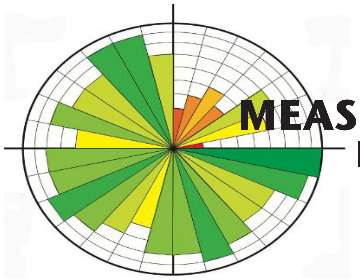
Roundtable on Science and Technology for Sustainability
Science and Technology for Sustainability Program
Policy and Global Affairs

June 2015



MEASURING PROGRESS TOWARD SUSTAINABILITY
INDICATORS AND METRICS FOR CLIMATE CHANGE AND INFRASTRUCTURE VULNERABILITY

In 1999, the landmark National Academies of Sciences, Engineering, and Medicine's report *Our Common Journey: A Transition toward Sustainability* proposed a research strategy for using scientific and technical knowledge to better inform the field of sustainability science. The report noted that "indicators are essential to inform society over the coming decades how, and to what extent, progress is being made in navigating a transition toward sustainability.... There is no consensus on the appropriateness of the current sets of indicators or the scientific basis for choosing among them."

Nearly twenty years after the report was developed, despite the proliferation of sustainability metrics by a wide range of sectors, at different scales, and in various aspects of sustainability (environmental, economic, and social), the selection and application of sustainability indicators and metrics remains challenging. To spur a discussion of these challenges, the Academies' Roundtable on Science and Technology for Sustainability began an initiative in 2015 focused on the development and use of sustainability indicators.

Given the broad nature of this topic, the Roundtable decided to focus the first meeting in the series on the development and use of sustainability indicators and metrics in a specific context, climate change and infrastructure vulnerability. The purpose of the session, held on June 4, 2015, was to identify indicators and metrics that have been found to be useful for promoting sustainability, as well as knowledge gaps related to developing indicators that integrate across the ecological, social, and economic sciences in the context of climate change and infrastructure vulnerability.

To open the Roundtable meeting, **Lynn Scarlett** of The Nature Conservancy, who co-chairs the Roundtable, described the goals of the session to look at how to measure progress toward sustainability and in particular the state of the science on indicators and metrics in the context of climate change and infrastructure vulnerability.

In the last 25 years, as sustainability has become common parlance, there has been a proliferation of metrics and indicators. The Roundtable's goal over the next year is to examine the state of development of those indicators and their utilization and to identify gaps, needs, and challenges that remain. How do we drive the indicators forward in a way that makes them useable?

David Dzombak of Carnegie Mellon University, who also co-chairs the Roundtable, provided additional context for the session, noting that in addition to corporate sustainability metrics, which have been widely developed and used for nearly a decade, there are numerous examples of ecological indicators for assessing the health of ecosystems. However, remaining challenges include the need for science-based indicators and the data and knowledge necessary to support them, as well as indicators and metrics that can integrate and provide information across the three pillars of sustainability (economics, society, and environment).

CLIMATE CHANGE AND INFRASTRUCTURE VULNERABILITY

Andrew Hoffman of the University of Michigan offered keynote remarks focusing on the evolution of sustainability metrics in the private sector. Bringing sustainability into the business sector is critically important, he said; if we are going to solve the sustainability issues of our day, they need to be solved by business.

Dr. Hoffman described the evolution of sustainability reporting, noting that in the mid-1970s only 1 percent of Fortune 500 companies provided social responsibility material in their financial report, while in 2011, 53 percent of S&P 500 and 57 percent of Fortune 500 companies reported on their environmental sustainability goals. This indicates good progress and penetration into the market in terms of what companies are measuring and reporting, said Dr. Hoffman.

In 1989, the Valdez Principles were developed. These principles, eventually named the CERES Principles[1], evolved into the Global Reporting Initiative (GRI)[2]. The initial goal of the CERES/GRI effort was to develop metrics that investors could understand in financial terms and use when making decisions about whether and how to invest in a company based on environmental issues. Similarly, the Dow Jones Sustainability Index, developed in 1999, allowed external groups an opportunity to evaluate and rank companies based on their sustainability performance. Formed in 2008, the Carbon Disclosure Project was also an important arbiter of metrics. The following year, integrated reporting emerged, where financial and sustainability reports were compiled in a comprehensive manner, in an effort to tie environmental and social performance to the monetary metrics within a company.

Using data from the GRI, Dr. Hoffman described the level of country and corporate-sector engagement in sustainability metrics. It appears that the European Union, once aggregated, is more involved in reporting than the United States; however, the United States is the single nation most active in sustainability metrics. The organizations that gather and report metrics span both the private and the public sectors and also privately owned and publicly owned companies. There is a notion that only publicly owned companies will report because they are required by the Securities and Exchange Commission to report their financial information; however, privately owned companies are participating as well. A wide range of sectors is also engaged in sustainability reporting, said Dr. Hoffman.

Companies develop and implement indicators for a variety of reasons, particularly for use in internal decisionmaking and/or external reporting, and there is a lot of overlap in terms of the metrics. Regarding internal decisionmaking, a typical company tracks 35 to 40 environmental, social, and governance (ESG) metrics but has specific targets for only 50 percent of the metrics tracked[3].

Dr. Hoffman described external reporting efforts. Based on data from the GRI, the metrics can be put into categories representing the triple bottom line: economic, environmental, and social. The social metrics pose a particular challenge for companies, as they often must consider questions such as what is meant by social and how to measure social issues. Another important metric is what is reported to senior management, he noted. On average, about 18 metrics get reported to senior management. Most often, these are resource consumption metrics such as energy use, electricity usage, and water use.

1 Ceres. 2015. The Ceres Principles. Online. Available at http://www.ceres.org/about-us/our-history/ceres-principles. Accessed September 21, 2015.

2 GRI. 2015. The Global Reporting Initiative. Online. Available at https://www.globalreporting.org/Pages/default.aspx. Accessed September 21, 2015.

3 National Association of Environmental Management. 2011. Identifying Corporate EH&S and Sustainability Metrics: What Companies are Tracking and Why, Online. Available at http://c.ymcdn.com/sites/www.naem.org/resource/resmgr/Docs/gmtm-2012-p3-report-naem.pdf. Accessed September 21, 2015.

Every company and every industry or sector will have different foci for thinking about sustainability, he continued. Most of the metrics are driven more by economic and technological considerations than environmental boundaries and realities. For example, if a company announces a goal of reducing CO2 emissions by 20 percent, does that have any relation or bearing on societal goals for carbon reduction? Will that help society achieve its goal, whether it is holding global warming to 2 degrees or limiting atmospheric CO2 to 450 parts per million or 350 parts per million? Currently, the metrics are based on or bounded by economic and technological considerations, not by our environmental goals overall.

The discussion of sustainability metrics is part of a broad-scale issue: How do we think carefully about the impact of the market—the most powerful institution on earth—and its effect on controlling natural systems and on creating social inequities around the world?

SUSTAINABILITY INDICATORS AND METRICS: OVERVIEW OF CURRENT STATE OF THE SCIENCE

Lidia Berger of Dewberry described the challenges in developing and using sustainability indicators and metrics from the perspective of the engineering and architectural industry. Dewberry often focuses on the economic portion of the triple bottom line because the company is able to easily assess cash impacts and decisions related to capital investment, operation, maintenance, and so forth. Dewberry also uses available sustainability metrics related to infrastructure; very often those metrics are on point-based systems. For example, the Social Return on Investment (SROI) method gives the company an ability to monetize external costs and benefits that are related to environmental impacts as well as internal non-cash costs and benefits linked to areas such as health, safety, or mobility. The non-cash benefits related to environmental and societal impacts are quite important and vary in many ways, said Dr. Berger.

She discussed two case studies where metrics were used in assessing company decisions, the development of the Fort Belvoir Community Hospital and the National Mall Underground. The company used the SROI to assess the annual value of benefits from sustainable strategies on projects such as these. It is important to consider metrics in discussions with external stakeholders and the public, who often ask, “What’s in it for me?” Unless we have gotten financial answers about specific strategies and categories by using sustainability metrics, it is not possible to answer that question.

Ralph Sims of Massey University in New Zealand provided an overview of sustainability indicators used by cities, focusing on the work of the Global Environment Facility, which has initiated a new Integrated Approach Pilot on Sustainable Cities. Cities are an important part of the sustainability equation given their projected growth in population, energy and water use, etc. Also, new cities are being developed almost every year in places like China and India, which will have huge implications for the environment and for resource use in those locations. Dr. Sims added that cities are also making great strides in working toward a sustainable future. For example, Barcelona, Spain, now has a regulation in place requiring every new building to have a solar water heater. Similarly, London now has a regulation that requires each new building to obtain 10 percent of its energy from its own renewable energy sources.

Cities have also been developing and using indicators for some time now, said Dr. Sims. For example, the International Organization for Standardization (ISO) 37120[4] includes 100 indicators that have been developed to enable cities to measure their own sustainability. A pilot is currently underway with 20 cities that have volunteered to conduct their own monitoring. The incentive for these cities, many of which are in OECD countries, is to be certified to gain better creditworthiness.

Dr. Sims discussed efforts by the World Bank and the Scientific and Technical Advisory Panel (STAP) of the United Nations Environment Program to compile 180 sustainability indicators being used by cities, such as climate change mitigation, solid waste, water supply, waste water treatment, transport, governance, finance, and social indicators. Dr. Sims and others are working to identify four or five common indicators that can be used across cities. Having common indicators is a major challenge, he noted. He also described a related tool, the Resilience Adaptation Transformation Framework, which is being developed by STAP and the Australian Commonwealth Scientific and Industrial Research Organisation.

Dr. Sims also is working to develop a common set of tools to help cities develop and implement their sustainability plans, assess their short- and long-term outcomes, and arrive at comparable and agreed upon diagnoses between cities. Four tools have been identified, including (1) common metrics and consistent terminology; (2) urban metabolism assessments that can quantify energy and material flows; (3) identification and analysis of local and global system boundaries, key limits such as climate change and biodiversity, and consistency with the tenets of sustainable development; and (4) a hierarchy of urban management that prioritizes providing services, decreasing emissions and environmental impact, and increasing resilience.

Dr. Sims also described some principles for guiding the development of indicators, including selecting indicators that are intuitive and easy to understand; using existing datasets where possible; reflecting the economic circumstances of the country; grasping the achievements made over time; reflecting the characteristics of the project; not obstructing sustainable development; reflecting global trends, such as smart community infrastructure assessment indicators; allowing for "informal settlements"; and considering the whole project comprehensively along with individual components.

Overall, indicators for monitoring a city's movement toward sustainability can be used for benchmarking or for making comparisons between cities, but that should not be the main goal. Instead, these should be used to assess the quality of life for citizens, a city's overall sustainability, and its resilience to future shocks.

4 International Organization for Standardization. 2015. ISO 37120. Online. Available at http://www.iso.org/iso/catalogue_detail?csnumber=62436. Accessed September 21, 2015.

Satyajit Bose of Columbia University described the Earth Institute's work to develop a database and analysis of the use of sustainability metrics. This work is ultimately intended to serve as a foundation for a set of generally accepted sustainability metrics. The Institute created a database of nearly 600 environmental, social, and governance metrics, conducted a review of frameworks and indices to measure performance, and examined the financial benefits of sustainability. The next stage of the study involves analyzing the frameworks and indices that aggregate these indicators, and paring down indicators to begin to settle on a common core that replicates the applicability and universality of financial indicators and generally accepted accounting principles.

During the analysis, Dr. Bose noted, he came to the conclusion that the utility of sustainability metrics is in the eye of the user. There are many stakeholders using many different sustainability methods; thus the analysis focused on relatively few types of users, and Dr. Bose focused his comments on the role of investors.

Since 2008, and especially since the economic crisis, there has been a rapid increase in the number of long-term institutional investors who are interested in incorporating non-financial metrics into their asset allocation process, he explained. For example, one in three of all asset management companies say that they incorporate or integrate environmental, social, and governance factors into their decision-making process. The largest institutional investor in the United States, CalPERS, specifically states in its investment beliefs that it will only employ professional managers who fully integrate environmental, social, and governance indicators into their investment allocation process. What companies and investors have come to realize is that failing to account for prices for natural and human capital, which currently are not included in accounting systems, will inevitably lead to a long-term misallocation of resources. Large institutional investors such as CalPERS accept that better investment decisions require assessment of natural capital and human capital.

Regarding how indicators are used by investors, Dr. Bose noted that in 2011, Eccles et al.[5] conducted a study of how investors using the Bloomberg data service utilized non-financial metrics to make decisions about companies. The authors found that carbon data was the most requested by investors. Disclosure was viewed as a proxy for management quality, not performance, meaning that a company that discloses more information is seen to be well managed even though it may not be actually performing well.

Dr. Bose noted that many frameworks are being used to generate these indicators, including GRI, IIRC, CDP, UNPRI Stock Exchange Initiative, etc. Similarly, there are various raters (OEKOM, EIRIS, Inrate, etc.) and index providers (FTSE4Good, DJSI, etc.). Despite this proliferation of indicators, an underlying problem exists in that it is not clear where the value lies. Until the business case for sustainability indicators is well articulated for all kinds of stakeholders, it is hard to ask investors to pay for the computation and the analysis of that information.

5 Eccles, R. G., G. Serafeim, and M. P. Krzus. 2011. Market Interest in Nonfinancial Information. Journal of Applied Corporate Finance 23:113-127.

There is also an evolving array of sources of data for these indicators, including open data initiatives, such as the Environmental Protection Agency's (EPA's) Toxics Release Inventory, nongovernmental reports, including those from Oxfam and Greenpeace related to human rights, and subscription-based aggregators, such as LaborVoices and LaborLink.

Dr. Bose noted that without consensus, it is not possible to have meaningful regulations addressing these issues. The European Union, for example, currently has a directive requiring the disclosure of non-financial information. However, because there still is no consensus on this issue, that directive does not specify any metrics and has no real impact. Consensus is a prerequisite to regulation, but regulation is necessary as no other entity with the exception of the government can force disclosure. There is also a need to link metrics to value, Dr. Bose added.

EXAMPLES OF INNOVATIVE PUBLIC SECTOR SUSTAINABILITY INDICATORS AND METRICS

Michael Slimak of the U.S. EPA discussed the agency's work related to sustainability indicators, particularly those used in its Report on the Environment (ROE)[6]. The ROE provides trends, mostly on a national scale but with some regional information. The agency developed 85 specific indicators for the report. The purpose of the report was to inform the Agency's policies as well as communicate with the public.

The ROE was initiated in 2001 and a final report was released in 2008. Since 2008, EPA has been revising the current version, which was released in September 2015. The report is organized along a series of themes—air, water, land, human health, and ecological conditions. In the 2015 ROE, the agency began to look at the issue of sustainability and how it could be included in the report. Four sustainability indicators are contained in the 2015 version, including those related to energy use, freshwater withdrawals, municipal solid waste, and hazardous waste. In addition, there is a new section in the ROE that discusses the concept of sustainability, the importance of developing sustainability indicators, and the reason the agency thinks these four indicators are a good start. EPA hopes to expand the number and scope of indicators related to sustainability in future reports as well as provide more interpretation of trends.

EPA has also developed a searchable database of over 1800 worldwide indicators and indices related to sustainability, and the agency is working on other indices as well. The agency makes a distinction between an indicator and an index; for EPA, an indicator is a direct measure of something—a disease outcome such as cancer rate, or a greenhouse gas emission number—while an index usually incorporates weighting driven by a value judgment. EPA has developed several indexes, including the Environmental Quality Index (EQI) and the Human Wellbeing Index, which is an index at the county scale that takes a holistic approach by highlighting the link between wellbeing and the flow of ecological, economic, and social services. Also, EPA Assistant Administrator Thomas Burke has asked the Agency to develop what he calls a climate resilience screening index, which is an index that would allow a community to understand how resilient it is to climate change and other extreme weather events.

Joe Manous of the U.S. Army Corps of Engineers discussed sustainability metrics related to water resources and climate change adaptation. The Army Corps is somewhat unique among agencies in terms of its focus on specific projects, which has implications for how it approaches sustainability metrics. This is evidenced in the Army Corps' fairly active climate change program, said Dr. Manous. Through the program, the Corps is working with other partners, including universities, the U.S. Global Change Research Program (USGCRP), and other laboratories to identify indicators or best practices that allow the agency to adapt more effectively.

Dr. Manous described the concept of residual risk in discussions with decisionmakers, elected officials, and other stakeholders. Residual risk, as defined by the Corps, is the "flood risk that remains after all efforts to reduce the risk are completed."[7] Residual risk is the exposure to loss remaining after other known risks have been countered, factored in, or eliminated. Because the Army Corps is responsible for designing projects, many of which may be directly impacted by climate change, the Corps is charged with quantifying the residual risk.

Regarding adaptation metrics, the Army Corps does not have a systematic approach to developing these metrics; however, it is working aggressively on adaptation implementation, which asks the question, Have the desired outcomes been achieved? Dr. Manous said there is an important distinction between adaptation implementation and adaptation planning, in which all impacts, vulnerabilities, consequences, and uncertainties are considered. During planning for a new structure or a new watershed investment or in development or maintenance, the agency is looking for a higher level of resolution. Adaptation implementation means that some action must be taken now, without the option for waiting for more studies.

The agency has a resilience strategy, signed by leadership, which includes four main components: prepare and plan, absorb and withstand, recover and adapt, as well as a Climate Change Adaptation Plan. The latter applies to new infrastructure, with a requirement to implement adaptation as planned over the entire project life cycle, tied to trigger or threshold events. For existing infrastructure, the plan notes that there must be detailed assessments and progressively more detailed screening for climate vulnerabilities.

Melissa Kenney of the University of Maryland described the development of sustainability indicators for use in the USGCRP. The goal of this effort was to assess physical, ecological, and societal indicators that can communicate and inform decisions about key aspects of

6 U.S. Environmental Protection Agency. 2015. Report on the Environment. Online. Available at http://cfpub.epa.gov/roe. Accessed September 21, 2015.

7 USACE (U.S. Army Corps of Engineers). 2010. Flood Risk Management: Frequently Asked Questions. Online. Available at http://www.iwr.usace.army.mil/Portals/70/docs/frmp/revised_FINAL_FAQs_version_9-29-2010.pdf. Accessed September 18, 2015.

climate change impacts, vulnerabilities, and preparedness. There is a strong emphasis on impacts and vulnerabilities, most of which are multi-stressor in nature; climate is not the sole factor driving the changes that researchers are observing.

Among the key decision criteria for this effort is developing indicators that are scientifically grounded and that provide meaningful, authoritative, and relevant measures to the highest priority areas in order to inform decisions at multiple scales. The effort also seeks to identify climate-related conditions and impacts and ultimately to provide analytical tools by which user communities can drive indicators for their own potential purposes. Although indicators can be tools, ideally we want to use them to inform and promote effective decision-making, said Dr. Kenney.

Dr. Kenney noted that the USGCRP's Indicator System[8] has been a notable milestone, with strong support from the broader scientific community as evidenced by the 14 different working groups and over 200 scientists from nine federal agencies engaged in the effort. A significant amount of time was devoted to developing the goals, decision criteria, and process (see Figure 1). The implementation of the indicators involves a range of activities, from developing an idea to creating a dataset to implementing a visualization schema and then reviewing it through various channels.

She noted a number of opportunities for the future use and development of sustainability indicators, including the need to develop leading indicators that will inform future decisions; to improve understandability and optimal visualization of indicators for different audiences; and to develop linked indicator and metadata boundary objects. Finally, there is a need to understand the effectiveness of indicators for informing decisionmaking. Specific needs include in-depth synthesis of decision support and the use of indicators in the information landscape; greater understanding of whether indicators constrain or expand decision structuring; case studies that address spatial and temporal scalability and impacts on conceptual framing; and guidance about a small set of indicators of change, measured across projects and landscapes, to assess whether these are being used to make more sustainable and broadly informed decisions.

EXAMPLES OF INNOVATIVE PRIVATE/NGO SUSTAINABILITY INDICATORS AND METRICS

David Dornfeld (NAE) of the University of California, Berkeley, discussed efforts by the manufacturing industry to develop green metrics. Metrics can be developed to address the multitude of steps involved in converting materials into

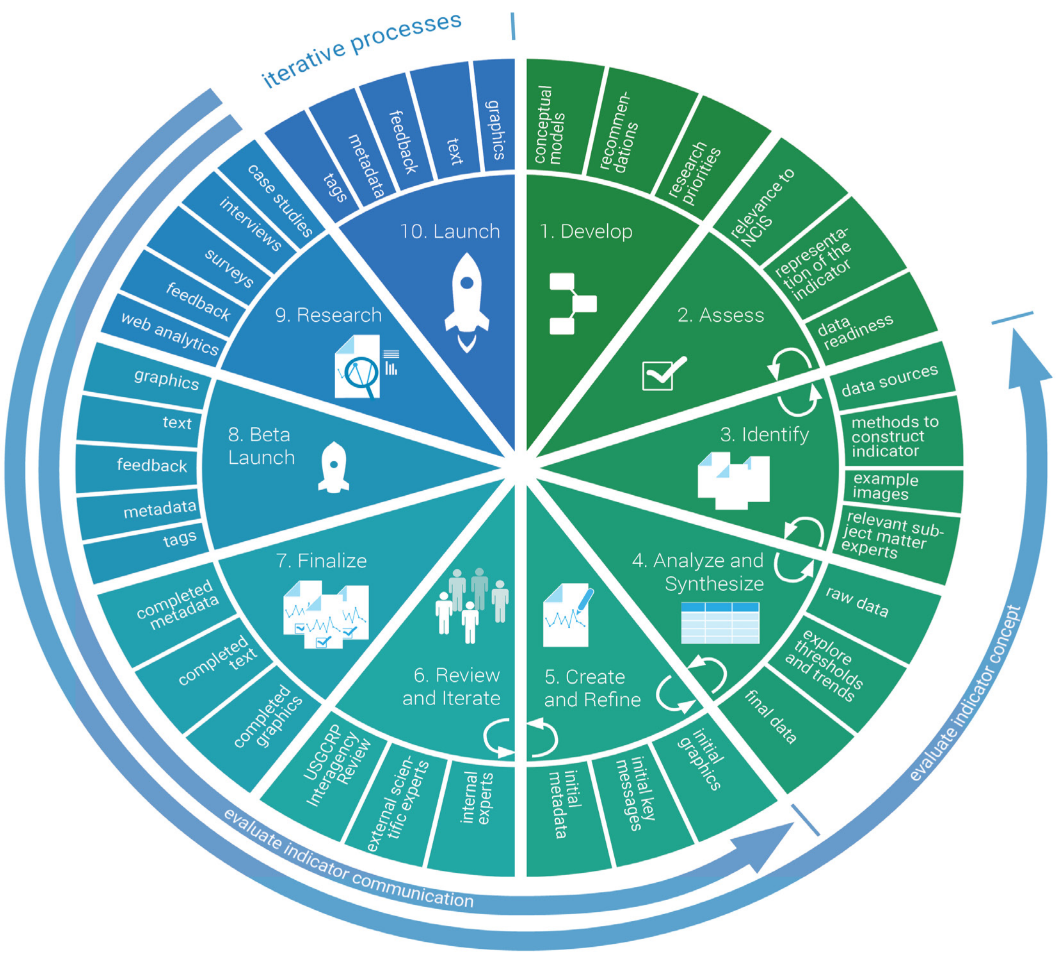


Figure 1. U.S. Global Change Research Program Indicator Process. Source: Kenney, 2015.

8 USGCRP. 2015. Indicators. Online. Available at http://www.globalchange.gov/explore/indicators. Accessed September 21, 2015.

a process or a product, then to the commercial market, followed by an end-of-life recovery or disposal process. However, most often there is a focus on metrics during product design; for example, Design for the Environment includes an assessment of environmental factors in the design of a product and considers the entire life cycle of the product.

There is a need to consider environmental impacts throughout the entire product supply chain, including developing measures of sustainability in this process, Dr. Dornfeld added. The key metrics for the manufacturing industry historically have included productivity, quality, throughput, utilization, availability, and other measures drawn from traditional scientific management analysis. Other metrics have included energy consumption as well as proxies that would include greenhouse gas emissions, etc. Efficiency and effectiveness have also been used as measures. The industry also focuses on resource productivity. For example, the aerospace industry uses this type of metric as a buy-to-fly ratio, asking the question, how much—in terms of resources and materials—comes into the facility and how much ends up in the aircraft? Often the analysis shows that very little in terms of resources and materials actually ends up in the final product.

One key issue is ensuring that all of the embedded resources are reduced over the life cycle of a product. A holistic approach must be used in measuring resource use, such as considering the embedded energy in a case of material per unit of product value. Companies are using a variety of assessment mechanisms—in particular supply chain analysis, risk assessment, and life-cycle assessment (LCA)—to assess the sustainability of their products and resource use. For example, Cummins focuses on remanufacturing, Unilever is studying product use phase, the Healthy Building Network is assessing substitutes, and Apple and Google are analyzing the multi-tiered supply chain.

Dr. Dornfeld noted the importance of the circular economy in this discussion (see Figure 2). This framework focuses on clos ing the loop in decisions related to materials choices, manufacturing, and reuse, and also on the connection between material flows categorized as biological nutrients and technical nutrients. Life-cycle assessment metrics do not address this circularity, and thus improved metrics should be designed that assess production and consumption systems.

Matthew Swibel of Lockheed Martin Corporation described the company's efforts to develop and use sustainability indicators, noting that discussions about the subject have been going on for several decades. The company did not arrive at the decision to incorporate sustainability as the result of a crisis or from a corrected on mandate. Sustainability is a core competency in how Lockheed addresses its customers' most complex challenges, particularly given the range of activities the company engages in, from building satellites to integrating software that allows for air traffic control and for more fuel-efficient aircraft routings. By formally developing sustainability indicators, the company can ultimately make better decisions in terms of where it should allocate investment in capital expenses to make operations more efficient.

Lockheed's Sustainability Management Plan is focused on six core issues (governance, product performance, information security, talent competitiveness, supplier sustainability and resource efficiency) and includes six aligned objectives with 41 total measures, each tied to an objective for each of these core issues, Dr. Swibel continued. Lockheed identifies measures of effectiveness to demonstrate and report performance, accountability, and traceability of sustainability initiatives across the company. The plan is purposely aligned with the global reporting initiative G4 framework and calls for first prioritizing the largest impact and then assessing appropriate indicators. The plan is used not only for external reporting but also for improving corporate performance, and as a result not all of the measures are publicly releasable.

In terms of integrating sustainability metrics with business decisions, Dr. Swibel noted that there are markers that are used for any sustainability indicator. One includes quantifying the customer benefit, whether or not it is monetarily described. The second is identifying the existing policy or procedure providing the data from which Lockheed can analyze an indicator. The last is finding an enterprise-wide measure, which can be challenging; identifying an indicator of sustainability performance is time consuming and can sometimes inhibit the rate of innovation at a local level.

David Allen of the University of Texas discussed sustainability metrics in the context of his work with the chemical manufacturing and engineering industry. Sustainability metrics have been developed for chemical manufacturing for about a decade and have been applied at a process level, he said. Metrics have included raw materials used per pound of product, energy used per pound of product, greenhouse gas emissions per pound of product, wastes per pound of product, and targeted pollutants per pound of product. In a manufacturing context, key metrics have also included productivity, efficiency/effectiveness, energy consumption, resource productivity, and capital investment. There have also been benchmarking efforts for major commodity chemicals identified by the U.S. Department of Energy.

In surveying efforts to develop metrics for chemical manufacturing, Dr. Allen noted, a question arises about how stable those metrics have been for the industry. To address this issue, a study was published in 2014 by the American Chemical Society's Green Chemistry Institute that surveyed and collected data from hundreds of chemical manufacturers and prepared detailed analyses of the metrics on particularly large manufacturers.[9] The authors found that a relatively stable set of metrics has been developed and used by the industry over the past decade, including those related to efficient use of materials, total waste generation, etc. The American Institute for Chemical Engineers (AICHE) has also developed sustainability metrics at the facility level. Over the past five years or so a consistent group of companies has been working through

9 Giraud, R. J., P. A. Williams, A. Sehgal, E. Ponnusamy, A. K. Phillips, and J. B. Manley. 2015. Implementing Green Chemistry in Chemical Manufacturing: A Survey Report. ACS Sustainable Chemistry & Engineering 2(10):2237-2242.

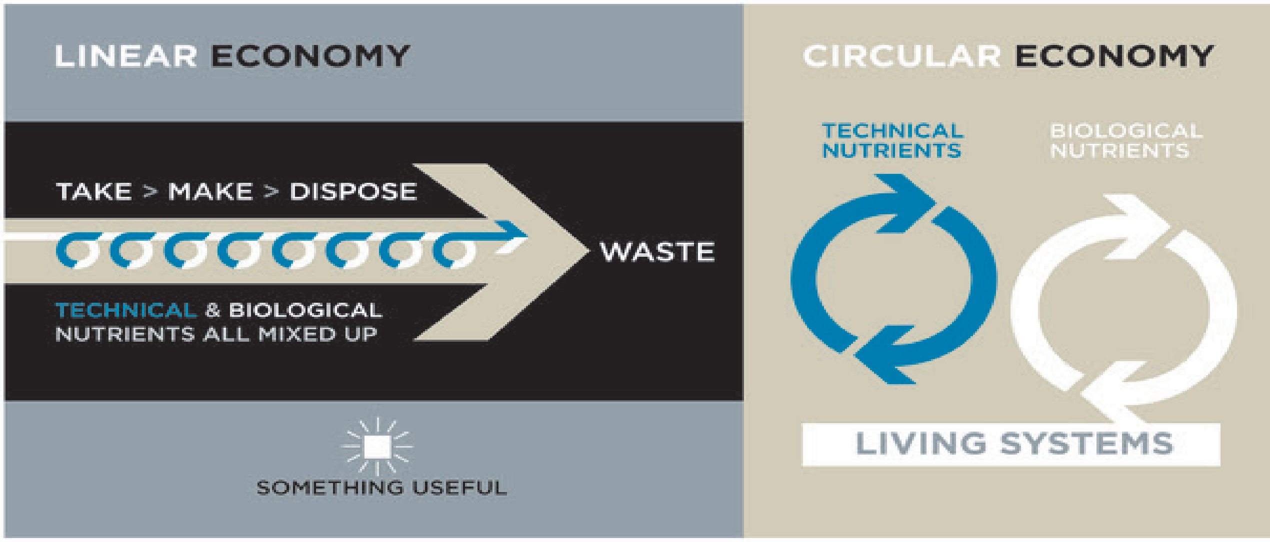


Figure 2. The Circular Economy. Source: Dornfeld, 2015.

the AICHE to benchmark itself against these indicators and, in general, broad progress has been made in all of these with the exception of one type of indicator, social responsibility.

Dr. Allen said that the chemical manufacturing industry is thinking about metrics in terms of sequential and iterative design at multiple scales. Scales at which metrics are applied in the industry include the molecular scale, process scale, and system scale. Multiple combinations of processes can be used to transform raw materials into products; the optimal process within a network may not be the same as the optimal process for a single transformation.

In general, the chemical manufacturing industry has shown much progress in the area of sustainability metrics, having developed a stable group of indicators, the ability to track progress over time, and tools at multiple scales of systems. However, the chemical manufacturing system is not monolithic; for example, pharmaceutical manufacturing, which would appear to have similar processes, has fundamental differences in terms of metrics, tools, and systems. Even within chemical manufacturing, subsystems use very different metrics.

Dr. Allen added that ACS Sustainable Chemistry and Engineering, a new journal that was launched in 2012, will be conducting an experiment to encourage authors to quantifiably define metrics related to the relationship between their research and sustainability, which will likely yield a wide range of information.

SUMMARY DISCUSSION

David Dzombak led the final session, which highlighted some of the key issues discussed during the meeting related to the development and use of sustainability indicators and metrics in the context of climate change and infrastructure vulnerability. Several key ideas were discussed, including:

- **Effectiveness and Use of Indicators:** Many participants noted that it would be useful to examine how various entities develop indicators,and for what purpose. In particular, there is a need for a rigorous evaluation of sustainability indicators for decisionmaking and a broader evaluation of the efficacy of those efforts.
- **Indicators Framework:** Several participants indicated the need for a framework for sustainability indicators. Components of the framework could include priorities related to how, and if, indicators are being used for decisionmaking; stakeholder engagement and partnerships for building and sharing indicators; and systems approaches for indicators development.
- **Addressing Uncertainty:** Also discussed was the need to develop a systematic approach for handling of uncertainty in the development and use of indicators.
- **Availability and Reliability of Data:** Data to inform decision-making and metric development is lacking, noted several participants.
- **Lack of Indicators to Address Social Issues:** Many participants indicated a significant lack of social indicators and limited integration of existing social indicators with ecological indicators.

Presenters: David Allen, University of Texas; **Lidia Berger**, Dewberry; **Satyajit Bose**, Columbia University; **David Dornfeld** (NAE), University of California, Berkeley; **Andrew J. Hoffman**, University of Michigan; **Melissa Kenney**, University of Maryland; **Joe Manous**, U.S. Army Corps of Engineers; **Michael Slimak**, U.S. Environmental Protection Agency; **Ralph Sims**, Massey University, New Zealand; and **Matthew Swibel**, Lockheed Martin Corporation.

Planning Committee: Lynn Scarlett, The Nature Conservancy (Chair); **David Dzombak** (NAE), Carnegie Mellon University; and **Suzette Kimball**, U.S. Geological Survey.

Academies Staff: Jerry Miller, director, Science and Technology for Sustainability (STS) Program; **Jennifer Saunders**, senior program officer, STS Program; **Dominic Brose**, program officer, STS Program; **Mark Lange**, program officer, STS; **Emi Kameyama**, program associate, STS Program; and **Yasmin Romitti**, research assistant, STS Program.

DISCLAIMER: This meeting summary has been prepared by Jennifer Saunders as a factual summary of what occurred at the meeting. The committee's role was limited to planning the meeting. The statements made are those of the author or individual meeting participants and do not necessarily represent the views of all meeting participants, the planning committee, STS, or the Academies.

The summary was reviewed in draft form by **Richard Wright** (NAE), American Society of Civil Engineers. The review comments and draft manuscript remain confidential to protect the integrity of the process.

ABOUT SCIENCE AND TECHNOLOGY FOR SUSTAINABILITY (STS) PROGRAM

The long-term goal of the National Academies of Sciences, Engineering and Medicine's Science and Technology for Sustainability (STS) Program is to contribute to sustainable improvements in human well-being by creating and strengthening the strategic connections between scientific research, technological development, and decision-making. The program examines issues at the intersection of the three sustainability pillars—social, economic, and environmental—and aims to strengthen science for decision-making related to sustainability. The program concentrates on activities that are crosscutting in nature; require expertise from multiple disciplines; are important in both the United States and internationally; and engage multiple sectors, including academia, government, industry, and non-governmental organizations. The program's focus is on sustainability issues that have science and technology at their core, particularly those that would benefit substantially from more effective applications of science and technology.

For more information about STS, visit our web site at http://sustainability.nationalacademies.org
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