Statement of Jonathan Lloyd Male
Chief Scientist, Energy Processes and Materials
Co-director of the PNNL–WSU Bioproducts Institute
Pacific Northwest National Laboratory

Before the
United States House of Representatives
Committee on Science, Space and Technology

March 16, 2022

Good morning. Thank you, Chairman Casten, Ranking Member Weber, and Members of the Subcommittee. I appreciate the opportunity to appear before you today to discuss the state of bioenergy research and development and how Pacific Northwest National Laboratory (PNNL) and its fellow Department of Energy (DOE) national laboratories are contributing to this important enterprise.

My name is Jonathan Male, and I am chief scientist for Energy Processes and Materials at PNNL, a DOE Office of Science national laboratory located in Richland, Washington. I am also an adjunct professor in the Biological Systems Engineering Department at Washington State University (WSU) and serve as the Co-director of the joint PNNL–WSU Bioproducts Institute, which advances science that reduces the environmental impact of fuels and products while providing renewable carbon resources for sectors of the economy that are not easily electrified. Prior to my return to the Pacific Northwest National Laboratory in May 2020, I served as the Director of the Bioenergy Technologies Office (BETO), in the Office of Energy Efficiency and Renewable Energy (EERE) at DOE for over six years. As Director of BETO, I led the Office's work to lower the costs of modeled fuels and products, reduce technology uncertainty, and accelerate research and development of bioenergy and renewable chemicals technologies in the emerging bioeconomy.

In my testimony today, I will discuss the state of bioenergy research, development, and demonstration (RD&D) activities led by DOE and the great potential for advancements in bioenergy and bioproducts to help deliver a cleaner energy future. In so doing, I will address three main points:

1) We must expand our understanding of *real-life* biomass feedstocks—the raw materials to be manipulated through various technologies to create bioenergy and bioproducts—to successfully apply emerging science and technology at the scales required to meet carbon-reduction goals.

2) We have great opportunity to turn today's waste carbon streams—from municipal solid waste and landfill gases to used carbon fiber—into tomorrow's carbon resources by

expanding our RD&D agenda to increase efforts on these important potential biomass feedstocks.

3) Bioenergy and bioproducts can and should play a critical role in reducing carbon emissions particularly in sectors of our economy that are difficult to electrify, including aviation, maritime, and industry.

Background

The bioenergy and bioproduct landscape presents a rich array of RD&D challenges ripe for federal investments that target near-, medium-, and long-term opportunities. DOE programs from basic research in the Office of Science to applied research and development through BETO to the new Office of Clean Energy Demonstrations (OCED) and Loan Programs Office (LPO) are advancing technologies across the full supply chain from feedstocks to conversion technologies and from the lab bench to pilot-, demonstration-, and commercial-scales. Each of these investments is important for advancing a diverse portfolio of technology approaches we will need to meet ambitious carbon-emission reduction goals.

Thanks to decades of strategic DOE investments in basic chemistry, biology, computational modeling, and other basic science disciplines, we have more insights, tools, and technologies than ever before to address many of these challenges. Basic science efforts in the bioenergy and bioproducts area— including those supported by the DOE Office of Science's Basic Energy Sciences (BES) and Biological and Environmental Research (BER) programs—have focused largely on using pristine sugars and model compounds to thoroughly understand how conversion processes can work to transform feedstock constituents into bioenergy and bioproducts. This basic research yields important insights into the mechanisms at work in these processes.

Thousands of DOE researchers and those funded by other federal agencies rely on world-class scientific user facilities like BER's Environmental Molecular Sciences Laboratory (EMSL), located at PNNL, and its Joint Genome Institute, located at Lawrence Berkeley National Lab. Researchers at these world-class scientific user facilities characterize biomass and microbes capable of processing the biomass, as well as probe the real-time conditions of conversion processes. This research has shown that microbes can serve as cellular factories to take biomass molecules and make compounds that can be chemical building blocks to polymers, textiles, solvents, fuels, and the myriad of carbon-based materials that help us in our everyday lives. Continually developing capabilities for characterizing how microbes function in even greater detail and at greater speed and volume is critical for speeding the march of basic science advances that power bioenergy and bioproduct technology development.

We must expand our understanding of real-life bioenergy feedstocks

To take the insights of basic research to scale and realize commercial impact, we must look beyond the pristine feedstocks used in controlled experiments and look at real biomass, with all its variability and imperfections. Applied research efforts, including those supported by BETO, look at “optimal” or “average” feedstocks and have yielded critical insights into how real-world biomasses can be pre-treated to create intermediates, such as a mixture of sugars, a bio-oil, or a synthesis gas (carbon monoxide and hydrogen). To produce bioenergy and bioproducts *at scale*, bioenergy technologies must work not only for the optimal or average but must be robust against the variations to be expected in the literal tons of feedstocks they will need to process.

Consider the example of corn stover as a feedstock. Researchers have developed highly efficient conversion processes for producing bioenergy components or bioproducts from corn stover at the lab bench. And more applied work has subsequently addressed some of the important systems engineering challenges of processing “real-world” samples of corn stover. However, at the pilot- and demonstration-scales, bioenergy facilities will receive bales of corn stover collected on real farms around the country. These bales are likely to be left out in the elements for some period of time, combined with other bales, potentially from multiple locations, and shipped to a refinery over the course of many days or weeks. These real-world bales are likely to contain extraneous elements from a working farm—from soil to wildlife to farming tools—and suffer the consequences of extended exposure to the elements. A plant producing bioenergy or bioproducts at scale will need to have processes that are robust against this variability. Indeed, dealing with feedstock variability is a significant reason we see demonstration- and commercial-scale facilities fail to meet their targeted outcomes. Characterizing real-world feedstocks and understanding how conversion processes operate in the face of real-world variability is a critical area for greater investment so that we can move science insights toward commercially viable technologies at scale.

To this end, DOE recently created the Feedstock-Conversion Interface Consortium (FCIC) to begin to address these challenges. The FCIC is an integrated and collaborative network of nine DOE national laboratories with goals of; (1) developing science-based knowledge and tools to understand biomass feedstock and process variability, and (2) improving overall operational reliability, conversion performance, and product quality across the biomass value chain from harvest through preprocessing and conversion. FCIC researchers provided a critical review of advanced methods for characterizing feedstock variability; discussing advanced analytical methods that measure density, moisture content, thermal properties, flowability, grindability, rheology properties, and micromorphology; and examining methods that have not traditionally been used to characterize lignocellulosic feedstocks but have the potential to yield important insights on intrinsic biomass feedstock variability (Yan 2020).

We can turn today’s wastes into tomorrow’s carbon resources

DOE estimates that there is potential for a billion dry tons of biomass that could be converted to approximately 62 billion gallons of gasoline fuel equivalent annually (Brandt 2016, Rogers 2017). This would be enough gasoline equivalent fuel to completely supply aviation, marine, rail, and a significant fraction of the heavy-duty trucking market. However, these analyses have assumed that approximately 23% of those billion dry tons would be derived from woody and herbaceous energy crops, whose production has been slower to scale-up than expected.

If we expand our view of viable biomass feedstocks beyond traditional agricultural and forest residues, we find significant additional potential carbon resources in our waste streams. If we considered all forms of municipal solid waste (MSW), biosolids, food wastes, off-specification chemical streams, waste polymers, water streams with organic chemical contamination, and waste gases (biogas, methane, flue gas, landfill gas, tail gases and carbon oxides), we gain both useful carbon sources and the opportunity to solve another problem: waste disposition. By utilizing these waste streams as a carbon source, we can reduce landfill volumes, disposal costs, and land use changes needed for producing additional bioenergy crops. Waste streams also present potential advantages for the conversion to bioenergy and bioproducts in that some "pre-processing" may have already been done, whether by human and animal guts and their menagerie of microbes, or by food or chemical processing facilities.

Biomass and wastes are widely available, but no single feedstock is sufficient on its own to meet demand. We will need several different regional solutions that leverage locally available resources, which will have the co-benefit of diversifying our supply chains and increasing resilience to disruptions and affordability challenges. PNNL and the National Renewable Energy Lab (NREL) recently leveraged an existing waste-to-energy feedstock database for the conterminous United States that shows different waste streams' potential for bioenergy production on a site-specific basis. The analysis indicates that with conversion by hydrothermal liquefaction—a process that combines biomass with intense heat and pressure to create a biocrude oil, essentially a dramatically sped up version of what the earth does naturally over millions of years to create crude oil—carbon-rich waste streams have the potential to produce up to 5.9 billion gallons/year of biocrude oil that can be upgraded and refined into a variety of liquid fuels, in particular renewable diesel.

It is important to note here that current U.S. Code (42 USC 16232) states that DOE's bioenergy program may consider some waste streams, "but not including municipal solid waste, gas derived from degradation of municipal solid waste or paper that is commonly recycled." The Environmental Protection Agency (EPA) defines municipal solid waste (MSW) as consisting of everyday items we use and then throw away, such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. This comes from our homes, schools, hospitals, and businesses. As of 2012, despite efforts to increase recycling and composting, EPA estimated we still discard 164 million tons of MSW, and this MSW contains significant amounts of carbon that could be used as a resource while avoiding landfills and emissions.

Beyond conversion of biomass and wastes to bioenergy and bioproducts the repeated use of a carbon in multiple applications—not necessarily in a circular economy but perhaps more of an elliptical economy—can also provide significant carbon intensity reduction. Re-use of carbon in molecules that have embodied energy (i.e., energy was used to produce the molecules) is extremely beneficial.

In an economy that reuses carbon, there are new ways to look at renewable products and materials especially regarding multiple uses in different applications with the need for greater industrial symbiosis. Industrial symbiosis is an approach to commercial operation which uses, recovers, and redirects resources for reuse, resulting in resources remaining in productive use in the economy for longer. This in turn creates business opportunities, reduces demands on the earth's resources, and provides a stepping stone towards creating a more circular or elliptical economy.

Take the example of carbon fiber, an extremely useful, but highly energy-intensive molecule. Carbon fiber composite has a wide variety of useful applications, each with different requirements on its properties. An elliptical carbon fiber composite economy could involve first use in aerospace, where quality requirements are highest, followed by reuse in wind turbine blades and eventually long-term use as an additive for construction beams. Multiple uses like these present important opportunities for reducing carbon intensity and waste output in sectors that are hard to decarbonize.

With biomass and waste streams there will not be just one solution. Numerous solutions will be needed across the U.S. to address the diversity in biomass and waste carbon in different geographies. Further, there is potential for a balanced portfolio of short- and longer-term use renewable products, from renewable diesel produced by hydrothermal liquefaction and consumed over the short term to cements with integrated biopolymers that improve structural properties and lock up carbon in the built environment for decades.

Bioenergy and bioproducts can play a critical role in hard to electrify sectors of our economy

To achieve a net zero carbon economy by 2050, it is necessary to pursue carbon reduction across all segments of the power, transportation, industry, commercial, residential, and agricultural sectors. Bioenergy and bioproducts can provide valuable low- or zero-carbon energy and products to many sectors of our economy, but they will be most valuable in hard-to-electrify sectors, such as aviation, maritime, and industry. These sectors also have large existing infrastructures built around the use of fossil fuels where low- and net-zero-carbon fuels derived from biomass have the potential to reduce emissions while maintaining compatibility with those existing and soon to be built facilities and processes.

Electrified aviation of wide-body jets remains far from viable despite the many real advances in battery and electric drive technologies—thanks in large part to DOE RD&D at PNNL, Argonne National Laboratory (ANL), and elsewhere. There is, however, commercially viable technology today for converting fats, oils, and greases (FOGs) of the appropriate quality to sustainable aviation fuels (SAFs), and about 3 million gallons were produced in the U.S. in 2019. However, the U.S. used 26 *billion* gallons of jet fuel in 2019 and there simply are not enough FOGs available as a feedstock to meet the needs of the aviation sector. Current and future research is needed on the utilization of other waste streams—landfill gas, biogas, renewable natural gas, carbon oxides, gasification of solids. These can each be converted to components that can be efficiently fermented to alcohols by technology developed by LanzaTech. Research developed at PNNL in collaboration with LanzaTech has shown that these alcohols can then be converted into high-quality SAFs to start to fill the void and drive towards the DOE, DOT, USDA Sustainable Aviation Fuel Grand Challenge of producing 3 billion gallons in the U.S. by 2030 and 35 billion gallons of SAF by 2050 (100% of the projected SAFs market), while achieving a minimum of a 50% reduction in life cycle greenhouse gas emissions compared to conventional fuel.

Heavy duty trucks that travel over 200 miles per day and ocean-going marine vessels are two additional examples of hard to electrify applications responsible for significant emissions today. PNNL and others have been researching the conversion of wet wastes such as biosolids, food wastes, manures, etc. using hydrothermal liquefaction to produce a bio-oil that can be upgraded to renewable diesel. PNNL researchers have shown that this sped up version of earth’s natural processes for producing crude oil can efficiently produce high yields of high quality bio-oil from sewage sludge, while avoiding the expense of disposal costs.

Conclusion

While there is a scenario for a potential of one billion tons of biomass in the U.S., there is equal potential to expand the number of carbon resources considered in waste streams and biomass to mitigate concerns of scaling-up supply of feedstocks. The use of waste streams and multiple uses of carbon offer ways to be more responsible with an important resource that makes our everyday lives easier. We are increasingly gaining the scientific insights and advancing technologies capable of turning today’s waste into tomorrow’s carbon resource.

Introducing less carbon-intense energy into the electrical power grid will be important in decarbonizing America. However, there will be segments of the transportation, industrial, and agriculture sectors that will be hard to electrify such as: the aviation sector, the marine sector, chemicals sector, the built environment, and numerous additional applications where carbon makes our lives more comfortable. Biomass and waste streams offer a means particularly during an energy transition to leverage existing infrastructure while we seek to reduce the carbon intensity of the entire U.S. economy.

In terms of cost per unit of energy, bioenergy will continue to be more expensive than that derived from fossil fuels for the foreseeable future. We cannot overcome the fact that the earth and millennia of time provide free conversion processes for fossil fuels. However, when we account for the additional values of reducing our carbon intensity and wastes while delivering ecosystem services and beneficial coproducts, the costs can in fact be competitive. Governments can help realize these additional benefits with incentives, and corporations can value how these additional benefits advance corporate social and environmental goals.

Thank you again for the opportunity to testify on this important topic. I would be happy to answer any questions you may have.

Bibliography

J. Yan, O. Oyedeji, J. H. Leal, B. S. Donohoe, T. A. Semelsberger, C. Li, A. N. Hoover, et al., “Characterizing Variability in Lignocellulosic Biomass: A Review,” ACS Sustainable Chemistry & Engineering, (2022), 8, 22: 8059–8085. https://doi.org/10.1021/acssuschemeng.9b06263.

C. C. Brandt, M. R. Davis, B. Davison, L. M. Eaton, R. A. Efroymson, et al., “2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 1: Economic Availability of Feedstocks.” United States: N. p., 2016. Web. doi:10.2172/1435342.

J. N. Rogers, B. Stokes, J. Dunn, H. Cai, M. Wu, Z. Haq, H. Baumes, “An assessment of the potential products and economic and environmental impacts resulting from a billion ton bioeconomy.” Biofuels, Bioprod. Bioref. (2017) 11:110–128. DOI: 10.1002/bbb.

R. L. Skaggs, A. M. Coleman, T. E. Seiple, A.R. Milbrandt, “Waste-to-Energy biofuel production potential for selected feedstocks in the conterminous United States.” Renewable and Sustainable Energy Reviews, (2018), 82, 3, 2640-2651.https://doi.org/10.1016/j.rser.2017.09.107

Proposed Jonathan’s Bio for PNNL/WSU

Dr. Jonathan Male rejoined Pacific Northwest National Laboratory (PNNL) in the Energy Processes and Materials Division in May 2020 and in December 2020 became an adjunct faculty in the Biological Systems Engineering Department of Washington State University. In June 2021 Jonathan became the co-director of the WSU-PNNL Bioproducts Institute. Jonathan is interested in developing affordable technologies for the reuse of carbon.

Previously Jonathan was in the in the role of the Director of the Bioenergy Technologies Office (BETO) in the Office of Energy Efficiency and Renewable Energy (EERE) at the Department of Energy (DOE) for over six years. As Director of BETO, he led the Office’s work to lower modeled costs, reduce technology uncertainty, and accelerate research and development of bioenergy and renewable chemicals technologies in the emerging bioeconomy.

Jonathan was at PNNL from 2006-2013 where he held a variety of research and management positions, including Lab Relationship Manager for Bioenergy, Management and Operational detail with the Office of Biomass Program, and Scientist with projects in aftertreatment catalysts, scintillators, and catalysts to produce renewable chemicals.

Before joining PNNL Jonathan worked at General Electric where he developed programs in heterogeneous and homogeneous catalysts at the GE Global Research Center in Niskayuna, New York.

Jonathan has more than 20 years of research experience in catalysts, inorganic materials, high throughput experimentation, greenhouse gas emissions reduction technologies, production of chemicals, and fuels. He has numerous publications, patents, and presentations in these fields.

Dr. Male received his Bachelor of Science degree in Applied Chemistry from the University of Greenwich, England, and his Ph. D. in Organometallic Chemistry at Simon Fraser University, Canada.