



**THE  
SUSTAINABLE  
SOLUTIONS  
AGENDA**

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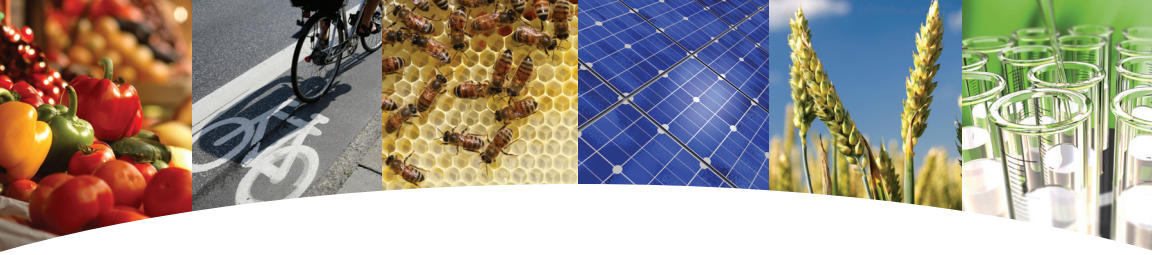
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Progress toward a more sustainable society is usually described in a “knowledge-first” framework, where science characterizes problems in terms of their causes and mechanisms as a basis for subsequent action. Here we present a different approach, which seeks from the outset to identify the possible pathways to enhanced sustainability.

The Sustainable Solutions Agenda (SSA) focuses on uncovering paths to sustainability by improving current technological practice, and applying existing knowledge to identify and evaluate technological alternatives. The SSA enables people and organizations to transition toward greater sustainability without sacrificing essential technological functions, and therefore does not threaten the interests that depend on those functions.

Whereas knowledge-first approaches view scientific information as sufficient to convince people to take the right actions, even if those actions are perceived as against their immediate interests, SSA allows for values to evolve toward greater attention to sustainability as a result of the positive experience of solving a problem.



## SUSTAINABILITY AND SCIENCE

The challenge of reconciling societal aspirations and environmental limits is captured by the term “sustainability.” There are good reasons to believe that society is on an unsustainable path for the longer term. And, while no one knows exactly what a sustainable path might look like, we think we know good ways to start down that path – reducing fossil fuel dependencies, for example. We are told nearly every day that global climate change is the most urgent consequence of our current unsustainable path, and a complex web of causes and effects can already be seen in recent spikes in oil and food prices all around the planet. These ripples in the global economy illustrate how everything really is connected to everything else; how the long-term consequences of actions taken in the present are very difficult to predict; how the social, environmental and economic costs and benefits of even well-intentioned actions may be unevenly distributed; and how the momentum of a society committed to continual economic growth via competitive markets can be extraordinarily difficult to redirect.

Recognition of the urgent need to identify effective solutions to planetary problems like global warming has focused increased attention on studying the complex systems, like climate, from which these crises seem to arise. There are many efforts underway to define and develop “sustainability science,” “systems science,” and other related approaches (Clark and Dickson 2003; Komiyama and Takeuchi 2006). We are also exploring these concepts, and in this paper, we explain our view of how best to link knowledge and action to the quest for greater sustainability, and contrast what we have learned in the course of our scientific work with other perspectives.

Science is widely recognized as a crucial tool for moving toward a more sustainable world. This recognition flows from the assumptions that:

1. additional scientific understanding about society-nature interactions is necessary to define a path toward sustainability;
2. greater understanding will guide the decisions allowing society to follow that path; and
3. this understanding will also motivate people to make the behavioral changes necessary to act more sustainably.

In this view, which we think is implicitly and widely held, knowledge comes first, then action. The “knowledge first” approach is a core assumption of modern society, where rational action is viewed as deriving from factually correct assessments of the causes of a problem.

One example of a knowledge-first approach to sustainability is risk assessment (and related methods like cost/benefit analysis): first characterize the costs and benefits, and then make choices accordingly. Risk assessment is widely viewed as a necessary input into rational decision making for sustainability issues such as environmental health, and is enshrined in many policies that regulate chemicals and materials. Risk assessment has also been justly criticized for being overly narrow — focusing on a single technology or chemical, and reducing social questions like: “do we want this technology?” down to the narrow “is there strong evidence that this technology is too risky?” (Bailar and Bailer 1999).

While risk assessment is reductionist, other knowledge-first approaches have a systems-level focus. “Sustainability science” was born from a critique of conventional science as not up to the challenge of confronting complexity. In strong contrast to risk assessment and its cousins, sustainability science “seek[s] to address the essential complexity” of human-environment interactions, recognizing that “understanding the individual components of nature-society systems provides insufficient understanding about the behavior of the systems themselves.” Sustainability science demands “close collaboration between scholars and practitioners,” and it aims at “creating and applying knowledge in support of decision making for sustainable development.” (Clark and Dickson 2003). This approach has been central



## KEY CONCEPTS

1. The role of science in sustainability is often portrayed as establishing the basis of understanding of a problem necessary to guide action – the “knowledge -first” approach.
2. Knowledge-first approaches, such as risk assessment, often become mired in technical disputes about weight of evidence and uncertainty, and have failed to yield sustainable solutions.
3. Research focusing on solution paths and technological alternatives, rather than problem characterization, can avoid or reduce the obstacles to action common to knowledge-first approaches.
4. Technologies that harm the environment are often integral to people’s livelihoods and ways of life. The Sustainable Solutions Agenda helps overcome the problems of complexity, uncertainty, and political conflict by allowing people to maintain livelihoods while making progress toward greater sustainability.
5. Ongoing work at the Toxic Use Reduction Institute and the Lowell Center for Sustainable Production provides real-world examples of the SSA approach.

to the strategy followed thus far for climate change, where a comprehensive international research program is intended to both inform and motivate a global transition away from fossil fuels. However, while we support the call for studying systems rather than individual risks, both risk assessment and sustainability science remain well within the bounds of the “knowledge first” paradigm.

## RESEARCH FOR SOLUTIONS

We are setting out a different way to find pathways to a more sustainable society. Acknowledging the complexity of the planet and of societies, we will draw a distinction between our approach and all “knowledge first” views of science for sustainability. What we call the Sustainable Solutions Agenda (SSA) responds to the reality that humans live in and depend on a technological world. Humans and their organizations produce and use technologies continually to accomplish important tasks with high reliability. At the same time, technologies play a central role in the important threats to sustainability. SSA recognizes and responds to these dual realities by focusing on the uses of technology in the real world, in the present, to ask: what opportunities exist for steering the design, production, and use of technologies away from unsustainable practices toward more sustainable ones, without sacrificing the value of these technologies?

SSA is thus at once visionary and pragmatic. On the one hand, it aims at a world where technologies are less harmful to humans and to nature, but on the other hand it assumes that often this vision can be most rapidly achieved through incremental introduction of alternatives and solutions without waiting for comprehensive knowledge of the relevant nature-technology systems. SSA of course recognizes that action must be informed by evidence. But rather than assuming that detailed systems knowledge will be the key to action, SSA recognizes that the possibility of positive change will motivate further change, without waiting for a convergence of people’s values and interests. SSA seeks to identify a path for incremental political evolution toward sustainability in a world where political power is often concentrated in organizations, institutions, and corporations that are structured to resist such change.

SSA has the goal of helping humanity live sustainably on the Earth. It is a program of integrated research and practice whose purpose is not simply to understand the world better, but to inform and motivate social actions towards sustainability.

SSA is informed by a long-term vision of technological change, but it is focused on uncovering paths to sustainability by improving current technological practice, applying admittedly limited knowledge to identify

and evaluate technological alternatives. This practical and immediate emphasis is tempered by a commitment to continuous improvement in the future—and the recognition that some solutions will turn out to be mistakes, or deadends. It is inherently collaborative: the users of unsustainable technologies are sources of expertise that are essential to identifying feasible paths of change. Its orientation toward near-term solutions creates positive feedbacks and a sense of progress, empowerment, and shared mission. SSA integrates research and analysis with action aimed at social and technological change; these activities are inseparable and simultaneous. In our view, more knowledge is not a prerequisite for action; knowledge and action advance together. SSA therefore creates major challenges for institutions devoted to advancing sustainability, since many such institutions—universities especially—are structured around knowledge-first approaches.

### **THE MONTREAL PROTOCOL: AN UNRECOGNIZED EXAMPLE OF SSA**

An historical example may help to contrast SSA with knowledge-first approaches. The Montreal Protocol on Substances that Deplete the Ozone Layer is often cited as a signal success in applying systems-level knowledge to a problem of sustainability. The standard portrayal of this international agreement to phase out the production of chlorofluorocarbons (CFCs) follows the knowledge-first model: researchers discovered that CFCs depleted the Earth's stratospheric ozone layer, and as knowledge became increasingly certain, action ramped up to deal with the problem, culminating in an international agreement to phase out production signed by most of the world's nations.

Different tellings of this story emphasize different aspects, such as diplomacy (Benedick, 1998), corporate incentives (Maxwell and Briscoe, 1997), and scientific assessment activities (Parsons, 2003). But they all largely neglect a critical aspect of “the system” CFCs provided essential functions as refrigerants and solvents upon which many sectors of society depended. These functions could not have been sacrificed without social disruption and financial losses for important economic sectors. Early actions, such as the phase-out of CFC-propelled aerosol cans,



were easy because alternatives for non-essential functions already existed; roll-on deodorants could substitute for spray cans for example. Such changes occurred even when scientific uncertainty about CFC impacts was high, but they created a sense of possibility and momentum, consistent with the SSA approach. A complete production phase out become practically and politically possible only when alternative chemicals serving the same essential functions (like keeping food cold and semiconductors clean) began to come on line. While the standard story is one of knowledge compelling action, the SSA perspective shows that decisive action only became possible once alternatives were identified, and that there was a dynamic relationship between knowledge and action that was more complex than first one, then the other.

Why is the CFC story conventionally related as one of action enabled by new knowledge rather than one of problem-solving enabled by technological substitution? The idea that problems are solved first by generating necessary new knowledge, and then taking rational action, is powerfully held in modern culture and is an enduring legacy of the Enlightenment. As we will discuss below, “knowledge first” is also an important justification for academia, with its emphasis on “pure” knowledge acquisition and academic freedom.

## PROBLEM SYSTEMS VERSUS SOLUTION SYSTEMS

Sustainability science, in the knowledge-first mode, seeks to holistically characterize a problem in terms of its *causes and mechanisms* as a basis for subsequent action—the system of interest is that which contains the problem. The SSA, in contrast, seeks to identify the possible pathways to solutions within the system—the *system of interest is that which contains the solutions*. This is a key distinction. For example, the industrial solvent methylene chloride is known to be toxic, but the mechanisms of its toxicity are not well understood. A knowledge-first approach might focus on developing a better understanding of how methylene chloride behaves in the environment and in the body as prerequisites for developing interventions. SSA focuses on understanding why and where methylene chloride is used as a basis for identifying alternative practices of production and use, and approaches to implementing those practices.

A more familiar example is global warming. The problem space for global warming is the climate system; the solution space is the global energy system. The latter is nested in the former and of course cannot be ignored, but the energy system (including energy consumers) must be understood in order to identify feasible, practical steps to reduce and mitigate global warming. By far the greatest focus of research on global warming, consistent with the knowledge-first mode, has been aimed at better understanding of the coupled atmosphere-ocean system and its links to the biosphere and society. The idea is that this research will motivate the right political responses. Yet if one views the problem from the perspective of the solution system—the energy system—alternative technological pathways toward greater sustainability have always been available, and the problem becomes one of how to motivate exploration of these pathways.

The result of emphasizing knowledge of the problem system over action in the solution system is that we now find ourselves with strong evidence that the planet is warming, but decades behind where we might have been in developing and disseminating solutions, had we taken more seriously the political opportunities created by technological alternatives.

## **FROM KNOWLEDGE TO ACTION**

The SSA obviously depends upon scientific evidence, typically created in the knowledge-first mode, about the environmental and health implications of various phenomena, chemicals, materials, and practices. Moreover, SSA is not an argument against efforts to better characterize those implications. Rather, SSA is a mode of integrated inquiry and practice that moves from a domain of imperfect knowledge and ever-present uncertainty that always characterize a problem, to a domain of potential action based on the search for and availability of a solution.

The need to act in the face of uncertainty has different implications for researchers depending on assumptions about the links between evidence and action. The “knowledge first” approach often ends with the publication of results in a scientific journal or report, without specifying possible avenues of action. This caution appears justified both because absolute proof is not possible, and because knowledge acquisition is conceived as separate from

action. Again turning to the climate change example, the scientific assessment activities of the Intergovernmental Panel on Climate Change are intentionally insulated from implementation activities, for example those occurring under the UN Framework Convention on Climate Change. In bringing science and action together, SSA assesses the weight of evidence needed to draw conclusions, and views the potential for action in terms not just of the strength of evidence of harm or benefit, but also in terms of the ability to identify and implement potential solutions.

Lead, a neurotoxin and probable carcinogen, is still used pervasively in the production of electronic equipment, which in turn is the fastest growing source of waste in industrialized countries. If the challenge is to reduce the use of lead in the electronics industry, this means simultaneously conducting research to identify substances and processes that can substitute for lead solder and other uses of lead in electronics; working directly with the electronics industry to encourage substitution; working with policy makers to create incentives for substitution; and encouraging feedbacks among these and related activities to allow for learning and accelerated change.

Or if the challenge is to eliminate PCE, a volatile and toxic chlorinated hydrocarbon used in the highly decentralized, low-tech dry-cleaning industry, this means developing pilot programs to demonstrate that alternative wet-cleaning technologies perform as well or better than dry-cleaning; creating an atmosphere where learning and technology adoption can proliferate among the thousands of small, locally owned establishments; and providing resources to aid in the initial investment in new wet-cleaning equipment for first adopters.

Or, if the challenge is to deal with a cancer cluster in a community, this may mean working with community members to address the most likely cause of the problem (for example, to seek alternatives to toxic chemicals used in a nearby factory) directly and in the short term, rather than engaging in lengthy epidemiologic studies which in any case are unlikely to find a “smoking gun” because the available research methods are still quite weak.

These thumbnail examples illustrate how SSA deals with the most vexing aspects of the sustainability challenge: *complexity, uncertainty about risk, and political conflict*. In essence, SSA avoids the obstacles created by these

factors by focusing on available solutions, incremental change, and preservation of functionality. It eases the tension between risk assessment and precautionary approaches by moving the discussion away from risk uncertainties and onto the potential benefits offered by technological alternatives. It avoids never-ending demands for more knowledge about complex system behavior by focusing on clear paths of positive change within the larger system. And it engenders a shared sense of progress by focusing on incremental and measurable improvement.

## DEALING WITH COMPLEXITY

SSA deals with *complexity* by focusing on **unsustainable practices** in society. SSA does not seek to fully characterize such practices within complex social and environmental systems. Rather it seeks intervention points where an activity (say, producing shoes) is tightly linked with an unsustainable practice (say, using volatile and toxic organic glues) for which more sustainable alternatives (say, using water-based glues) are either available or potentially available.

SSA deals with *uncertainty about risk* by moving discussions away from risk characterization and toward **alternatives assessment** (Quinn, Fuller et al. 2006; Rossi, Tickner et al. 2006). Complete understanding is never possible in characterizing the risk of a particular process, chemical, material, or practice. The continual existence of uncertainty supports competing views about acceptable risks, and sustains conflict about how to respond to risks (or even about whether the risk is “real”).

But because SSA allows people and organizations to transition toward greater sustainability without sacrificing essential technological functions, it does not threaten the interests that depend on those functions. The question is not (for example) “how toxic is this chemical or process?” or “what are the mechanisms by which this chemical affects human health” but “how can we change from using this plausibly toxic substance to using a plausibly more sustainable substance that allows us to do the same job?”

Thus, SSA deals with *conflict* by **changing and often lowering the stakes** associated with social change. The focus moves from characterizing a problem for which a person or organization is responsible, to specifying a solution

## PLAUSIBLY MORE SUSTAINABLE?

A challenge for SSA is to develop robust principles of “plausibly safer.” For example, the search for alternatives to hazardous chemicals and materials needs criteria for evaluating risks based on incomplete knowledge. An alternative might be considered an improvement over current practice if:

- The current chemical is persistent or bioaccumulative, and the alternative is biocompatible, biodegradable, or renewable; and
- The current chemical shows strong evidence of harm, and the alternative shows evidence of less harm, or shows little or no evidence of harm.

Because knowledge is always provisional, in most cases it will not be possible to entirely eliminate uncertainties about the benefits of potential solutions relative to current practice.

Thus, under the SSA framework:

- The alternative should always be subject to future surveillance; and
- The alternative should be amenable to flexible production or future substitution as part of a process of continuous improvement.

that offers potential benefits (some of which may have been previously unrecognized) and manageable costs.

SSA allows for values to evolve toward greater attention to sustainability as a result of the positive experience of solving a problem. This process contrasts markedly with knowledge-first approaches to sustainability, which view scientific information (typically focused on proving the causes and magnitude of future impacts) as sufficient to convince people to take the right actions, even if those actions are perceived as against their immediate interests.

## TRICHLOROETHYLENE REDUCTION IN MASSACHUSETTS

Trichloroethylene (TCE) is a solvent that has been targeted by US EPA and numerous states for replacement because of toxicity, including potential carcinogenicity, even as its human health effects remain disputed. TCE is commonly found at Superfund sites, and is particularly problematic because it can persist in groundwater and migrate into drinking water supplies. A main use of TCE is for degreasing metal parts, an application that creates a high risk of exposure to workers, especially in small firms that may be below the regulatory radar. These cleaning tasks can be performed with alternative organic solvents or with water-based cleaners. The latter are preferred because of the likelihood that the water-based cleaners are considerably safer and healthier than either TCE or any of the less toxic synthetic solvents.

The Massachusetts Toxics Use Reduction Institute (TURI), has been working with metal manufacturers to help them shift from TCE to safer cleaning solutions. TURI determined that a critical impediment to firms adopting safer alternatives was their concern that productivity and product specifications might suffer if they changed their standard metal cleaning procedures. To address this concern, the Institute built the Surface Solutions Laboratory specifically to evaluate the effectiveness of alternatives to TCE. TURI surveyed firms in Massachusetts that were potential TCE users to develop a roster of target firms, and then offered its services in assessing alternative parts cleaners. Assessments included tests at the Surface Solutions Lab using actual parts that the firms themselves needed to have cleaned, followed up in some cases by pilot projects involving on-site testing of alternatives in the firm's own facility. TURI also helped to develop cost-benefit-analyses for alternatives, and worked with State agencies and professional organizations to demonstrate TCE replacement possibilities at workshops and meetings in an effort to reach more firms.

Working in Massachusetts and Rhode Island, TURI's efforts have thus far led to a 67% decrease in TCE use among cooperating firms, from a total of more than 280,000 lbs/yr to 95,400 lbs/yr (TURI 2008). This effort has also led to the reduction in use of other volatile cleaning solvents. TCE replacements included non-chlorinated solvents with no known health risks, and water-based, ultrasonic cleaning processes.

In finding a path to sustainability, societies must make extremely difficult decisions. When we arrive at one of these decision points, we often find that facts are uncertain, values are in dispute, the stakes are high, and decisions are urgent (Funtowicz and Ravetz 1990). Under these conditions, conventional science is often too narrowly focused, slow, and overly cautious. Mistakes like the “Type III error” (providing an accurate answer to the wrong question) are common (Kriebel, Tickner et al. 2001). Also, the central question of causality (“how much global warming is due to anthropogenic greenhouse gases?” “how many people die from urban air pollution?”) is often a stumbling block for traditional science because of its insistence on the existence of a single truth which science can, with enough resources, identify (Sarewitz, 2004; Kriebel 2009). SSA views these questions differently, asking not “does X cause Y?” but instead “Given the possibility that X causes Y, is there a way to move toward more sustainable practice by replacing X while still preserving some or most of its benefits?”

Both SSA and sustainability science are committed to multi-stakeholder collaboration as an essential component of effective action. For sustainability science, collaboration between scientists and stakeholders aims at the production of knowledge that is “socially robust,” meaning both technically sound and socially acceptable (Gibbons, 1999). SSA, in contrast, is not centrally focused on knowledge production as a stimulus for action, but on stimulating concrete steps toward sustainability. Collaboration between SSA researchers and technology users (ranging from large firms to communities to individual households) aims directly at improving practice through technological substitution and changing contexts for decision making.

## **SSA IN ACADEMIA**

“Knowledge first” sustainability science is a product of the aspirations, organization and social structure of the American research university and its commitment to creating new knowledge. University programs focusing on sustainability are notably more interdisciplinary than most other academic fields, yet they are still populated by professors and students whose job is to generate new knowledge that can advance their careers, largely through publication in peer-reviewed journals and grants from government agencies. Rational action motivated by rigorously produced knowledge

is the model for how science stimulates social change, and sustainability science is the product of this culturally and professionally embedded view.

In contrast, SSA requires innovative institutional arrangements that do not fit easily into existing organizational models for universities, or anywhere else for that matter. The skills required to implement the SSA agenda include, but go far beyond, those necessary for conventional academic research, and demand not just scientific expertise in relevant areas but strong organizing, training, and community-building skills. And the measures of success lie not in new knowledge created, but in real-world solutions achieved. These criteria offer a stark challenge to universities, whose model of professional success starts with academic researcher as producer of new knowledge, yet whose missions increasingly include a focus on contributing more effectively to societal well-being.

## **WHAT'S NEXT?**

We have outlined an agenda for pursuing sustainability that starts with the recognition that humans are technological beings, and that people and organizations can make more sustainable choices about technological alternatives without sacrificing the functionality upon which they depend. SSA can thus help to create a new politics of sustainability, one catalyzed by the positive experience of incremental, beneficial change. While SSA neither obviates the need for more scientific knowledge, nor for new types of regulatory regimes, it does not demand that people change their behavior based on new knowledge or incentives, rather it highlights the options for positive change based on existing knowledge, laws, and technological alternatives. In this way, the path toward greater sustainability is discovered simultaneously with the evolution of both knowledge and values.

SSA as described here has been developed and is currently practiced at the Lowell Center for Sustainable Production (<http://sustainableproduction.org/>), and its partner institution, the Massachusetts Toxic Use Reduction Institute (<http://www.turi.org/>). An important short-term step for advancing the SSA agenda is to further develop easily communicated and relatively unambiguous criteria for making decisions about technological substitutions.



A core principle of SSA is that the path toward greater sustainability can be discovered by substituting “plausibly more sustainable” technologies and practices for existing, unsustainable technologies and practices. Formalizing such criteria would enable and encourage the wider adoption of SSA. We have presented some possible criteria for “plausibly more sustainable” as applied to toxic chemicals, and explained why such criteria are likely to be less scientifically and politically contentious than more traditional risk-assessment-based frameworks for regulating technologies. However, what we have offered is at best a first step based on our own experiences and knowledge.

An important next step is to convene international groups of practitioners working on alternatives assessment and technological substitution in areas ranging from toxic materials to agro-chemicals to energy technologies to develop a robust and expansive set of criteria for “plausibly more sustainable.” The continued political gridlock in the U.S. over regulation and management of new and existing chemicals, materials, and processes provides strong motivation for pursuing this alternative framework.

Over the longer term, progress in advancing SSA can be promoted along paths of education and of public policy. For example, the idea that at any given time, many technological paths are available for achieving a particular desired functionality (e.g., Edgerton, 2007) is not a central aspect of science and engineering education—but it should be. The gradual rise of sub-fields like green chemistry, and of new ways to think about functionality, like biomimicry, speak to the potential for more sustainable technological alternatives, but they remain rather marginalized relative to conventional disciplinary approaches. Creating a culture that encourages scientists and engineers to explore multiple paths to a desired functionality is probably best done during undergraduate and graduate training, and curricular modules could be developed to advance this goal.

Mainstreaming of SSA, however, will still require appropriate incentives created by government funding. Government programs for applied research and technological development, as well as health effects research, should always include assessment of alternative technological possibilities and opportunities. All major grants aimed at advancing particular avenues of technology, or

advancing knowledge about the health effects of chemicals, materials, and processes, should include alternative assessment activities. Agency program managers are thus a key population of potential change agents, and government “requests for proposals” a key vehicle for incentivizing the necessary change. Importantly—and consistent with SSA principles—both the educational path and the funding incentive path require only marginal shifts in resource allocations and practitioner behavior, rather than wholesale changes in priorities and practice.

A more ambitious policy goal would be the creation of a national Toxics Use Reduction Program aimed at institutionalizing SSA across a broad cross-section of technological and economic activities. The Massachusetts Toxic Use Reduction Act (TURA) provides one successful model and shows how states can test innovations in governance (Sarewitz, 2009). Key features of TURA include a surveillance process that identifies and lists chemicals of concern but does not directly regulate them, a focus on technological substitution rather than regulatory proscription, and support for capacity building to identify less hazardous substitutes for toxic materials. As newer areas of innovation such as nanotechnology and synthetic biology begin to bring new chemicals, materials, and processes into the world, a national-scale SSA-TURA approach to assessing and introducing these technologies could help ensure that innovation paths are more sustainable, and that the bruising political battles of past decades are defused and replaced by shared commitments to the continual discovery and exploration of a more sustainable future.

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