I. Introduction

The biobased sector of the U.S. economy, despite its relatively young state, is very multidimensional. For example, there are many different biobased product groups, e.g., fuels, solvents, and containers, to name a few. Within each of these product groups there are wide varieties of distinct product types and production locales, each of which employs a variety of types of feedstocks, labor, machinery, and technology. In addition to the production of biobased products, activities in the biobased economy include a wide array of research and development activities, government policymaking activities at the local, state, and federal levels, employee training programs, and so on. In light of the very dynamic, diverse, and complex set of economic activities associated with the biobased economy, it is natural and useful to consider the development of efficient methods to quantitatively summarize these activities in ways that would be informative and easily digestible with regard to the overall magnitudes of and trends in major components of the bioeconomy.

Combining or aggregating information from distinct economic activities to provide succinct summaries of these activities is standard practice in economics, particularly in macroeconomics. For example, the economy’s production of the many different final goods and services produced is summarized by the well-known gross domestic product (GDP) measure. GDP summarizes the economy’s current production of goods and services by measuring the market value of this output: The economy is producing so many dollars worth of goods and services per year. While the dollar value in and of itself is not particularly informative, changes in (real) GDP from one year to the next provide useful information of the rate at which economic production is increasing (or decreasing). One can imagine a bioproduct analogue to GDP in which the market value of current biobased output could be constructed and used to measure changes over time in biobased output. Similarly, measures of total labor employment in biobased activities, research and development expenditure, capital investment, patent applications, among others, could be constructed to produce a manageable and digestible set of indicators of key components of the biobased economy.
In addition to indicators that summarize various dimensions of biobased economic activities, it would be helpful to have an even more highly aggregated composite indicator to summarize the overall state of the bioeconomy. Composite indicators, such as the Composite Leading Economic Indicator, combine related but distinct indicators to provide barometers of the overall levels of activity in the manufacturing sector of the economy or the economy itself, respectively. These indicators are dimensionless index numbers that condense related but distinct indicators to provide barometers of the overall health of the manufacturing sector of the economy or the economy itself, respectively.

This paper proposes a variety of economic indicators of the biobased economy.

II. Measures of Output and Employment

II.1 Biobased Domestic Product

What is the current rate of biobased production in the U.S. economy? How rapidly is this production increasing over time? What is the relative importance of biobased production in the economy and how is it changing over time? These are among the most fundamental questions regarding the bioeconomy from the point of view of the public, bioproducers and investors, and government policymakers.

The most natural way to think about answering these questions is to construct a measure of biobased production analogous to GDP, which is produced quarterly by the U.S. Department of Commerce’s Bureau of Economic Analysis (BEA). Such a measure might be called biobased domestic product or BDP. Like GDP, BDP would measure the market value of biobased products produced in a given period, expressed as dollars worth of output per year. Movements in BDP from one year to the next can be interpreted as annual changes in overall biobased production. The BDP-to-GDP ratio can be used to measure the relative size of biobased product and changes in this ratio over time can be used to measure changes in the relative size of biobased product.

The economy’s BDP will be constructed by adding up of the value of the production of the array of goods and services that define biobased output. Consequently, an important bi-product of the BDP indicator will be indicators of the production of the various component outputs. These indicators are of interest in of themselves. They can also be used to help determine the relative importance of the different sources of growth in BDP.

At first glance, the construction and interpretation of BDP seem very straightforward. However, as with GDP, issues such as distinguishing intermediate and final goods (to avoid double counting), removing the effects of inflation on BDP (to avoid misinterpreting movements in BDP due to price changes as being due to output changes), and properly accounting for the biobased service sector would need to be addressed. These ought to be viewed as relatively minor concerns since methods have been designed
by the BEA to resolve analogous problems in the computation of GDP. The most pressing concern is clearly the lack of data on biobased production at the industry level. It would seem to be desirable to obtain assistance and support from the BEA in data collection and resolving issues of the sort noted above.

II.2 Labor Employment in the Bioeconomic Sector

An alternative way to view the importance of the bioeconomic production sector in the U.S. economy is in terms of the absolute and relative amounts of inputs used in biobased production. In particular, it would be interesting and valuable to know how much labor is employed in these activities in order to track biobased labor employment over time and to compare biobased labor employment to total labor employment in the economy.

The most straightforward way to measure labor employment over a given period of time is to simply measure the number of workers employed over that period of time. The U.S. Department of Labor’s Bureau of Labor Statistics (BLS) uses business survey data and payroll data to construct economy-wide monthly measures of labor employment, expressed as 1000’s of workers employed. These data are also available at the industry and sectoral levels and are broken down into job types (e.g., service employment, manufacturing employment,…).

It seems that the survey methods used by the BLS could be directly applied to measure total employment in the biobased sector of the economy and employment in the biobased sector broken down by industry, location, type of job, etc. It also seems that the BLS could be encouraged to share, if not take on, this responsibility. Not only would this be cost efficient, but comparisons between biobased labor employment measures and other BLS labor employment measures constructed from a consistent methodology would be especially meaningful.

III. Measures of Other Dimensions Bioeconomic Activity

The output and employment measures discussed above seem to be the “bottom line” numbers that describe bioeconomic production activities. However, there are many other activities related to the bioeconomy taking place that will help determine bioproduction and employment in bioproduction in the future. It is equally important to construct indicators to measure these activities. These activities include, but are not limited to:

- Investment in physical capital (plant and equipment)
- Investment in research and development (of new products and technologies)
- Patent awards and scholarly publications
- Financial incentives provided by the government
- Public attitudes and understanding
III.1 Investment in Physical Capital

In the short-run, biobased production levels can be adjusted through adjustments in firms’ purchases of feedstocks, other raw materials, and labor services. And, while plant utilization levels can also be adjusted, in the short-run output is constrained by existing plant capacity and equipment. Firms purchase new plants and purchase new equipment partly for replacement purposes, as existing physical capital wears out. They also purchase new plants and equipment to expand future production capacity. In other words, net capital investment, the part of newly purchased plant and equipment that exceeds replacement needs, reflects producers’ plans to increase output in the future. Net capital investment in bioeconomic plant and equipment is an important measure of growth of capacity and future output. Firms will not build new plants, expand existing plants, and buy new machinery unless they plan to produce more output.

Measuring net capital investment in the biosector runs into the same problem as measuring bio-output: How can we aggregate across different types of plants and equipment to come up with a meaningful indicator of net investment? A solution can be drawn from the proposed solution to the output measurement problem. That is, use the market value of the newly purchased plant and equipment to measure investment. In fact, one the main components of the economy’s GDP is (gross) investment which the measures the dollar value of newly purchased plant and equipment in the economy (plus the value of business sector inventory adjustments and residential construction). The economy’s net investment indicator is derived by subtracting a depreciation measure (called the “capital consumption allowance”) from gross investment.

It is proposed, therefore, that net capital investment expenditure in the biosector be used as an indicator of growth in the biosector’s physical capital stock. It can be measured along the lines of the Department of Commerce’s BEA measure of net investment expenditure for the U.S. economy. Support from the BEA in this undertaking would be useful since many of the technical problems that will arise in constructing the investment measure will have been encountered and resolved in their construction of the economy-wide investment indicator.

III.2. Investment in Research and Development

Among the most visible and exciting activities taking place with regard to the bioeconomy are the research and development activities taking place in industry, academia, and the federal government. These R&D activities are aimed at developing new bioproducts and developing new and more efficient biotechnologies for producing new and existing products. Increased investment in R&D, like increases in physical plant and equipment, increases the likelihood of sizeable growth in the bioeconomy. Consequently, indicators of R&D activities are particularly important indicators of current bioeconomic activity and the future production of biobased commodities.

The National Science Foundation’s National Science Board publishes measures of R&D expenditures (and other R&D indicators) in its biennial report, *Science and Engineering*...
Indicators. These include a measure of total R&D expenditures, as well as measures of R&D expenditure broken down by character of work (basic research, applied research, or development), performing sector (industry, universities and colleges, nonprofit institutions), and source of funds (industry, universities and colleges, nonprofit institutions). In 2001, for the first time, NSF began collecting data on industrial R&D for biotechnology, although it’s not clear that this effort has been sustained in a meaningful way. In any event, NSF’s existing work on R&D indicators for the U.S. economy provides a natural starting point for the development of a measure of R&D expenditure on biobased product development and production technology. The construction of this measure would also provide measures of bioeconomic R&D expenditure broken down by character of work, performing sector, and source of funds. In order to separate out the effects of inflation on R&D expenditures from “real” changes in R&D expenditures, these measures should be adjusted for inflation.


Research and development activities are inputs that generate new products and production processes and scholarly publications as outputs. Product and processes can be viewed as outputs of applied R&D activities while scholarly publications can be viewed as outputs of basic research.

The number of new patent awards for bioproducts and bioproduction techniques is a natural measure of applied bio-R&D output. The U.S. Patent and Trademark Office already maintains a data base for biotechnology patents. So, this measure should be readily available.

The number of relevant scholarly papers published measures basic bio-research output. Constructing this number may be problematic, since many papers will only make indirect contributions of varying degree to the bio-knowledge base. In other words, it will not be obvious as where to draw the line between those papers that should be included in this measure and those that should not be included. One way to resolve the problem would be to define a set of keywords and include any paper whose keywords overlap this set. The Science Citation Index and the Social Sciences Citation Index would likely be useful in this regard.

III.4. Financial Incentives Provided by the Government

U.S. state and federal government authorities are putting forward policies and financial support favoring the development and expansion of bioeconomic activities, especially as they relate to the increased production and consumption of biofuels. The federal government justifies subsidizing biofuel development in terms of broader national goals such as increased energy independence and a cleaner environment. State governments promote fuel and bioproduct development partly to support these national goals, partly to support more local concerns (e.g., rural development), and partly to promote new sources of jobs and economic growth within their borders.
Financial support by the government for bioeconomic development comes in a variety of forms including, but not limited to, subsidies, tax credits, grants, and loan guarantees for: the production of feedstocks for biobased production, the production and consumption of biobased products, building infrastructure to support the needs of the bioeconomy, building new plants and purchasing new equipment, and biobased research and development in academia and industry.

Some of the government’s current financial support will increase current production and consumption of bioeconomic products, some will be expected to increase both current and future production and/or consumption, and other will affect only the future of the bioeconomy. So, changes in the total (inflation-adjusted) dollar amount of government support for the bioeconomy reflect changes in the government’s degree of commitment to growth in the bioeconomy and changes in the current and future states of the bioeconomy itself.

### III.5 Public Attitudes and Understanding

Public attitudes toward and understanding of bioproducts are important for the growth of the bioeconomy for at least two reasons. First, the government’s commitment and ability to financially support the growth of the bioeconomy relies on a willing and, ideally, enthusiastic public. Second, public attitudes toward and understanding of bioproducts will influence the demand for these products which ultimately will determine the future of the bioeconomy.

Typically, attitudes and understanding are measure by surveys. The National Science Board’s biennial *Science and Engineering Indicators*, for example, reports the results from the NSB’s survey of domestic and international public attitudes toward and understanding of science and technology. The survey includes questions designed to measure S&T literacy, primary sources of information about S&T, understanding of the nature of science inquiry, and attitudes toward S&T, to name a few.

The Conference Board’s Consumer Confidence Index (CCI) provides a model that could be used to provide an indicator of public attitudes and understanding regarding the bioeconomy. The Conference Board oversees a monthly survey of 5,000 representative U.S. households to measure consumer attitudes toward a number of dimensions of the economy. The survey includes questions about consumer attitudes toward current and expected future business conditions, current and expected future labor market conditions, current and expected future income, future buying plans, future vacations plans, perceptions of the stock market, expectations about inflation, and so on. The survey results are aggregated into a single number, the CCI. Increases (decreases) in the CCI are interpreted to mean that consumers are more optimistic (pessimistic) about the current and expected direction in which the economy is heading. (A more detailed discussion of index numbers, like the CCI, is presented in the next section.)
An indicator of public attitudes toward the bioeconomy could be developed by applying
the Conference Board’s index number methodology to the results of a survey similar to
the attitude/understanding survey used by the National Science Board.

IV. A Composite Indicator of the Biobased Economy

Each of the indicators discussed and proposed above describes a certain dimension of the
biobased economy that is distinct from, though related to, the other indicators. In this
section we propose aggregating these indicators into a composite index, i.e., a single
dimensionless number whose movements over time reflect changes in the overall state of
the bioeconomy.

A composite index summarizing the information contained in the array of individual
indicators will help the public, industry, media, and policymakers see an overall picture
that is not so obvious from the component indicators themselves. Put another way, the
introduction of a composite bioeconomic index will provide a focal point to facilitate and
enhance public and policy-oriented discussions regarding the state of the bioeconomy. In
addition, by providing information regarding the state of the bioeconomy in an
accessible and easily digestible form, the bioeconomic index will contribute toward
greater public interest in and understanding of the bioeconomic enterprise in the U.S.

The public is already familiar and comfortable with a variety of composite indices such
as the Consumer Price Index (CPI) and the Dow-Jones Industrial Average (DJIA), which
provide information about the economy’s inflation rate and stock market, respectively. In
addition, the Consumer Confidence Index discussed above provides valuable information
to businesses and policymakers about consumer attitudes concerning the health of the
U.S. economy.

The monthly CPI is constructed by the U.S. Department of Labor’s Bureau of Labor
Statistics (BLS). The BLS specifies a particular “basket of goods and services” assumed
to characterize the purchases of a “typical” household. This basket will include food and
beverage items, apparel, medical care services, recreation activities, housing services, and
so on. The fact that the available goods and services and the quality of goods and services
are changing over time, complicates the construction and interpretation of the CPI and are
important problems facing the BLS on a continuous basis. Each month, employees of the
BLS determine the cost of buying this basket. If the cost of buying the basket increases,
say, by 0.5 percent from one month to the next, the CPI is increased by 0.5 over its
previous value. The index is set at 100 for an arbitrarily selected base period. For example, the April 2007 CPI is 206.686 and the March 2007 CPI is 205.352. From this
we can infer that the cost of living grew by 0.6 percent between March 2007 and April
2007. We can also infer that the cost of living has more than double from the base period,
1982-1984 when the CPI was 100.

The DJIA is produced and maintained by *The Wall Street Journal*. Thirty stocks traded
on the New York Stock Exchange (NYSE) are used in the construction of the DJIA. The
Thirty stocks are highly reputable and major stocks, widely held by individual and institutional investors. Stocks included in this group of 30 change over time, but very infrequently. A portfolio of the 30 stocks (i.e., a certain number of shares of each stock) is specified. The market value of the portfolio is defined by adding up the price per share times the number of shares held for each of the 30 stocks in the portfolio. Changes in share prices change the value of the portfolio. If the value of the portfolio increases by, say, two-percent, then the DJIA will increase by two-percent. The value of the DJIA at the close of the NYSE on June 11 was 13,424.96 and the closing value on June 12, 2007 was 13,295.01. Note that these are dollar values; they are simply numbers. We can infer that the value of the DJIA stock portfolio fell by nearly one-percent on June 12. Although the DJIA only measure changes in the DJIA portfolio, movements in the DJIA are widely interpreted by the public as reflecting trends in the overall stock market.

Composite indices, such as the CPI, DJIA, and CCI, have at least a couple of common features.

First, composite indices are dimensionless numbers, i.e., they are pure numbers which have no meaning in and of themselves. The April 2007 CPI value of 206.686 is only meaningful in comparison to other CPI values. The June 12, 2007 DJIA value of 13,295.01 is only meaningful in comparison to other DJIA values. The May 2007 CCI value of 108.0 is only meaningful in comparison to other CCI values. In particular, it is the direction and magnitudes of changes in composite indices that are meaningful.

Second, composite indices depend on what components are used in their construction and how the components are put together. For example, the CPI is derived by looking at the prices of a particular sample of goods and services and the DJIA is derived by looking at the prices of a particular sample of stocks. Once the sample of goods and services (or stocks) is chosen, the importance or weight that each goods or service (or stock) is given in constructing the index must be determined. In constructing the CPI, the number of units of each good in the basket must be determined. In constructing the DJIA, the number of shares of each company’s stock that will make up the portfolio must be determined. Prices of items that make up a relatively large (small) share of a typical household’s expenditures get a relatively large (small) weight in the construction of the CPI. Prices of stocks that make up a relatively large (small) share of the DJIA portfolio get a relatively large (small) weight in the construction of the DJIA. The CCI asks a number of questions and asks respondents to select from a small number of possible answers. For example, respondents are asked to characterize current business conditions as “good,” “bad,” or “normal” and are asked whether they plan to buy a new car within the next year (i.e., “yes”, “no,” or “uncertain”). The percentages of respondents answering a particular question in a particular way make up the components that are aggregated into an index. The Conference Board must decide whether to weight each question equally or to assign more weight to certain questions than to others.

Another important economic index, which may be conceptually closer to the index proposed here is the Conference Board’s Composite Index of Leading Indicators. The Leading Indicators Index is a monthly index which combines information about an array
of macroeconomic activity in a single number to convey information about whether the economy is heading toward an expansionary or recessionary future. The 10 indicators that make up this index include: the average weekly hours worked by manufacturing workers, the average number of initial applications for unemployment insurance, the amount of manufacturers' new orders for consumer goods and materials, the speed of delivery of new merchandise to vendors from suppliers, the amount of new orders for capital goods unrelated to defense, the amount of new building permits for residential buildings, the S&P 500 stock index, the inflation-adjusted monetary supply (M2), the spread between long and short interest rates, and consumer sentiment. Changes in each one of these are thought to precede changes in future overall economic activity, however each can change for other reasons so that none is a perfect predictor of future economic activity. Combining or averaging these indicators into a single measure filters out some of the “idiosyncratic” movements in the individual indicators, providing a more reliable (though still imperfect) measure of future aggregate economic activity. In practice, two several consecutive monthly declines in the Leading Indicators are thought to portend the onset of a recession within the following six-to-nine months.

The proposed composite index of bioeconomic indicators is like the index of leading indicators in the sense that it is composed of quantities that cannot be easily or naturally aggregated, but are combined through a weighted average into a dimensionless number (or index) whose changes in magnitude and sign are meaningful. In Sections II and III, a set of bioeconomic indicators was proposed. Having selected the indicators, the problem is how to weight them to derive the composite index.

The simplest weighting approach is to weight the indicators equally. Ignoring the dollar, time, or other dimension associated with an indicator, simply add up the numbers to get the composite index. In practice, this approach would be modified in a couple of ways. First, if the indicator numbers differ from another by orders of magnitude, changes in those components with the largest order of magnitude will drive the index. So, the component indicators should be rescaled to be of the same order of magnitude before being averaged. Second, it is common to select a “base year” for which the index is defined to be 100. Then, for example, if for some year the average value of the component indicators is 10-percent larger than the average value for the base year, the value of the index for that year would be 110.

The equal-weighting approach is conceptually simple and straightforward to implement. However, implicit in this approach is that the “common bioeconomic effect” driving the individual components is equally important, relative to the idiosyncratic effects present in these components. It would seem that components reflecting relatively small (large) idiosyncratic effects ought to be given a relatively large (small) weight in the construction of the index.

Assigning different weights to different indicators raises the issue of how these weights should be selected. That is, how can we determine the relative importance of the various component indicators? This can be done subjectively or objectively. A subjective weighting scheme assigns differential weights to different components according to an
informed subjective valuation of their relative importance in the construction of the index. An objective weighting scheme derives the weights from a formal statistical model (see, e.g., Stock and Watson (1989)). An advantage of the objective approach is that the derived weights are optimally derived from a set of explicit assumptions. That is, the approach is formal and transparent. A major practical disadvantage of this approach, particular in the bioeconomic setting, is that the derivation of the weights based on formal statistical methods will require many observations over time of the component measures in order to uncover the “regularities” needed to estimate the appropriate weights.

In the short-run, the subjective weighting scheme is likely to be the best available approach. As data bases for the bioeconomy become longer and more regular, consideration of more objective procedures can be seriously considered.

V. Summary

This paper has proposed a variety of indicators to describe the current and expected future state of the U.S. bioeconomic enterprise. The availability of such indicators provides the public, media, industry, and policymakers with valuable information in the formulation of appropriate decision-making including, for example policymaking, legislation, and business strategies.

The proposed indicators include “bottom line” measures of current bioeconomic production: a GDP-type measure of bioproduction and a measure of labor employment in bio-related economic activities. Additional indicators of bioeconomic activity that portend the future state of bioeconomic production are proposed including measures of: investment in physical capital (plant and equipment), investment in research and development (of new products and technologies), patent awards and scholarly publications, financial incentives provided by the government, and public attitudes and understanding. It is important to note that the construction of these indicators will produce many more highly disaggregated indicators as bi-products.

The compilation of the proposed indicators should be facilitated by the fact that there are economy-wide analogues of each of these indicators that have long been compiled by various federal agencies. Working closely with these agencies to adapt their data collection and statistical methodologies seems to be a critical step in rapidly and efficiently developing the new indicators.

Finally, it is recommended that a composite bioeconomic index be constructed from the component indicators listed above to provide a concise and digestible measure of the overall state of the bioeconomic enterprise and how it is changing over time.
1. Pharmaceuticals, which are sometimes included in bioproducts groupings, are explicitly excluded for current purposes.

Appendix - Sources and References

U.S. Department of Commerce, Bureau of Economic Analysis

Primary website: http://www.bea.gov/
GDP: http://www.bea.gov/national/index.htm#gdp

U.S. Department of Labor, Bureau of Labor Statistics

Primary website: http://www.bls.gov/

National Science Foundation, National Science Board


U.S. Patent and Trademark Office

Primary website: http://www.uspto.gov/

The Conference Board

Primary website: http://www.conference-board.org/
Consumer Confidence Index: http://www.conference-board.org/economics/consumerConfidence.cfm

Dow Jones Industrial Average:

Science Citation Index: http://scientific.thomson.com/products/sci/

Social Sciences Citation Index: http://scientific.thomson.com/products/ssci/