPEX/OPEX for various plants	
	3		
	4		
	5		
Build/locate demonstration unit to confirm numbers	1	Locate & permit site	Step 1, Step 2, Step 3, Step 4; 1/2014 – 1/2015 – 1/2016 – 1/2017 – 1/2018
	2	Achieve financing	
	3	Build demo plant	
	4	Feedback into proforma	

Additional Information:

Other:

Other:

Other Guidance:

Logistics & Compatibility: Steps to Meet Challenge #4B

Challenge Name: Scaling of pyrolysis plants and capitalization

Description of Challenge:

Describe how you perceive the nature of the challenge (logistical, compatibility, process and conditioning enhancement, operational)

What scale of pyrolysis plants give economy of scale. How to capitalize these plants.

Is this a new technology, a technology improvement, or something else? This is an economic issue rather than technical/engineering

Addressing the Challenge, Specifications and Metrics:

Identify the 1-4 critical advancements that are needed to address the challenge and provide metrics information for each advancement with respect to the current status the desired end state or metric goal and the year at which this advancement can reasonable be achieved.

	Technology Advancement Description	Indicator of Success (How will you know you're done!)	Metric Values: 2011 Status	Metric Values: Target	Metric Values: By what year?	Comments
A	What is a viable biomass feed rate - based on regional biomass density and transport issues	Ability to secure long term supply contracts	Ensyn commercial plant = 100 DMTD Envergent design = 400 BDMTD	Economic size for upgrading multiple X 400 ton/day	Commercial (400 T/day) by 2014	
B	Equity position by end-user in pyrolysis production plant. Equity position by technology provide (Ensyn)	Project-by-project basis, long term off-take agreement	Commercial projects under development	Multiple commercial units in operation	2015	Project unlikely to be funded unless end user signed long term off-take or has equity position
C	Bio-oil qualifies as an advanced biofuel and RINs available	EPA grants pyrolysis oil advanced biofuel status	Petition to EPA required	EPA releases final notice on RINS for pyrolysis oil and/or derivatives thereof	2015	Petition to EPA will require significant data to be generated and shared
D						

Additional Information:

Key Assumptions:

Other Guidance:

Note: As mentioned in Section 3.2, this challenge was raised by the Feedstocks & Production group, but the topic was reassigned to Logistics based on similarity to Logistics Challenge 4.

LOGISTICS & COMPATIBILITY: MILESTONES FOR CHALLENGE #4B

Challenge Name: Scaling of pyrolysis plants and capitalization

Technology Advancement Specifications and Metrics:

Identify the 1-5 critical steps required to complete each of the advancements related to the technology and place them along the timeline.

Technology Advancement (*short description of advancement from the Metrics Worksheet, include current and target metrics*)	#	Major Steps	Time Line (*Place approximate completion dates for the major steps along the time line*)
Optimal sizing of pyrolysis plant	1	Identification of feedstock supply and end-use requirement	1-2 year activity
	2	Techno-economic analysis	
	3	Preliminary engineering design study	
	4		
	5		
Development of project team (equity partners)	1	Supplier & end-user equity?	1-3 years
	2	Pro-forma developed	
	3	Incentives qualified	
	4	Approach funding institutions	
	5		
Validation of yield & product quality from feedstock	1	Performance guarantee by technology provider	Step 1: 6 mos - 1 year
	2	Final Engineering design	
	3	Final project ISBL and OSBL costs (capex/opex)	Step 3: 6 mos - 2 year
	4		
	5		
Procure project funding	1	Loan from funding institution	6 months to 1 year
	2		
	3		
	4		

Additional Information:

Other:

Other:

Other Guidance:

Operational Issues: Steps to meet Challenge #1

Challenge Name: Identification of the level of upgrading required to improve stabilization

Description of Challenge:

Describe how you perceive the nature of the challenge (logistical, compatibility, process and conditioning enhancement, operational)

Pyrolysis oil treatments to reduce corrosion

Is this a new technology, a technology improvement, or something else? New technology

Addressing the Challenge, Specifications and Metrics:

Identify the 1-4 critical advancements that are needed to address the challenge and provide metrics information for each advancement with respect to the current status the desired end state or metric goal and the year at which this advancement can reasonable be achieved.

	Technology Advancement Description	Indicator of Success (How will you know you're done/)	Metric Values			Comments
			2011 Status	Target	By what year?	
A	Reduction of acid components during production of bio-oil	Light acid content	Level in baseline fast pyrolysis oil	Level defined by fuel specs to be infrastructure compatible	2017	Changes to pyrolysis unit, catalytic pyrolysis, hydropyrolysis, other liquefaction technology
B	Separation of acid species	Light acid content	Level in baseline pyrolysis oil	Level defined by fuel specs to be infrastructure compatible	2017	Could possibly include use of membrane separation, phase separation, etc.
C	Upgrading of bio-oil to modify acid components	Light acid content	Level in baseline pyrolysis oil	Level defined by fuel specs to be infrastructure compatible	2017	Could utilize technologies like hydrotreating, esterification, etc.
D						

Additional Information:

Key Assumptions: Pyrolysis product will be blended into #2 at greater than 10%. Includes known target specs for acid content to reduce corrosion. Assume significant actors in corrosion are formic and acetic acid based on discussion with Jim from ORNL & corrosion studies, instead of total TAN as measured by ASTM method

Other Guidance:

OPERATIONAL ISSUES: STEPS TO MEET CHALLENGE #2

Challenge Name: Corrosion associated with the combustion of bio-oil

Description of Challenge:

Describe how you perceive the nature of the challenge (logistical, compatibility, process and conditioning enhancement, operational)

Pyrolysis oil contains species that may result in enhanced corrosion of residential heating nozzles and boiler tubes or downstream equipment exposed to condensates (species such as K, Na, Cl, S, Si, Al, etc.).

Is this a new technology, a technology improvement, or something else?

Addressing the Challenge, Specifications and Metrics:

Identify the 1-4 critical advancements that are needed to address the challenge and provide metrics information for each advancement with respect to the current status the desired end state or metric goal and the year at which this advancement can reasonable be achieved.

	Technology Advancement Description	Indicator of Success (How will you know you're done/)	Metric Values: 2011 Status	Metric Values: Target	Metric Values: By what year?	Comments
A	Laboratory-scale tests to focus on specific corrosion mechanisms with well-controlled conditions		Tools exist for testing	Provide quantitative corrosion data to equipment manufacturers	2015	Need to understand whether standard equipment is useable, or whether equipment retrofit of existing systems – and new equipment specifications are necessary
B	Pilot-scale tests to scope out a variety of operating conditions and obtain data under realistic firing scenarios		Tools exist	Complete 1000 hours of pilot-scale firing where burner and heat recovery are integrated in test unit	2016	Demonstrate corrosion using representative commercial component parts such as spray nozzles, igniters, and heat-exchange materials.
C	Full-scale demonstration tests to narrow set of conditions		Tools exist	Complete a 1000-2000 hour operating test in prototype commercial heating furnace; demonstrate flame characteristics are compatible with heating oil.	2017	Assuming starting in 2014; will help achieve UL-listing or equivalent for commercial equipment.
D	Compile data on emissions and condensate effluents for use in future regulatory needs/issues					

Additional Information:

Key Assumption, Other Guidance:

OPERATIONAL ISSUES: STEPS TO MEET CHALLENGE #3

Challenge Name: Correlate corrosion with concentration of suspect species and other indicators

Description of Challenge:

Describe how you perceive the nature of the challenge (logistical, compatibility, process and conditioning enhancement, operational)

Oxygen content alone is not a direct correlation with corrosion, need to use TAN, pH, CAN or quantify concentrators of "bad actors" once they have been identified.

Is this a new technology, a technology improvement, or something else?

Addressing the Challenge, Specifications and Metrics:

Identify the 1-4 critical advancements that are needed to address the challenge and provide metrics information for each advancement with respect to the current status the desired end state or metric goal and the year at which this advancement can reasonable be achieved.

	Technology Advancement Description	Indicator of Success (How will you know you're done!)	Metric Values			Comments
			2011 Status	Target	By what year?	
A	Characterization of corrosive components of bio-oil (acidic species, other species that may contribute, K, Cl, etc.)		Tools exist			Characterization both the reactions between molecules in solution and the reactions of molecules on the surfaces of materials
B	Conduct systematic corrosion studies to relate resistance of various materials to levels of suspect species and corrosion indicators		Tools exist		2016	Use immersion tests or electrochemical noise sensors to measure corrosion as function of composition, T, P – assuming at start in 2013
C	Provide recommendations for material compatibility for various grades of pyrolysis oils		Tools exist			
D	Evaluate impact of various methods of neutralization on oil properties and characteristics					

Additional Information:

Key Assumptions:

Other Guidance:

OPERATIONAL ISSUES: MILESTONES FOR CHALLENGE #3

Challenge Name: Correlate corrosion with concentration of suspect species and other indicators

Technology Advancement Specifications and Metrics:

Identify the 1-5 critical steps required to complete each of the advancements related to the technology and place them along the timeline.

Technology Advancement (short description of advancement from the Metrics Worksheet, include current and target metrics)		Major Steps	Time Line (Place approximate completion dates for the major steps along the time line)
Characterization of corrosive components of pyrolysis oil	1	TAN	
	2	pH	
	3	Capillary electrophoresis	
	4	ICP	
	5	Standard elemental analysis	
Conduct corrosion studies	1	Immersion test	Conduct systematic study as function of composition, temperature, pressure; 3-year study
	2	Electrochemical noise	
	3	Expose samples in operating systems	
	4		
	5		
Recommend materials for various grades of pyrolysis oil	1	Use data generated in corrosion studies	
	2		
	3		
	4		
	5		
Impact of neutralization methods on oil quality	1	Test modified oils for: stability, viscosity, combustion properties, etc.	
	2		
	3		
	4		

Additional Information:

Other:

Other:

Other Guidance:

OPERATIONAL ISSUES: STEPS TO MEET CHALLENGE #4

Challenge Name: Determining acceptable blend ratios for blending with No. 2 fuel oil and associated upgrading required to meet performance and market needs

Description of Challenge:

Describe how you perceive the nature of the challenge (logistical, compatibility, process and conditioning enhancement, operational)

Compatibility with No. 2 oil & existing users; market acceptance

Is this a new technology, a technology improvement, or something else? Product improvement leading to market penetration

Addressing the Challenge, Specifications and Metrics:

Identify the 1-4 critical advancements that are needed to address the challenge and provide metrics information for each advancement with respect to the current status the desired end state or metric goal and the year at which this advancement can reasonable be achieved.

	Technology Advancement Description	Indicator of Success (How will you know you're done/)	Metric Values: 2011 Status	Metric Values: Target	Metric Values: By what year?	Comments
A	Achieve complete miscibility at levels of at least 10%	Complete miscibility	Limited miscibility studies, none in No. 2	100% miscibility at 10% blends for sufficient time in different temperatures	2015	Focus has been on transportation fuels. We have produced miscible oils, but they are overly-upgraded.
B	Achieve odor reductions to levels acceptable to consumers	Determination of acceptable odor level	No odor studies are likely available, but we know it smells	Acceptable levels - target to be determined	2015	Refer to ASTM odor parameters, e.g.: - ASTM E679-91 - ASTM E544-99
C	Combustion certification	Reliable combustion in commercial equipment	Combustion studies with No. 2 may have been done, but are unknown	Combustion systems approved for 10% blends (existing & new)	2017	
D	TEA & market analysis to determine optimum upgrading levels for market acceptance/market penetration	Market acceptance	TEAs for N0. 2 are in very preliminary state	Identification of optimum upgrading levels for market acceptance	2018	

Additional Information:

Key Assumptions: Blendability of bio-oil product at a level of 10% (or more, as a cost and performance optimization)

Other Guidance:

Operational Issues: Milestones for Challenge #4

Challenge Name: Determining acceptable blend ratios for blending with No. 2 fuel oil and associated upgrading required to meet performance and market needs

Technology Advancement Specifications and Metrics:

Identify the 1-5 critical steps required to complete each of the advancements related to the technology and place them along the timeline.

Technology Advancement *(short description of advancement from the Metrics Worksheet, include current and target metrics)*		Major Steps	Time Line *Place approximate completion dates for the major steps along the time line*
Reduction of acid components during production	1	Technology identification & evaluation	(1) 2013 (2) 2013-2015 (3) 2015-2016 (4) 2016-2017 (5) 2013-2017
	2	Lab-scale parameters optimization GO/NO-GO decision	
	3	Scale-up design	
	4	Demonstration of scale-up	
	5	Techno-economic analysis	
Separation of acid species	1	Testing/evaluation of separation alternatives	(1) -2014 (2) 2014 (3) 2014-2017 (4) 2014-2016 (5) 2016-2017
	2	Down-select of technologies	
	3	Blending/corrosion testing	
	4	Develop scaled-up demonstration skid	
	5	Demonstrate performance	
Upgrading of pyrolysis oil to remove acid components	1		
	2		
	3		
	4		
	5		
	1		
	2		
	3		
	4		

Additional Information:

Other:

Other:

Other Guidance:

Challenge Name: Determining acceptable blend ratios for blending with No. 2 fuel oil and associated upgrading required to meet performance and market needs

Technology Advancement Specifications and Metrics:

Identify the 1-5 critical steps required to complete each of the advancements related to the technology and place them along the timeline.

Technology Advancement (*short description of advancement from the Metrics Worksheet, include current and target metrics*)		Major Steps	Time Line (*Place approximate completion dates for the major steps along the time line*)
Lab-scale tests – well-controlled conditions	1	Need data on gas composition and deposit composition	Three year study
	2	Use simulated conditions for careful study	
	3	Study gas-phase corrosion, solid deposit corrosion and condensate corrosion	
	4	Demonstration of scale-up	
	5	Techno-economic analysis	
Pilot-scale tests – variety of conditions	1	Collect & characterize deposits in different zones	Characterization: 1-year study; Compatibility/optimization: 2 years (2) 2014 (3) 2014-2017 (4) 2014-2016 (5) 2016-2017
	2	Monitor corrosion in different zones with electrochemical noise & coupons, including downstream equipment with condensed acids	
	3	Monitor emissions of acid gas species and standard exhaust gas species	
	4	Explore fuel blends	
	5		
Full-scale demonstration tests to narrow set of conditions	1	Identify boiler using pyrolysis oil	~ 18 months, delay due to availability of operating boiler; ~ 3-6 months plus, data collection
	2	Same as above	
	3	Perhaps expose some new materials in probes	
	4		
	5		
Compile all data on emissions and effluents for addressing future regulatory questions	1		
	2		
	3		
	4		

Additional Information:

Other:	**Other:**

Other Guidance:

Challenge Name: Determining acceptable blend ratios for blending with No. 2 fuel oil and associated upgrading required to meet performance and market needs

Technology Advancement Specifications and Metrics:

Identify the 1-5 critical steps required to complete each of the advancements related to the technology and place them along the timeline.

Technology Advancement *(short description of advancement from the Metrics Worksheet, include current and target metrics)*		Major Steps	Time Line *Place approximate completion dates for the major steps along the time line*
Achievement of 100% miscibility at 10% blends for sufficient time periods at varying (but relevant) temperatures	1	Produce upgraded oils at various levels	(1) 2014
	2	Acquire No. 2 fuel mix	(2) 2015
	3	Perform test matrix (t, T)	(3) 2015
	4	Analyze data, publish	(4) 2015
	5		
Determination of acceptable odor levels	1	Create an odor intensity referencing scale	(1) 2015
	2	Determine "dilution-to-threshold" factors	(2) 2015
	3	Compare to scales from similar products	(3) 2015
	4		
	5		
Approval of commercially available furnaces for use with 10% blends	1	Contact UL, API, NFPA, etc.	(1) 2016
	2	Commission required testing	(2) 2017
	3	Analyze, publish data	(3) 2017
	4		
	5		
Optimization of cost and upgrading levels for market acceptance	1	Build a process model	(1) 2015
	2	Conduct market analysis	(2) 2015
	3	Optimize scenarios	(3) 2016
	4	Deploy (demo in households)	(4) 2017-2018

Additional Information:

Other:

Other:

Other Guidance:

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