Pacific Northwest
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Testimony Regarding

The Role of Biomass Pyrolysis in Bioenergy

21 October 2009

Submitted by
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Introduction

Chairman Baird and distinguished members of this Sub-Committee, thank you for providing me an opportunity to testify today regarding biomass pyrolysis and its potential for contributing to our nation's energy needs.

My name is Don Stevens, and I am a Senior Program Manager in the Energy & Environment Directorate at Pacific Northwest National Laboratory (PNNL). In this role I am responsible for developing PNNL's technical approach to sustainable production of biopower and biofuels. I have over 30 years of research and development experience in the area of biomass power and fuels, and much of that work has focused on the use of pyrolysis and gasification. During this time, I have worked with the U.S. Department of Energy's Office of the Biomass Program as well as a variety of other U.S. and international clients, including the International Energy Agency's Implementing Agreement on Bioenergy.

Today I will provide information on biomass pyrolysis and its potential for contributing to our national needs for sustainable energy. I will:

- explain why biomass pyrolysis offers potential advantages for producing both biopower and "drop-in" biofuels from biomass
- address the current state of development for the technology
- describe technical barriers that, if overcome, could speed technology deployment
- describe national and international research efforts that are addressing these technical barriers.

The Importance of Biomass Pyrolysis

Over the past three or four years, biomass pyrolysis has attracted increasing attention as a technology with the potential to more effectively utilize biomass resources. Pyrolysis provides a flexible pathway to convert solid biomass to a liquid intermediate. Following stabilization and upgrading, the resulting product can be used to fuel higher-efficiency electric power generation technologies such as gas turbines or integrated combined cycle systems. With additional upgrading, the bio-oil can potentially be used in highly efficient fuel cells or can be refined to liquid transportation fuels. *Biomass pyrolysis thus provides a continuum of options for efficiently producing electricity or fuels to meet a variety of our national needs.*

The production of bio-oil as an intermediate has several potential benefits. Liquid intermediates have higher bulk energy densities than the solid biomass and can be transported at lower cost. Liquid intermediates are more readily fed into advanced biomass conversion technologies than solids, and they are more readily fed, with other fuels, into to co-firing facilities. The liquid intermediates are particularly important because they are compatible with advanced conversion technologies such as industrial turbines, which more efficiently utilize our biomass resources. These high-efficiency systems are a priority because they can achieve the highest impact from our limited biomass resources. Biomass is also the only source of renewable liquid fuels to displace petroleum, and the bio-oil liquid intermediate is a promising opportunity for producing renewable “drop-in” gasoline and diesel transportation fuels.

The impact of using pyrolysis to increase utilization efficiency is shown in Figure 1. The raw bio-oil, as produced, can be combusted in conventional steam boilers with current biomass-to-electricity generation efficiencies typically ranging from about 15% to 25% depending on scale and other factors. Following moderate stabilization and upgrading, the bio-oil can potentially be combusted in industrial turbines which have electrical efficiencies of about 30%, or in combined cycle gas/steam turbines that have efficiencies of 35% or more. Additional stabilization and upgrading would potentially permit the pyrolysis product to be used in advanced solid oxide fuel cells with electric generation efficiencies of 40% or more. These ranges are approximate. The same type of upgrading needed for fuel cell use would also be relevant to producing liquid transportation fuels. This range of opportunities provides flexibility in meeting national and regional energy needs.

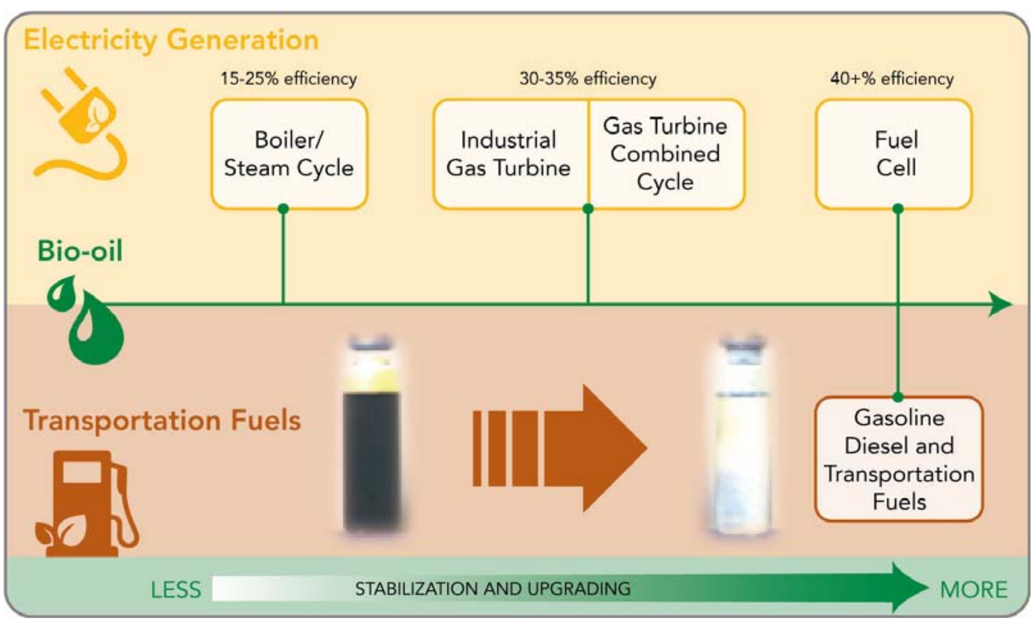

Figure 1. Pyrolysis provides a pathway to higher efficiency utilization of biomass.

Overview of Pyrolysis and Bio-oil

Biomass consists of a complex arrangement of natural, oxygen-containing polymers, including cellulose, hemicelluloses, and lignin, which have fairly low energy density. A challenge exists in converting these constituents into a state that can be shipped inexpensively to large-scale central processing facilities and used efficiently in high technology conversion systems. Pyrolysis, which is defined as the heating of biomass in the absence of air, is one option for converting biomass to a liquid intermediate. Pyrolysis processes generate a liquid bio-oil along with gas and solid (biochar) by-products, and the relative portions of each can be controlled by the processing conditions. While pyrolysis has been used historically to produce charcoal, most current efforts are focused on advanced processes that maximize the yield of bio-oil.

Fast Pyrolysis

At present, fast pyrolysis is the most developed pyrolysis technology for producing liquid bio-oil. In fast pyrolysis, the biomass is reacted at moderately high temperatures (450-550 °C), for very short times (less than 1 second). This produces bio-oil with physical properties superficially similar to #4 fuel oil, but different chemically. The bio-oil is less stable and more acidic than petroleum oil, and also may contain small percentages of inorganic mineral salts from the biomass. These characteristics make the raw product unsuitable for longer-term storage, for use in higher-efficiency electric generation systems, or for use as a liquid transportation fuel. However, the oil can be stabilized and upgraded using processes such as hydrotreating to produce stable fuels for advanced technologies such as industrial gas turbines for power generation. Depending on the extent of upgrading, the refined bio-oil can also potentially be used in advanced fuel cells or even gasoline- and diesel-range hydrocarbons for transportation fuels. The overall process is depicted in Figure 2.

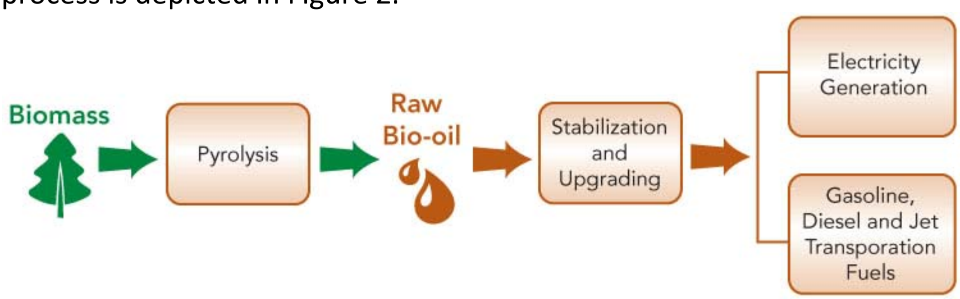

Figure 2. Biomass Pyrolysis Pathway

Distributed Pyrolysis and Refining

Pyrolysis technology provides a means by which biomass can be collected and initially converted near its source. Fast pyrolysis units can be located near biomass resources where the biomass would be converted to the higher energy density bio-oil. The resulting bio-oil can be collected from multiple facilities and transported to larger-scale central facilities for stabilization or end-use (Figure 3), taking into account economies of scale to help reduce costs. This provides an effective way to decouple the biomass resource from the eventual conversion and potentially can reduce the costs of collecting and transporting biomass.

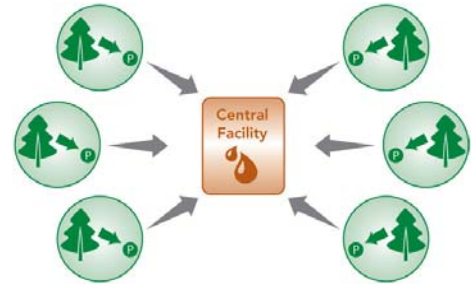

Figure 3. Distributed Pyrolysis

Related Pyrolysis Technologies

In addition to fast pyrolysis, other pyrolysis technologies of value exist. Hydrothermal liquefaction has also been examined to convert feedstocks such as wet biomass to bio-oil. This technique liquefies wet biomass streams at temperatures of about 350°C and high pressures (200 atm) to produce a bio-oil with less oxygen than fast pyrolysis. This approach could be useful in cases where the biomass resource has high moisture content, such as the residual biomass from algae production.

Pyrolysis is also used to produce solids. The oil yield from biomass decreases while the solid (biochar) content increases to about a 30% yield. The biochar is being examined as a method to remove atmospheric carbon (via plant growth) for storage in soil. As a soil amendment, biochar not only acts as a carbon pool, but it has been shown to reduce fertilizer requirements while enhancing crop yields and reducing phosphorous and nitrogen chemical runoff in some soils in certain geographical regions.[1]

Summary of the Current Biomass Pyrolysis Industry

Presently, the use of fast pyrolysis to produce liquid bio-oil intermediates for energy uses is at the near-commercial stage. Smaller-scale fast pyrolysis technologies are used by companies in the United States, Europe, and elsewhere to produce “liquid smoke,” which is processed into a food flavoring and additive. Larger-scale fast pyrolysis demonstration facilities are being built or operated in the United States, Canada, Europe, and Asia with companies such as Ensyn, Dynamotive, BTG, Renewable Oil International, and others. These demonstration units have capacities ranging from about 5 to 200 tons/day of biomass feed, and they will produce bio-oil that could potentially be used in energy applications. At present, there are no integrated, fully commercial facilities where the bio-oil is converted to either electricity or transportation fuels.

Conventional, slow-pyrolysis continues to be used to produce commercial charcoal for cooking and industrial purposes throughout the world. The efficiency of these

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[1] J. Lehmann and S. Joseph. 2009. "Biochar for environmental management: An introduction." Chpt. 1 in J. Lehmann and S. Joseph (eds.) *Biochar for Environmental Management: Science and Technology*. Earthscan Publishers, London, UK.

processes varies widely depending on the type of process used. The charcoal is frequently sold as "lump" charcoal or briquetted to provide consistency in the product. Commercial charcoal may also contain carbon from other sources such as coal or residual petroleum.

Biochar is produced using the same slow pyrolysis technologies as those for charcoal, but additives common to commercial charcoal are omitted. Several smaller companies have recently been established to produce biochar using slow pyrolysis technologies, but at present there is an uncertain market for the product. The value of biochar, to the producer or the user, has yet to be quantified.

Technology Barriers

Although the capability to produce pyrolysis bio-oils exists, there are currently no integrated, pyrolysis-based facilities commercially producing either electricity or transportation fuel, as noted previously. Technical barriers impede the deployment of these technologies.

Stabilization and Upgrading:
The primary technical barrier for biomass pyrolysis is related to the characteristics of the bio-oil. At a molecular level, the raw bio-oil contains 30-35% oxygen by weight, with that oxygen coming from the biomass feedstock. The crude product is less stable than petroleum and will begin to change at room temperature over a period of several weeks or months, or more rapidly upon heating to even moderate temperatures. The product slowly becomes more viscous, and may separate into multiple phases. The oxygen content makes the raw bio-oil mildly acidic, and that can potentially lead to corrosion of tanks used for transportation and storage. The bio-oil also may contain small quantities of inorganic mineral salts that were part of the original biomass. When the bio-oil is subsequently burned, the salts can volatilize and then condense on cooler locations downstream, potentially creating deposits that reduce system performance or can cause significant damage in systems such as gas turbines with high rotation speeds.

Effective, low-cost stabilization and upgrading of the bio-oil is needed to help biomass pyrolysis more rapidly enter the market. Stabilization and upgrading processes improve the quality of the oil by removing oxygen, reducing the acidity, and removing mineral salts from the intermediate.

The extent of upgrading required will depend on the end-use for the bio-oil. In electric generation systems, raw bio-oil can potentially be used in simple boiler/steam systems, but stabilization is needed to ensure the bio-oil can be stored for reasonable periods of time at a variety of different temperatures. Additional upgrading is needed for more advanced conversion technologies, such as advanced boiler systems, industrial gas turbines, or combined cycle systems. The upgrading would reduce the acidity of the bio-oil and remove mineral content to be fully compatible with these advanced systems. The advanced systems provide higher electric generation efficiencies that better utilize the biomass resource. As is found with refining petroleum, additional upgrading would be required to provide a fuel for advanced fuel cells or for transportation fuels. The upgrading would remove small amounts of sulfur from the product and further reduce its oxygen content. Similarly, the more extensive upgrading is also needed to produce "drop-in" gasoline, diesel, and jet fuels for transportation fuels. The need for stabilization and upgrading can be viewed as a continuum where stabilization is desirable for even the simplest conversion technology, and additional upgrading is required to produce a fuel that can be used in advanced technologies, either for electric generation or for transportation fuels.

Improving the Bio-oil Quality:
The need for stabilization and upgrading of the bio-oil could potentially be reduced if a higher quality bio-oil could be produced. Current fast pyrolysis systems have been optimized to produce high liquid yields, and there is limited ability to change the properties of the bio-oil. Modified systems, such as those using catalysts during the pyrolysis process, could produce bio-oil that would also require less upgrading. The catalysts would enhance the rate of chemical reactions that remove oxygen from the biomass, thus providing an intermediate with lower oxygen content. Other processing techniques can also potentially be applied to bio-oil improvement. Improvement of the original bio-oil quality is needed for either electricity generation or for producing transportation fuels.

Expanding Bio-oil Standards:
For bio-oil to enter the marketplace, standards are needed to define its characteristics and qualities. Working within the International Energy Agency's Bioenergy Agreement, PNNL recently helped establish the first standard for use of bio-oil as a burner fuel, ASTM Standard D-7544-09. This standard provides definition of the qualities the intermediate must have for use in boilers. Additional standards are needed to quantify the qualities necessary for higher efficiency uses of the bio-oil.

Improving Utilization of Byproducts:
Pyrolysis creates a combination of liquid, gaseous, and solid (char) products. The liquid will primarily be used for energy purposes, but it also contains precursors to higher-value chemicals. Better extraction and utilization of these precursors for chemical products can potentially increase the economic rate of return for the pyrolysis-based conversion facility (biorefinery). The bio-oil is a complex mixture of many individual components, and there is a need to better characterize the intermediate and better understand the processing involved in generating chemical byproducts.

In addition to liquids, pyrolysis also produces solid char. The term *biochar* has been applied to the use of that material as a soil amendment. The impact of biochar is only partially understood at this time. While biochar can produce significant yield improvements in some soils, it has very little effect on others. This arises both from the variability of soils as well as the variability of biochar produced by different pyrolysis approaches. Improved understanding of the characteristics of the biochar and how those influence plant growth are needed. That information will provide a better quantification of the value of biochar to the farmer. In addition, work is needed to understand the sustainability impacts of biochar. For example, it is not presently clear whether there would be greater carbon savings to pyrolyze biomass and put biochar in the ground, or to alternatively convert that same biomass to liquid transportation fuels, thus displacing petroleum fuel emissions. Additional information on the total “value” of biochar is needed before effective markets can be established.

Industry Acceptance of Bio-oil:
Bio-oil is a relatively new product, and the industries which might use it effectively are not familiar with bio-oil. Changing fuel presents both a market risk and a market opportunity. Programs to reduce the technical and financial risk of using bio-oil may be helpful to assist with deployment.

The implementation of biomass pyrolysis also will depend on the complex match between regional feedstock resources, their availability, and the corresponding regional needs for fuels, power, and products, including chemicals and biochar. Analyses such as life-cycle studies, technoeconomic projections, and related work will assist industry in making educated decisions on the most effective use of biomass on both a regional and a national basis.

Current Research

Overview of National and International Research:

Biomass research is being conducted by many groups, both in the United States and in other countries.

In the United States, research has been focused primarily on the production of liquid transportation fuels that will be “drop-in” hydrocarbon replacements for gasoline, diesel, and jet fuels. As such, these are compatible with the existing fuel supply, distribution, and utilization infrastructure. Research on pyrolysis-derived biofuels has focused on the major barriers of stabilization and upgrading the bio-oil intermediate. The research in this area has included a range of thermal and catalytic techniques to convert biomass to refinery feedstock that can be finished to transportation fuels. This research has been funded primarily by the U.S. Department of Energy with additional efforts funded by the U.S. Department of Agriculture. The stabilization and upgrading research is directly relevant for producing bio-oil intermediates used in high-efficiency electric generation systems. While the amount of upgrading needed for electric power generation will be less than that needed for hydrocarbon fuels, the same types of processing techniques are likely to be used in both.

In other countries including Canada, Finland, Germany, the United Kingdom, the Netherlands, Australia, and others, researchers are examining the use of pyrolysis bio-oil both for transportation fuel and electricity generation. There is international recognition of the flexibility of pyrolysis to meet a variety of fuel and electricity needs. The interest in producing electricity is particularly strong in countries such as Finland where renewable portfolio mandates provide very significant cost incentives to produce biopower. By comparison, incentives of that magnitude do not exist in the United States. In some countries, biopower is seen as the earliest use of bio-oil, with transportation fuels being viewed as an attractive alternative as the upgrading technology advances.

International cooperation in the area of biomass pyrolysis is fostered by the International Energy Agency's Bioenergy Agreement through their Task 34, Biomass Pyrolysis. This Agreement promotes information exchange, exchange of researchers, and production of original scientific reports. The interests of this group are based on the priorities of the participating countries and include pyrolysis for both biofuels and biopower. The International Energy Agency's Bioenergy Pyrolysis Task has been renewed for a three-year period starting January 2010 through the end of 2012. Douglas C. Elliott, an international expert on biomass pyrolysis at PNNL, leads this Task.

PNNL's Research in Pyrolysis:

PNNL is conducting research in each of the technical barrier areas described above. A primary area of research at PNNL focuses on stabilizing and upgrading bio-oil. Through the Laboratory's Department of Energy-funded program, PNNL teams with key partners, including other national laboratories and industry partners such as Ensyn, a pyrolysis oil company, UOP, a major petroleum refinery technology provider, and others to examine upgrading to produce transportation fuels. PNNL also has privately funded efforts exploring technology development for use with biomass feedstocks unique to Asia.

PNNL is also working in two international collaborations, one with Canada and one with Finland, to examine the extent of stabilization and upgrading needed for utilization of bio-oil for either electric generation or biofuel applications. This work is examining the characteristics of bio-oils produced from a range of biomass feedstocks, including beetle-killed pine, with the intent of matching those with end-use requirements. The work leverages DOE's funding with equivalent amounts from Canada and Finland to organizations such as Finland's VTT Laboratory, Natural Resources Canada (Canmet) laboratory, and the University of British Columbia.

PNNL also conducts research on ways to improve the quality of bio-oil to reduce the need for stabilization and upgrading. Catalytic processing during the initial pyrolysis step is being used to remove more oxygen from the bio-oil. This work, funded by the DOE Office of the Biomass Program is relevant to production of bio-oil for either biopower or biofuel use.

Research to assist in the establishment of bio-oil standards is being conducted at PNNL in association with the efforts of the International Energy Agency's Pyrolysis Task. As noted previously, PNNL leads this Task and helped establish the first ASTM standard for bio-oil quality for boiler use in 2009. Additional work to establish standards for bio-oil use in more efficient applications is ongoing. The International Energy Agency Task also is coordinating research on higher-value chemical products that can potentially be produced from biomass pyrolysis in so-called biorefineries.

Researchers at PNNL also are examining the use of biochar as a soil amendment as part of their work with DOE's Office of the Biomass Program. In collaboration with the U.S. Department of Agriculture at the Prosser Experimental Station, we are focusing on the characterization of biochar from various biomass sources and correlating those differences with changes in soil productivity.

We are also completing a research Cooperative Research and Development Agreement (CRADA) with Archer Daniels Midland Company (ADM) and ConocoPhillips on hydrothermal liquefaction for producing bio-oil from wet biomass feedstocks. Finally, PNNL is involved in engineering studies aimed at developing technoeconomic models for pyrolysis technologies and evaluating life cycle impacts of pyrolysis versus other fuel production options.

It is important to note that biomass pyrolysis must be accomplished in a sustainable manner that minimizes impacts to our water resources and the environment. PNNL, with part of its DOE funding, is examining the sustainability of biomass thermal conversion processes, including pyrolysis. We are also developing water availability and land-use change models that will help ensure a wide range of technologies, such as biomass pyrolysis that can be done on a sustainable basis.

Summary

In summary, biomass pyrolysis offers a flexible and effective way to create a liquid intermediate that can be used for either transportation fuels or electricity generation. Converting the solid biomass to a liquid both increases the energy density and makes the intermediate easier to feed to conversion systems than solid biomass. These characteristics allow expanded use of biomass.

Stabilization and upgrading of the bio-oil intermediate is important. While some systems can potentially operate with raw bio-oil, stabilization and upgrading greatly expands the opportunities for bio-oil utilization. The upgraded bio-oil can be used in higher efficiency electric generation technologies to achieve higher productivity from our finite biomass resources. In addition, upgrading technologies can be utilized to produce "drop-in" transportation fuels compatible with present infrastructure.

Current research programs internationally are addressing the key barriers to biomass pyrolysis utilization. The federal government can further advance these research efforts by funding strong core research programs. While emphasis on implementation is vital, it also is important to invest in our nation's science base, which provides the necessary foundation for developing next-generation technology aimed at addressing key research challenges within the scope of DOE's implementation projects and beyond.

Finally, the nation needs to conduct analyses such as life-cycle assessments, technoeconomic projections, and others to help prioritize what the most important uses of our biomass resources are, both nationally and regionally. With finite amounts of biomass available annually, we need solid technical information on a regional and national basis to decide whether it is better to convert these to electricity, to fuels that reduce imported oil, or to some combination of both. This information will be essential to assist industry in determining how to best use biomass resources as they deploy these technologies.

Thank you for this opportunity to share this information.