INL/EXT-11-23538

Biofuels Fuels Technology Pathway Options for Advanced Drop-In Biofuels Production

Kevin L. Kenney

September 2011

The INL is a U.S. Department of Energy National Laboratory
operated by Battelle Energy Alliance

INL/EXT-11-23538

Biofuels Fuels Technology Pathway Options for Advanced Drop-In Biofuels Production

Kevin L. Kenney

September 2011

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Assistant Secretary for Energy Efficiency and Renewable Energy
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Biofuels Fuels Technology Pathway Options for Advanced Drop-in Biofuels Production

September 27, 2011

Advanced drop-in hydrocarbon biofuels require biofuel alternatives for refinery products other than gasoline. Candidate biofuels must have performance characteristics equivalent to conventional petroleum-based fuels. The technology pathways for biofuel alternatives also must be plausible, sustainable (e.g., positive energy balance, environmentally benign, etc.), and demonstrate a reasonable pathway to economic viability and end-user affordability.

Viable biofuels technology pathways must address feedstock production and environmental issues through to the fuel or chemical end products. Potential end products include compatible replacement fuel products (e.g., gasoline, diesel, and JP8 and JP5 jet fuel) and other petroleum products or chemicals typically produced from a barrel of crude. Considering the complexity and technology diversity of a complete biofuels supply chain, no single entity or technology provider is capable of addressing in depth all aspects of any given pathway; however, all the necessary expert entities exist. As such, we propose the assembly of a team capable of conducting an in-depth technology pathway options analysis (including sustainability indicators and complete LCA) to identify and define the domestic biofuel pathways for a Green Fleet. This team is not only capable of conducting in-depth analyses on technology pathways, but collectively they are able to trouble shoot and/or engineer solutions that would give industrial technology providers the highest potential for success. Such a team would provide the greatest possible down-side protection for high-risk advanced drop-in biofuels procurement(s).

Technology Pathway Options:

- **Oilseed Route** – this would be the near-term route for producing diesel, jet, and boiler fuel products. Much of the oil extraction and conversion technology is commercially available. Non-food oil-producing crops such as Rapeseed, Camilina, Jatropha, etc. would be considered as feedstocks. Special consideration would be given to the production potential of these crops in Hawaii. Some of the significant barriers to this pathway are agronomy and genetics of feedstock production, final product yield per acre, and feedstock cost.
- **Sugar Route** – this would be a near- to mid-term route for producing diesel, jet, and boiler fuel. This route follows the approach taken by Brazil, also a viable approach for Hawaii, to leverage the infrastructure of the existing sugar cane industry. Challenges of this route will be the economics of converting sucrose to fuels, something that Hawaiian Commercial and Sugar Company (HC&S) has already studied extensively. Additionally, conversion technologies for converting sugars to biofuels other than ethanol are still in the development phase. Like the oil route, sustainability and yield per acre of final product using only the sucrose fraction of the crop may become a challenge for sustainability and final volume goals. However, this route

might provide a viable bridge to future advanced lignocellulosic routes and continue as a hybrid cellulose/sugar route in the future.

- **Advanced Biofuels (Lignocellulose and Algae) Route** – this would be the longer-term and ultimately the hoped-for solution to a viable and sustainable Green Fleet. At present, this pathway has significant technology risks and uncertainties in several areas:
  - Feedstock production technologies are required for new, highly productive and low input cellulosic feedstocks
  - Harvesting, handling, and preprocessing of multiple lignocellulosic biomass resources into uniform "on-spec" feedstock intermediates for the conversion platform options (e.g., biochem, thermochem gasification, thermochem pyrolysis) are new and developing technologies
  - Large-scale farming of algae is still unproven
  - Harvesting and dewatering of algae bodies is inefficient and requires new production and harvesting technologies
  - Conversion technologies to produce final fuel products, as well as bio-oil intermediates (which are defined by petroleum refinery infeed specifications and performance criteria and petroleum crude-oil compatibility criteria) are still under development and not yet commercial.

  In spite of the infancy of this pathway at present, by 2017–2022, it is expected that the next few years of R&D investment will advance this technology pathway to demonstration and pre-commercial scale.

Technology Pathway Analysis and Assessment Team:

The team necessary to define and develop a complete and detailed analysis product for technologies that could be proposed within each of these pathways must have demonstrated expertise, capabilities, and existing models and technologies for all aspects of each respective pathway. It is proposed that such a team can be organized through the following five institutions/organizations:

- **USDA-ARS** – The United States Department of Agriculture (USDA) Agriculture Research Service (ARS) laboratories has developed extensive databases (e.g., REAP and GRACEnet projects) and models (e.g., CEQUESTER, others?) that provide the foundational tools necessary to assess and design sustainable biomass productions systems. The network of USDA-ARS laboratories have extensive capabilities in developing (i.e., breeding, genetic improvement, etc) biomass crops, including, switchgrass, sugar cane/energy cane, sorghum, etc. They have also developed oil crops not only for food, but also for energy (e.g., high oil peanut in GA). Point of Contact is Dr. Jeff Steiner, Jeffrey.steiner@ars.usda.gov, 301-504-4644.
- **Sun Grant Initiative Feedstock Partnership** – The Sun Grant Initiative is a consortium of land-grant university research, education, and extension programs. This partnership represents the necessary capabilities and technologies for feedstock production of conventional crops, new oil seed crops, and dedicated lignocellulosic energy crops. More importantly, this consortium

represents every state and growing region in the United States, including Hawaii. Point of Contact is Dr. Terry Nipp, Sun Grant Executive Director, tlnipp@ilioco.com , 202-460-3639.

- **US-DOE Idaho National Laboratory** – Idaho National Laboratory (INL) has technology development, analysis, and modeling capabilities in feedstock preprocessing and logistics, including algae harvesting/dewatering. This includes harvesting and collection, transport and handling, storage, and preprocessing (including advanced preprocessing options such as thermal treatments and densification). INL has a biomass preprocessing pilot demonstration unit, support laboratories, biomass library, logistic models, and extensive partnerships with original equipment manufacturers of harvesting and preprocessing equipment. Point of Contact is Dr. Richard Hess, INL, jrichard.hess@inl.gov , 208-526-0115.
- **US-DOE National Renewable Energy Laboratory** – The National Renewable Energy Laboratory (NREL) has technology development and analysis/modeling capabilities in biomass conversion using both biochemical and thermochemical (gasification and pyrolysis) pathways. NREL also has capabilities in algae biofuels, including participation in many of the legacy algae programs. NREL has several biomass conversion pilot demonstration units, which include technologies for biochemical (e.g., pretreatment, enzyme catalysis, fermentation, biomass characterization, etc.) and thermochemical (e.g., gas clean up, fuel synthesis, etc.) approaches. NREL also has extensive analysis capabilities, including well-developed ASPEN models for the respective conversion pathways. NREL's industrial partnerships include many biorefinery companies and technology providers. Point of Contact is Dr. Adam Bratis, NREL, Adam.Bratis@nrel.gov , 303-384-7852.
- **US-DOE Pacific Northwest National Laboratory** – The Pacific Northwest National Laboratory (PNNL) has technology development, analysis, and modeling capabilities in biomass conversion and biological and chemical catalysis. PNNL was also awarded one of the DOE advanced biofuels algae centers, with focus on the development of algae-based biofuels. PNNL's laboratory and bench-scale pyrolysis units are capable of testing feedstock performance through the pyrolysis process and hydrotreating to a final fuel product. PNNL has also developed advanced biofuels technology pathway models that can assess technologies and define performance targets for thermochemical conversion processes. PNNL and NREL work very closely on conversion process development from the PNNL bench scale to NREL pilot scale. Point of Contact is Dr. Jonathan Male, PNNL, jonathan.male@pnl.gov , 509-372-6358
- **DoD Navy** – The fifth and critical team member would be the DoD Navy, which would include Navy fleet personnel working with and representing the needs of the Pearl Harbor and other Navy fleet operations.

Network of Pilot Demonstration Capabilities

In addition to sophisticated analytical and modeling capabilities for biomass crop production, logistics and conversion to biofuels, this team of USDA laboratories/universities and DOE laboratories possesses a network of pilot scale production, logistics and conversion facilities that can functionally produce and convert any biomass to various process intermediates (e.g., solid, liquid sugar, liquid bio-oil, etc) and biofuels products, including advanced drop-in biofuels. These Capabilities include:

USDA-ARS

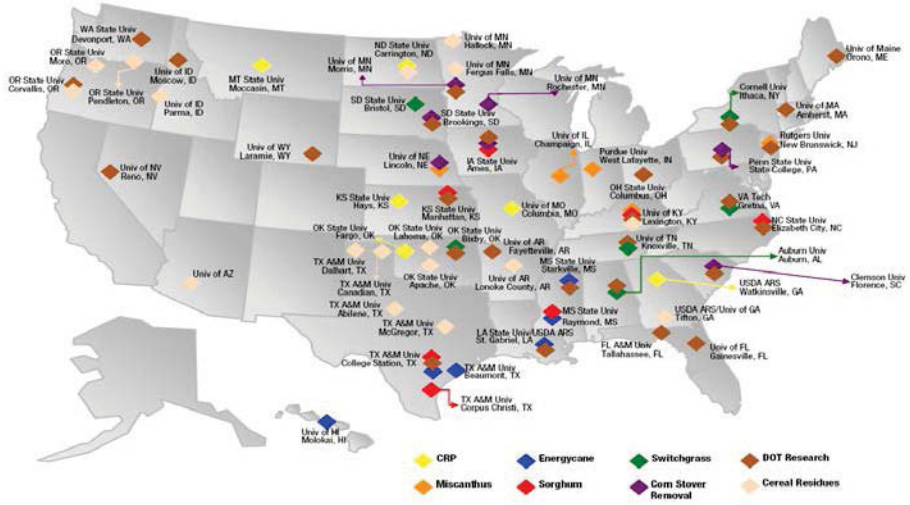
The Agricultural Research Service (ARS) is the U.S. Department of Agriculture's chief scientific research agency. ARS bioenergy research focuses on three components:

1. Feedstock Development**:** Enables new varieties and hybrids of bioenergy feedstocks with optimal traits.
2. Sustainable Feedstock Production Systems: Enables new optimal practices and systems that maximize the sustainable yield of high-quality bioenergy feedstocks.
3. Biorefining and Co-Products: Enables new, commercially preferred biorefining technologies.

ARS bioenergy research in the three Components is integrated through five USDA Regional Biomass Research Centers. The Centers are networks of ARS and Forest Service research facilities and are designed to accelerate the establishment of sustainable biomass supply for the commercial production of biofuels, biopower, and other bio-based products. The Centers leverage the collective efforts of USDA research, USDA action agencies, and partners in universities, industry and commercial ventures, other Federal and state agencies, non-government organizations, tribal nations, and international entities.

Sun Grant

The Sun Grant Initiative is a national network of land-grant universities and federally funded laboratories working together to further establish a biobased economy. The Sun Grant Initiative is working with the Department of Energy- Energy Efficiency and Renewable Energy Office of Biomass Program to develop and implement a Regional Biomass Partnership to address barriers associated with the development of a sustainable and predictable supply of biomass feedstocks. The Feedstock Partnership has been charged by the DOE Office of Management and Budgets with three tasks; 1) biomass resource assessment, 2) biomass resource development, and 3) biomass resource education and outreach. The Feedstock Partnership is assembling national task teams to complete these OMB tasks. Field trials are an important part of the Regional Feedstock Partnership program. Current plot locations for research trials associated with the Partnership are presented below. Plots are currently being planned, implemented, and monitored for a variety of feedstocks through our feedstock teams.



INL

Transforming raw biomass into uniform-format commodity feedstocks is the focus of the Bioenergy program at Idaho National Laboratory (INL). The Feedstock Process Demonstration Unit (PDU) at INL provides a venue for bioenergy developers to test preprocessing technologies and advance feedstock engineering into the development phase. *The Feedstock PDU is a flexible research system developed to 1) test feedstock formulation processes, 2) collect process data, and 3) produce large quantities of formulated feedstocks for conversion testing.*

NREL

The National Renewable Energy Laboratory (NREL) has unique, state-of the-art research tools and facilities to research, develop, and demonstrate both biochemical and thermochemical conversion pathways for producing *a range of sustainable, energy-dense advanced biofuels that are compatible with our existing transportation fuel infrastructure.* The Integrated Biorefinery Research Facility and the Thermochemical Users Facility are available for testing feedstocks, processes, and equipment at the laboratory and pilot scales.

The Thermochemical Conversion Process Demonstration Unit (TCPDU) is a pilot-scale conversion plant consisting of several complementary unit operations that can be configured to accommodate the testing and development of various reactors, filters, catalysts, and other unit operations. The TCUF offers clients the capability to test new processes and feedstocks in a timely and cost-effective manner and to quickly and safely obtain extensive performance data on their processes or equipment.that can be used by researchers, industry partners, and stakeholders to test a wide variety of potential biomass feedstocks and thermochemical conversion processes and technologies.

The Integrated Biorefinery Research Facility (IBRF) is a pilot-scale facility capable of supporting a variety of advanced biofuels projects. This facility can handle a wide range of feedstocks and allows for the testing of conversion processes using a variety of technologies under a wide range of conditions.

PNNL

Through liquefaction of biomass, the Biomass Program at Pacific Northwest National Laboratory (PNNL) is developing a spectrum of upgraded bio-oils, chemicals, and biofuels that are essential to enabling the 2017 Biomass Program performance goals and diversifying bioenergy applications. Liquefaction and Bio-Oil Upgrading PDU systems at PNNL include hydrothermal liquefaction reactors, fast pyrolysis reactors, and bio-oil upgrading reactors.