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Before the
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Committee on Science, Space and Technology

"Bioenergy Research and Development for the Fuels and Chemicals of Tomorrow

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Good morning Mr. Chairman, Mr. Ranking Member and Members of the Subcommittee. Thank you for providing LanzaTech the opportunity to participate in this important hearing on "*Bioenergy Research and Development for the Fuels and Chemicals of Tomorrow*. I appreciate the opportunity to share our experience in bioenergy technology development and commercialization, as well as a perspective on the unique and important role that the U.S. Department of Energy can play in accelerating the transition to a clean energy future.

Introduction

LanzaTech is a carbon capture and transformation company, headquartered in Skokie, Illinois, with offices in the UK, Europe, India, and China. The company was founded 17 years ago with the goal of eliminating the need for virgin fossil carbon by changing the way the world sources and uses carbon. Fossil carbon is in everything we use in our daily lives. It is not just in fuels and power, but in our clothes, cosmetics, toys and home goods. All of these products start life in a refinery based mostly on petroleum or natural gas. Unfortunately, in 2022 this carbon economy is not sustainable given our current understanding of the impact of emitted and waste carbon on our environment and climate. We absolutely must stop putting carbon into our atmosphere and to do that we need to change our entire carbon economy.

LanzaTech is a business that enables a closed loop, circular carbon economy where carbon is reused rather than wasted. Through technology designed to touch all points of carbon use we believe we can offer a profitable solution to decarbonizing carbon intensive businesses, while providing sustainable raw materials to make the things we use in our daily lives.

We do this using biotechnology based on nature that mimics the original carbon recyclers – trees. Nature served as the inspiration for the amazing idea that became LanzaTech. We use a biocatalyst – a bacteria or microbe - which metabolizes carbon and produces useful chemicals. We often use an analogy which compares our process to making beer via fermentation. Rather than using yeast, we use bacteria and instead of sugar, we use waste carbon.

The beauty of this process is that it is based on biology, which is inherently flexible. The flexibility allows us to use a variety of different waste streams, from industrial emissions to solid waste, including biomass residues and municipal solid waste. Over the past 17 years, we've developed the bacteria, or biocatalysts, the bioreactor and refined and scaled the technology. We have proven the entire process at scale, with two commercial plants operating today and several others in various stages of design and construction. In addition, our continued R&D innovations have enabled us to create custom microbes capable of producing new, differentiated products for our customers with a pipeline of over 100 molecules.

Our focus is on substituting carbon from wastes for fresh fossil resources and on directing that carbon to applications where it will continue to be needed even as power becomes increasingly carbon free. While there are many ways to make renewable or carbon-free power, jets will continue to need energy-dense liquid fuels and our clothing will still require carbon-based textiles. Therefore, when we think about "bioenergy", we think about all the aspects of a bioeconomy that can enable the transition from fresh fossil to waste or recycled carbon that has already seen a primary use.

From that vantage point, the bioeconomy includes biological processes, such as LanzaTech's, that can be used to transform essentially any carbon waste, such as emissions created during the steel making process that would traditionally be emitted into the atmosphere as CO_2 or carbon found in solid waste streams like our daily trash and the landfill gases formed at municipal solid waste sites. It also includes the myriad pathways, biological and not, that transform biological feedstocks such as agricultural and forestry wastes, into sustainable fuels and chemicals. Furthermore, it includes hybrid pathways, combining the best technology at each step along the way. The key to a successful energy transition is maximizing carbon efficiency during transformation of waste carbon into final products.

The bioeconomy not only allows us to move away from virgin fossil carbon but also allows us to move away from today's paradigm of massive, centralized, refining facilities. The scales of biotechnology and of waste and residue feedstocks can be matched to allow production facilities to be located near heavy manufacturing to utilize industrial emissions, in communities where municipal wastes are creating environmental hazards, and in rural communities where biomass residues are plentiful. In each instance, transforming waste carbon into products improves the local environment while creating new local cleantech jobs.

LanzaTech's experience during our 17-year journey from an idea to a new carbon capture and transformation industry offers unique insights into the importance and role of Research and Development at all stages of technology development and deployment. I will begin with comments derived from our work with the U.S. Department of Energy during development of our gas fermentation technology and then focus on a case study: development and commercialization of technology to produce Sustainable Aviation Fuel from ethanol in partnership with the DOE's Pacific Northwest National Laboratory (PNNL).

Role of R&D: From Concept to Commercial

The U.S. DOE will be crucial to not only enable but, more importantly, to accelerate the transition to a clean energy future. DOE has a critical role to play at all stages of the development of new technology, from basic research to scale up and commercialization. I will offer some examples from LanzaTech's experience to illustrate the importance of DOE support at different stages:

- **Understanding of basic biological mechanisms** leading to core knowledge which can lead to new biomanufacturing processes. One example is funding from EERE-BETO (Bioenergy Technologies Office) of a collaboration between LanzaTech and Oak Ridge National Laboratory

(ORNL) to develop a new biosynthetic route to acetone, an important platform chemical, from syngas. LanzaTech has subsequently scaled up a process from gas to acetone building on the basic knowledge developed during the project.

- **Sophisticated computational tools for machine learning and modeling** related to organisms, systems, and processes. The EERE-BETO Agile Biofoundry Program supports a number of collaborative projects between industry and National Laboratories to develop new tools to address computational problems identified by industry.
- **Experimental platforms to accelerate discovery** of new organisms and processes. As an example, the DOE Office of Science (SC) is supporting a collaboration between Northwestern University and LanzaTech to develop a biofoundry for high-throughput discovery of new biocatalysts combining computational modeling, systems-level analysis, and cell-free engineering.
- **Diversification of the bioenergy feedstock pool.** EERE-BETO has funded a variety of projects to develop and demonstrate syngas as an intermediate that can be produced from cellulosic residues, municipal wastes, and waste plastics via gasification; the syngas can then be converted to fuels and chemicals via biological methods, like LanzaTech's gas fermentation, or thermochemical techniques. Both SC and EERE-BETO have supported collaborations between LanzaTech and electrolysis partners to develop and validate methods to convert CO_2 to CO as a feedstock for gas fermentation. EERE's Advanced Manufacturing Office (EERE-AMO) is supporting a collaboration between LanzaTech, Lululemon, Waste Management and InEnTec to develop a pathway for producing plastics using non-recyclable textiles and non-recyclable plastics from municipal wastes. EERE-BETO is supporting projects to produce ethanol feedstocks for Sustainable Aviation Fuel from landfill gas/biogas and from waste CO_2 coupled with renewable H_2.
- **Process intensification** to improve carbon, water, and energy efficiency. The Advanced Research Project Agency - Energy (ARPA-E) supported initial prototype development and piloting of LanzaTech's next generation bioreactor which reduces energy requirements and increases reaction rates; the technology is now being scaled up in partnership with Emissions Reduction Alberta.[1] EERE-BETO has also supported collaborations with PNNL and Oregon State University to develop microchannel reactor technology for converting ethanol to hydrocarbon products.
- **Integration and scale up.** EERE-BETO's Systems Development and Integration Program, formerly known as the Advanced Development and Optimization Program, offers cooperative funding for scale up including pilot and pre-commercial demonstration plants (see Case Study below). The purpose of scale up projects should be to identify and address key elements that require attention, which is typically specific to conversion technology and feedstock.
- **Deployment at scale.** While not necessarily falling under the "Research and Development" umbrella, it is vitally important that the DOE support be used to reduce investment risk for first commercial implementations of new technologies. This is where the mission offices interface with the Loan Programs Office.

The examples above also illustrate an important but often overlooked role for DOE: catalyzing collaborations among universities, national laboratories, and industry. Industry partners, even in early-

[1] https://eralberta.ca/projects/details/carbon-sequestration-via-next-generation-bioreactor-technology/

stage R&D projects, can provide feedback regarding industrial relevance and the likelihood that the research will ultimately lead to commercial implementation and real-world impact.

Case Study: Sustainable Aviation Fuel

The ethanol-based LanzaJet™ Alcohol-to-Jet (ATJ) Sustainable Aviation Fuel (SAF) technology is an excellent illustration of the role that DOE can and needs to play in advancing new technologies. The ATJ pathway is also a good example of a hybrid biological-thermochemical process: 1) ethanol is a platform chemical that can be produced readily from a wide variety of feedstocks using **biochemical** processes but is difficult to produce using thermochemistry; 2) ethanol is **thermochemically** converted to the long-chain hydrocarbons required for aviation fuel, which is extremely difficult biochemically.

LanzaTech developed the ethanol-based ATJ technology platform in collaboration with PNNL. Starting in 2010, PNNL researchers demonstrated that ethanol could be used as a feedstock for preparing an all-hydrocarbon jet fuel blendstock that met ASTM International specifications for jet. After initial proof of concept at PNNL, LanzaTech and PNNL were awarded cost-shared funding from EERE-BETO to develop a hybrid pathway from biomass to jet by combining biomass gasification to syngas (thermochemical), syngas fermentation to ethanol (biochemical), and ethanol conversion to jet (thermochemical).

PNNL worked with LanzaTech to develop laboratory and small pilot-based conversion of the ethanol into a renewable "drop in" jet fuel blendstock that will work in today's existing aircraft. With DOE funding, PNNL researchers demonstrated catalyst lifetime and process performance for the key process steps extensive time on stream at the bench and small pilot scales.

With internal funding and support from HSBC and Virgin Atlantic, LanzaTech scaled up the ATJ process developed by PNNL to demonstration scale and produced 4,000 gallons of jet fuel blendstock and 600 gallons of diesel from waste gas-derived and grain-derived ethanol, demonstrating that the process was independent of ethanol source.

In April 2018, ASTM International published the revision of ASTM D7566 on its website, including the approved ethanol based ATJ pathway, based on the Research Report **RR D02:1884**[2] led by LanzaTech and submitted to ASTM which contained detailed data measured by Air Force Research Labs (AFRL), Southwest Research Institute (SwRI) and University of Dayton Research Institute (UDRI) on ethanol-based ATJ produced using the LanzaTech-PNNL technology. As a result, ethanol-based ATJ is qualified for use in commercial aviation at up to a 50% blend with conventional jet.

A portion of the fuel was used in a transatlantic commercial passenger 747 flight with Virgin Atlantic in 2018, a transpacific flight 777-300 ER with ANA in 2019, as well as numerous flights by the National Research Council Canada measuring contrail and emissions data.[3] In addition, the fuel was used in the FAA Continuous Lower Energy, Emissions, and Noise (CLEEN II) Technologies Program.[4]

In 2017, LanzaTech was selected for cost-shared funding from EERE-BETO to support construction of an ethanol to jet facility, called "Freedom Pines Fuels", with a total production capacity of 10 million gallons

[2] https://www.astm.org/Standard/researchreports.html
[3] https://nrc.canada.ca/en/stories/national-research-council-canada-investigates-aircraft-contrails-sustainable-aviation-fuels
[4] https://www.faa.gov/about/office_org/headquarters_offices/apl/research/aircraft_technology/cleen

per year, located at LanzaTech's Freedom Pines Biorefinery in Soperton, Georgia. In 2020, LanzaTech formed a spinout company, LanzaJet,[5] to commercialize the ATJ technology. LanzaJet's investors include LanzaTech, Shell, Mitsui & Co, Suncor Energy, and British Airways. Development of Freedom Pines Fuels ATJ has continued to advance with both DOE and private sector support, including financing from the Microsoft Climate Innovation Fund recently announced by LanzaJet.[6]

The case study illustrates the importance and value of DOE R&D investment at all stages in the development and deployment of a new technology. DOE partnership with industry has led to a Sustainable Aviation Fuel technology that is now being rapidly commercialized around the world through LanzaJet and LanzaTech.

Closing Remarks

In closing, I would like to highlight a few observations and recommendations regarding the future of Bioenergy Research and Development within and supported by the Department of Energy.

First, all waste carbon must be brought to the table to replace fresh fossil inputs. Furthermore, all technically- and economically-viable pathways to produce chemicals and fuels from waste carbon will be needed, if we are to achieve our objectives for a clean energy future. Therefore, DOE programs should be technology- and feedstock-agnostic. This may in some instances require legislative corrections to remove outdated constraints on the scope of DOE funding.

Second, DOE funding is needed throughout the technology development timeline – from basic research through commercialization. While DOE has a strong history of supporting early-stage research, the urgency of meeting U.S. climate objectives, and doing so in a just and equitable fashion, means that DOE must expand its support for at-scale deployment, creating more flexibility regarding scope and scale in its R&D-pilot-demonstration paradigm, and with increasing attention to pre-commercial demonstration facilities. We cannot afford long project development timelines due to perceived risks in building first of a kind (or even first few of a kind) commercial plants. DOE support is also needed to ensure that plants, to the extent possible, are built in underserved and/or economically depressed locations.

Third, a clean energy transition must include replacement of fresh fossil carbon in both fuels and in chemicals ("products"). Thus far EERE has limited demonstration projects to fuels for the aviation and marine sectors. This focus should be expanded to include chemicals and materials that require carbon. In many cases, such products have a different and longer CO_2 cycle than fuels which are designed to be immediately combusted, therefore offering enhanced carbon reduction potential.

Finally, DOE needs to be provided the necessary tools to accelerate the pace of project selection and execution. Such tools include expansion of program staff and streamlining of procedures to enable projects to move forward at a pace consistent with the timeframes required to address climate change, and coordination across EERE and the DOE Loan Programs Office regarding due diligence.

I would again like to thank the Subcommittee for the invitation to testify today and look forward to Members' questions.

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[5] https://www.lanzajet.com/

[6] https://www.lanzajet.com/lanzajet-secures-industry-leading-innovative-financing-with-microsoft-climate-innovation-fund-to-construct-the-worlds-first-commercial-alcohol-to-jet-sustainable-fuel-plant/

Dr. Laurel Harmon

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Dr. Harmon provides policy direction and leadership on international legislative and regulatory matters and develops public-private partnerships to support collaborative research and demonstration projects. LanzaTech is the global leader in gas fermentation technology, offering novel and economic routes to a variety of products, including aviation fuel, from waste carbon streams, including industrial emissions. LanzaTech's carbon capture and transformation technology enables recycling of carbon to mitigate carbon emissions from industry without adversely impacting food or land security. LanzaTech's unique process, currently protected by over 1115 granted patents, enables a closed loop, circular carbon economy where carbon is reused rather than wasted, so that products such as sustainable aviation fuel and platform chemicals can be produced from carbon that has already served a primary purpose. Dr. Harmon received her Ph.D. in Physical Chemistry from the University of Michigan and has over 30 years of experience in policy matters and technology development. She serves on the Board of LanzaJet and is Vice Chair of the Board of the Roundtable on Sustainable Biomaterials.