Bioeconomies
Ecosystems and Society

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UIDP
Strengthening
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Workshop Report

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Contents

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UIDP staff and leadership provided the foundation of this event. Michael Brizek, Program Director, managed much of the communications (before and after the event). Natoshia Goines, Events Coordinator, had a lead support role in conference planning and execution. Additional UIDP staff who provided critical support included Sandy Mau, Marketing and Communications Director, and Morgan Jones-King, Events Content Manager. Finally, UIDP thanks all the workshop participants who contributed their time to create a valuable discussion and conference report. Senay Agca, Professor of Finance and Chief Diversity Officer, The George Washington University School of Business, served as a workshop technical advisory committee and as the lead author of this report. She was a key contributor throughout the two-day event. Austin Lai and Dylan Saez from The George Washington University also provided assistance.

Executive Summary

The bioeconomy ecosystem encompasses innovation, technology platforms, products, systems, and services, with implications for wide-ranging human-environment and societal issues, including health, climate, and food. Developing a successful bioeconomy ecosystem requires an understanding of unique features of bioeconomy, social, behavioral, and economic implications, translational opportunities and challenges, diverse workforce development paths, and consideration of local-regional aspects.

The National Science Foundation (NSF) is developing programs and partnerships to create and advance successful bioeconomy ecosystems by progressing science and by paving the way for the translation of research to benefit society. This workshop was convened to better understand the pathways for successful and sustainable bioeconomy ecosystems that incorporate societal, economic, and behavioral underpinnings, and to uncover the challenges and opportunities that arise within a bioeconomy ecosystem. The workshop explored the implications of these factors on innovation, entrepreneurship, and growth within the bioeconomy.

Over two days, a diverse group of more than 100 scientists and researchers participated in the conference, representing academia, industry, government, and nonprofit organizations. The participants provided input on eight topics:

- Development of bioeconomy ecosystem and innovation hubs;
- Diversity, equity, and inclusion;
- Implementation and adaptive management;
- Regional and geographic considerations in bioeconomy;
- Responsible and ethical scaleup;
- Risk assessments;
- Social challenges and opportunities that arise in a bioeconomy ecosystem; and
- Value chains and markets.

The workshop participants recommended that additional time, energy, and resources be devoted to :

- Creating better approaches to communicate the importance of science to the public;
- Defining bioeconomy and understanding how value is created in a bioeconomy ecosystem;
- Embedding social, behavioral, and economic sciences in all stages of bioeconomy ecosystem development;
- Engaging stakeholders earlier in the process;
- Incorporating diversity, equity, and inclusion in all aspects of bioeconomy, with emphasis on workforce development and entry points to the ecosystem; and
- Valuing human-centered design of bioeconomy ecosystems.

Purpose of the Workshop

The purpose of the workshop was to recognize and identify areas of importance in developing a successful and sustainable bioeconomy ecosystem that spurs innovation, creates economic growth and societal value, enhances diversity, equity, and inclusion, and provides an ethical translation of science to implementation. For the purpose of this workshop, the bioeconomy refers to the share of the economy based on products, services, and processes derived from biological resources (e.g., plants and microorganisms).[1] The workshop focused on several broad topics:

- Understanding the opportunities and challenges that arise within the bioeconomy ecosystem;
- Exploring how societal, behavioral, and economic factors promote a successful and sustainable bioeconomy and the implications of the bioeconomy for financial well-being and society at large;
- Considering regional and geographic aspects of the bioeconomy;
- Stakeholder engagement; and
- Incorporating diversity, equity, and inclusion in research and technology development.

Workshop Findings in Brief

- **The definition of bioeconomy** should be broad to give opportunities to different regions and ecosystems to define more narrow objectives within the greater definition and develop appropriate measures for the bioeconomy ecosystem.
- **Diversity, equity, and inclusion** should be a priority and embedded in bioeconomy ecosystem development in all aspects, including entry points and workforce development.
- **Risk assessment** should incorporate high-level strategy for a dynamic and sustainable bioeconomy and encompass barriers to translation by considering financial, societal, and informational challenges over different time horizons.
- **Societal, behavioral, and economic sciences** should be integrated into bioeconomy development early in the process to maximize its impact and avoid unintended consequences. Human-centered design should be embedded in this development.
- **Stakeholder engagement and communication** are crucial and should carry through all stages and through multiple channels, including early stages and during scaleup, to understand different views and objectives and to foster collaborations.
- **Team science and interdisciplinary collaborations** should be the driving force of bioeconomy research and translation.
- **Further understanding end-use perceptions** should be considered as research and programs translate from lab to consumer.
- **Workforce development efforts** should consider education in a broader framework (to include community colleges) and foster an entrepreneurial mindset to catalyze a vibrant, diverse, and equitable workforce in the bioeconomy.

A range of challenges and opportunities arise in the development of a successful, sustainable bioeconomy.

Challenges

The definition of bioeconomy must be comprehensive to allow alternative ecosystems to develop more specific definitions and the corresponding metrics within this broader and interdisciplinary context.

Translational challenges exist, including licensing and intellectual property rights, impacts of regulations, incentives for researchers to pursue goals-based product development, shared infrastructure, access to capital, and creating both economic and social value.

Varied perspectives should be incorporated at all stages through stakeholder engagement, beginning at the start of bioeconomy ecosystem development and during scaleup.

Opportunities

A broader concept of development that considers social and behavioral factors in addition to economic growth along the value chain should be incorporated into bioeconomy ecosystem advancement.

Integration of diversity, equity, and inclusion to bioeconomy ecosystem development provides opportunities for underrepresented groups to participate in an emerging field. This entails well-defined entry points and long-term partnerships to build a strong and diverse workforce that is closely aligned with industry needs.

Team science that incorporates social, behavioral, and economic research can have valuable impacts, allowing grand challenges to be addressed holistically while avoiding unintended consequences.

Recommendations and Next Steps

Participants proposed actionable recommendations for developing high-impact bioeconomy ecosystems.

Create leadership and workforce development programs that integrate diversity, equity, and inclusion to cultivate an emerging workforce and empower champions who can help build new initiatives via both nonprofit and commercial ventures.

Develop public engagement programs in partnership with universities and other relevant organizations while considering how these efforts impact the views of stakeholders and scientists.

Design and plan major infrastructure investments, including shared data and tools to enable access and innovation in the bioeconomy. These should consider different models (e.g., distributed or decentralized) with varying governance strategies.

Engage social, behavioral, and economic scientists and legal scholars in envisioning the bioeconomy ecosystem. Foster collaboration between natural sciences/engineering and social sciences through funding initiatives and support universities and other organizations to encourage specific types of collaborations.

Invest in centers with equal influence between social scientists and natural science and engineering partners to foster cross-directorate efforts in developing bioeconomy ecosystems and incorporate social, behavioral, and economic sciences beyond "broader impacts" in these engagements.

Introduction

The European Commission defines the bioeconomy as

"the production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, bio-based products and bioenergy. Its sectors and industries have strong innovation potential due to their use of a wide range of sciences, enabling and industrial technologies, along with local and tacit knowledge."[2]

What is less understood is how bio-based value production chains can evolve in practice to achieve these goals. Policymakers face the challenge of balancing supply- and demand-side measures across disparate sectors, involving industrial manufacturing, agriculture, forestry, marine resources, and waste management. The bioeconomy consists of economic activity based on innovation, technology platforms, products, systems, and services centered on life sciences. The bioeconomy ecosystem has implications for human-environment and societal issues, including health, environment, climate, and food. Many constituents comprise the bioeconomy ecosystem: a range of sectors and firms (startups to large companies), R&D institutes, government laboratories, venture capitalists or other financiers, consumer groups, end users, universities, community colleges, K-12 schools, local government, trade associations, regulatory agencies, legal systems, and complementary services. A multitude of

issues are important for the success of a bioeconomy innovation hub and the bioeconomy overall, such as spurring innovation, entrepreneurship, combining local knowledge with external expertise, bringing in financing, facilitating the growth of industries related to the bioeconomy and those that provide services to it, ensuring public acceptance of new products and services, and educating and accessing a potential labor force. In developing a bioeconomy ecosystem, understanding its unique features, including the local-regional aspects, and considering the historical perspective on industrial agglomeration and innovation together with potential recent technological changes such as remote working environments as well as spatial, economic, social, and behavioral factors are vital in understanding opportunities and challenges. The implications of the developments in the bioeconomy for underrepresented groups and the promotion of diversity and inclusion are critical to broadening participation and socioeconomic wellbeing.

There is a need to understand the challenges--societal, economic, behavioral, and potentially others—and opportunities that arise in developing a bioeconomy ecosystem and how these factor into growth of bioeconomy innovation hubs, encourage entrepreneurship, and enlarge the bioeconomy. Expertise from academia, industry, and the public sector brings important perspectives and knowledge to these areas.

Workshop Goal

The goal of this workshop is to help understand and design successful and sustainable bioeconomy ecosystems, and bioeconomy innovation hubs with specific emphasis on nine overarching questions:

- What are the opportunities and challenges in designing bioeconomy innovation hubs and bioeconomy ecosystems?
- What are the unique features of bioeconomies that need to be incorporated?
- What are the economic, societal, behavioral, and other factors that promote a successful and sustainable bioeconomy?
- What issues are important in considering the implications of a bioeconomy on society at large?
- How can the greatest benefit for a wide spectrum of society be ensured?
- What are the ethical, social, and legal aspects of bioeconomy systems?
- What are the regional geographic considerations for biotechnological advances as related to working conditions, technological change, and local, national, and international regulation, policy, and oversight?
- How can bioeconomy institutes and bioeconomy innovation, in general, promote diversity, inclusion, and participation of underrepresented groups?
- How can diverse stakeholders and non-traditional stakeholder participation be integrated into all aspects of bioeconomy hubs and/or ecosystems?

Level-Setting: Challenges and Roadblocks

A pre-event survey was distributed to participants to identify key opportunities related to supporting societal activity in the bioeconomy. Using a scale of 1 (not important) to 5 (very important), these rankings were condensed into weighted averages. The survey questions corresponded to the four themes discussed in the workshop breakout sessions: bioeconomy ecosystem and innovation hubs, societal challenges and opportunities in the bioeconomy, regional and geographic considerations in the bioeconomy, and diversity, equity, and inclusion in the bioeconomy.

Bioeconomy Ecosystem and Innovation Hubs. Participants equally ranked *factors influencing stakeholder interactions* as the area of highest importance with a weighted average of 4.3, along with *social, behavioral, and economic factors impacting the success of the bioeconomy ecosystems and innovation hubs* with a weighted average of 4.3.

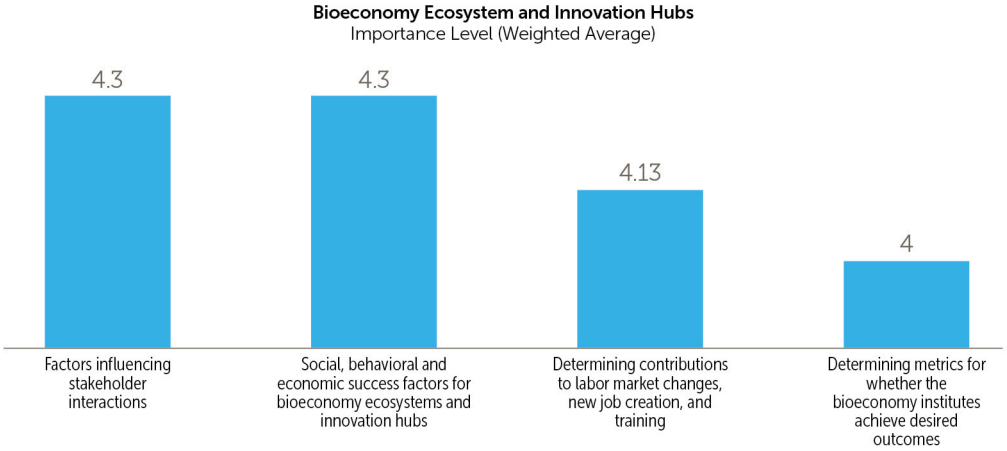

Figure 1 | Survey results on the importance for industry and academia to collaboratively expand knowledge and remove barriers to achieving a circular bioeconomy: Bioeconomy ecosystem and innovation hubs. Participants scored a level of importance on a scale of 1 ("Not important") to 5 ("Very important"). Numbers above bars represent the weighted average across n=23.

Societal challenges and opportunities in bioeconomy. Participants ranked *incorporation of societal, behavioral, economic, and other factors involving research in the bioeconomy* as the area of highest importance with a weighted average of 4.26, followed by *societal acceptance and market adoption of advances in the bioeconomy* with a weighted average of 4.22.

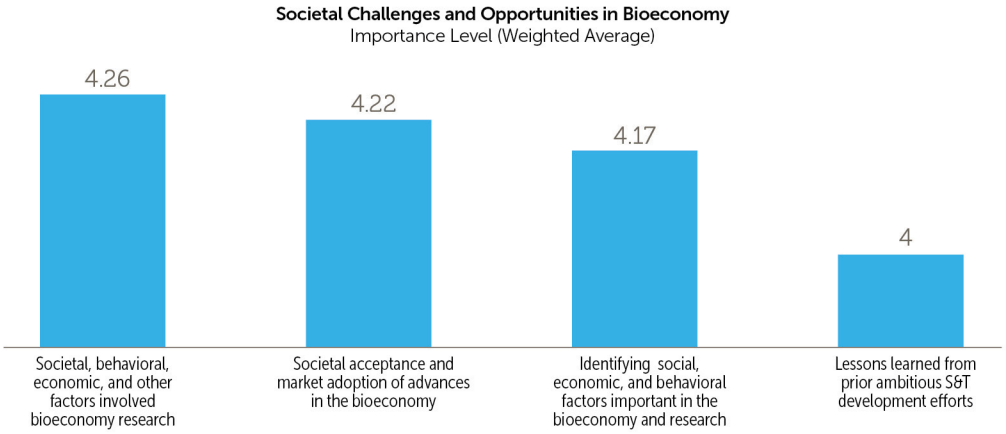

Figure 2 | Survey results assessing the importance of societal challenges and opportunities in the bioeconomy. Participants scored level of importance on a scale of 1 ("Not important") to 5 ("Very important"). Numbers above bars represent the weighted average across *n*=23.

Regional and geographic considerations in the bioeconomy. Participants ranked *government regulation, policy, and oversight affecting the ability of speed and location in which new biotechnology products and services are adopted universally* as the area of highest importance with a weighted average of 4.61, followed by *understanding the unique spatial and place-based features of the bioeconomy across multiple scales including local-regional aspects; historical perspective on industrial agglomeration and innovation* with a weighted average of 4.04.

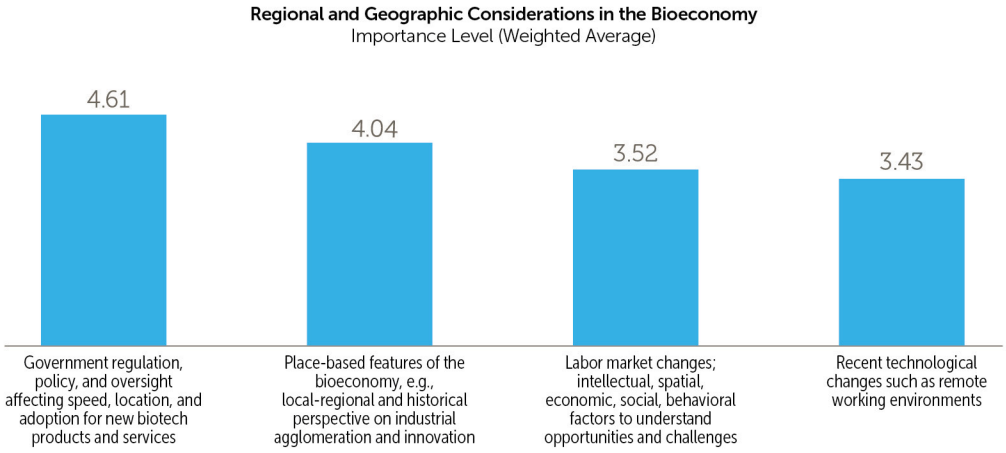

Figure 3 | Survey results assessing regional and geographic considerations in the bioeconomy Participants scored level of importance on a scale of 1 ("Not important") to 5 ("Very important"). Numbers above bars represent the weighted average across *n*=23.

Diversity, equity, and inclusion in bioeconomy. Participants ranked *incorporating a diversity of partners, individuals, and communities to identify potential frameworks, challenges, and strategies to ensure the full participation of underrepresented individuals in the bioeconomy* with a weighted average of 4.32, followed by *supporting education institutions serving underrepresented groups, economic development zones involving the bioeconomy of highest importance* with a weighted average of 4.27.

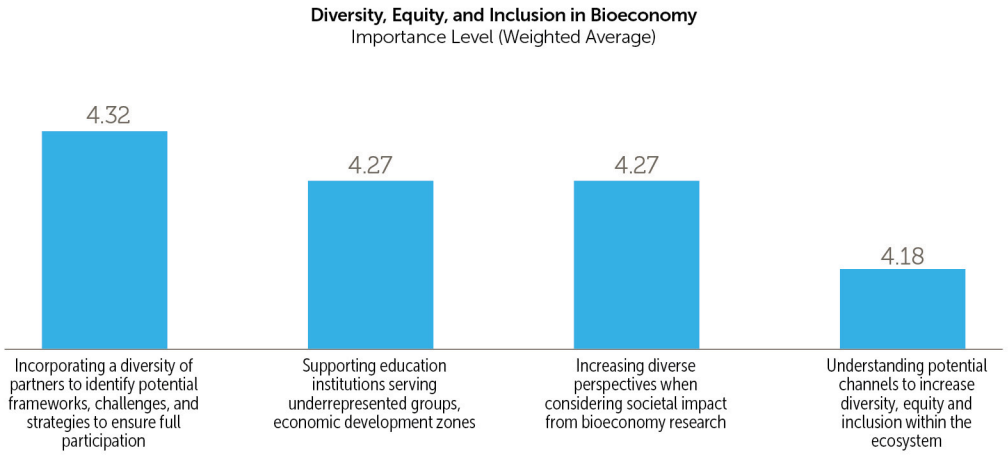

Figure 4 | Survey results assessing diversity, equity, and inclusion in bioeconomy. Participants scored level of importance on a scale of 1 ("Not important") to 5 ("Very important"). Numbers above bars represent the weighted average across *n*=22.

CASE STUDY

Ecosystem Development: Opportunities and Challenges

Christy Wyskiel, senior advisor to the president of Johns Hopkins University for Innovation & Entrepreneurship and executive director of Johns Hopkins Technology Ventures

Christy Wyskiel discussed the innovation and entrepreneurship infrastructure and the local technology ecosystem in Baltimore at Johns Hopkins University. She presented critical gaps and fundamental components of innovation, the path of translation from innovation to product in the marketplace, the resources needed for successful translation, venture capital fundraising efforts, and the history of local ecosystem development in Baltimore, including activities by Johns Hopkins University.

The critical gaps in innovation and translation are threefold: Space, funding, and support for innovation. There are 43,000 square feet of space available in Baltimore for innovation activities, and support is provided for 174 startups. Johns Hopkins University quadrupled venture funding over the last five years, raising $3 billion since 2015. In 2015, around 15% of the companies were regional to the Baltimore-Washington area, but more recently, Johns Hopkins has found that this figure has increased to around 41%. Thus, local ecosystem development in Baltimore is promising, indicating that the efforts to develop and advance the ecosystem are contributing to the local and regional economy.

The fundamental components of successful innovation are infusing new ideas into the market, attracting and retaining talent, generating outside investment opportunities, and promoting local and regional development. The translation path to the marketplace starts with discovery, followed by the review of potential challenges and then production.

Successful translation of research to the marketplace requires access to critical resources such as education, quality mentorship, robust support services, adequate and appropriate types of space, and funding. The ability to access knowledgeable faculty, staff, and industry partners to provide necessary knowledge is critical. Mentoring is also fundamental for successful translation and can be achieved, in many regions, by working with alumni networks. Important support systems include pro-bono legal advising, accounting, business analysis, and pitching and presentation coaching. Providing accessible and affordable locations and space for mixed lab use is critical to support translation from bench to market. Finally, there must be funding support. The funding can be through federal and state grants or from connections to investors and corporations. NSF I-Corps translational grants are valuable; most of the successful translation activities in Johns Hopkins' model have gone through these programs.

Commercialization strategies were framed using questions. The first set of questions relates to the problem and unmet need: What problem does this invention solve? What is the size of the unmet need? The next step is the value proposition, which asks what products will be created from the proposed technology, and whether the innovation would be a marginal or groundbreaking improvement to current technology. Understanding the customer by types of companies that may license the technology or end-users that may use the product is the next step. Then comes understanding the level of funding raised and what needs to still be raised. The final commercialization step focuses on the milestones for stages of development and the work required for translation through commercialization or industry collaboration.

Conclusions from the Research Landscape

Elsevier research analysts Daniel Calto and Bamini Jayabalasingham provided results of a review of the research landscape on this topic, focusing on the period from 2001 to 2020. The analysis includes a large spectrum of social, behavioral, and economic science research that advances knowledge in understanding and designing a successful and sustainable bioeconomy system. (See the full analysis in Appendix A.)

Global research on the intersection of bioeconomy and social, behavioral, and economic sciences has been growing at a rapid pace (Figure 5 and Figure 6). The compound annual growth rate of publications was 11.2% over 2001–2020, nearly double the compound annual growth rate of 5.1% observed for all publications. Growth has been particularly high over the past five years; 43% of the 93,284 publications since 2001 were published between 2016 and 2020. While the United States had an increasing trend in publications until 2011, the research output in the United States leveled off after 2011, during which time the research in Europe and China accelerated.

The publications are categorized based on the four key areas that were the focus of the workshop:

- Bioeconomy ecosystem and innovation hubs;
- Societal challenges and opportunities in the bioeconomy;
- Regional and geographic considerations in the bioeconomy; and
- Diversity, equity, and inclusion in the bioeconomy.

As these categories are not mutually exclusive, publications may be classified as more than one category. As observed in Figure 6, research on societal challenges and opportunities, as well as research on regional and geographic considerations in the bioeconomy, has grown exponentially over the past two decades, while the other two categories remained more stable.

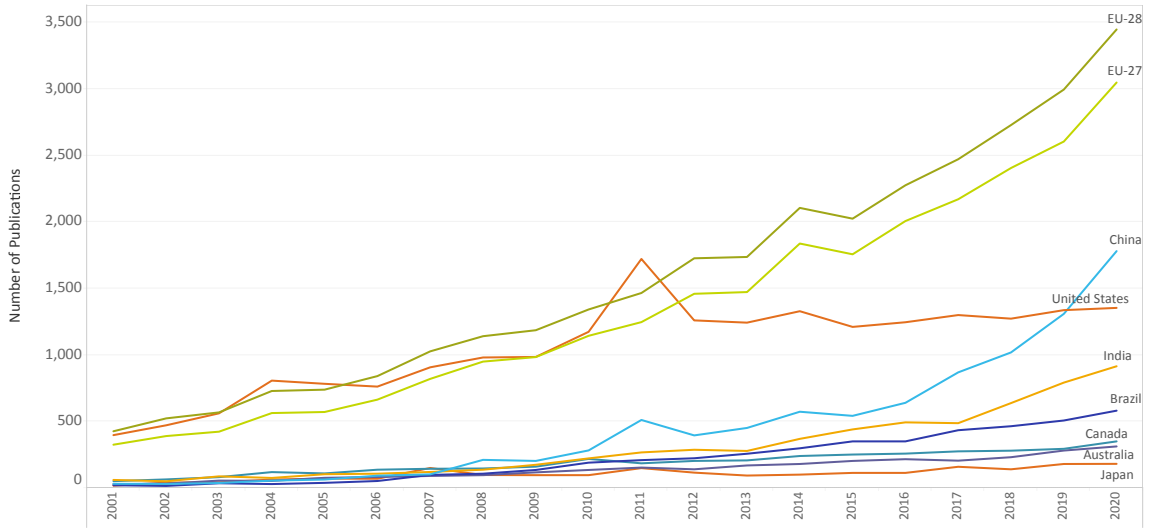

Figure 5 | Number of publications by country. Source: Scopus data.

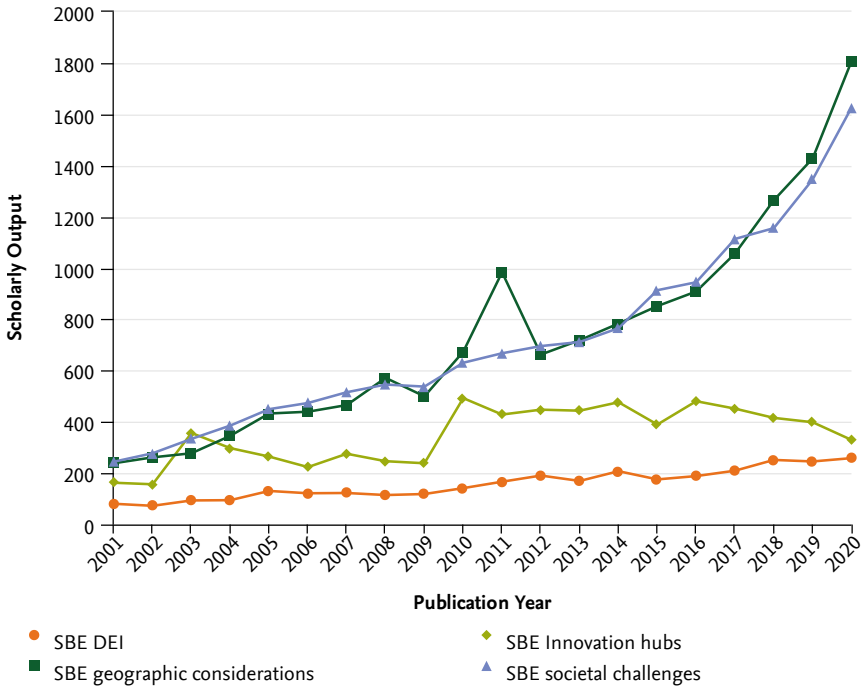

Figure 6 | Annual number of publications among research subcategories, 2001–2020. Source: Scopus data

Growth in these areas of research output has been driven by many European countries, as well as by China, India, and Brazil. While the United States was the major contributor to the research area, other countries have outpaced it in recent years. India, the Netherlands, and Brazil dedicate a greater percentage of their research portfolio (0.3%) to these research areas than the United States, European Union, or China, highlighting the high priority of research in addressing social, behavioral, and economic issues related to the bioeconomy in those countries.

Since 2015, the United States largely contributed to several research areas within the corpus of research on bioeconomy and society, including renewable energy directive, agricultural price, biodiesel, techno-economic analyses of bioeconomy research, jet engine fuel, hydrothermal liquefaction, biorefining, bioenergy, and circular economy.

Research dedicated to social, behavioral, and economics topics spans various sectors of activity, with academic institutions represented in approximately 51% of U.S. publications. Most notably, non-governmental agencies in the United States are active in publishing—more so than other non-academic sectors. They contributed to 28% of all research from 2016–2020, collaborating on 12% of the overall research with academia. Corporations contributed only 6% of these publications.

Session Highlights from Day 1: Bioeconomies: Ecosystems and Society

The first day of the virtual workshop explored the intersection of bioeconomy ecosystems and society. Opportunities and challenges that arise in bioeconomy ecosystems were considered from alternative perspectives. The participants joined a framing session and devoted time to understanding the research landscape of bioeconomies and society. Following these sessions, participants were organized into breakout groups that collaborated to answer the following overarching questions for Day 1 sessions:

1. What are the regional geographic considerations for bioeconomy advances as related to economic and social conditions, technological change, regulation, policy, and governance? What factors advance or impede the connection and coherence of bioeconomy innovation hubs across various levels of space and scale?

2. What are the opportunities and challenges in designing bioeconomy innovation hubs centered on biological resources that enable bioeconomy ecosystems to thrive? What are the unique features of bioeconomies that need to be incorporated into a successful design?

3. How can bioeconomy hubs and broader bioeconomy innovation efforts promote diversity, inclusion, and participation of underrepresented groups? How can diverse stakeholders and non-traditional stakeholder participation be integrated into all aspects of bioeconomy hubs and/or ecosystems?

4. What social, behavioral, and economic factors must be considered to promote a successful, sustainable, and ethical bioeconomy? How can policies and practices be aligned to maximize positive societal impacts and mitigate the risk of unintended consequences?

Facilitated Breakout Sessions

Regional and Geographic Considerations in the Bioeconomy

Regional and geographical considerations are important in developing a successful bioeconomy ecosystem. There are opportunities and challenges that arise within the context of the bioeconomy both within and across regions.

Key Takeaways

Define "bioeconomy." The definition of bioeconomy should include sustainable use of renewable materials in the development of biotechnology, services, and energy. The definition should be interdisciplinary, incorporating societal, behavioral, and economic sciences together with biotechnology. Research on biotechnology and social, behavioral, and economic sciences should be fostered to understand what a low-carbon bioeconomy would look like.

Define goals for universities and local communities, foster an entrepreneurial mindset, and develop the economy and workforce. Universities should partner with local communities to

understand differences and work collaboratively to align goals. Fostering an entrepreneurial mindset among youth can leverage regional perspectives and create hubs of opportunity and development. Economic development should transcend job creation to include creating more remote modes of production that require fewer on-site workers. Rural-urban or urban-rural migration should also be considered in developing bioeconomy goals.

Seek to overcome translational challenges. There are challenges in encouraging academic scientists to pursue a goals-based product development approach alongside open-ended scientific inquiry. Among the barriers to creating a bioeconomy marketplace are financial challenges (high upfront costs with longer returns on investment), setting standards (how to differentiate bioproducts from existing products), societal challenges (reconfiguration of society to undercut current paradigms), and information challenges (combatting disinformation and distrust in scientific research and boosting scientific literacy).

Social Challenges and Opportunities in the Bioeconomy

Bioeconomy ecosystem development should have an interdisciplinary approach and incorporate differences in perception.

Key Takeaways

Consider aspects of valuation and their consequences. The valuation of the bioeconomy should include social, behavioral, and economic aspects. Research in these areas should be embedded early in the development process to ensure a positive impact and to avoid unintended consequences. Sustainability of emerging bioeconomy ecosystems and the ability of system tools to address grand challenges should be an integral component of bioeconomy ecosystem valuation. The structural differences in organizations and policies should be considered and, when possible, aligned when developing bioeconomy ecosystems.

Broaden the definition of "bioeconomy." The definition of bioeconomy should include the following traits: interdisciplinarity, multidimensionality, and the genealogy of what bioeconomy was and how it has evolved. The definition of bioeconomy should be broadened to include social, behavioral, and economic sciences perspectives. Bioeconomy comprises a whole range of biological resources, how they are used and developed, and the political, economic, and social-cultural structures in this ecosystem. The spatial-temporal interpretation of the bioeconomy must also be considered.

Incorporate diverse perceptions. There are important differences between the perceptions of consumers and of those with an economic requirement to make a profit. The inequalities that may arise during the development of the bioeconomy ecosystem, as well as the differing needs of small-scale farmers and large entities, should be carefully weighed and balanced. Self-perception and the organizational structure of family-owned firms differ from those of commercial firms, and investment strategies to advance the development of the bioeconomy should account for these differences.

Bioeconomy Ecosystem and Innovation Hubs

A broad definition of "bioeconomy" provides opportunities for different ecosystems to co-exist under a large umbrella. Fostering communication across different stakeholders and creating a diverse workforce are critical for developing a successful bioeconomy ecosystem.

Key Takeaways

Communication between stakeholders is crucial for success. There are many different stakeholders with competing interests and without a common understanding of the issues. Alignment between stakeholders, their perceptions, and their ideas is essential. Communication between stakeholders, a common understanding of the underlying issues, and clarity about different goals and interests are fundamental for the success of bioeconomy ecosystems.

Defining bioeconomy ecosystem metrics within the context of society. A broad concept of bioeconomy offers different regions and different ecosystems an opportunity to develop context-specific objectives and formulate their own definitions within a broader framework. This flexibility allows for the development of a range of metrics appropriate for bioeconomy ecosystems, including measures for quality of life; number and quality of jobs; public, venture capital, or other funding sources; and private sector revenue.

Ensure equity and diversification in the workforce. Developing a workforce for a bioeconomy ecosystem should begin in middle and high school. Community colleges should be an integral part of bioeconomy ecosystem workforce development and will reach a larger share of the potential workforce than a sole focus on four-year universities, thus helping to achieve workforce diversity and equity. Social, behavioral, and economic sciences research should be promoted to build a strong and diverse workforce and to ensure that training closely aligns with industry needs.

Diversity, Equity, and Inclusion in Bioeconomy

Bioeconomy ecosystems should be designed to increase diversity, equity, and inclusion among stakeholders. Social, behavioral, and economic sciences have the potential to make significant contributions to increase participation of underrepresented groups and advance the integration of diversity, equity, and inclusion goals.

Key Takeaways

Define entry points. Developing bioeconomy ecosystems provides opportunities to increase the participation of underrepresented groups in an emerging field. It is imperative to define entry points for underrepresented communities to participate in the bioeconomy. Underrepresented community considerations include geographic, demographic, and socio-economic dimensions.

Establish societal engagement within the bioeconomy. Social, behavioral, and economic sciences should participate in significant ways to understand the barriers to participation of underrepresented communities. This line of thinking will pave the way for new

research with defined and measurable outcomes for diversity, equity, and inclusion in the bioeconomy ecosystem.

Establish strong partnerships considering diversity, equity, and inclusion strategies. Diversity, equity, and inclusion strategies should be prioritized as an integral part of bioeconomy ecosystem development. Sustainable approaches should be developed, and long-term partnerships should be formed across sectors to foster diversity, equity, and inclusion.

Concluding Group Discussion

All participants joined a session to share and discuss the key takeaways from each breakout group.

- **Entry points for underrepresented communities to participate** in the bioeconomy should be a priority.
- **Public perception is a major challenge;** consumer perceptions do not always align with the economic perspective of those creating new products and services and bringing them to market.
- **The definition of "bioeconomy" should include** the following traits: interdisciplinarity, multidimensionality, genealogy of what bioeconomy was, and how it has evolved.
- **There are educational gaps in understanding** the skills and other workforce preparation needed for short-, medium-, and long-term bioeconomy ecosystem development. Bioeconomy workforce development should focus not only on graduate education but also on community colleges and undergraduate education to enable strong, diverse participation in the bioeconomy ecosystems.
- **There must be an understanding of the impact of externalities,** who pays for them, and how to integrate them into economic valuation. Examples include societal and environmental tradeoffs involving the cost of development and expansion of innovation hubs.
- **Democratization of production** is important for forming a sustainable, diverse, equitable, and inclusive bioeconomy ecosystem.
- **Science communication** is crucial, particularly across stakeholders with varying perspectives, interests, and expertise.
- **Translating science to policy** should be a component of bioeconomy ecosystem development.
- **The bioeconomy should be relatable to everyone, including diverse populations.** This is critical for shaping public perception and for advancing workforce development.

Additional suggestions for the advancement of bioeconomy ecosystems:

- **Biological systems are complex;** researchers should look for alternative ways to make bioeconomy systems more accessible to a larger group of researchers and potential startups.
- **Open tools and reliable, usable open data sets** lower the barrier of entry into the field.
- **The NSF I-Corps program** seeks to improve diversity in academic startups and has the potential for greater impact.

Session Highlights from Day 2: Translation, Value Chains, and Risk Assessment

The focus on the workshop's second day was on opportunities and challenges in the translation phase of the topics under discussion. After a presentation of a case example of a successful bioeconomy translation, the participants organized into breakout groups on the same topics explored on Day 1 to elaborate on these questions:

1. How can innovation and discovery be promoted and accelerated for an ethical scaleup?
2. How can solutions be implemented on a global scale? How do we ensure benefits are distributed broadly and equitably?
3. What are the ethical, social, behavioral, economic, and cultural issues that need to be prioritized?
4. Where are the most compelling opportunities and major challenges?
5. What policy and governance approaches will advance these goals?
6. Who are the major and minor stakeholders, and how can the public be engaged early in the process?
7. How will opposing viewpoints be engaged and accommodated?

CASE STUDY IN TRANSLATION

HudsonAlpha Institute for Biotechnology

Mary Shirley-Howell, Director of Business Recruitment, HudsonAlpha Institute for Biotechnology
Rick Myers, President and Science Director, HudsonAlpha Institute for Biotechnology
Darrell Ezell, Director of Diversity, Equity, and Inclusion, HudsonAlpha Institute for Biotechnology
Neil Lamb, Vice President for Educational Outreach, HudsonAlpha Institute for Biotechnology
Peggy Sammon, CEO, and co-founder, GeneCapture.

Highlight

HudsonAlpha Institute for Biotechnology (HudsonAlpha) serves Huntsville, Ala., and the surrounding region, creating opportunities for collaboration for genomic services and generating economic and societal impact for local, state, and regional stakeholders.

Background

With more than 35 years of experience in human genetics, including playing a role in the Human Genome Project, Rick Myers and his partners Jim Hudson and Lonnie McMillan developed the concept of an institute with interlinked biotech companies on the same campus. HudsonAlpha began with five companies in 2008.

HudsonAlpha is located in the second largest research park in the United States. It has an internationally significant investment in long- and short-read genomic sequencers. To support the data load that comes

with these sequencers, HudsonAlpha maintains a high-performance computing capability. It has 152 acres of space, including four buildings with approximately 500,000 square feet of mixed office and lab space.

Huntsville is also the location of the NASA Marshall Space Flight Center and Redstone Arsenal. HudsonAlpha is proximate to several universities, including two historically black universities (HBCUs), Alabama A&M and Oakwood University; a community and technical college, Drake State Community College; and the University of Alabama, Huntsville. The company was founded by successful serial entrepreneurs in telecom and genomic sequencing who focused on establishing an institute to move research from bench to market by building the workforce, educating the public about the emerging field, and supporting companies that want to bring solutions to the marketplace. Hudson-Alpha contributed $750 million over the past two years to the Alabama economy.[3]

Enabling Entrepreneurship

Peggy Sammons is the founder of Gene Capture, a HudsonAlpha-associated company. She discussed entrepreneurship and her work in three areas: clustering in the institute, perception of the institute, and networking with associations, businesses, and academia.

There is value to clustering for bioeconomics by emphasizing academic research, growing jobs, and bringing products to market. Co-location for research is valuable; company startups need technology, teamwork, capital, and a very clear pathway to market. The ability to share resources for these needs with others in the institute accelerates learning while providing inspiration and encouragement.

Positive public perception of the company attracts new employees and investors, including those graduating from local universities and community colleges. HudsonAlpha's internship program, Biotrain, is helpful for hiring employees with lab skills.

Long-term vision and a strong network are critical for success; Alabama recently launched an innovation coalition to meet this need. Collaboration with trade associations and local, regional, national, and international universities are crucial.

Education Programs

Biotrain began shortly after the institute opened. Between 45 and 50 undergraduate students participate each summer, working in the genomic research labs and with associated biotechnology companies as well as in supportive teams in communications, education, economic development, and business development. Students get exposure to multiple career fields with all programs under one roof.

To reduce barriers in education, the institute provides transportation and pays for classroom substitutes so teachers can participate in workshops. The company offers online games and apps to help students understand the field of genomics and how the concepts apply in the real world.

The HudsonAlpha education team also provides context for individuals to make informed decisions about genomically-related topics such as health care, agriculture, and energy.

Focus Areas and Synergies

Myers said that public-private partnership is an important aspect of the business. The company works with researchers who have university appointments. HudsonAlpha focuses on human health and disease, as well as agriculture genetics, and promotes a combination of curiosity-driven, discovery-based science with real-world applications.

Diversity, Equity, and Inclusion

HudsonAlpha leverages external community perspectives and partners for initiatives with associate companies, education outreach programs, business development, and academic and genomic research entities. The company established a diversity roadmap and relies on input from members of the community, its board and scientific advisory committee, and workforce participants to understand barriers to entry. HudsonAlpha advanced diversity partnerships with 11 HBCUs across Alabama. It also hosts publicly accessible informational webinars.

Facilitated Breakout Sessions

Responsible and Ethical Scaling-Up

Both stakeholder engagements early in the scaleup and human-centered design are important factors in developing a successful bioeconomy ecosystem. Diverse governance and engagement strategies should be an integral component of scaling up.

Key Takeaways

Build infrastructure and engagement. Scaling up requires infrastructure to support broad-based relationships in the bioeconomy ecosystem, including multi-disciplinary teams within universities, university-entrepreneur relationships, and community stakeholders. There should be multiple nodes for engagement to support distributed capabilities and vertical engagement. To achieve this, investment is needed in technology transfer models and basic science, particularly at the early stages.

Engage stakeholders early. Before scaling, it is important to have an inclusive agenda with a human-centered design process. This agenda should allow diverse stakeholders to be involved in establishing the type of bioeconomy they want to create and identifying who will benefit. Those beneficiaries' perspectives should be included, from planning through scaleup. This stakeholder involvement should go beyond basic consumer acceptance of new technologies.

Include varying perspectives and governance. Alternative governance and engagement strategies should be developed to address several important issues:

- Broadening access to bioeconomy data, instrumentation, and knowledge;
- Reconsidering regulation of intellectual property and material transfer;
- Protecting and safeguarding a virtuous bioeconomy;
- Incorporating diverse perspectives on the rights to biological resources; and
- Integration of ethical standards and methods.

Value Chain and Markets

Bioeconomy contributes to both economy and society across the value chain. Societal context within the value chain should be embedded in bioeconomy valuation. Social, behavioral, and economic sciences have the potential to contribute meaningful and effective perspectives and solutions along each step of the value chain.

Key Takeaways

Define value. A definition of value should incorporate contributions to both the economy and society. Engaging companies with more diverse communities, such as underrepresented groups or rural communities, and considering diversity, equity, and inclusion in developing the bioeconomy workforce are potential channels to achieve value to the society through the bioeconomy.

Embed trust and communication with social, behavioral, and economic sciences. Trust and communication require ongoing engagement, relationships, and investment. There is a need to better understand best practices in identifying assumptions and developing an ethical roadmap that engages community priorities while considering the regulatory environment. Social, behavioral, and economic sciences can contribute substantially along the value chain by examining existing paradigms that support or inhibit engagement, potential barriers, and unintended consequences.

Provide social context. Innovation occurs in different social contexts, and those influence the effectiveness of solutions. Social contexts should be considered along the value chain. Engaging companies and stakeholders is important to ensure value is accomplished within the bioeconomy ecosystem.

Risk Assessment

Ecosystems should develop high-level strategies for a dynamic and sustainable bioeconomy by evaluating the landscape and planning for short-, medium-, and long-term risks. Barriers to translation are an important component of risk assessment.

Key Takeaways

Be strategic. Set goals and objectives, determine the expectations for the bioeconomy, and differentiate between the goals and objectives for medical, agriculture, and emerging biotechnologies. A high-level strategy should encompass a dynamic and sustainable bioeconomy structure by considering the optimal speed and scales of efforts, defining success, and anticipating unintended consequences, both locally and globally.

Consider high-level risks. Risks should be considered based on appropriate time frames. In the near term, it is important to effectively communicate goals and benefits and to engage stakeholders by considering the disparity in definitions, perceptions, competing interests, and priorities. In the medium term, the emphasis should be on stakeholder involvement, democratization of interest, and the ability to accelerate and sustain efforts. For the long term, track the size and shape of bioeconomy trends by agencies, monitor the trends over time, and adjust goals and objectives as needed.

Understand barriers to translation. In terms of technology, it is important for society to understand the point of entry to the bioeconomy, IP and licensing rights, and the different protocols for sharing rights relative to academia and industry. Regulatory implications must be considered as well. Infrastructure is a crucial component of translation, including wet lab space availability, the presence and participation of anchor companies, and implications for scaling locally, regionally, or globally. Capital access is critical for translating basic science to the bioeconomy sector, and a diverse, prepared workforce is critical.

Implementation and Adaptive Management

Research on the bioeconomy should build on team science when appropriate. Stakeholder engagement—through multiple channels early in the process—and high-quality communication of the implications of the science to society are important in developing and sustaining a successful bioeconomy ecosystem.

Key Takeaways

Communicate well. High-quality communication at every level helps more people understand the value of the bioeconomy and drives future innovation. Multiple channels should be leveraged to ensure that science is communicated well, so the public understands the contributions of the bioeconomy to society's health and growth.

Enable inclusive stakeholder engagement. It is crucial to include a broad range of stakeholders, beginning at the very early stage of project development. Case studies on initiatives that cultivate diverse stakeholder engagement to drive their mission can inform future efforts. Research on stakeholder engagement should be promoted to facilitate fruitful collaboration. Community outreach and education, including studies on staffing and supporting the research team, are important to enable meaningful and impactful programs.

Leverage team science. Research on the bioeconomy should integrate the knowledge from team science to accelerate scientific research. There should be thoughtful development of metrics to measure progress and impact, as these metrics affect behaviors and outcomes.

Concluding Group Discussion

At the end of Day 2, participants joined a session to discuss the key takeaways from each breakout group and for concluding remarks.

Setting Goals and Objectives

- **Consider the differences among medical, agriculture, and new emerging biotechnologies**, as well as the areas that intersect among these fields.
- **Set a high-level strategy** for a dynamic and sustainable bioeconomy structure. It will be useful to investigate the strategies other countries employ that have advanced faster than the United States.
- **The United States may prefer to take a different approach** to advancing the bioeconomy than other countries and to explore different avenues. Past performance in this country does not guarantee future relative success, and new approaches should be considered.
- **Understand the optimal speed and scale of efforts,** how success is measured, and how to mitigate unintended consequences locally and globally.

Overarching Gaps and Prospects

In terms of research on social, behavioral, and economic sciences, and interdisciplinary research:

- **Critically examine existing paradigms that support or inhibit engagement** and develop solutions that will be valuable in the bioeconomy. Incorporating the range of social, behavioral, and economic science fields can benefit the development of a successful and sustainable bioeconomy ecosystem.
- **Interdisciplinary research relations take time to develop.** Fellowship programs are useful to foster interdisciplinary research by bringing together people to learn about other disciplines, form new research programs, and start new companies.
- **Social scientists can contribute to meaningful and effective** solutions as innovation in the bioeconomy should consider the social context.
- **Strong collaboration is needed** across different social, behavioral, and economic science areas as well as with natural sciences and engineering to advance research on the bioeconomy.

Considering the value chain:

- **Examine different social contexts.** As innovation in the bioeconomy occurs in various contexts that influence the effectiveness of solutions, these contexts should be considered along the value chain. This will increase value throughout.
- **Engage with companies that want to develop relations with more diverse communities.** The value for companies and society begins to align with these interactions that advance diversity, equity, and inclusion.
- **Engage underrepresented groups and specific communities, such as those in rural areas.** This is crucial for creating a sustainable, diverse, inclusive, and equitable value chain.
- **Start with the stakes rather than the stakeholder.** To understand the value of the bioeconomy for society, it is useful to start with the stakes themselves by exploring who benefits and how and by understanding the unintended consequences.

Considering trust and communication:

- **Consider communication strategies** and best practices such as identifying assumptions, defining terms for shared understanding, and developing an ethical roadmap by engaging the priorities of communities.
- **Trust and communication require ongoing engagement, relationships, and investment.**
- **Understand the regulatory environment,** which can set the ethical boundaries for innovation and is important for developing trust.

In terms of technology and regulation:

- **Regulation may mitigate risk** but also may **create negative perceptions.**
- **Research protocols in academia and industry may be better aligned** to advance research and translation.

- Technology ownership and licensing beyond the local ecosystem can have a big impact on the development of the bioeconomy ecosystem.

Conclusion and Charge for Action

The workshop aimed to explore key issues in developing a sustainable bioeconomy ecosystem by incorporating social, behavioral, and economic underpinnings. This exploration is needed to foster innovation and entrepreneurship and to create economic and societal value by considering societal implications and potential unintended consequences. The workshop further considered regional development, stakeholder engagement, and diversity, equity, and inclusion within this framework.

Several major takeaways developed. First, developing a definition for "bioeconomy" poses both a challenge and an opportunity. Different regions and ecosystems may define more narrow objectives within a larger framework and then develop corresponding metrics. Second, social, behavioral, and economic sciences should be an integral component of bioeconomy development, and social science collaboration with natural science and engineering should be fostered through multiple initiatives. Third, for a successful bioeconomy, stakeholder engagement, communication, and interdisciplinary collaborations are essential. Furthermore, different perceptions and organizational structures should be considered in developing strategies to foster bioeconomy ecosystems. Fourth, diversity, equity, and inclusion should be incorporated at each stage of development and prioritized to enable a pathway for a vibrant workforce with an entrepreneurial mindset. Investing in education within a broader framework, including community colleges is crucial. Fifth, translational challenges, including intellectual property rights, regulations, access to capital, and access to infrastructure, should be considered. Finally, investment in infrastructure to enable access and innovation in bioeconomy ecosystems should be promoted.

Appendix A:
Review of the Bioeconomy and Society Research Landscape

A Social Scientific View of the Bioeconomy: The Research Landscape

Executive Summary

The executive summary presented herein summarizes preliminary data presented by Elsevier on January 11th, 2022, at the UIDP's NSF-supported workshop, Emerging Bioeconomies: Ecosystems and Society.

This work was commissioned to provide insight into global bioeconomy research pertaining to societal, economic, behavioral, and regulatory issues. The analyses will endeavor to provide insight into how much research has been done, who the global leaders in the research areas are, what sectors are leading the research, and how the research is being used to support other research and innovations. Approach and Key Results

Scope

Bibliometric analyses were based on peer-reviewed publications (articles, reviews, and conference papers) and focused on the period 2001¬–2020. The source for all bibliometric data was the Scopus database. Scopus includes data and linkages across 83 million items from 80 thousand affiliations and 17 million authors. It is the largest curated abstract and citation database of peer-reviewed literature and provides a comprehensive view of the research landscape.

Defining the research area

The query for defining this research was developed using information provided in the workshop framing document on the key themes considered for the workshop. The terms used to search publication titles, abstracts, and keyword text were extensive and account for a large spectrum of social science research that plays a role in understanding and designing a successful and sustainable bioeconomy system, including but not limited to the bioeconomy, agronomy, biopharma, and other terms and combinations of terms. This publication set was then focused on only those publications pertaining to societal, economic, behavioral, and regulatory issues on the bioeconomy using journal classifications and terms, resulting in a final publication set of inherently interdisciplinary papers.

It should be noted that the approach taken to identify social science research on the bioeconomy (SBE) is one that is provisional and not definitive. The definition of SBE that was used to identify relevant research, and thus the papers included in the analyses, were determined by the creation and application of multi-factor, multi-term queries. Research areas—particularly multidisciplinary ones such as SBE—have fuzzy edges and may be defined more narrowly or more broadly by individual scholars or groups of experts. Nonetheless, we believe that the set of papers gathered by the query is a good representation of the research area overall.

Results

Over the past 20 years, global research on SBE has been growing at a rapid pace (Figure 1). The compound annual growth rate of SBE publications was 11.2% over the years 2001–2020, which is more than double the compound annual growth rate of 5.1% observed for all publications. Over the past two decades, SBE publications have grown to represent 0.31% of all research in 2020, up from 0.11% of all research in 2001. Growth has been particularly high over the past five years; 43% of the 93,284 SBE publications since 2001 were published between 2016 and 2020.

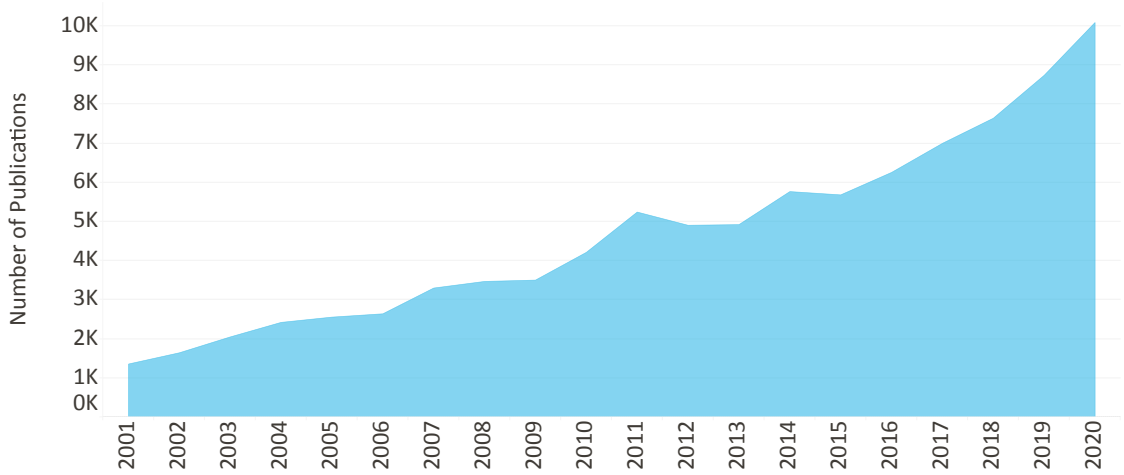

Figure 1 | Number of SBE publications, 2001–2020. Source: Scopus data

Growth in SBE publication output has been driven by continued focus on the research area from many European countries, as well as an increase in publications from China, India, and, to a lesser extent, Brazil (Figure 2). The EU displayed the largest output volume between 2001 and 2020 (approximately 7,000 publications in total from EU-27, which excludes the United Kingdom), with the EU-27 publishing over 3,000 publications in 2020 alone. China's research output in SBE is now second to the EU's research output in SBE, with almost 2,000 publications in 2020. It is notable that, while the United States used to be a major contributor to the research area, U.S. publications in this research area have plateaued since 2011, while those of other countries have continued to increase. If such trends remain in the coming years, it is expected that India's output in SBE will surpass that of the United States.

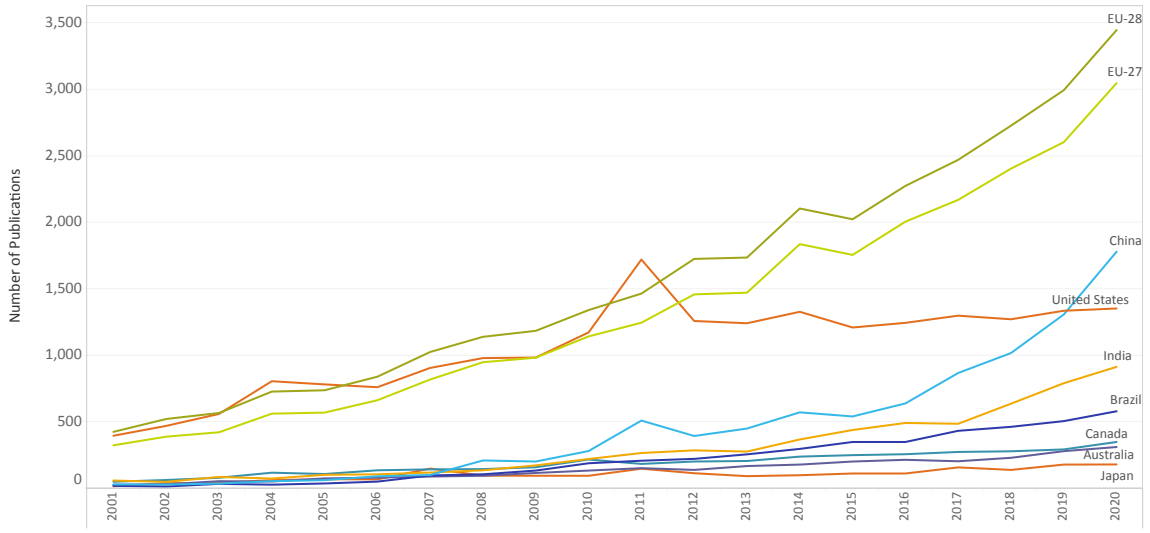

Figure 2 | Number of SBE publications by region/country, 2001–2020. Source: Scopus data

In terms of research priorities and efforts over the past two decades, the EU-27, the United States, and several other countries have each dedicated a similar proportion of their research portfolio to SBE research from 2001 to 2020, with research in this area accounting for roughly 0.25% of each country's total output (Figure 3, green data points). In contrast, among the top regions publishing SBE research over the past two decades, the emerging research nation Brazil stands out by dedicating over 0.4 % of its research portfolio to SBE research, highlighting the importance of societal issues related to the bioeconomy in influencing the research portfolio in these countries. India and the Netherlands are two other countries dedicating a greater share of their research portfolio to SBE research.

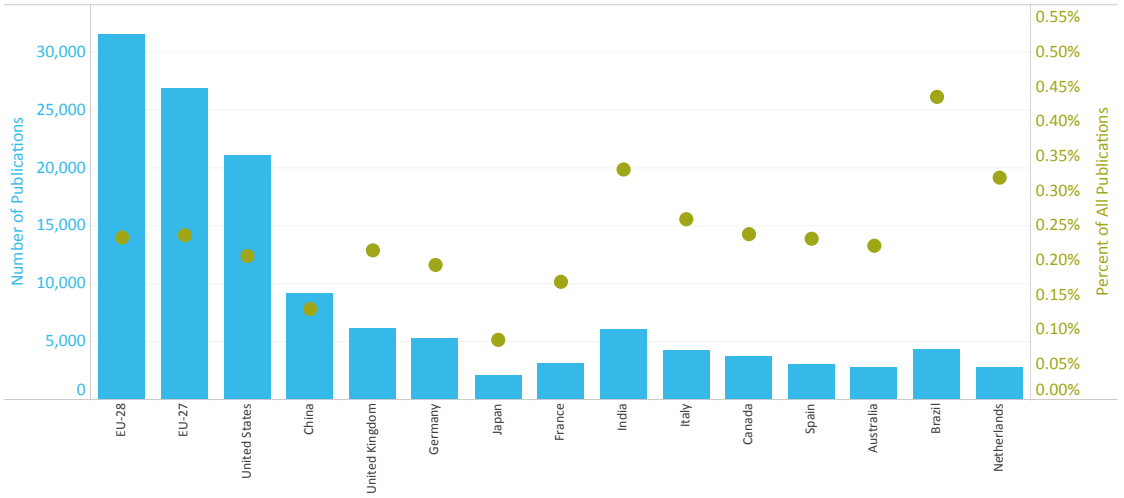

Figure 3 | Overall number of SBE research publications (blue bars) and percent of the regional/country research portfolio represented by SBE research (green dots), 2001–2020.

One way of looking into the type of scientific research underlying the field of SBE in the United States and globally is by topic modeling global research using citation pattern-based clustering methods. This involves clustering publications into sets based on citation patterns. The resulting topics provide a more granular perspective of research communities and can identify research areas with common intellectual interests, even if they are interdisciplinary. In addition to providing a granular perspective on research, topics also provide insight into the popularity of research through the prominence score, a metric calculated for each topic that is based on recent trends in citations to the papers in the topic, the relative frequency with which the publications were viewed in Scopus, and the CiteScore of the journals that the research is being published in. This prominence score can be broadly described as an analog for the current momentum of the topic, including the level of funding and underlying publication trends over time, and is used to identify growing areas of research.[4,5]

Table 1 shows the seven topics that are most highly represented in the field of SBE worldwide. Topics are named after the three of the most frequent terms among publications in the topic, considering the frequency in other topics as well as other topics' most frequent terms, and do not necessarily represent the breadth and depth of the publications included.

The topics most highly represented in the field of SBE vary greatly with respect to their prominence trends between 2016 and 2020. Two of the topics have maintained a stable momentum since 2015 (Table 1, yellow topics). Of interest, two topics have experienced positive trends (Table 1, green topics), indicating that they represent growing areas of interest. These topics are biorefining, cogeneration system, value-added product and biorefining, bioenergy, and circular economy. The United States has contributed to 30.5% and 12.2% of publications on these topics, respectively. However, looking at the prominence score trends between 2016 and 2020, and the percent change in prominence percentile, it appears that three of the seven research topics are losing momentum (Table 1, red topics). Among the topics that are most highly represented, the United States contributed the most to one topic by far: Renewable Energy Directive, Agricultural Price, Biodiesel (U.S. contribution represents 41.6% of global publication output). This was followed by Techno-Economic Analysis; Jet Engine Fuel; Hydrothermal Liquefaction (U.S. contribution represents 47.8% of global publication output). However, both topics have declined in prominence over the 2016–2020 period, with a 1.7% decrease in prominence percentile for the former and a 27.4% decrease in prominence percentile for the latter.

Topic	World Pubs	US Pubs	US Pub Share	Prominence Trend	% change in Prominence Percentile
Biorefining | Cogeneration System | Value-Added Product	87	9	10.3%		12.3%
Biorefining | Bioenergy | Circular Economy	456	50	11.0%		9.6%
Renewable Energy Directive | Agricultural Price | Biodiesel	2,254	938	41.6%		-1.7%
Biotechnology | Regional Innovation System | New Product Introduction	132	39	29.5%		-2.0%
Social Inclusion | Castor Bean | Biodiesel	192	23	12.0%		-12.8%
Techno-Economic Analyse | Jet Engine Fuel | Hydrothermal Liquefaction	113	54	47.8%		-27.4%
Punjab | Pesticide Industry | Biotech	53	11	20.8%		-99.1%

Table 1 | Topics of Prominence represented in SBE literature, 2001–2020. Prominence trend and percent change are shown for 2016–2020. Source: Scopus data

Cross-sectoral collaboration in SBE

Table 2 illustrates the share of SBE research conducted by each sector, while Figure 4 illustrates the share of SBE research conducted by different sectors, both by a single sector and at the intersection of multiple sectors. The data show that just over half of all publications in the field of SBE resulted from efforts of academic institutions alone, while approximately 30% of all publications resulted from cross-sectoral collaboration that included academic institutions with some combination of governmental institutions, non-governmental organizations (NGOs), or corporate entities. Corporate entities contributed the least to SBE research, contributing only 6%.

Sector	Percent of SBE publications to which the sector contributes
Academic	82%
Government	22%
NGO	28%
Corporate	6%

Table 2 | Percent of U.S. SBE research publications to which each sector contributes (contribution is based on representation in the author byline), 2016-2020. Source: Scopus data

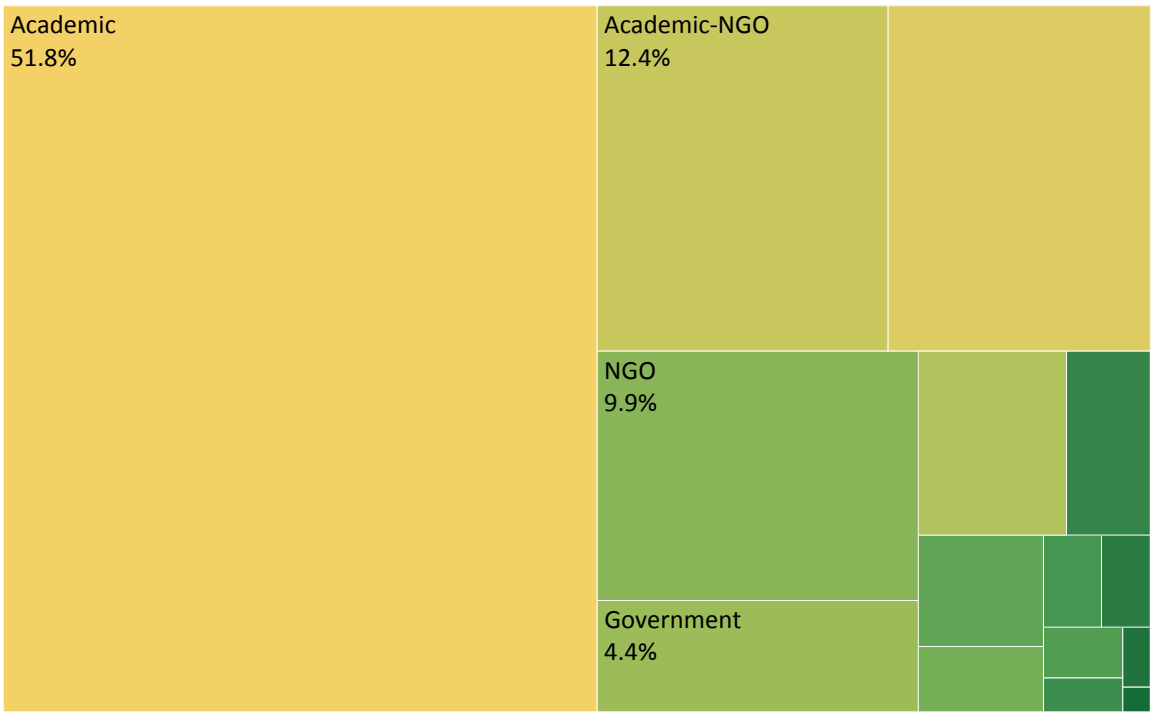

Figure 4 | Cross-sectoral collaboration in research on SBE, 2016–2020. Source: Scopus data

In the United States, several institutions appear key in the community of SBE research (Figure 5). The network analysis shows that the top two governmental organizations in terms of output, the U.S. Department of Agriculture (USDA) and the U.S. Department of Energy (DOE), are central to the network. From 2016 to 2020, these federal agencies have contributed to more publications in SBE than any single university. The DOE is strongly connected to several academic institutions and many other governmental institutions. Its strongest academic links are with the University of Wisconsin-Madison and the University of California at Berkley, and its strongest governmental links are with the federally funded research and development centers (FFRDCs) of Lawrence Berkeley National Laboratory and the Argonne National Laboratory. The USDA is mainly connected to several academic institutions and fewer governmental institutions compared to the U.S. Department of Energy, with its strongest connections to the University of Illinois at Urbana-Champaign and the University of Minnesota Twin Cities. The University of Wisconsin-Madison is strongly connected to both the DOE and the USDA. Other highly connected institutions in the network include Harvard University and the University of California at Los Angeles.

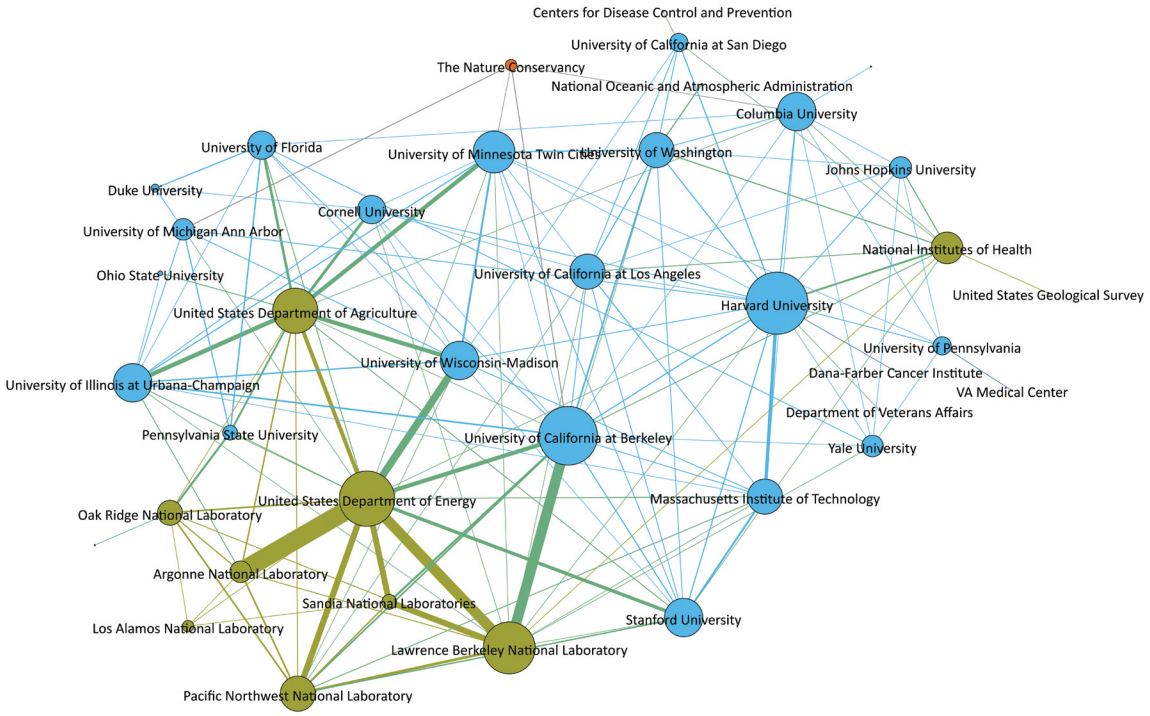

Figure 5 | Network collaboration map based on the U.S. institutions in each sector (academic, government, and NGO), according to their output in SBE research from 2016–2020. The map is limited to institutions that have published at least two publications in collaboration with at least two other institutions. Academic institutions are shown in blue; governmental institutions are shown in green; NGOs are shown in orange. Circle size represents publication output during the period 2016–2020 and the thickness of connecting lines represents the number of publications co-authored by the connected institutions. Source: Scopus data

It should be noted that the DOE and individual DOE labs are an important part of this network, in part because some DOE-assigned publications may be published by multiple labs, and in part because the lab is sometimes not attributed in the publication and is assigned to DOE. It's also notable that the Nature Conservancy is one of the top institutions here, the only non-academic and non-governmental institution.

Additionally, although publications in SBE research involving the private sector accounted for 6% of all U.S. research in this field from 2016–2020, no corporate institutions were tied to the network map (Figure 5), indicating that corporate entities were not connected to two or more institutions in the network by at least two collaborative publications. Similarly, NGOs accounted for 28% of all U.S. research in this field from 2016–2020 but are only represented once (by the Nature Conservancy) on the network map. Data indicating the contributions of institutions across sectors in the United States to SBE publications from the full 2001–2020 period is indicated in tables available in the full Elsevier research intelligence report on the UIDP website.

Categorization of global SBE research

Among publications on SBE, four key categories were identified by UIDP that reflect different clusters of society-related issues, as follows:

- Bioeconomy ecosystem and innovation hubs
- Societal challenges and opportunities in bioeconomy
- Regional and geographic considerations in the bioeconomy
- Diversity, equity, and inclusion in bioeconomy

Note that these categories are not mutually exclusive, so publications may be classified into more than one category. This is particularly true for the second and third clusters, which both involve behavioral, social, and economic research on the bioeconomy, and therefore have publications included in both of their publication sets. The trends in output for each category show that the number of publications in the United States has increased at different rates over the past two decades (Figure 6). These trends reveal a shift in SBE research. Research on societal challenges and opportunities, as well as research on regional and geographic considerations in the bioeconomy, have grown exponentially over the past two decades, while the other two categories have remained stagnant.

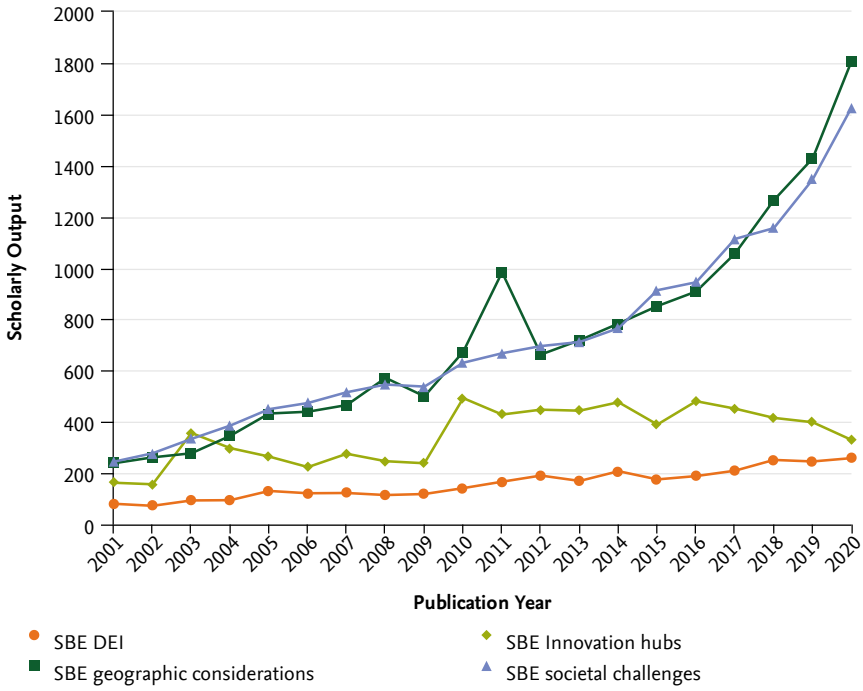

Figure 6 | Annual number of publications among U.S. SBE research subcategories, 2001–2020.Source: Scopus data

The subcategories also vary in attention and uptake. Figure 7 looks at two metrics—one that reflects how much the research is cited (using FWCI), and another based on how much the research is viewed (using field weighted views impact, or FWVI, a normalized value reflecting a publication's views on Scopus). Mapping the four subcategories of interest reveals that research on innovation hubs is somewhat of an outlier, as this research is not cited nor viewed as much as the other subcategories. This kind of information can form the basis of policies to increase the uptake and visibility of certain research areas.

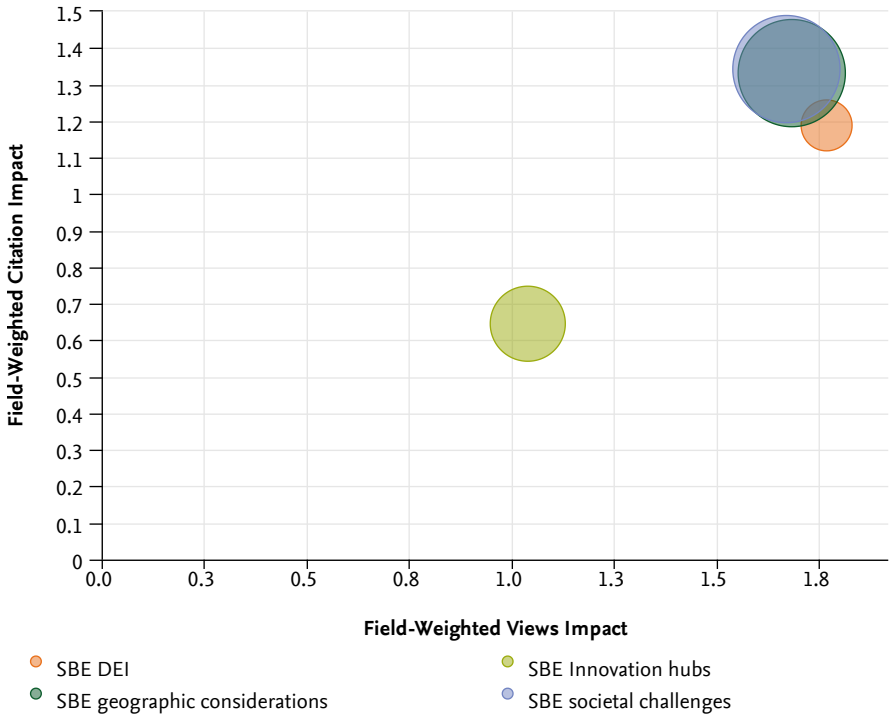

Figure 7 | Field-weighted citation impact (FWCI) and field-weighted views impact (FWVI) for U.S. research in SBE subcategories, 2001–2020. Source: Scopus data

Conclusion

Over the past two decades, global research focused on society and the bioeconomy (SBE) has grown rapidly, with 93,284 research publications produced globally over the period 2001–2020. Since 2001, global research output focused on SBE grew at a compound annual growth rate of 11.2%, outpacing the compound annual growth rate of overall global research output by over 6 percentage points. Between 2001 and 2011, the United States was neck-in-neck with the European Union on research in this field, with constant growth in output and similar output volume as the European Union as a whole. Since 2011, however, the publication output of the United States has remained stable, while that of other countries continued to increase. Currently, the European Union continues to publish the most SBE research, but China is poised to become the leading country in the field if recent trends continue. The U.S. output is now comparable to that of India, an emerging leader in this field that is likely to surpass the United States in the coming years. India, the Netherlands, and Brazil dedicate a greater percentage of their research portfolio to SBE than the United States, European Union, or China, allocating approximately 0.3% or more of their research portfolio to SBE. This highlights the high priority status of research as a means of addressing societal issues related to the bioeconomy in those countries.

Since 2015, the United States largely contributed to several topics within the corpus of research on SBE. These include

- Renewable Energy Directive, Agricultural Price, Biodiesel;
- Techno-Economic Analysis, Jet Engine Fuel, Hydrothermal Liquefaction; and
- Biorefining, Bioenergy, Circular Economy.

However, these topics are not the topics with the greatest global output, and the first two have been researching areas of stagnant or declining interest over the past few years. Among the most represented topics in SBE research, only two have been areas of growing research interest worldwide: biorefining, bioenergy, circular economy and biorefining, cogeneration system value-added product. The United States' contribution to these growing topics accounted for 11.0% and 10.3% of publications, respectively.

Research dedicated to SBE spans across various sectors of activity, with academic institutions represented in approximately 51% of U.S. publications. In the United States, most notably, NGOs are active in publishing more so than other non-academic sectors. They contributed to 28% of all SBE research from 2016–2020, collaborating on 12% of the overall research with academia. In contrast, corporations contributed very little to the research, contributing to only 6% of publications on SBE.

Finally, two of the subcategories of interest within the SBE literature—societal challenges and opportunities in bioeconomy; and regional and geographic considerations in the bioeconomy—are increasing in output, while research on two other subcategories—bioeconomy ecosystem and innovation hubs; and diversity, equity, and inclusion in bioeconomy—have stagnated in output. However, all subcategories except for bioeconomy ecosystem and innovation hubs have high citation impact and views impact. This indicates that regardless of output, research in these three subcategories receives greater-than-average attention from both academics (who are citing the research in their work) and the public at large (who are viewing the research in Scopus).

Appendix B:
Bioeconomies Agenda

Tuesday, January 11, 2022

11–11:15 a.m.	**Workshop Introduction** Anthony Boccanfuso, UIDP Theresa Good, The National Science Foundation
11:15–11:45 a.m.	**Opening General Framing Session** Christy Wyskiel, Johns Hopkins University Charge to participants and research intelligence report.
11:45 a.m.–12:45 p.m.	**Review of the Current R&D Landscape** Bamini Jayabalasingham, Elsevier Daniel Calto, Elsevier Elsevier will provide findings from their review of the nation's current sustainable agriculture capabilities and benchmark against global activities.
1–2:30 p.m.	**Concurrent Breakout Sessions:** **Key Workshop Themes** Participants will be assigned to groups before the workshop. Groups will be interdisciplinary and from different industries. Each group will determine the state-of-the-art methods in each field, discuss limitations/gaps, and determine how to integrate biological and computational methods toward desired outcomes in mitigating climate change.
1–2:30 p.m.	**Bioeconomy Ecosystem and Innovation Hubs** Jennifer Ozawa, RTI International (Facilitator) Nicholas Vonortas, The George Washington University (Annotator) Bioeconomy hubs aim to spur innovation and contribute to basic science, accelerate the translation of basic science to industry, and thus lead to U.S. competitiveness and economic growth in the bioeconomy. To enable a successful innovation hub and bioeconomy ecosystem requires an understanding of how different stakeholders interact, which factors facilitate these interactions, and the opportunities and challenges faced. What factors are unique to the bioeconomy, and what can be learned from prior and ongoing efforts to spur S&T innovation in other sectors (e.g., nano- and quantum technologies)? Discussion on what metrics are appropriate to determine whether the Bioeconomy hubs are achieving the outcomes (spurring innovation, contributing to basic science, meeting societal needs, engaging in participatory, interdisciplinary collaborations, etc.) and what are the contributions of bioeconomy to labor market changes, new job creation, and training.

Tuesday, January 11, 2022

1–2:30 p.m.

Social Challenges and Opportunities in Bioeconomy
Holly Hapke, UC-Irvine (Facilitator)
Ekuadayo Shittu, The George Washington University (Annotator)

Advancement in the bioeconomy brings opportunities as well as challenges for human beings, society, and the economy. Understanding these issues is important in developing a bioeconomy ecosystem that increases welfare for human beings and society at large.

Discussion on which social, economic, and behavioral factors are important in the bioeconomy and bioeconomic research and what lessons can be learned from prior ambitious S&T development efforts at ambitious scales, e.g., the human genome project, NSF's investments in nanotechnology, and, more recently, in quantum technology. Research in the bioeconomy should incorporate similar and potentially broader societal, behavioral, economic, and other factors.

1–2:30 p.m.

Regional and Geographic Considerations in the Bioeconomy
Jacqueline Olich, RTI International (Facilitator)
Christopher Griffin, University of Arizona (Annotator)

Discussion on understanding the unique spatial and place-based features of the bioeconomy across multiple scales, including local-regional aspects; historical perspective on industrial agglomeration and innovation; potential recent technological changes such as remote working environments, labor market changes, and protecting intellectual and the spatial, economic, social, behavioral factors vital in understanding opportunities and challenges. These regional and geographic considerations include global governance and the bioeconomy, which requires cooperation across numerous governmental institutions. Government regulation, policy, and oversight affect the ability of speed with which and location in which new biotechnology products and services are adopted universally.

1–2:30 p.m.

Diversity, Equity, and Inclusion in Bioeconomy
Antwan Jones, The George Washington University (Facilitator)
Sari Mahon, UC Irvine (Annotator)

Discussion to ensure broad participation in all aspects of the biotechnology ecosystem. By developing bioeconomy hubs, we can incorporate a diversity of partners, individuals, and communities to identify potential frameworks, challenges, and strategies to ensure the full participation of underrepresented individuals in the bioeconomy in meaningful ways. By understanding potential channels to increase diversity, equity, and inclusion within the bioeconomy ecosystem will support education institutions serving underrepresented groups, economic development zones, and innovation and adoption of biotechnologies, among others.

Tuesday, January 11, 2022

3–4 p.m.	**Report Outs** Jennifer Ozawa, RTI International Nicholas Vonortas, The George Washington University Holly Hapke, UC Irvine Ekuadayo Shittu, The George Washington University Jacqueline Olich, RTI International Christopher Griffin, University of Arizona Antwan Jones, The George Washington University Sari Mahon, UC Irvine The facilitator and note-taker from each break-out group will present each group's answers to the key questions.
4–5 p.m.	**Concluding Session/Identification of Key Takeaways** Senay Agca, The George Washington University Participants will come together as a group to summarize answers from each breakout topic and identify key takeaways from Day 1.

Wednesday, January 12, 2022

11–11:30 a.m.	**Welcome and Day 1 Recap** Senay Agca, The George Washington University
11:30 a.m.–12:30 p.m.	**Translational Case Study** Mary Shirley-Howell, HudsonAlpha Institute for Biotechnology
1–2:30 p.m.	**Concurrent Breakout Sessions:** **Risk Assessment** Brian Ellerman, University of Arizona (Facilitator) Bruce Burgess, University of Arizona (Annotator) Discussion on how we can minimize the chances of unanticipated ecological, ethical, and/or negative societal impacts. Considerations of public perception of negative impacts of adopting biotechnological solutions and products and how the potential risks and costs, as well as potential negative perception, can be balanced against the potential benefits of adoption.
1–2:30 p.m.	**Responsible and Ethical Scaling-Up** Tom Milner, UC Irvine (Facilitator) Jane Zavisca, University of Arizona (Annotator) Discussion on the challenges and barriers to adoption of biotechnological solutions. Discussion on products on a scale that is sufficient to achieve global impacts. Consideration of governance and engagement strategies are needed to support and enable responsible and ethical adoption of solutions and products that work to improve conditions in the entire biotechnology ecosystem.
1–2:30 p.m.	**Implementation and Adaptive Management** Jacqueline Olich, RTI International (Facilitator) Mary O'Reilly, Flinn Foundation (Annotator) Discussion on how the effects of interventions will be evaluated; what mechanisms and metrics are needed to ensure that adoption of biotechnological solutions and products meet the intended outcomes; how social and behavior sciences inform and impact biotechnology development and knowledge; what technology and monitoring capabilities are needed to determine the efficacy of the biotechnology ecosystem; and what unique challenges are associated with unregulated and overregulated sectors of biotechnological solutions and products.
1–2:30 p.m.	**Value Chains and Markets** Sari Mahon, UC Irvine (Facilitator) Candice Chen, The George Washington University (Annotator) Discussion on how supply chains will be implemented to ensure sufficient raw materials to achieve production at a scale that advances the adoption of ethical biotechnological solutions and socially responsible products in the biotechnological ecosystem; what new products will be created, how these products should be marketed, to which populations these products should be marketed, and why.

Wednesday, January 12, 2022

3–4 p.m.	**Report Outs** Brian Ellerman, University of Arizona Bruce Burgess, University of Arizona Tom Milner, UC Irvine Jane Zavisca, University of Arizona Jacqueline Olich, RTI International Mary O'Reilly, Flinn Foundation Sari Mahon, UC Irvine Candice Chen, The George Washington University The facilitator and note-taker from each break-out group will present each group's answers to the key questions.
4–5 p.m.	**Concluding Group Discussion** Senay Agca, The George Washington University Come together as a group to summarize answers from each breakout topic and identify key takeaways from Day 2.

Appendix C: Participant List

Senay Agca, The George Washington University

Farhan Ahmad, INVISTA

Darius Alexander-Jones, Lam Research Corporation

Poonam Arora, Manhattan College

Shadi Atallah, UIUC

Emmanuel Atta-Obeng, Coppin State University

Sharmistha Bagchi-Sen, Arizona State University

Jacob Beal, Raytheon BBN Technologies

Richard Bendis, BioHealth Innovation

Bryan Berger, University of Virginia

Kean Birch, York University

Mark Brown, South Dakota School of Mines and Technology

Bruce Burgess, University of Arizona

Wolfgang Busch, Salk Institute for Biological Studies

Daniel Calto, Elsevier

Laura B. Cardinal, University of South Carolina

Alta Charo, University of Wisconsin

Candice Chen. The George Washington University

James Cotner, University of Minnesota - Twin Cities

Michael Daniele, NC State University/UNC Chapel Hill

Payman Dehghanian, The George Washington University

Wenjing Duan, The George Washington University

Cassie Edgar, McKee, Voorhees & Sease

Brian Ellerman, University of Arizona

Daniel Engebretson, University of South Dakota

Darrell Ezell, HudsonAlpha Institute for Biotechnology

Maryann Feldman, University of North Carolina-Chapel Hill

Michael Fero, TeselaGen Biotechnology, Inc.

Laura Foster, Indiana University Bloomington

George Frisvold, University of Arizona

Joel Gehman, The George Washington University

Wendy Goodson, Ginkgo Bioworks

Christopher Griffin, University of Arizona

Gigi Gronvall, Johns Hopkins Center for Health Security

Kaiyu Guan, University of Illinois at Urbana-Champaign

Teis Hansen, University of Copenhagen

Holly Hapke, UC Irvine

Brittany Hillyer, Arkansas Economic Development Commission

Andrea Hodgson, Schmidt Futures

Mignonne Hollis, Arizona Regional Economic Development Foundation

Ben Holmes, Nanochon

Erin Hopper, University of North Carolina-Chapel Hill

Ben Hurlbut, Arizona State University

Jared Hutchins, University of Illinois at Urbana-Champaign

Bamini Jayabalasingham, Elsevier

Kels Jensen, Aspire

Nancy Johnston, North Carolina Biotechnology Center

Antwan Jones, The George Washington University

Fehmida Kapadia, Kapamed Consulting

Madhu Khanna, University of Illinois at Urbana-Champaign

Katrina Knauer, NREL

Michael Koepke, LanzaTech

Jennifer Kuzma, North Carolina State University–Genetic Engineering and Society Center

Georgia Lagoudas, White House Office of Science and Technology Policy, Executive Office of the President

Hannah Landecker, UC Los Angeles

Miguel Lejeune, The George Washington University

Kathleen Liang, North Carolina A&T

Sheng Lin-Gibson, National Institute of Standards and Technology

Rob Lindberg, North Carolina Biotechnology Center

Michaele Linden Johnson, Medical Center of the Americas Foundation

Peter Lohse, Massachusetts Institute of Technology

Robert Macy, University of Nebraska at Kearney

Sari Mahon, UC Irvine

Stanley Maloy, San Diego State University

Susan Martinis, University of Illinois at Urbana-Champaign

Bill Maurer, UC Irvine

Jonathan McFadden, University of Oklahoma

Thomas Milner, Beckman Laser Institute, UC Irvine

Jenny Molloy, University of Cambridge

Bryant Moore, University of North Carolina at Chapel Hill

Steven Moss, National Academies of Sciences, Engineering, and Medicine

Pamela Norris, The George Washington University

Mary O'Reilly, Flinn Foundation

Olugbenro Ogunrinde, University of Nebraska at Kearney

Joshua OHair, Tennessee State University

Jacqueline Olich, RTI International

Jason Owen-Smith, Institute for Research on Innovation & Science (IRIS)

Jennifer Ozawa, RTI International

Nino Paichadze, The George Washington University

Megan Palmer, Stanford University

Kelly Parsons, University of North Carolina at Chapel Hill

Kim Patten, University of Arizona

Kuide Qin, Verdesian

Basheer Qolomany, University of Nebraska at Kearney

Cynthia Reifsnider, University of North Carolina at Chapel Hill

Kimberly Ritola, University of North Carolina at Chapel Hill

Jorge Rivera, The George Washington University

Michel Robe, University of Illinois at Urbana-Champaign

Sharlini Sankaran, Duke University Office of External Partnerships

Lisa Schulte Moore, Iowa State University

Mary Shirley-Howell, Hudson Alpha Institute for Biotechnology

Ekundayo Shittu, The George Washington University

Jason Shogren, University of Wyoming

Laurel Smith-Doerr, University of Massachusetts, Amherst

Emilie Snell-Rood, University of Minnesota

Katie Stebbins, Tufts University Food & Nutrition Innovation Institute

David Stern, Boyce Thompson Institute

Ye Su, Lincoln University of Missouri

Deepti Tanjore, Lawrence Berkeley National Laboratory

Pamela Templer, Boston University

Eudora Thompson, Michigan State University

Michael Travisano, University of Minnesota

Rosemarie Truman, The Center for Advancing Innovation

Thomas Tubon, BioMADE Manufacturing Innovation Institute

Mel Ustad, South Dakota EPSCoR

Nicholas Vonortas, The George Washington University

Zhiyue Wang, University of Minnesota

Toby Warden, BioMADE

Evandrew Washington, Fayetteville State University

Christy Wyskiel, Johns Hopkins University

Josh Young, Phoenix Bioinformatics

Jane Zavisca, University of Arizona

Appendix D: Workshop Observers

Mitra Basu

Wenda Bauchspies

Adrienne Cheng

Karen Cone

Steve DiFazio

Steven Ellis

Claudia Gonzalez-Vallejo

Theresa Good

Georgia Kosmopoulou

Ela Mirowski

Linda Molnar

Thyaga Nandagopal

Juliana Nazare

JD Swanson

Alan Tomkins

Lee Walker

Clifford Weil

Joseph Whitmeyer

Antoinette WinklerPrins

Appendix E:
Pre-Event Survey

We look forward to your participation in the upcoming workshop. Our goal is to identify partnership strategies for how basic research can lead to innovations that understand and support societal, economic, behavioral, and other challenges and opportunities that arise in developing a bioeconomy ecosystem.

1. Bioeconomy ecosystem and innovation hubs
2. Societal challenges and opportunities in bioeconomy
3. Regional and geographic considerations in the bioeconomy
4. Diversity, equity, and inclusion in bioeconomy.

So, our exploration of each of those theme areas is efficient and productive, we ask that you give us your feedback on the following. We also welcome your written comments below.

Please help us set the stage for the workshop by completing the survey below. Please respond by January 6, 2022.

FFor each theme below, please rate the importance of the topics for industry and academia to collaboratively expand knowledge in and remove barriers to achieving a circular bioeconomy.

Bioeconomy Ecosystem and Innovation Hubs	Not Important	Slightly Important	Moderately Important	Important	Very Important
Factors influencing stakeholder interactions	◯	◯	◯	◯	◯
Determining metrics appropriate to whether the bioeconomy institutes are achieving the desired outcomes	◯	◯	◯	◯	◯
Determining the contributions of bioeconomy to labor market changes, new job creation, and training	◯	◯	◯	◯	◯
Social, behavioral and economic factors impacting the success of the bioeconomy ecosystems and innovation hubs	◯	◯	◯	◯	◯

Societal Challenges and Opportunities in Bioeconomy	Not Important	Slightly Important	Moderately Important	Important	Very Important
Identifying which social, economic, and behavioral factors are important in the bioeconomy and bioeconomic research	◯	◯	◯	◯	◯
Lessons learned from prior ambitious S&T development efforts	◯	◯	◯	◯	◯
Incorporation of societal, behavioral, economic, and other factors involving research in the bioeconomy	◯	◯	◯	◯	◯
Societal acceptance and market adoption of advances in the bioeconomy	◯	◯	◯	◯	◯

Regional and Geographic Considerations in the Bioeconomy	Not Important	Slightly Important	Moderately Important	Important	Very Important
Understanding the unique spatial and place-based features of the bioeconomy across multiple scales including local-regional aspects; historical perspective on industrial agglomeration and innovation	◯	◯	◯	◯	◯
Recent technological changes such as remote working environments	◯	◯	◯	◯	◯
Labor market changes; protecting intellectual and the spatial, economic, social, behavioral factors vital in understanding opportunities and challenges	◯	◯	◯	◯	◯
Government regulation, policy, and oversight affecting the ability of speed and location in which new biotechnology products and services are adopted universally	◯	◯	◯	◯	◯

Diversity, Equity, and Inclusion in Bioeconomy	Not Important	Slightly Important	Moderately Important	Important	Very Important
Incorporating a diversity of partners, individuals, and communities to identify potential frameworks, challenges,and strategies to ensure the full participation of underrepresented individuals in the bioeconomy	◯	◯	◯	◯	◯
Understanding potential channels to increase diversity, equity and inclusion within the bioeconomy ecosystem	◯	◯	◯	◯	◯
Supporting education institutions serving underrepresented groups, economic development zones involving the bioeconomy	◯	◯	◯	◯	◯
Increasing the incorporation of diverse perspectives when considering societal impact from bioeconomy research outcomes	◯	◯	◯	◯	◯

Please offer any additional relevant topics or additional comments you'd like to share.

References

[1] *Congressional Research Service, 2021.*

[2] *"Innovating for Sustainable Growth - A Bioeconomy for Europe" 2012.*

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