

Overcoming Nontechnical Barriers to the Implementation of Sustainable Solutions in Industry

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Maintaining sustainable practices will require a concert of efforts including industry-wide cooperation, governmental openness, and education reform.

Though nature has long practiced an amazing range of chemical transformations, humans have been systematically dabbling at the atomic and molecular level for only a few hundred years. During that time we have created stronger, more durable, flexible, and functional molecules whose applications such as water treatment, pharmaceuticals, and primary materials have vastly improved the quality of life. However, we have often neglected aspects of toxicity, environmental persistence and impact, or limitations of the earth's resources, and the unintended ecological and health consequences have become increasingly apparent.



SHUTTER STOCK

Society must become sustainable—economically, socially, and environmentally—and the chemical enterprise is uniquely positioned to aid in this transition. The chemical enterprise includes the chemical and related industries, research organizations, and academic programs. It has both the vast, industrial-scale impact and the technical knowledge to enable sustainable choices. Chemical research can and has provided innovations toward sustainability and the knowledge to guard against unintended consequences. Meanwhile, chemical industries—part of high-volume supply chains with significant material, energy, and water inputs—can massively leverage and magnify improvements in material sourcing, process efficiency, or end-use fate (1).

To its credit, the chemical enterprise is already applying technical expertise to societal challenges including renewable energy, potable water, safe food, and clean air. Research in academic labs has a strong and growing record of engagement in sustainability (2), and chemical companies have advanced many green technologies, such as those recognized annually since 1996 by the Presidential Green Chemistry Challenge Awards (3). Chemists are developing greener products and processes, switching to renewable feed stocks, finding innovative energy supplies, and developing catalysts for more efficient reactions. An excellent summary of past successes and remaining technical demands can be found in the 2006 National Academies report “Sustainability in the Chemical Industry” (4), among others (1, 3, 5, 6).

However, while the chemical enterprise is rising to the technical challenges, as a whole it continues to struggle with the more holistic aspects of sustainability. As in many sectors of society, there are large barriers to implementing sustainable practices, many of which cannot be fixed with technology. Switching to more sustainable processes, practices, and

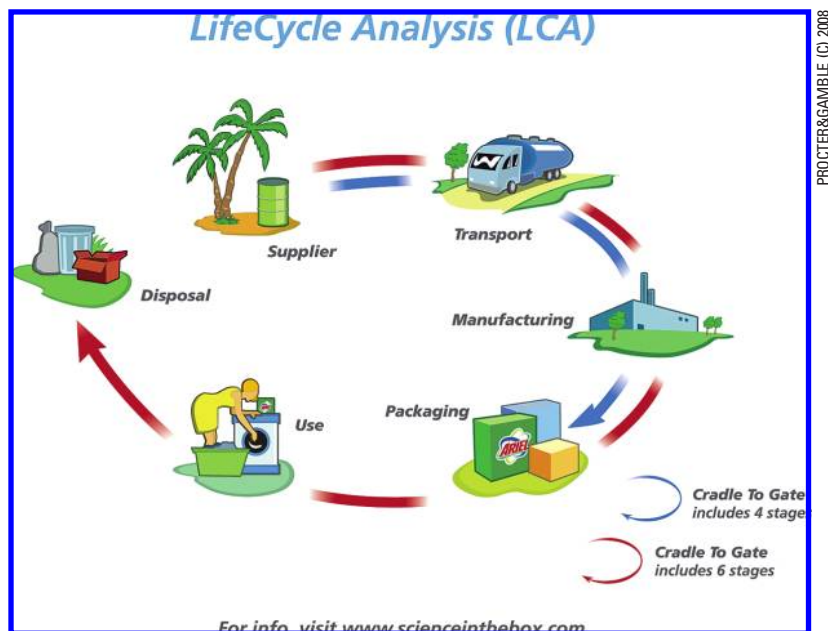


FIGURE 1. Life cycle analysis (LCA) as illustrated by Procter & Gamble. See the SI for a longer discussion of this particular example.

products often involves disruptive changes for a manufacturing plant and, within the context of conventional business practices, can be difficult to justify. Other nontechnical barriers include slow turnover of existing equipment, higher upfront costs, slow return on investment, limited incentives, inflexible regulations, and customers' demand that sustainable alternatives must also be superior to existing products. Case studies and discussion of these barriers can be found in refs 2 and 6.

The academic frameworks of "innovation systems" (7–10) and "technological transitions" (11) have analyzed social and other nontechnical barriers and incentives to technology adoption and provide useful heuristics for the problem at hand. The reader interested in exploring these models is directed to references 7–12. However, the discussion presented here does not aim to position itself as a study of socio-technical evolution. While this topic would and has benefited from such analysis (9, 12, 13), the authors leave that work to the discipline's practitioners.

A recent American Chemical Society (ACS) and American Institute of Chemical Engineers (AIChE) workshop explored the nontechnical barriers and incentives to industrial implementation of sustainable technologies and practices. This workshop was specifically designed both to gather information from those driving this transition "on the ground" and to help inform their ongoing efforts. The workshop assembled approximately 40 academic and industrial scientists, engineers, consultants, and educators—all respected practitioners of sustainability—at the April 2008 joint AIChE/ACS national meeting in New Orleans.

Prior to the workshop the participants received background reading (2, 14–23). An oral symposium of invited keynote (24–26) and case study presentations (27–31) kicked off the event, framing issues of sustainability in the broadest context and giving attendees a starting point for further discussion. (The workshop format, background, and symposium presentations are available at www.acs.org/sustainability_barriers.) An evening poster session then provided an initial opportunity for participant input.

The following morning, the participants divided into four groups for discussion of barriers and incentives to sustainability in industry. Each group focused on one previously

identified barrier class: (A) Economic and Financial; (B) Regulatory: Environment, Health, Safety, and Product Quality; (C) Educational: Students and Professionals; and (D) Organizational and Cultural. Following group discussions, the participants reassembled to present and discuss their conclusions.

The workshop's organizers collected the comments and identified common themes among the breakout groups. This Viewpoint is the authors' synthesis of those presentations and discussions. It should be noted that the ideas of this paper are presented for the purposes of promoting discussion and have not been adopted by ACS, AIChE, or any other institution associated with this work.

Outcome and Discussion

The workshop discussion produced five overarching themes on overcoming nontechnical barriers to sustainability: (1) establish a clear, measurable, actionable, and universally accessible definition of sustainability; (2) create and disseminate better information for better decision-making; (3) reframe sustainability as an opportunity, investment, and pathway to innovation so it becomes a top priority; (4) tear down silos within and among organizations and build cross-functional teams; and (5) develop forward-thinking, collaborative regulations or incentives that can adapt to changing circumstances.

Similar barriers have been identified previously (2, 6, 13). Many of these challenges involve shifting from a current attitude to another, more sustainable outlook, as summarized in Table S1 in the Supporting Information (SI), itself drawn from a poster at the meeting (32). Sustainability requires a new way of thinking, whether about the value of our resources, the costs of our actions on society as a whole, the relationship of our job function within the corporate structure, or any of a number of similar philosophical concepts. Business as usual will not bring about a sustainable chemical industry, and participants made their recommendations with a clear sense of urgency. Each recommendation theme is discussed below, with specific examples from the workshop presentations provided in the SI.

Establish a Clear, Measurable, Actionable, and Universally Accessible Definition of Sustainability. An accurate, concise, and well-known definition of sustainability has existed since the 1987 Brundtland Report (33) and been echoed widely (4, 34), including (notably for this discussion) by member organizations within the chemical enterprise such as in the ACS policy statement “Sustainability of the Chemical Enterprise” (35). However, discussion of definitions continues (36, 37), both in terms of proper messaging (38) and practical applications such as metrics: indicators, objectives, and criteria (13, 19). The workshop participants identified the need for an actionable definition of sustainability as a major barrier to its attainment.

The complexity of the chemical and related industries requires focused “working definitions” that translate sustainability into the language of each sector to answer each employee’s question “What does sustainability mean for me?” The answer needs to address both technical and nontechnical issues and be actionable and measurable, defined by clear goals and associated metrics to monitor progress. Further, the definitions must be flexible—able to respond to improving information and changing problems and opportunities. Sustainability is not a “landing place” but a dynamic state (13, 39), as described by the AIChE Institute for Sustainability, which has called it “a path of continuous improvement” (40).

Many of these needs are being addressed with green engineering and chemistry principles (41), and efforts to develop sustainability metrics (19, 42–44). Dave Gustashaw of Interface America emphasized the need to translate sustainability into engineering language (Figure; explained in SI) (29). However, a key challenge is that the definition developer must have expertise in two areas: intimate knowledge of the specific audience and a strong understanding of the elusive concept of sustainability.

Create and Communicate Better Information for Better Decision-Making. Decision-making occurs on a variety of scales: a customer choosing products, a company sourcing raw materials, or a corporation making capital investments. Larger scale decisions have larger and more long-lasting impacts, both financially and environmentally, but decisions at all levels can aid or impede a shift toward sustainability. All decisions would benefit from more timely, complete, and accessible information, which would allow decision-makers to see the impact of their choices. The most sustainable choice is not always intuitive and can shift with evolving technology, new information, or simply a change in locality.

Each product needs a sustainability profile to inform purchasing decisions, including a life cycle analysis (LCA) that travels both up and down the supply chain. At the workshop symposium Procter & Gamble presented examples of how their LCA work informs their sustainability decision-making (Figure S2) (31). LCA is an excellent framework for evaluating sustainability, ensuring consideration of impacts at each stage of a product’s life. Other LCA examples can be found in references 45 and 46 and elsewhere.

Workshop discussions mirrored suggestions found in the literature (2, 13, 37) and specifically called for information that would quantify the value of sustainability and translate it into the dollars-and-cents language that is currently engrained in business decisions. This “sustainability accounting” would include direct costs: storage, transportation, treatment and disposal of materials; and also indirect costs: regulatory compliance, liability (20), worker health and safety, corporate reputation, and community relations. Sustainability accounting should also capture the social and environmental consequences that currently vanish into externalities. Knowledge of true costs would improve the consumer market for sustainable products and create a business case for decisions that favor sustainability. It would also help inform corporate investment decisions, improve

management and shareholder understanding, control return-on-investment expectations, and—another well-recognized need (13, 19)—encourage longer-term thinking.

However, generating, managing, and distilling the quantity and quality of information needed for reliable sustainability accounting and LCA is a massive undertaking. Furthermore, the information must be continually refreshed with updated or improved knowledge.

The participants called for governments and academia to provide tools for creating and disseminating this information including decision aids and databases, and for corporations and governments to find ways for companies to share information while protecting confidential business data and intellectual property. The participants echoed a point made in John Warner’s presentation (Figure S3) (24) and elsewhere (1): scientists and engineers have a particular role to play in developing the required information. Just as researchers originally determined the physical and chemical properties of substances such as melting and boiling point, solubility, and electrical conductivity, they are now best equipped to determine new properties of interest—toxicity and environmental impact—and to help quantify the environmental life cycle costs of a product or process. An interesting discussion of the necessary information can be found in reference 36.

Finally, better decision-making also requires better education and communication. The consumer choosing products, the employee sourcing raw materials, and the executive making investments must all know how to gather and use the available information. The participants called for improved grade-school curricula and workplace training while also emphasizing unconventional opportunities. In particular, policies that avoid “preaching to the choir” were advocated such as continuing education credits for teachers, green building certification that requires public buildings to educate their users, and sustainability grant programs for employee workshops, museums, news outlets, advertising, Internet sources, and other informal learning programs.

Make Sustainability a Top Priority; Reframe Sustainability As an Opportunity, Investment, and Pathway to Innovation. Though sustainability is of paramount global importance, workshop participants noted that it remains too low a priority at the local scale. Sustainability is still approached as environmental compliance issues have been for decades: after product development and only to meet regulations. This end-of-pipe approach typically adds cost and operational burden, but if sustainability were more fully integrated—considered in initial project planning and each subsequent step—it would present opportunities for innovation, superior product development, and cost savings. This notion is inherent within the principles of green chemistry and green engineering (4, 18, 41, 47, 48).

Participants echoed a point made in Andrea Larson’s (26) and Mark Curran’s (27) presentations and often discussed by practitioners of industrial ecology (49, 50) and cradle-to-cradle design (15): sustainability should be reframed as a competitive advantage and driver for innovation to make it a priority for decision-makers (Figure S4.)

In turn, realizing the full innovative potential of sustainable design requires the vision and commitment of leadership to make it each employee’s mission and build it into every stage of product and process development. The need for strong leadership has also been recognized elsewhere (14, 19). A truly sustainable company must also integrate environmental and human welfare concerns into every aspect of operations, from the corporate mission to product launch(es) to the selection of office supplies. Mark Curran’s presentation (Figure S5) (27) describes how the Shaw Group embeds sustainability in its client’s corporate structure to encourage both horizontal and vertical buy-in.

Research has developed technical methods for considering sustainability at the outset of process design (39, 44), and strategies to incorporate sustainable thinking into a corporate culture can be taken from successful quality programs such as Six Sigma. These programs build quality within and without—from the supply chain out to the customer—and make production quality the responsibility of all employees and the mission of the company.

Other, more far-sighted policies such as making sustainability an educational priority would more fully embed its values into society and cultivate leaders and staff who promote sustainability in the workplace. Sustainability should be incorporated into all curricula, featured in school operations (described in 51), and even added to high-stakes events such as accreditation, achievement tests, and grant awards to make sustainability as important in school as for the world. Professional societies can similarly promote sustainability: practicing it themselves, recognizing and rewarding sustainability achievements, and requiring sustainability assessments in submitted papers and presentations.

Tear Down Silos and Build Cross-Functional Efforts. Sustainability deals equally and simultaneously with environmental, social, and economic issues, and necessitates multi-disciplinary, multi-stakeholder work. The workshop discussions identified the conventional tendency of organizations to “stove-pipe” or operate within silos as a barrier to sustainability, particularly within academia, industry, and government.

Academia: Schools must incorporate sustainability into all disciplines and consider it a general educational requirement. This topic has been inappropriately confined to the environmental science curriculum, though it is actually a core concept embodying social welfare, culture, science, and economics. In addition to new texts and courses, curriculum changes should make a concerted effort to nurture creative and collaborative problem solving across disciplines (science, law, or business management) and among varied stakeholders such as the public, industry, and government. Academia should similarly increase its support for collaborative research among the traditional scientific, economic, and social science fields. Such initiatives should include specific recognition for interdisciplinary work which is still difficult to publish, vet, and fund within conventional systems. The work done at Arizona State University is a flagship example of such efforts.

Industry: Operations within industry divide sharply at the business unit and corporate level with each silo concerned only with its function: research and development, manufacturing, marketing, etc. Sustainability concerns go only to the environmental compliance office, while other employees consider it “not my job” (26, 27), a holdover from the conventional and simplistic treatment of environmental and health needs as regulatory compliance. However, sustainability requires buy-in and cooperation across an entire organization, with agreement on common goals and methods for accountability (13). The Six-Sigma-style program suggested earlier would encourage such collaborative work, establishing an infrastructure of cross-discipline teams.

Government: Government agencies are also organized as silos and do not communicate well within or between agencies or among local, state, and federal levels. This obstructs the development of the sort of cross-jurisdictional regulatory measures that are needed to encourage innovative and sustainable solutions (see below).

In addition to cross-functional work within organizations, there is a need for external work between organizations: companies with each other, with nongovernmental organizations (NGOs), and with governments. This need has been recognized widely in the literature (2, 13). Input and

interactions outside an organization can inspire improvements, seed new ideas, and help corporations stay abreast of this emerging field. However, the workshop participants noted that legal concerns such as trade secrets, price fixing, and *ex parte* communication often hinder collaboration and communication among companies. Legal prohibitions also restrict cooperation between regulatory agencies and the regulated community, resulting in stilted and incomplete negotiations rather than problem-solving. Many participants had also found that while NGOs have successfully helped organize voluntary programs for companies to overcome such barriers, other programs have been challenged as collusion and/or avoidance of agencies’ regulatory authorities. Out of this mistrust, a widespread agreement to collaborate must emerge. As discussed below, governmental policy is needed to create “safe harbors” for partnerships that can fairly and openly involve all stakeholders (2).

Develop Forward-Thinking, Collaborative Regulations or Incentives with the Capability to Adapt. The workshop participants envisioned a sustainable path for the chemical and related industries that will be fundamentally different from current practice. Traditional government regulations have become an inappropriate tool to help industry evolve toward this goal. Even worse, they stand to hinder that evolution. For example, attempts at industrial ecology encounter regulatory hurdles such as the classification of a potential feed stream as “waste”. Similarly, the approval burden for green process improvements is the same as for other changes, though a fast-track approval option would encourage greener practices. Corporations find that it costs too much time, labor, and external legal or consultant fees to achieve sustainable outcomes within the myriad regulatory systems. Participants identified five qualities of governmental management strategies that would encourage a transition to sustainability:

- (1) Regulations that are outcome-oriented to drive innovation and sufficiently flexible to accommodate it. Engineers and scientists need freedom from overly prescriptive regulations to envision, build, and evaluate the changes needed to achieve sustainability (2).
- (2) Government management strategies that are broad enough to have industry-wide impacts and ensure a level playing field, yet flexible enough to be tailored to specific industrial operations. Different industry sectors will have different sustainability issues depending on products and processes, location, supply chain, and life-cycle considerations.
- (3) A regulatory framework that integrates local, regional, national, and international concerns to avoid conflicts in jurisdiction and allow issues to be addressed on their appropriate geographical level. A plant’s sustainability issues depend on its locality, and unsustainable practices have impacts with widely varying spatial and temporal scales. For example, smog is mostly local and temporary, greenhouse gases are long-lived and global, water use has local and regional impacts, and excessive packaging or tainted products have impacts wherever customers reside. As also described in reference 52, jurisdiction should logically follow these scales and be coherently integrated.
- (4) Careful, ongoing evaluation to ensure that regulations are delivering the anticipated benefits and are not negated by unanticipated outcomes. History is full of examples of unintended consequences, and the literature stresses the value of such reassessment (13, 52).
- (5) Government regulations that identify and prioritize sustainability challenges by consulting a range of stakeholders. As alluded to above, the process for selecting stakeholders and evaluating and weighing

their input must be well-defined and established to avoid the appearance of collusion or favoritism. Stakeholders' work should assess the relevant sustainability and life-cycle issues (48) of each significant industrial sector or facility in their jurisdiction and prioritize improvements within the context of the local, national, and international needs.

If governments adopt these guidelines to promote and manage evolutionary change and industries and educators work to integrate, foster, and prioritize sustainability, the ultimate outcome should be more sustainable industries.

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Supporting Information Available

Elaborated discussion of the themes presented here including specific examples. This information is available free of charge via the Internet at <http://pubs.acs.org>.

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