World without Waste

A Circular Bioeconomy

A UIDP Bioeconomy Workshop
Aug. 19-20, 2021

Executive Summary

UIDP
Strengthening University-Industry Partnerships

UIDP conducted this workshop on behalf of the NSF Biology Directorate to leverage top scientific minds to identify biotechnology research areas for strategic investments and acceleration.

Executive Summary

Creating a future without waste or pollution is among society's most pressing challenges and greatest opportunities to improve the human condition. Achieving this goal in our lifetime requires rapid technological innovation, which can only be achieved when transformative discoveries from basic science and engineering research are translated to practice. Federal agencies such as the National Science Foundation (NSF) are coordinating efforts to develop partnerships to advance a circular bioeconomy. This workshop convened stakeholders from multiple sectors and disciplines to identify partnership strategies for use-inspired research that can be rapidly translated to advance an innovative, economical, and sustainable circular bioeconomy.

More than 100 participants from academic, industry (large and small), government, and nonprofit sectors convened virtually for two days in August 2021 to define priorities and enumerate the challenges for advancing the circular bioeconomy. The invited scientists and researchers were strategically selected to ensure that diverse perspectives and expertise were represented in the workshop deliberations.

Purpose of the Workshop

By and large, society's use of materials follows a straight pattern. In recent years, particular attention has centered on the linear nature of plastics as an environmental challenge. The high volume of waste at the end of the plastics lifecycle causes adverse environmental effects, and the direct system wastes the valuable carbon and energy that end-of-life plastics contain. Plastics represent just one linear material system; society loses a dramatic amount of metals when spent lithium-ion batteries and other electronics make their way to landfills, when storms sweep nutrients from farms into rivers, and when industrial waste like kraft liquor or sludge from wastewater plants is not tapped for the energy, materials, or nutrients within them. At the current rate of plastic waste generation, there will be more plastic (by weight) than fish in the ocean by 2050.[1]

Biological systems offer a dramatic opportunity to increase circularity in our material systems. However, the circular bioeconomy must overcome numerous challenges before it can be realized, which include:

- Barriers to development because of the complexity of these systems;
- High costs to economically scale up necessary bio-based solutions;
- Large knowledge gaps, including those in data and biological systems;
- Proven ability to economically compete with lower-cost, linear systems; and
- A severe lack of infrastructure for waste collection in many regions.

The workshop's goals were to define the needs for a zero-waste, circular bioeconomy, identify gaps to progress, and articulate short- and long-term goals to achieve successful outcomes. Use-inspired research should be directly connected with and lead to innovations that translate knowledge into practical outcomes. Established partnerships among all sectors (public, private, nonprofit) are essential for achieving these common goals and, thus, inherent to success. Industry-academic research consortia are one example of the kind of partnership that will contribute to developing the circular bioeconomy. Both those participating in the research and those investing in it will benefit from collaborative R&D efforts.

Workshop Findings in Brief

Steps to Address Areas of Concern

- Assess technologies early in the development cycle and account for how they fit with existing materials infrastructure.
- Collaborate with social scientists on messaging that is tailored to unique audiences.
- Design and produce circular bioeconomy products with market pull and with a life-cycle mindset.
- Develop industry-university collaborations with streamlined intellectual property and funding models targeted toward increasing scale-up successes.
- Engage the myriad diverse stakeholders earlier and more frequently (both the general public and across the value chain) in product, process, and systems development.
- Explore emerging employment opportunities through the realization of the circular bioeconomy.
- Enable cross-region fundamental science sharing while adopting customized local approaches.

Necessary Technical Advances

- Address challenges in the scale up of biological systems.
- Create and sustain pre-competitive common spaces that enable data sharing to address common challenges technology developers face.
- Determine the performance advantages of strategies for basing the circular bioeconomy on small chemical building blocks versus unique but complex bio-derived compounds.
- Develop low-cost conversion technologies that use low-cost feedstocks and are supported by a strong business case for competition with low-cost incumbent materials and processes.
- Develop robust waste management and sorting technologies that can operate cost-effectively in distributed environments.
- Develop technology that uses microbes to break down complex end-of-life materials into high-quality components that can be reused.
- Employ life cycle assessment, technoeconomic analysis, and material flow analysis to shed light on the space between infinite circularity and today's linear systems.
- Expand priorities for circularity beyond carbon to emphasize nitrogen, phosphorous, and even waste heat and byproducts in bioprocesses.
- Expand the knowledge base that underpins the circular bioeconomy from the fine scale (atom, enzyme, microbe) to the systems scale (waste collection infrastructure, product and process design).
- Explore universal, scalable and cost-effective strategies to effectively incorporate biobased content into synthetic materials.
- Evaluate the appropriateness of different technologies for modular distributed approaches, as opposed to the centralized approaches on a regional basis that account for feedstock availability.
- Identify new material paradigms for overcoming the limitations of biobased materials in high-performance applications, for example, low fire-tolerance, low hydrophobicity, and long-term durability.
- Improve the fundamental science that informs our understanding of non-ideal, ecologically robust biological systems.
- Leverage biology, chemistry, and hybrid approaches to improve recycling processes.
- Produce models that improve understanding of circular, biobased materials at multiple scales.
- Produce and maintain inventories of biomass and wastes globally to inform economically viable feedstocks that are regionally available.
- Understand how to separate synthetic and biobased components from materials into waste streams that can be independently processed or valorized in an energy-efficient way.
- Improve the scientific understanding of microbial signaling.

Key Findings: Participants discussed specific questions and focused on key topics in biological systems design, sustainable biosourced materials and products, biomanufacturing, enabling circularity, regional and international approaches, innovation recipes and collaboration, public engagement, and reducing risk. The need to address societal aspects of the circular bioeconomy was also a consistent theme throughout the workshop. These discussions produced specific recommendations for research and collaboration activities which are described below:

» **Build data repositories on shared, transparent, and consistent platforms.** Shared data resources pertaining to material properties (of recycled and/or bio-based materials), biological systems and their behavior, and other common components of a circular bioeconomy will help remove barriers to technology development.

» **Characterize regional differences** in feedstocks, waste generation types, amounts, and distribution, along with societal approaches to waste management, to build successful regional approaches to a circular bioeconomy.

» **Design biological processes holistically from the outset**, with clear goals accounting for biological components' tolerance of processing conditions.

» **Develop quantitative definitions and targets** for the circular bioeconomy to mobilize efforts toward common goals.

» **Devise successful strategies for biological processes and manufacturing scale up** given their unique and complex nature.

» **Expand scientific knowledge to capture data** reflecting the complexity and non-ideality of biological systems.

Participants identified **overarching knowledge gaps for additional research**, to include the need for:

- **Clear focus on short-term scalable processes** that can utilize existing infrastructure to enable quick wins both from an economic and sustainability standpoint;
- **Clearly identified strategies and business models** to enhance the waste handling infrastructure in the United States; and
- **Consensus, as well as consistent standards and definitions**, for product features critical to a circular bioeconomy, such as "biodegradability;"
- Data and data sharing infrastructure for the circular bioeconomy.

Recommendations and Next Steps

Achieving the goal of a circular bioeconomy requires consensus in the scientific and policy communities and commitment at a high level to:

- **Develop a framework** to steer circular bioeconomy research and collaboration efforts in a consistent direction based on economic viability, environmental and societal sustainability;
- **Develop an entrepreneurial, circular bioeconomy workforce**; and
- **Identify best practices in developing partnerships** among suppliers and end-product manufacturers (e.g., from the electronics industry).

This report summarizes the key insights from the workshop and is not intended to be a detailed record of the entire proceedings. We encourage you to share this document with interested parties.

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