Developing a National Measure of the Economic Contributions of the Bioeconomy

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Bureau of Economic Analysis
U.S. Department of
Commerce

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This report fulfills the requirements of Executive Order 14081, Section 10.b.i, issued September 12, 2022 (87 Fed. Reg. 56849, 56856):

> "Within 180 days of the date of this order, assessing, through the Department of Commerce's Bureau of Economic Analysis, the feasibility, scope, and costs of developing a national measurement of the economic contributions of the bioeconomy, and, in particular, the contributions of biotechnology to the bioeconomy, including recommendations and a plan for next steps regarding whether development of such a measurement should be pursued."

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Executive Summary

In recent years, interest in biotechnology, biomanufacturing, and the bioeconomy has grown steadily. Researchers in the United States and other countries have sought to measure the bioeconomy and have developed a variety of definitions and approaches for doing so. Executive Order 14081, issued September 12, 2022, directs the U.S. Bureau of Economic Analysis (BEA) to assess "the feasibility, scope, and costs of developing a national measurement of the economic contributions of the bioeconomy" (White House 2022). BEA produces measures of specialized slices of the economy through its system of satellite accounts, which provide focused insights not directly apparent in BEA's official National Income and Product Accounts (NIPAs). This report analyzes the "feasibility, scope, and costs" of developing a satellite account for the bioeconomy.

Defining the subject of interest is often the most important phase of a satellite account because it provides the overall framework for the new account and influences the goods and services chosen to be part of the resultant economic statistics. In the case of the bioeconomy, researchers, potential datausers, and other stakeholders have different (and competing) ideas of how the bioeconomy should be defined and which industries should be included or excluded. These different ideas can be summarized into three distinct visions for the bioeconomy: biotechnology, bioresources, and bioecology (National Academies of Science, Engineering, and Medicine (NASEM) 2020; Bugge, Hansen, and Klitkou 2016). The biotechnology vision focuses on emerging industries and products enabled by innovation in the life sciences, particularly in genetic engineering; in this vision, established industries such as agriculture and forestry are typically not included. The bioresources vision focuses on understanding the flow of biological resources, such as biomass and biofuels, through the economy; in this vision, the agriculture and forestry industries are included as foundational components of the bioeconomy. Finally, the bioecology vision focuses on the contributions of the bioeconomy to sustainability and the environment; this vision may specifically exclude some products or industries, such as genetically engineered crops (NASEM 2020).

This report finds that developing a comprehensive bioeconomy satellite account encompassing all concepts of the bioeconomy appears technically feasible. Such a broad approach would roughly correspond to similar efforts by the European Union (EU) and other international organizations but would not address data users' preferences for an account more focused on a specific vision of the bioeconomy. Developing a consistent, ongoing bioeconomy satellite account broken down along the lines of specific visions of the bioeconomy, such as biotechnology, is likely infeasible at this time due to both a lack of existing data on which to base such an account and a lack of consensus on practical measurement definitions.

1. Introduction

Historically, the United States has been a world leader in biotechnology and its applications. To maintain this competitiveness and to promote further growth and advancement of the U.S. bioeconomy, Executive Order 14081, on "…Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy" (White House 2022), was issued on September 12, 2022, and outlines the importance of the bioeconomy, its expected growth, and its potential environmental and security implications. The order discusses the importance of measuring the bioeconomy in laying the foundations for data-driven decisionmaking and understanding the various impacts of the bioeconomy. Understanding these impacts, and their evolution over time, requires consistent, unbiased measurement of the bioeconomy. BEA produces such measures for selected slices of the economy through its system of satellite accounts and is therefore directed by the Executive Order to assess "the feasibility, scope, and costs of developing a national measurement of the economic contributions of the bioeconomy" (White House 2022). BEA's satellite accounts, such as those for the digital economy, the marine economy, and outdoor recreation, provide focused insights that are not directly apparent in BEA's core statistical products—presented under the North American Industry Classification System (NAICS)—since economic activity for these subjects spans multiple industries. Like BEA's core statistical products, BEA satellite accounts adhere to the *System of National Accounts 2008* (*SNA 2008*), the internationally accepted standard for measuring economic activity.

Measuring the bioeconomy in a consistent and unbiased way requires an explicit, consistently applicable definition of what constitutes the bioeconomy. This definition must delineate what products and industries are considered part of the bioeconomy. For products or industries that are only partially attributable to the bioeconomy, the definition must also indicate how the bioeconomy share for these products or industries should be determined. Answering these questions poses a challenge, as many possible definitions exist in the literature.

This report will outline a broad measurement definition for the bioeconomy, guided by the language of Executive Order 14081,[1] that includes industries and products reliant on biotechnology or biomanufacturing as well as mature industries such as agriculture and forestry. These mature industries form a crucial part of the supply chain for biomass and other biological raw materials, but their sheer size could mask important trends in emerging industries. Depending on availability of funding and secondary data sources, it may be possible to develop a broadly defined satellite account for the bioeconomy. This report also outlines three competing visions (biotechnology, bioresources, and bioecology), commonly held by potential data users, for what bioeconomy measurement should focus on more narrowly.

1. As part of the whole-of-government approach outlined in Executive Order 14081, the National Institutes of Standards and Technology (NIST) led an interagency working group (which BEA participated in) to develop a lexicon defining terms related to the bioeconomy (NIST 2022). In the lexicon and executive order, the bioeconomy is defined as "economic activity derived from the life sciences, particularly in the areas of biotechnology and biomanufacturing, and includes industries, products, services, and the workforce" (White House 2022). The lexicon's purpose is to enhance communication; an operationalizable definition for economic measurement requires additional detail and specificity.

Developing a consistent, ongoing bioeconomy satellite account with a narrow focus on any of these visions is likely infeasible at this time due to both a lack of existing data on which to base such an account and a lack of consensus on practical measurement definitions. Section 2 of this report provides an overview of existing research related to the bioeconomy. Section 3 summarizes the general process of establishing an economic satellite account. Section 4 describes the potential for developing a bioeconomy satellite account, including challenges related to both data and methods. Section 5 concludes with a description of possibilities for a bioeconomy satellite account and recommendations for potential next steps.

2. Literature Review

To measure the bioeconomy, it is necessary to develop a specific, detailed, and operational definition of which industries and products are to be included. This section begins with a review of U.S.-specific work on bioeconomy definitions and measurement before reviewing selected international efforts. Then, three different (and sometimes competing) common perspectives on the bioeconomy and their implications are outlined.

2.1 U.S. Bioeconomy Measurement Efforts

2.1.1 National Academies of Science, Engineering, and Medicine

NASEM's recent report *Safeguarding the Bioeconomy* reviews the current state of the literature on bioeconomy measurement and proposes a biotechnology-centric definition of the bioeconomy: "economic activity that is driven by research and innovation in the life sciences and biotechnology, and that is enabled by technological advances" (NASEM 2020). This report constructs an estimate of the size of the bioeconomy under this definition using a NAICS-code-based classification of industries (appendix table 1). In keeping with their biotechnology-centered definition of the bioeconomy, they include only a very specific set of crop products and exclude both animal-based agriculture products and forestry. For hybrid industries, assumptions about the percentage of the industry to be allocated to the bioeconomy were made based on existing literature. *Safeguarding the Bioeconomy* estimates the bioeconomy's value added in 2016 as $402.5 billion, or 2.2 percent of gross domestic product (GDP) that year.

2.1.2 Department of Agriculture

The U.S. Department of Agriculture (USDA) conducts surveys and analyses of many aspects of the bioeconomy as related to agriculture, forestry, and resulting products. For example, the USDA Economic Research Service has a value-added statistics product that highlights the biofuel-based demand for agricultural feedstocks (Ramsey 2023) and, through the USDA's National Agricultural Statistics Service, data products related to the adoption of genetically engineered crops in the United States (Dodson 2022).

The USDA's BioPreferred Program (Golden and Handfield 2014; Golden et al. 2018) promotes biobased products. Products are defined as biobased or not according to their ratio of biobased content (generally from recently harvested biomass) to fossil-based content (generally from petroleum), as determined by chemical analysis. Biobased content can also be understood as a ratio of "new" organic carbon to "old" organic carbon. Since the focus is on product characteristics rather than production techniques, this conception of the bioeconomy is less focused on biotechnology and more focused on the movement of biological resources through the economy.

A recently updated economic impact analysis estimates that the biobased products industry directly added $150 billion to the U.S. economy in 2017, while biobased chemicals and enzymes contributed an additional $6.2 and $21.7 billion, respectively (Golden et al. 2021; Daystar et al. 2020).

A recent USDA report, *Indicators of the U.S. Biobased Economy* (Golden et al. 2021), includes biofuels and biofuel crops along with biobased products as part of the biobased economy. Indicators for biofuel crops include acres planted, total production, prices, and percentage used for biofuel production. Indicators for biofuels include production, consumption, imports, exports, and number of production facilities.

2.1.3 Department of Energy

The U.S. Department of Energy's (DOE) *2016 Billion-Ton Report* (Oak Ridge National Laboratories 2016) considers the potential availability of biomass to supply U.S. energy needs under various future scenarios, beginning with an indepth analysis of the current state of U.S. biomass supply and demand for energy uses.

DOE researchers have also constructed a harmonized time series of supply and use tables (SUTs) to analyze the direct and indirect economic and environmental impacts of corn ethanol and soybean biodiesel, and how those impacts have evolved over time (Avelino et al. 2021). Both reports are detailed but not directly applicable to the problem of measuring the whole bioeconomy, due to their restricted scope.

2.1.4 Other U.S. Bioeconomy Definition and Measurement Efforts

Robert Carlson, frequently cited by the NASEM 2020 report, defines the bioeconomy using a biotechnology-based definition—the use of genetic engineering technology (Carlson 2016). This restricted definition reduces ambiguity in definitions, but also means that he leaves out important elements of biotechnology, such as some forms of precision medicine (NASEM 2020). Carlson also proposes three specific changes to the NAICS classification system to allow for more detailed statistics on the bioeconomy: first, a new code under NAICS 3254 (pharmaceutical and medicine manufacturing) for protein- and nucleic-acid-based medications; second, one to three new codes under NAICS 325 (pharmaceutical and chemical manufacturing) to capture nonpharmaceutical bioproduction of chemicals; and third, new codes for biofuels.

A report by Schmidt Futures, *The U.S. Bioeconomy: Charting a Course for a Resilient and Competitive Future*, uses a broader biotechnology-based definition of the bioeconomy: "Economic activity that is driven by research and innovation in the life sciences and biotechnology, and that is enabled by technological advances in engineering and in computing and information sciences" (Hodgson, Alper, and Maxon 2022). Like Carlson, they recommend amending the NAICS (and North American Product Classification System (NAPCS)) classification systems to allow for easier bioeconomy data collection and measurement.

2.2 International Bioeconomy Measurement Efforts

2.2.1 European Union

Though EU countries do not have a uniform definition of the bioeconomy, a common feature is a focus on the production of biological outputs or use of biological inputs, rather than on biotechnology.[2] For instance, many EU countries consider agriculture, food, and forestry to be fully included in the bioeconomy (Kuosmanen et al. 2020).

The 2020 European Commission report *How big is the bioeconomy?* (Kuosmanen et al. 2020) describes in detail the commission's bioeconomy definition and measurement strategy. They define the bioeconomy as the set of industries (or portions of industries) that produce biological outputs or use biological inputs. For example, computers are not included in the bioeconomy, even though they are widely used by industries in the bioeconomy. For hybrid industries (only partially biobased), the percentage allocated to the bioeconomy is a weighted average of the percentage of biological inputs and the percentage of biological outputs.

2.2.2 Organisation for Economic Co-operation and Development (OECD)

OECD bioeconomy definitions have historically been biotechnology focused (OECD 2009), though a recent report observes that bioeconomy definitions have been expanding rapidly in terms of which industries are included (OECD 2018), reflecting a shift—particularly in the EU—away from a narrow focus on biotechnology and toward a broader view that commonly includes mature industries such as agriculture and forestry. OECD currently collects data on firms engaged in biotechnology, including their research and development (R&D) spending and number of biotechnology patents (OECD 2021).

The OECD report *Meeting Policy Challenges for a Sustainable Bioeconomy* states that the bioeconomy forms a link between economic growth and the environment, while noting that environmental benefits from a bioeconomy transition cannot simply be assumed, and that estimates of the environmental impacts of the bioeconomy vary greatly (OECD 2018).

If a biotechnology-focused definition of the bioeconomy is to be used for a bioeconomy measurement time series, it will be necessary to measure and understand the development and obsolescence of biotechnology innovations. The OECD *Oslo Manual* discusses ways to measure innovation (not specific to the bioeconomy) and stresses that innovation is not a process that necessarily involves R&D, recognizing the existence of organizational, marketing, and service innovations. It also stresses that innovation requires implementation, not just discovery. The *Oslo Manual* recommends the use of surveys for data collection. It says little about obsolescence, except that it could be useful to collect survey data on obsolescence of technologies as well (OECD 2018).

2. Note that attitudes in the EU may be less favorable toward the use of genetically engineered organisms in agriculture (Woźniak, Tyczewska, and Twardowski 2021). For instance, many EU countries have regulations banning the growth of genetically modified organism crops (European Commission 2015).

2.2.3 Canada

Statistics Canada periodically measures Canadian production of bioproducts, defined as "'non-conventional products produced from biomass with the goal of commercialization." They conduct a special census of firms identified as producers of bioproducts and measure such statistics as sales of bioproducts, purchases of biomass as inputs to bioproducts, and R&D spending by bioproduct firms (Rancourt, Neumeyer, and Zou 2017).

2.2.4 Other International Bioeconomy Definition and Measurement Efforts

Other international organizations involved in efforts to define and quantify the bioeconomy include the Japanese Bioindustry Association, the Bioeconomy Corporation in Malaysia, and the Science and Innovation Department in South Africa. These three countries take a broad approach to defining the bioeconomy, especially in relation to health care. In addition to health care areas commonly associated with the bioeconomy, such as genetic treatments, Japan also considers lifestyle-improvement-focused health care and digital health to be part of the bioeconomy (Japanese Bioindustry Association 2020). Malaysia and South Africa include all health care as part of the bioeconomy, aligning with the view that the "bioeconomy encompasses all industries and economic sectors that produce, manage and utilise biological resources" (Malaysian Bioeconomy Development Corporation 2022; NASEM 2020).

Researchers with Bolsa de Cereales, in Argentina, also take a broad approach, defining the bioeconomy as all industries using biological or biotechnological inputs. In addition to including agriculture and forestry, these researchers include the production of food as well as pulp and paper in the bioeconomy. Using this broad definition, they construct a bioeconomy satellite account for Argentina based on guidance from the System of National Accounts (Wierny et al. 2015). Researchers in Colombia measure the bioeconomy using an input-output (I-O) table-based approach very similar to that described for the EU in Kuosmanen et al. (Alviar et al. 2021).

McKinsey Global Institute recently released a report—*The Bio Revolution*—that estimates the possible future global economic impact of biotechnology (Chui et al. 2020). Their methodology is based on estimating the impact of each of about 130 categories of biotechnology application. Estimates of consumer surplus, including health and environmental benefits, are included in their measure of economic impact, making their estimates not directly comparable with BEA's statistics, which represent market-based economic production.

2.3 Visions for the Bioeconomy

There is a clear lack of consensus in the existing bioeconomy measurement literature on which industries and products should be considered part of the bioeconomy. This can be explained in part by the existence of three distinct visions for the bioeconomy and its role: biotechnology, bioresources, and bioecology (NASEM 2020; Bugge, Hansen, and Klitkou 2016; Bracco et al. 2018). These three visions have different primary objectives. These objectives—and some implications—are summarized in table 1 and discussed below (for more detail, see Bugge, Hansen, & Klitkou, 2016).

Table 1. Key Characteristics of the Bioeconomy Visions

Adapted from Bugge, Hansen, and Klitkou 2016

	Biotechnology	*Bioresources*	*Bioecology*
Aims and objectives	Economic growth and job creation	Economic growth and sustainability	Sustainability, biodiversity, ecosystem conservation
Value creation	Application of biotechnology, commercialization of research and technology	Conversion and upgrading of bioresources (process oriented)	Development of integrated production systems and high-quality products with territorial identity
Criteria for inclusion	Products or processes enabled by innovation in the life sciences	Products composed wholly or in large part of biomass. Processes using biomass as significant inputs or that are biological in nature.	Sustainable processes and sustainably sourced products
Spatial focus	Global clusters/central regions	Rural/peripheral regions	Rural/peripheral regions

2.3.1 Biotechnology

The most common vision for the bioeconomy in the United States has historically been the biotechnology vision, due in part to historic U.S. leadership in the biotechnology field (NASEM 2020). This vision is based on innovations in the life sciences (sometimes with an explicit focus on genetic engineering technology) and the commercial and industrial applications of these innovations (Bugge, Hansen, and Klitkou 2016; Carlson 2016).

Major industries using biotechnology include agriculture, medicine, and biomanufacturing (NASEM 2020). Each of these are “hybrid” industries from a biotechnology perspective, with establishments using methods all along the spectrum from traditional to cutting-edge technological. A precise definition of what constitutes “innovation” and “technology” is therefore necessary for measurement.

Constructing a time series of bioeconomy measurements using a biotechnology vision would require determining criteria for what constitutes innovation and estimating the extent to which innovations have come into use in different industries, as well as determining criteria for when an innovation is no longer considered innovative.

2.3.2 Bioresources

The bioresources vision of the bioeconomy focuses on the use of biological raw materials, biomanufacturing, and the formation of new biologically based supply chains in place of existing (often petroleum based) supply chains (Bugge, Hansen, and Klitkou 2016); it may not include, for example, biotech R&D or health care. This is the most common bioeconomy vision used in Europe.

Bioresources play a fundamental role in the circular economy (Sherwood 2020), though the two are separate and distinct. Sustainability is a secondary aim of the bioresources vision and is often assumed to be an inherent feature of bioresources. However, not all bioresources are sustainable (Pfau et al. 2014).

Large, mature industries (such as agriculture and forestry) and smaller, emerging industries (often, if not always, biotechnology enabled) are both part of the bioresources vision. If these are aggregated together, trends or new developments in emerging industries may be swamped by trends in the mature industries. For this reason, some authors consider emerging industries and/or biotechnology-enabled portions of mature industries as elements of the bioeconomy, but not other portions of mature industries (NASEM 2020).

Biomanufacturing and biologically based supply chains, with their potential security considerations, are a primary focus of the Executive Order on Advancing Biotechnology and Biomanufacturing Innovation (White House 2022).

Measuring the bioeconomy according to a bioresources vision and including industries such as agriculture and forestry would allow for greater comparability with European bioeconomy accounts. However, if these are included, they could mask developments in smaller, emerging industries.

2.3.3 Bioecology

The bioecology vision for the bioeconomy focuses on ecological processes and sustainability, which tend to be secondary concerns under the bioresources vision and are often neglected under the biotechnology vision (Bugge, Hansen, and Klitkou 2016). It is closely related to both the circular economy (Tan and Lamers 2021) and natural capital accounting (Neil, O'Donoghue, and Stout 2020), though is distinct from both. In common with natural capital accounting, but unlike the other two visions for the bioeconomy, the bioecology vision may extend outside the traditional boundary of the economy to include measures such as species diversity and soil quality.[3]

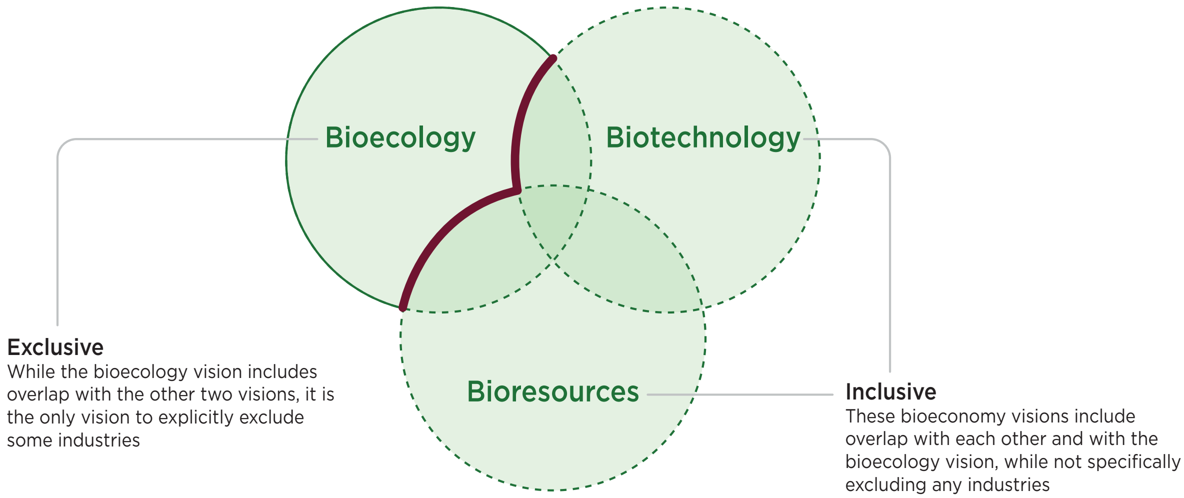
The bioecology vision may be incompatible with some elements of the biotechnology and bioresources visions (figure 1).[4] The European Commission's *How big is the bioeconomy?* observes, "[It] is not self-evident

3. We note recent efforts by the federal government to expand environmental and natural capital accounting efforts in the United States, in particular the *National Strategy to Develop Statistics for Environmental-Economic Decisions* (White House Office of Science and Technology Policy, Office of Management and Budget, and Department of Commerce 2022).

4. For example, genetically engineered crops (an important part of the biotechnology vision) may threaten biodiversity—most EU countries currently ban the growing of such crops for this reason—and thus are explicitly ruled out in the bioecology vision (Bugge, Hansen and Klitkou 2016).

that activities included in the bioeconomy are conducted on a sustainable basis… While the term *bioeconomy* is often associated with such terms as *sustainable economy* or *green economy*, …such an interpretation may be misleading" (Kuosmanen et al. 2020).

Figure 1. Relationship Between Bioeconomy Visions



An important implication of following a bioecology vision for the bioeconomy is the exclusion of major biotechnology-enabled industries that are also important for biological supply chains. *Not* following a bioecology vision implies that care must be taken in using bioeconomy statistics to inform decisions with sustainability and conservation impacts.

The next section of this report discusses the process of developing satellite accounts at BEA and illustrates the importance of clear definitions, scope, and boundaries in constructing economic measures. The existence of multiple different visions for the bioeconomy underscores the importance of communicating these definitions, scope, and boundaries clearly to data users as well.

3. Developing a Satellite Account

BEA produces measures for selected slices of the economy through its system of satellite accounts, which refers to statistics that complement official economic statistics. One use of satellite accounts is to measure areas of the economy that are not easily identifiable under the standard industry classification commonly used to organize U.S. economic statistics, the NAICS. Satellite accounts can also show how certain areas of the economy change over time and how these areas compare to other sectors of the economy. The System of National Accounts is the international statistical standard that governs national economic accounting methodologies and provides guidance for developing satellite accounts (*SNA 2008*). Since satellite accounts are developed using data and methods consistent with official economic statistics, they can be used to identify what share of the economy is attributable to the satellite account area. For example, a recent BEA report showed that the digital economy represented 10.2 percent of total GDP in 2021 (Highfill and Surfield 2022). BEA's satellite accounts cover various topics, including travel and tourism, outdoor recreation, the marine economy, the digital economy, and arts and culture. Inclusion of products and industries in one satellite account does not prohibit inclusion from another, so satellite accounts cannot be aggregated. This section outlines the general procedures used to develop a satellite account.

Most of BEA's satellite accounts begin with the SUTs.[5] The SUTs provide insight into the internal workings of the U.S. economy by detailing the contribution of specific industries and products to GDP and related economic measures. Industries are classified using the NAICS, and products are classified in a similar fashion using the NAPCS. The SUTs show the value of the product that is purchased by consumers, businesses, and government, plus the value that is imported and exported. The Economic Census from the U.S. Census Bureau is the primary data source for the SUTs. The Economic Census collects data from U.S. establishments that provide the foundation for the SUTs, including receipts and expenses of business establishments and of government, sales by detailed industry (NAICS) and product line (NAPCS), final industry and product shipments, input costs by general category, inventories, and trade margins (Census 2022). Other data sources include the U.S. Departments of Agriculture, Education, and Energy, plus private organizations (BEA 2009).

The goods and services (products) ultimately included in a satellite account are chosen from BEA's comprehensive list of nearly 5,000 categories of goods and services that constitute the SUTs. In practice, a satellite account is a rearrangement of the data underlying the SUTs to isolate spending and production for a specific area of the economy.

5. Other satellite accounts, such as the Household Production Satellite Account, expand the production boundary of the NIPAs. See Definitions Used for Various BEA Satellite Accounts for more information.

Developing a satellite account involves three main steps:

1. Identify relevant product categories within SUTs
2. Isolate relevant shares of economic activity within product categories, when necessary
3. Use the SUT framework to determine economic activity by industry, including contribution to GDP, gross output, employment, and compensation

3.1 Step 1: Identify Relevant Product Categories Within SUTs

Identifying relevant product categories to include in a satellite account requires a solid definition of the subject being measured. Determining the definition for the subject of interest is often the most important phase of creating a satellite account because it provides the overall framework for the new account and influences the goods and services chosen to be part of the resultant economic statistics. The products chosen as in-scope to a satellite account reflect existing research about the subject of interest, as well as feedback from experts in the private sector, academia, and domestic and international organizations. Definitions Used for Various BEA Satellite Accounts (next page) presents the definitions used to develop BEA satellite accounts. Some definitions include a list of specific criteria for relevant goods and services, such as the definitions for the digital economy, the marine economy, and others. In the case of outdoor recreation, both a narrow and broad definition were used to reflect the various, valid conceptions of what constitutes an outdoor recreation activity. In all cases, the intent is to present a clear distinction of which types of goods and services directly constitute each subject area.

Products in the SUTs are split into two categories: intermediate inputs and final demand. Intermediate input commodities are goods and services used up in the production of other commodities. Final demand commodities are goods and services purchased or consumed for "final use" and comprise GDP. Final use consists of the personal consumption expenditures (PCE); gross private fixed investment; change in private inventories; exports of goods and services; imports of goods and services; and government consumption expenditures and gross investment.[6] For BEA's satellite accounts, typically only final demand products need to be identified because intermediate inputs are inherently accounted for within the SUTs. For example, to capture the production of bicycles for the outdoor recreation satellite account, intermediate inputs such as tires and metal body do not have to be separately identified because those inputs are captured by default within the SUTs accounting framework.

6. Private fixed investment measures spending on assets in the U.S. economy by private businesses. Assets are structures, equipment, and intellectual property products that are used in the production of other commodities for at least 1 year. This includes investment in equipment with service lives of 1 year or more that are normally capitalized in business accounting records, construction of buildings, and investments in software and R&D. For more information on how BEA measures the U.S. economy, please see the NIPA handbook.

Definitions Used for Various BEA Satellite Accounts

Arts and Cultural Production Satellite Account. BEA defines arts and cultural production narrowly to include creative artistic activity; the goods and services produced by it; the goods and services produced in the support of it; and finally the construction of buildings in which it takes place.

Digital Economy Satellite Account. BEA includes in its definition of the digital economy three major types of goods and services:

1. The digital-enabling infrastructure needed for an interconnected computer network to exist and operate
2. The e-commerce transactions that take place using that system
3. Digital media, which is the content that digital economy users create and access

Household Production Satellite Account. Market-like output of households as the goods and services produced for own-consumption within the household that could be produced by a third person.

Marine Economy Satellite Account. Includes the following goods and services:

1. Items receiving any essential input from the ocean or coastal ecosystems or from the physical structures or process of the oceans—minerals, mining, fisheries, and saltwater aquaculture
2. Producing outputs or is an output for exclusive or predominant use in the ocean environment—shipbuilders, marine technology, commercial fishing vessels, surfboard rentals, etc.
3. Where the ocean/coastal relationship is identified and measured by geographic location in a shore-adjacent location

The geographic location refers to all U.S. oceans, marginal seas, and the Great Lakes.

Outdoor Recreation Satellite Account. Conventional definition: all recreational activities undertaken for pleasure that generally involve some level of intentional physical exertion and occur in nature-based environments outdoors. Broad definition: all recreational activities undertaken for pleasure that occur outdoors.

Please see the special topics section on BEA's website for more information about these and other BEA satellite accounts.

3.2 Step 2. Isolate Relevant Shares of Economic Activity Within Products, When Necessary

The SUTs comprise thousands of product categories that are oftentimes very specific, but this is not always the case. For example, while the SUTs separately track production of three types of ladders (wood stepladders, wood rung ladders, and metal ladders), there is only one general category for engineering services. For each satellite account, external data sources are used to isolate production in the case of these general categories. As one example, to include only bicycles used for recreation in the Outdoor Recreation Satellite Account, a survey commissioned by PeopleForBikes was used that shows the percentage of people who ride bicycles for recreation versus solely for commuting (Corona Insights 2017).

The ability to accurately isolate specific production within general product categories in the SUTs depends on availability of consistent and high-quality external data sources. Ideally, data from other government agencies are used because these data are more representative and have a much higher response rate than private data sources. And in many cases, government data collections are compulsory for businesses. When government data are unavailable, data from private vendors can sometimes be acquired. A main advantage of data from private companies is the possibility to conduct surveys and collect data in a more immediate and flexible fashion than government data collection. One disadvantage to relying on private data is the purchase price, which may be expensive and necessitate special funding. Private data sources can also change methodologies from year to year or simply stop being available, which are additional disadvantages to relying on them.

3.3 Step 3. Use SUTs to Calculate GDP, Gross Output, Employment, and Compensation by Industry

Once relevant products have been identified and pertinent economic activity is isolated, economic statistics can be calculated using the SUTs. Satellite account statistics include gross output, value added (GDP), employment, and compensation by NAICS industry.

- **Gross output** of an industry is the market value of the goods and services produced by an industry. The primary component of gross output is revenue or receipts, but it also includes commodity taxes, other operating income, and inventory change. Consumption of fixed capital (CFC) is also part of gross output. CFC is a measure of capital used up in production and reflects the decline in the value of the stock of fixed assets due to physical deterioration, normal obsolescence, and accidental damage. Gross output by industry for a satellite account represents the share of each product's gross output specific to the satellite account area for every industry that produces the good or service.
    - Measuring market production for services that are not traded in a typical marketplace, such as government services and own-account R&D (R&D carried out in-house), are typically measured in terms of the cost of production, including employee compensation, capital expenditures, and intermediate inputs such as utilities.

- **Value added (GDP)** is the gross output of an industry less its intermediate inputs. Intermediate inputs are goods and services that are used in the production process of other goods and services and are not sold in final-demand markets. Value added summed across all industries is equal to GDP. Value added for a satellite account is derived from the relationship between the industry output for the subject of interest and total industry output. This means the ratio of intermediate consumption associated with the industry output for the subject of interest is assumed to be the same as the ratio of total industry intermediate consumption to total industry output.
- **Employment and compensation** are derived through the same procedure as value added. Specifically, the ratio of an industry's satellite account output to total output is applied to total employment and compensation for the industry. Compensation consists of wages and salaries (primarily the monetary remuneration of employees) and supplements (employer contributions for employee pension and insurance funds and employer contributions for government social insurance). Employees include both full- and part-time employees.

3.4 Presenting Satellite Account Statistics by Activity

In addition to BEA's standard presentation of gross output and value added by NAICS industry, select satellite accounts also present these statistics by activities that are salient to data users. The ORSA includes statistics by outdoor activity, such as bicycling and camping/hiking. In this way, users can see total output related to bicycling that span multiple industries, including manufacturing of bicycles (NAICS 31–33), retail trade of bicycle gear and apparel (NAICS 44–45), and repair services for bicycles (NAICS 81). The Marine Economy and Digital Economy Satellite Accounts also present statistics by activity. Tables 2a and 2b show the different presentations for digital economy gross output in 2021. The activity tables allow for additional flexibility in the presentation of statistics by highlighting areas not identifiable using the NAICS, such as cloud services (under the NAICS, cloud services are part of the larger industry, "data processing, hosting, and related services"). Whether statistics can be presented by activity depend on the availability of necessary source data.

Table 2a. Digital Economy Gross Output by Major NAICS Sector, 2021

[Millions of dollars]

Major NAICS sector	Gross output
Digital economy	3,701,722
Information	1,600,191
Wholesale trade	792,532
Professional and business services	615,714
Retail Trade	308,818
Manufacturing	303,349
All other industries	81,118

Table 2b. Digital Economy Gross Output by Activity, 2021
[Millions of dollars]

Activity	Gross output
Digital economy	3,701,722
Infrastructure	1,167,116
Hardware	445,089
Software	722,027
E-commerce	941,970
Business-to-business e-commerce	642,998
Business-to-consumer e-commerce	298,972
Priced digital services	1,592,217
Cloud services	186,589
Telecommunications services	802,139
Internet and data services	213,290
All other priced digital services	390,200
Federal nondefense digital services	420

3.5 The Scope of Satellite Account Measures

As with BEA's core economic statistics, satellite account statistics are consistent with the SNA, the internationally agreed standard for measuring economic activity. The SNA acknowledges that these boundaries do not include everything of value to society. Under the SNA, BEA does not produce measures of the value of externalities arising from an economic activity, including social costs or benefits, return on investment, or the value of future benefits from an innovation. While economic measures are often treated as welfare measures (notably GDP), the SNA conventions argue against welfare interpretations of the economic statistics (*SNA 2008*). It is also important to note that there is no consensus on how to measure consumer surplus or other welfare-oriented measures. With any approach, many assumptions are involved, some of which are very subjective. BEA's statistics ensure that the estimates are objective. These statistics can be used to estimate consumer surplus or welfare using a variety of techniques.

Commonly used economic impact reports that include estimates of direct, indirect, and induced spending differ from satellite account statistics that only include the direct value of production. A goal of economic impact reports is to capture how an initial influx of spending permeates throughout the economy so a "total" economic impact from the initial spending can be quantified. This information is useful for state and local government policymakers to understand how a specific business or project contributes to the local economy. However, the estimated indirect and induced economic impacts cannot be interpreted as being directly caused by the initial increase in spending.

3.6 Resources Needed to Develop an Official Satellite Account

Research, development, and regular production of an official satellite account require dedicated staff resources, including economists, information technology specialists, and administrative personnel. Additionally, most satellite accounts require data purchases from private vendors, and some require contracts with external subject matter experts. Funding for official satellite accounts comes directly from budget initiatives approved by Congress or through agreements with other government agencies. The initial, annual cost for BEA to research, develop, and produce a new satellite account is typically about \$2.0 million, with future recurring annual costs dependent on the labor and other input costs required to maintain and update the account. A new satellite account often takes years to develop because of the time it takes for domestic and international outreach with subject matter experts to determine definitions and scope; identifying, vetting, and acquiring source data, sometimes requiring the support of external contractors; and preparing, reviewing, and producing the final statistics. The more complicated the satellite account, the more resources are required.

A comprehensive satellite account using a broad bioeconomy definition as outlined in this report would likely require similar resources to other BEA satellite accounts. Developing a focused bioeconomy satellite account broken down by specific areas of the bioeconomy, such as biotechnology, would require additional specialized resources; regardless, such a specialized account is likely infeasible at this time due to a lack of existing data.

4. Measuring the Bioeconomy

A practical definition of the goods and services that constitute the bioeconomy is necessary to develop a bioeconomy account that is consistent with international economic accounting. As described in the literature review, there exist many varied definitions of the "bioeconomy." Although each differ in scope, foundationally all describe the use of biological systems and life sciences in economic production. A comprehensive or broad measure of the bioeconomy would take into account the existing varied definitions, making the statistics amenable to more data users. Once a comprehensive measure is developed, it may be possible in the future to disaggregate the statistics by activities that focus on specific areas of the bioeconomy corresponding to narrower viewpoints such as the three visions outlined in the literature review (bioecology, bioresources, and biotechnology), though this approach is likely infeasible at this time, as discussed below.

4.1 Information Available to Measure Economic Contributions of the Bioeconomy

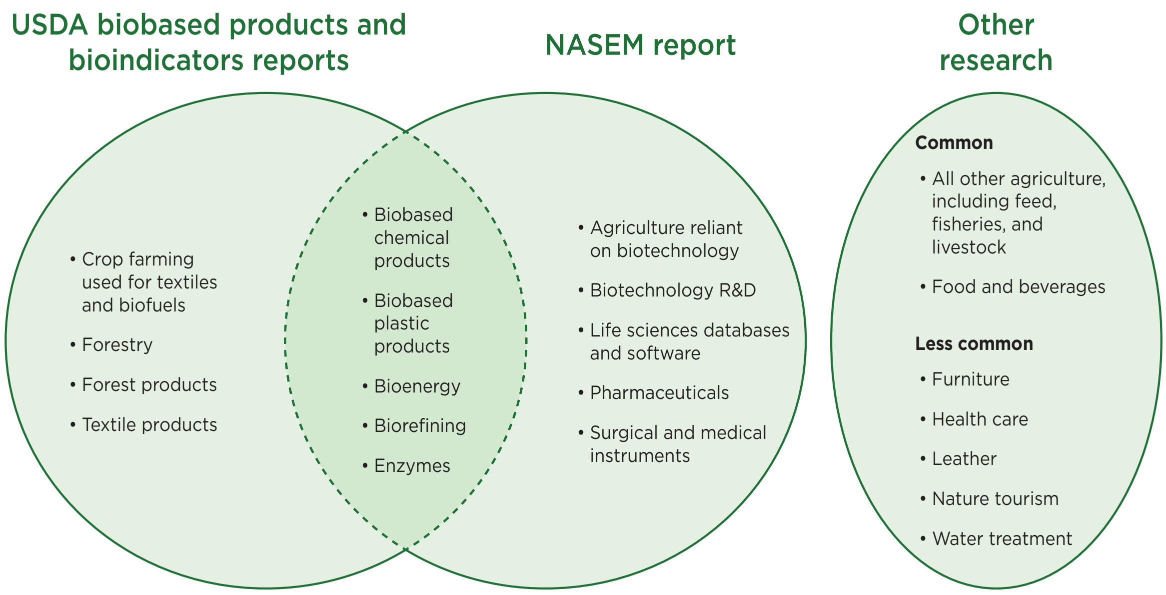
Executive Order 14081 defines the bioeconomy as "economic activity derived from the life sciences, particularly in the areas of biotechnology and biomanufacturing, and includes industries, products, services, and the workforce" (White House 2022). It also defines biotechnology as "technology that applies to or is enabled by life sciences innovation or product development," and defines biomanufacturing as "use of biological systems to develop products, tools, and processes at commercial scale" (White House 2022). For the purposes of this report, we use these definitions to guide the scope of a potential bioeconomy satellite account. That said, a key part of developing a satellite account is conducting extensive outreach with subject matter experts and data users to determine a practical definition suitable for economic measurement purposes. If outreach and expert advice established that certain products should not be included in a bioeconomy satellite account, BEA would take that feedback into consideration when constructing the account and would likely develop a more nuanced and practical definition of the bioeconomy than what is in the Executive Order (while still using the definitions in the Executive Order as a foundation for more explicit criteria).[7]

As described in section 3.1. of this report, the first step in developing a bioeconomy satellite account is to identify product categories within the SUTs that correspond to the given definition of the bioeconomy. Reports on the bioeconomy from USDA and NASEM provide relevant products and industries, including NAICS codes (appendix tables 1–2), and could serve as a starting point for products to include in a bioeconomy satellite account. Figure 2 shows there is substantial overlap in the products and industries

7. BEA interviewed various U.S. and international subject matter experts to discuss practical definitions for measuring the bioeconomy—ones that would be suitable for economic measurement purposes. However, determining alternate definitions to those listed in the Executive Order is outside of the scope of this feasibility report.

included in these reports, with some exceptions that align with each organization's mission focus. Since the focus of the NASEM evaluation was on newer, smaller, or innovative industries, it specifically excluded more mature industries such as forestry and related products. The USDA bioindicators reports cover biobased products included in the USDA BioPreferred Program,[8] biofuels, and related agriculture. Both sets of reports recognize that the included products are not an exhaustive list of bioeconomy products. In particular, both reports note that most of agriculture should be considered part of the bioeconomy because it represents economic production from the use of biological systems and life sciences (USDA 2018, 7; NASEM 2020, 61). Other research, especially from international organizations, includes a broader scope of products as part of the bioeconomy (Bracco et al. 2018). These products range from food and beverages to health care to nature tourism. The broadest measure of the bioeconomy would include all products identified in past research listed in figure 2 since they conform to the given definition of the bioeconomy—economic production from the use of biological systems and life sciences.

Figure 2. Composition of the Bioeconomy as Found in Existing Research



In addition to the products listed in figure 2, a comprehensive satellite account would also include the margins associated with selling these products, including transportation costs, retail trade markups, and wholesale trade markups. Margins are already linked with products within the SUTs, so those values are inherently included in satellite account statistics.

8. Biobased products are "determined by the Secretary of Agriculture to be a commercial or industrial product (other than food or feed) that is (A) composed, in whole or in significant part, of biological products, including renewable domestic agricultural materials and forestry materials, or (B) an intermediate ingredient or feedstock."

With the relevant bioeconomy products chosen, the second step in developing a bioeconomy satellite account is to isolate economic activity within product categories, when necessary. Many bioeconomy products are available using data from the SUTs including agriculture, biotechnology R&D, enzymes, food and beverages, forestry and related products, furniture, health care, leather products, pharmaceuticals, surgical and medical equipment, textile products, and water treatment. However, many other potential bioeconomy products in the SUTs are comingled with non-bioeconomy products. For example, bioenergy is not separately identifiable in the SUTs. Appendix tables 1 and 3 show the data sources the USDA and NASEM reports used to isolate bioeconomy production within industries.[9] Some of these data sources could also be useful for isolating production within SUT categories, specifically the USDA, U.S. Environmental Protection Agency, and U.S. Department of Energy data on biofuels, biorefining, and bioenergy production. Additionally, statistics on nature tourism could potentially be taken directly from BEA's Outdoor Recreation Satellite Account, which includes estimates of trips and travel expenditures related to outdoor activities.

4.2 Information Needed to Develop a Comprehensive Measure of the Bioeconomy

Products not identifiable in the SUTs or that are not available from consistent and reliable external data sources identified above include biobased chemical products, biobased plastic products, and life sciences databases and software. Biobased chemical products include a wide array of goods, including cleaning products, cosmetics, and lubricants. Biobased plastic products likewise include various goods. While there may be potential to acquire data on certain retail purchases from private data vendors, or to identify revenue for certain products from public U.S. Security and Exchange Commission (SEC) annual filings, there does not appear to be a comprehensive dataset that would allow for isolation of these products within the SUTs. Indeed, a lack of source data has driven the authors of the USDA bioproduct economic impact reports to rely on one-off reports and anecdotal information for their estimates. This issue has led to various proposals via a *Federal Register* notice that advocates for updates to the official industry and product classification systems (NAICS and NAPCS), which happens every 5 years, to formally recognize biochemical and bioplastic manufacturing separately (U.S. Census Bureau (Census) 2021).[10] As a result of those advocacy efforts, new products are being added to the 2022 NAPCS, including manufacturing of biobased plastics bottles; manufacturing of biobased thermoplastic resins and plastics materials, cellulose-, glucose-, starch-, or synthetic-based; and manufacturing of biobased thermosetting resins and plastics materials, cellulose-, glucose-, starch-, or synthetic-based (Census September 2022). These data will not be available until the late 2020s as it takes multiple years to incorporate updates to the official classification systems, so estimates by BEA in the meantime would need to be made using the approach by USDA, using source data proxies, or potentially excluding these products from the satellite account and acknowledging that the estimates are not comprehensive.

9. While a product can be made by multiple industries, in practice most products are made by a primary industry, so this approach is mostly consistent with the satellite account process of isolating economic activity within products.

10. NAICS and NAPCS are coordinated through the Office of the Chief Statistician of the United States.

Life sciences databases are another category in which data specific to the bioeconomy do not currently appear to be available. Databases created internally by businesses, government, and academia for their own use exist. However, their value is currently outside the scope of the production boundary as defined by the SNA and therefore are not included in BEA's core economic statistics. With that said, the upcoming revision to the SNA in 2025 is expected to include guidance for including these data, sometimes referred to as "data as an asset," in the economic accounts (OECD 2021). To that end, research is underway at BEA to estimate the total value of data as an asset with initial estimates showing production of these databases comprising about $186 billion in total investment in 2021 (Santiago-Calderón and Rassier 2022). Once data as an asset is included in BEA's core accounts, the source data used for these statistics may also be useful to isolate the databases related to life sciences, such as genomic databases, including the U.S. Bureau of Labor Statistics (BLS) Occupational Employment and Wage Statistics (OEWS) Program data described below.

Software related to life sciences databases and bioeconomy R&D may be identifiable using data from the BLS OEWS data. The OEWS data provide employment and wage information for occupations within an industry and have been used in previous satellite accounts as a proxy to isolate production within general product categories. Within the software industry, a few occupations stand out in the OEWS data that could potentially be useful for identifying production related to the bioeconomy. Specifically, life, physical, and social science technicians; physical scientists; and data scientists and mathematical science occupations (BLS 2022). As with biobased chemical products and biobased plastic products, additional research is needed to identify and vet potential source data for isolating this economic activity within the SUTs.

Looking to the future, capturing production of new bioeconomy goods and services represents an additional measurement challenge. Identifying bioeconomy innovations as they occur would require consistent consultation with bioeconomy experts. Quantifying the value of new bioeconomy products would then necessitate identifying and acquiring relevant source data.

4.2.1 The Potential to Measure Specific Areas of the Bioeconomy

There is an obvious desire to develop statistics that focus on specific areas of the bioeconomy that accord to narrower viewpoints, such as the three visions outlined in the literature review: biotechnology, bioresources, and bioecology. In this section, we provide a brief overview of the additional challenges related to measuring only certain aspects of the larger bioeconomy.

As mentioned above, Executive Order 14081 defines biotechnology as "technology that applies to or is enabled by life sciences innovation or product development." From an economic measurement standpoint, determining an operationalizable definition of what constitutes "innovation" is a challenge because there is no clear distinction of when an innovation stops being innovative and becomes standard practice. From a source data perspective, information on the production of new products from private industry organizations would be necessary to fill in the gaps from government data collections. The bioeconomy estimates developed by NASEM that focus on biotechnology and innovation serve as a practical illustration of these challenges. Similar to the Executive Order, the NASEM report defined the bioeconomy broadly as "economic activity that is driven by research and innovation in the life sciences and biotechnology, and that is enabled by technological advances in engineering and in computing and information sciences" (NASEM 2020, 3). However, the industries chosen to be included in NASEM's estimates were only a subset of the bioeconomy and cannot be considered a comprehensive measure of the bioeconomy or even of biotechnology (something the authors explicitly state in the report). For example, timber and forestry products are excluded despite the presence and use of bioengineering and biotechnology in this sector (García-Fraile, Menéndez, and Rivas 2015) and despite the use of forestry products as feedstocks in the bioeconomy. Additionally, isolating relevant production within certain industries was a challenge for NASEM due to a lack of source data, as noted in the report, resulting in the use of assumptions as opposed to direct data in some cases. These are the same challenges BEA would face if attempting to measure biotechnology production within the U.S. economy and mirror challenges encountered in other satellite accounts, such as the Digital Economy Satellite Account.

Data needs are the biggest barrier to constructing measurements according to a bioresources vision for the bioeconomy. While USDA has extensive data on biofuels, consistent time series data are not available to separate out other chemical feedstocks based on whether they are of biological or other origin.

Two major barriers exist to constructing a bioecology-focused bioeconomy account. First, since this vision incorporates natural capital assets in addition to economic assets and production, constructing a single bioeconomy satellite account would not suffice. Second, this vision for the bioeconomy focuses on sustainability. As noted previously, not all biologically based production is sustainable. Consequently, constructing measurements according to this vision would require determining which biological processes and products are sustainable and which are not. The data to make these determinations across the whole of the economy do not exist.

4.3 Considerations for Developing a Bioeconomy Satellite Account

Given the current definition and availability of economic data for the bioeconomy, there is potential to generate prototype estimates that cover many aspects of the bioeconomy. However, there are key areas of the bioeconomy related to biochemicals and bioplastics where data may not be available in the short term and that may prevent a comprehensive set of statistics. Data availability issues encountered in other BEA satellite accounts have been resolved using a variety of solutions. For example, the first digital economy satellite account report only included products considered primarily "digital." Those that were only partially digital, like e-commerce and cloud services, were excluded because they required additional research and expertise to isolate within the SUTs (Barefoot et al. 2018). By 2021, BEA's digital economy estimates were expanded to include cloud services and e-commerce after suitable source data were acquired and vetted (BEA 2021). Similar solutions could be considered for a bioeconomy satellite account.

Using the Executive Order's bioeconomy definition as the foundation of a bioeconomy satellite account means taking a broad approach to measuring the bioeconomy, aligning with international standards, though this strategy could result in statistics that may not be ideal for certain data users. Including entire sectors like agriculture and health care could potentially dwarf or obscure growing areas of the bioeconomy that are of interest to some users. Since BEA presents satellite account statistics by industry, it is possible users could choose to include or exclude specific industries of interest to isolate only certain areas of the bioeconomy. However, this strategy could result in excluding products relevant to some users, for example, excluding the agriculture sector would eliminate crops used for biofuels and excluding health care would eliminate precision medicine.

Given the diversity of viewpoints related to the bioeconomy and weaknesses related to statistics organized using the NAICS, a potential long-run strategy may be to present the statistics by bioeconomy "activity" similar to other satellite accounts, perhaps corresponding to the three visions outlined in the literature review (bioecology, bioresources, and biotechnology). However, organizing the statistics by bioeconomy activity would require more precise and practical definitions than are currently available, as well as data that are not available at this time. Therefore, developing estimates based on a narrow conception of the bioeconomy seems infeasible at this stage.

5. Conclusion

Developing a bioeconomy satellite account using a broad, comprehensive definition of the bioeconomy appears to be technically feasible and would correspond to similar efforts by the EU and other international organizations. However, developing a consistent, ongoing bioeconomy satellite account broken down along the lines of specific areas of the bioeconomy, such as biotechnology, is likely infeasible at this time due to both a lack of existing data on which to base such an account and a lack of a general consensus on practical definitions. While it is not uncommon for BEA to develop practical definitions suitable for economic measurement as part of developing a satellite account, the conclusion of this report is that even if an operational definition could be developed, there is a dearth of reliable, timely, and consistent source data needed to produce an official bioeconomy satellite account that focuses on specific areas of interest. Given how widespread and prolific bioeconomy activity is throughout the U.S. economy, ranging from agriculture to manufacturing to software, it seems unlikely that government data alone will be the answer to the source data issue. Especially with regard to new innovations and products, such as consumer products like genetic testing services and lab-grown meats, source data would likely need to come from private sector reports or data sources that currently do not exist on a comprehensive scale. In addition to specialized data, identifying where new, emerging activity is occurring across all industry sectors in the economy would likely require significant, ongoing help from external experts to achieve.

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7. Appendix

Appendix Table 1. Industries in the Bioeconomy Identified by NASEM (2020)

	Segments	Classification (North American Industry Classification System [NAICS] code, where relevant)	Source of Estimate for Value Added[1]	Value Added in 2016 (millions of dollars)	
				Current	Potential
Private industry sector segments					
1.	Crop products	11111-6, 11119, 111900pt	Committee calculations; Carlson (2019)	36,740	46,141
2.	Biorefining (food)	311210, 221, 224, 225; 311300	Daystar et al. (2018)	3,023	36,830
3.	Biofuels (ethanol)	324110pt	See note 2	8,361	12,553
4.	Biopharmaceuticals	325412pt	See note 3	31,118	99,575
5.	Biologics (enzymes)	325414	Daystar et al. (2018)	16,918	16,918
6.	Other pharmaceuticals	325412pt	See note 3	93,354	24,894
7.	Biobased petrochemicals	35211	Carlson (2019)	6,726	16,304
8.	Other enzymes	32519pt	Daystar et al. (2018)	11,918	11,918
9.	Other biobased chemicals	325211, 32519, 32522, 325510, 325998, 325611, 325612, 325520, 25991, 325992, 325910, 325613	Daystar et al. (2018)	8,081	50,505
10.	Biobased plastic products	326	Daystar et al. (2018)	997	68,436
11.	Electromedical instruments	334510, 6, 7	Gross output (GO) adjusted to gross value added (GVA)	49,636	49,636
12.	Surgical and medical instruments	339112	GO adjusted to GVA	28,153	28,153
13.	Bioeconomy R&D services 541714, 541715pt	Annex 3-1 discussion	43,090	43,090	
Intangible investments not included in value added as detailed above					
14.	Data services/software purchases	Private bioeconomy segments listed above	National accounts and INTAN-Invest	5,615	7,880
14a. Memo:		*Private health care organizations*	INTAN-Invest	15,194	—
Public and nonprofit sector segments					
15.	R&D	Life sciences, bioengineering, and biomedical engineering	National accounts, NCSES surveys	44,546	44,546
16.	Software and data-related analytic services	Classification of functions of government, health	National accounts and SPINTAN project[4]	14,190	14,190
			Total[5]	343,730	571,569

1. Reports the source for the estimate of the share of national accounts value added in the "nearest" available detailed industry. The final value added estimate for each activity also includes the contribution of intangibles not in the national accounts developed from a detailed version of the estimates reported at www.intaninvest.net.
2. Estimate based on fraction of gasoline that is ethanol. Biomass electric power generation is not separately listed; available estimates suggest value added in this activity was $635 million in 2016.
3. Estimate based on Otto et al. (2014) and the National Center for Science and Engineering Statistics Business R&D and Innovation Survey data reviewed below in the section on the direction of the bioeconomy.
4. SPINTAN (Smart Public Intangibles) refers to a European Commission Framework–financed project whose research consortium included The Conference Board. See www.spintan.net. The estimates of public- and nonprofit-sector intangibles developed for the SPINTAN project are designed to complement those for the market sector found at www.intaninvest.net.
5. Excludes line 14a.

Note: Daystar et al. (2018) refers to the USDA bio-preferred economic impact report.
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Appendix Table 2. Agriculture and Forestry Industry Values from the USDA Biobased Products Economic Impact Report (2018)

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
16	113310	Commercial logging	129,000	$6,309,000,000
19	11511, 11531	Support activities for agriculture and forestry—animal production has been excluded	88,000	$3,300,000,000
8	111920	Cotton farming	52,000	$3,837,000,000
15	113110, 113210	Forestry, forest products, and timber tract production	14,000	$788,000,000
2	111150	Grain farming—only corn included	6,000	$184,000,000
9	111930, 111991	Sugarcane and sugar beet farming	300	$23,000,000
1	11111	Oilseed farming	1,000	$114,000,000
		Totals	**290,300**	**$14,555,000,000**

Source: USDA, *An Economic Impact Analysis of the U.S. Biobased Products Industry*

Appendix Table 3. Summary of Industry Shares in the USDA Biobased Products Economic Impact Report and Source Data (2018)

Sector	Percent Biobased	Source
Agriculture and forestry		
Cotton farming	100	
Forestry, forest products, and timber tract production	100	
Commercial logging	100	
Corn	2.0	USDA Economic Research Service[1]
Oil seed farming to glycerin	0.6	USDA Economic Research Service
Sugar	1.7	Godshall, M.A. Int. Sugar J., 103, 378-384 (2001)[2]
Support activities	14.4	Based on percentage of all agriculture, excluding food, ethanol, and livestock
Biorefining		
Wet corn milling	2.0	Scaled to include only agriculture biobased products
Processing soybean and other oilseeds	0.6	Scaled on agriculture biobased percentage
Refining and blending fats and oils	0.6	Scaled on agriculture biobased percentage
Manufacturing beet sugar	1.7	Scaled on agriculture biobased percentage
Sugar cane mills and refining	1.7	Scaled on agriculture biobased percentage
Textiles	51	White paper on small and medium enterprises and Japan (2012)[3]
Forest products	100	
Biobased chemicals	4.0	Current Status of Bio-based Chemicals, Biotech Support Service, 2015 (BSS)[4]
Enzymes	100	BCC research report (January 2011)[5]

1. USDA Economic Research Service, accessed May 2018. https://www.ers.usda.gov/.
2. Godshall, M.A. “Sugar and Other Sweeteners,” in Kent J. (eds) Handbook of Industrial Chemistry and Biotechnology, (Boston, MA: Springer, 2012), 378-384.
3. Japan Small Business Research Institute, “2012 White Paper on Small and Medium Enterprises in Japan: Small and Medium Enterprises Moving Forward through Adversity,” September 2012. http://www.chusho.meti.go.jp/pamflet/hakusyo/H24/download/2012hakusho_eng.pdf.
4. Jogdand, S.N., Current Status of Bio-Based Chemicals, (India: BioTech Support Services (BSS), 2015), http://biotechsupportbase.com/buy-biotechnology-books-online/e-books-downloads/bio-based-chemicals/.
5. BCC Research, “Enzymes in Industrial Applications: Global Markets,” January 2011, https://www.bccresearch.com/market-research/biotechnology/enzymes-industrial-applications-bio030f.html.

Source: USDA, *An Economic Impact Analysis of the U.S. Biobased Products Industry*

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