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Biography

Dr. Timothy M. Persons is the Chief Scientist and Managing Director of the Science, Technology Assessment, and Analytics team of the United States Government Accountability Office (GAO - the oversight, insight, and foresight entity of the U.S. Congress). In addition to leading advanced data analytic activities at GAO, he also directs GAO's science, technology, and engineering portfolio – including technology assessment, technical assistance, and engineering sciences groups as well as GAO's Audit Innovation Lab. In these roles he leads a large and diverse interdisciplinary team which advises Congress and informs legislation on various topics such as artificial intelligence, advanced data analytics, sustainable chemistry, biosafety and biosecurity, 3D printing, nanomanufacturing, homeland security systems, and freshwater conservation technologies, among others. He also directed the production and release of GAO's Best Practices Guides – Cost, Schedule, and Technology Readiness Assessment. Prior to joining GAO, Dr. Persons served as the Technical Director for the Intelligence Advanced Research Projects Activity (IARPA) as well as the technical lead for Quantum Information Sciences and Biometrics research groups for the Information Assurance Directorate at the National Security Agency.

Dr. Persons is a recipient of a 2016 James Madison University (JMU) Distinguished Alumnus Award, a 2014 recipient of GAO's Distinguished Service Award, a 2012 recipient of the Arthur S. Flemming award in recognition of sustained outstanding and meritorious achievement within the U.S. federal government; and a 2012 and 2010 recipient of GAO's Big Picture Award for significant project achievement involving the ability to look longer, broader, and more strategically at key national or global issues. He has also received numerous GAO Results through Teamwork awards for key accomplishments in high risk and high value transformative work for the Comptroller General.

In 2007, Dr. Persons was awarded a Director of National Intelligence Science and Technology Fellowship focusing on computational imaging systems research. He was also selected as the JMU Physics Alumnus of 2007. He has also served as a radiation physicist with the University of North Carolina at Chapel Hill. He received his B.Sc. (Physics) from JMU, a M.Sc. (Nuclear Physics) from Emory University, and a M.Sc. (Computer Science) and Ph.D. (Biomedical Engineering) degrees from Wake Forest University. He is a senior member of the Institute for Electrical and Electronic Engineers (IEEE), a council member (*ex officio*) of the National Academy of Sciences, Engineering and Medicine's (NASEM) Government-University-Industry Research Roundtable (GUIRR), a member (*ex officio*) of the National Academy of Medicine's Committee on Emerging Science, Technology, and Innovation, and a member of the Virginia Tech-Wake Forest University Biomedical Engineering and Mechanics (BEAM) Advisory Board.

United States Government Accountability Office

Testimony

Before the Subcommittee on Research and Technology, Committee on Science, Space, and Technology, House of Representatives

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CHEMICAL INNOVATION

Technologies for Making Products and Processes More Sustainable

Statement of Timothy M. Persons,
Chief Scientist and Managing Director,
Science, Technology Assessment, and Analytics

GAO-19-660T

GAO Highlights

Highlights of GAO-19-660T, a testimony before the Subcommittee on Research and Technology, Committee on Science, Space, and Technology, House of Representatives

Why GAO Did This Study

Chemistry contributes to virtually every aspect of modern life, and the chemical industry supports nearly 26 percent of the gross domestic product of the United States. While these are positive contributions, chemical processes and production can have negative health and environmental consequences. Mitigating these potential consequences requires thoughtful design and evaluation of the life cycle effects of chemical processes and products.

This testimony—based on a 2018 technology assessment, GAO-18-307—discusses (1) how stakeholders define and assess the sustainability of chemical processes and products, (2) available or developing technologies to make chemical processes and products more sustainable, (3) the roles of the federal government and others in supporting the development and use of more sustainable chemical processes and products, and (4) opportunities and challenges in the field of sustainable chemistry.

For the 2018 report, GAO selected for assessment three technology categories—catalysts, solvents, and continuous processing; interviewed stakeholders from various fields, such as government, industry, and academia; convened a meeting of experts on sustainable chemistry technologies and approaches; and surveyed a non-generalizable sample of chemical companies.

View GAO-19-660T. For more information, contact Timothy M. Persons at (202) 512-6412 or personst@gao.gov.

July 25, 2019

CHEMICAL INNOVATION

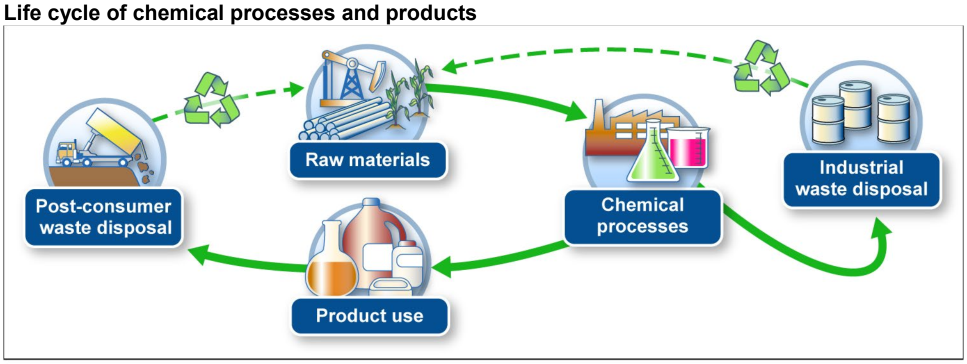
Technologies for Making Products and Processes More Sustainable

What GAO Found

Stakeholders vary in how they define and assess the sustainability of chemical processes and products; these differences hinder the development and adoption of more sustainable chemistry technologies. However, based on a review of the literature and stakeholder interviews, GAO identified several common themes underlying what sustainable chemistry strives to achieve, including:

- improve the efficiency with which natural resources are used to meet human needs for chemical products while avoiding environmental harm;
- reduce or eliminate the use or generation of hazardous substances,
- protect and benefit the economy, people and the environment using innovative chemical transformations;
- minimize the use of non-renewable resources; and
- consider all life cycle stages when evaluating a product (see figure).

Life cycle of chemical processes and products



Source: GAO. | GAO-19-660T

There are many technologies available and in development that can improve chemical sustainability at each stage of the chemical life cycle. GAO identified three categories of more sustainable chemistry technologies—catalysts, solvents, and continuous processing.

- Catalysts are used to make chemical processes run faster or use less material. Without catalysts, many everyday items such as medicines, fibers, fuels, and paints could not be produced in sufficient quantities to meet demand. However, the most common catalysts—including those used in automobile catalytic converters—are rare, nonrenewable metals such as platinum and palladium. Researchers are working to replace such metals with alternatives, including abundant metals (e.g., iron and nickel) where possible.
- Solvents are used to dissolve other substances so reactions can occur, to separate and purify chemicals, and to clean the equipment used in chemical processes, among other uses. Solvents constitute a large portion of the total volume of chemicals used in industrial chemical processes. However, many conventional solvents are considered hazardous. There are a variety of alternatives that can be used in some situations, including biobased solvents.

- An alternative to traditional batch processing is continuous processing, which allows chemical reactions to occur as the reaction mixture is pumped through a series of pipes or tubes where reactions take place continuously. Compared to batch processing, this approach can improve product yield, product quality, and process safety while reducing waste and costs.

The federal government and other stakeholders play several roles, sometimes in collaboration, to advance the development and use of more sustainable chemistry technologies. The federal government supports research, provides technical assistance, and offers certification programs, while other stakeholders conduct research, develop industry-specific standards, support workforce development development, and address chemicals of concern in consumer products, among other roles.

Strategic Implications

While using more sustainable options entails challenges--including technological, business, and industry-wide and sector-specific challenges, the field of sustainable chemistry has the potential to inspire new products and processes, create jobs, and enhance benefits to human health and the environment. Stakeholders identified strategic implications of sustainable chemistry and offered a range of potential options and realize the full potential of these technologies, including the following:

- Breakthrough technologies in sustainable chemistry and a new conceptual framework could transform how the industry thinks about performance, function, and synthesis.
- An industry consortium, working in partnership with a key supporter at the federal level, could help make sustainable chemistry a priority and lead to an effective national initiative or strategy.
- Integrating sustainable chemistry principles into educational programs could bolster a new generation of chemists, encourage innovation, and advance achievement in the field.
- A national initiative that considers sustainable chemistry in a systematic manner could encourage collaborations among industry, academia and the government, similar to the National Nanotechnology Initiative.
- There are opportunities for the federal government to address industry-wide challenges such as developing standard tools for assessment and a robust definition of sustainable chemistry. Federal agencies can also play a role in demonstrating, piloting, and de-risking some technology development efforts.

According to stakeholders, transitioning toward the use of more sustainable chemistry technologies will require national leadership and industry, government, and other stakeholders to work together.

Chairwoman Stevens, Ranking Member Baird, and Members of the Committee:

Thank you for the opportunity to discuss our work on sustainable chemistry, as the Committee considers the merits of H.R. 2051. The bill, among other things, encourages efforts to characterize sustainable chemistry among agencies and to incorporate sustainable chemistry into existing research and programs through the use of grants, loans, and other mechanisms. As we reported last year, chemistry contributes to virtually every aspect of modern life, from the production of food and clean drinking water to medicines, cleaners, personal care products, and a host of other products.[1] For example, the American Chemistry Council claims that in 2016 the chemical industry supported nearly 26 percent of the gross domestic product of the United States.[2] In addition, the Bureau of Labor Statistics estimates that the chemical manufacturing industry employed more than 858,000 people in June 2019 and the Department of Commerce estimated that the sector generated an additional 2.7 million indirect jobs via industry suppliers.[3] Despite these positive contributions to quality of life and other social and economic goals, chemical production can result in negative health and environmental consequences.

Many in the chemical industry are working to address these issues through improving the environmental sustainability of their own chemical processes and providing more sustainable products and technologies to others. For example, Pfizer won a Presidential Green Chemistry Challenge Award for redesigning the manufacturing process for the active ingredient in Zoloft®, an antidepressant. The company streamlined a three-step chemical process into a single step and eliminated the use of four hazardous solvents, including methylene chloride, by using a more

[1]GAO, *Chemical Innovation: Technologies to Make Processes and Products More Sustainable,* GAO-18-307 (Washington, D.C.: Feb. 8, 2018).

[2]American Chemistry Council, 2018 Elements of the Business of Chemistry, accessed June 25, 2019, https://www.americanchemistry.com/2018-Elements-of-the-Business-of-Chemistry.pdf.

[3]Bureau of Labor Statistics, U.S. Department of Labor, *Industries at a Glance*, accessed July 9, 2019, https://www.bls.gov/iag/tgs/iag325.htm; International Trade Administration, Department of Commerce, *Chemical Spotlight: The Chemical Industry in the United States* (based on 2016 data), accessed June 25, 2019, https://www.selectusa.gov/chemical-industry-united-states.

benign solvent, ethanol.[4] In the end, the new process used two solvents instead of five and reduced the total volume of solvents used by 76 percent.

Members of Congress have expressed interest in sustainable chemistry by including a provision in the American Innovation and Competitiveness Act that supports federal coordination of sustainable chemistry research and development, and by introducing H.R. 2051, the Sustainable Chemistry Research and Development Act of 2019, to provide for federal coordination of activities supporting sustainable chemistry, and for other purposes.[5]

In my testimony today, I will discuss (1) how stakeholders define sustainable chemistry and assess the sustainability of chemical processes and products; (2) available or developing technologies that can improve the sustainability of chemical processes and products; (3) how the federal government, industry, and others contribute to the development and use of such technologies; and (4) opportunities and challenges in the field of sustainable chemistry.

My testimony is based on a technology assessment we issued in 2018.[6] For that report, we reviewed key reports and scientific literature; interviewed approximately 80 stakeholders, including federal and state officials, chemical companies, industry and professional organizations, nongovernmental organizations (NGO), academics, and educational institutions; conducted site visits to federal laboratories; and attended two technical conferences. In addition, we collaborated with the National Academies to convene a 2-day meeting of 24 experts on sustainable chemistry technologies and approaches. We also surveyed a non-

[4]Methylene chloride, also known as dichloromethane, is a chemical solvent used in a wide range of industrial, commercial and consumer applications, such as paint stripping, pharmaceutical manufacturing, and chemical processing. In December 2016, EPA included it in a list of 10 chemical substances that are the subject of EPA's initial chemical risk evaluations. 81 FR 91927, Dec. 19, 2016. EPA was required to publish this list by the Toxic Substances Control Act as amended by the Frank R. Lautenberg Chemical Safety for the 21st Century Act. 15 U.S.C. § 2605(b)(2)(A). EPA issued a final rule in March 2019 to prohibit the manufacture (including import), processing, and distribution of methylene chloride in all paint removers for consumer use due to the unreasonable risk of injury to health. 84 FR 11420, Mar. 27, 2019.

[5]American Innovation and Competitiveness Act, Pub.L. No. 114–329 (2017); Sustainable Chemistry Research and Development Act of 2019, H.R. 2051 (2019).

[6]GAO-18-307.

generalizable sample of 27 chemical companies that were involved in or interested in developing and implementing relevant technologies. More detailed information on our objectives, scope, and methodology can be found in that report.

We conducted the work on which this statement is based in accordance with all sections of GAO's Quality Assurance Framework that are relevant to technology assessments. The framework requires that we plan and perform the engagement to obtain sufficient and appropriate evidence to meet our stated objectives and to discuss any limitations to our work. We believe that the information and data obtained, and the analysis conducted, provide a reasonable basis for the findings and conclusions in this product.

Background

The chemical industry relies on the use of natural resources as inputs to make chemical products, and the industry's outputs, in turn, can have an impact on the environment.[7] The International Trade Administration of the Department of Commerce identifies the chemical industry as one of the largest manufacturing industries in the United States, with more than 10,000 companies producing more than 70,000 products.[8]

The term 'sustainability' can have many interpretations depending on the context in which it is used. Sustainability may refer to economic, environmental, or social sustainability. Achieving all three—a concept known as the "triple bottom line"—has become a goal of some businesses, including many in the chemical industry.

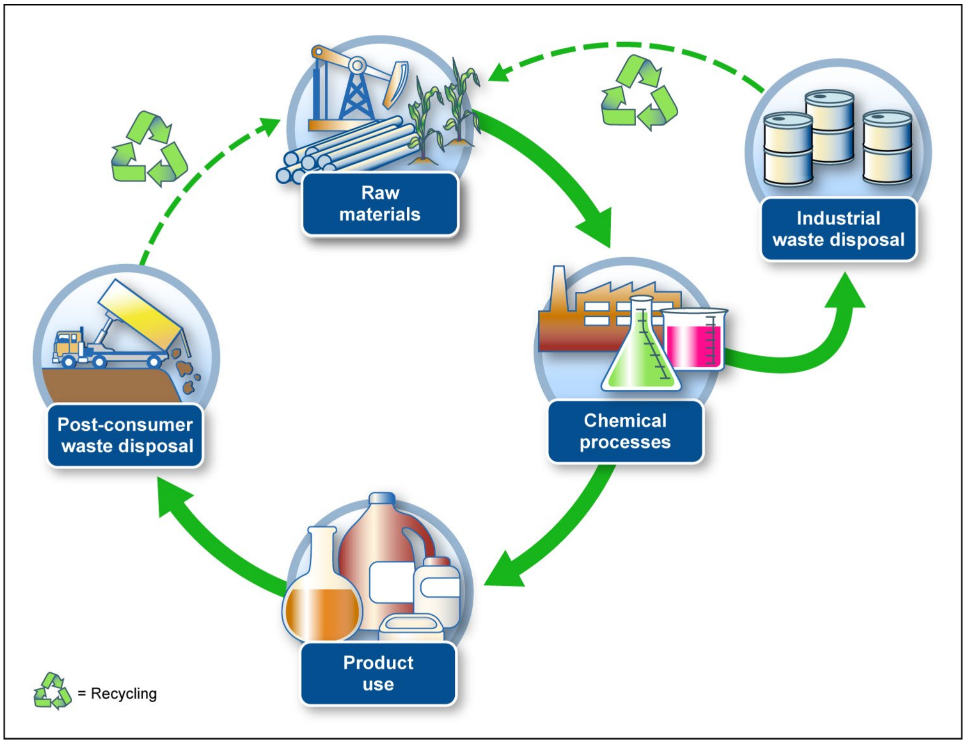
Mitigating the potential negative health and environmental consequences of chemical production requires thoughtful design and evaluation throughout the life cycle of chemical processes and products —that is, a thorough assessment of effects resulting from stages of the life cycle such as sourcing the raw materials, processing raw materials into products, handling and disposal of by-products and industrial waste, product use, and end-of-life disposal or recycling (see fig. 1). Attempting

[7]For purposes of this testimony, the term 'chemical product' includes a wide variety of products manufactured by chemical companies, including single chemicals (e.g., methanol, ammonia) and other products made with chemicals or mixtures of chemicals (e.g., pharmaceuticals, cleaning products, cosmetics).

[8] U.S. Department of Commerce, *Chemical Spotlight: The Chemical Industry in the United States*.

to improve one stage of the life cycle without considering the others runs the risk of moving sustainability problems around rather than solving them. Analyzing the full life cycle of a process or product can reveal benefits as well as trade-offs or unintended consequences of different choices along the way.

Figure 1: Life Cycle of Chemical Processes and Products



Source: GAO. | GAO-19-660T

Legal Framework

Consistent with the goals of sustainable chemistry, which include making chemicals in a purposefully more environmentally benign way, several federal requirements and directives address chemical and other risks to public health and the environment. For example, EPA's ability to effectively implement its mission of protecting public health and the environment is critically dependent on credible and timely assessments of the risks posed by chemicals. Such assessments are the cornerstone of scientifically sound environmental decisions, policies, and regulations under a variety of statutes, such as the Toxic Substances Control Act

(TSCA) (as amended),[9] which provides EPA with authority to obtain information on chemicals and to regulate those that it determines pose unreasonable risks; the Safe Drinking Water Act (SDWA) (as amended),[10] which authorizes EPA to regulate contaminants in public drinking water systems; and the Federal Food, Drug, and Cosmetic Act (as amended), which authorizes the Food and Drug Administration to oversee the safety of food, drugs, medical devices, and cosmetics.[11] The Federal Acquisition Regulation generally requires that federal agencies advance sustainable acquisition by ensuring that 95 percent of new contract actions for the supply of products and for the acquisition of services meet certain sustainability goals.[12]

Supply, Demand, and Economics

Various economic factors influence the development of sustainable products. Consumers are increasingly seeking products that help them reduce their own environmental footprints, and companies are responding by developing products made with safer chemicals and by increasing the use of recycled, biobased, and renewable materials. The supply of such products can be influenced by the costs of production, competitive advantage, and reputational effects. For example, if a more sustainable product or process helps a firm differentiate from another firm and creates a competitive advantage that consumers recognize and value, it will enable firms to create more sustainable products.

There are a number of inherent challenges in the market for sustainable products in the industry. For example, substantial upfront costs coupled with uncertainty about consumer demand may be a barrier to entering the market. If the benefits of taking a more sustainable approach are valued by consumers, companies may be able to recoup the higher costs by charging higher prices without reducing demand. However, if the benefits are not easily understood and measureable (e.g., long-term health benefits), or are external to consumers (e.g., broad environmental

[9]15 U.S.C. § 2601 et. seq. After many years of congressional committees considering legislation aimed at reforming TSCA, in June 2016, Congress passed and the President signed the Frank R. Lautenberg Chemical Safety for the 21st Century Act, which gave EPA greater authority to improve its processes for assessing and controlling toxic chemicals. Pub. L. No. 114-182, 130 Stat. 448.

[10]42 U.S.C. § 300f et. seq.

[11]21 U.S.C. § 301 et. seq.

[12]Federal Acquisition Regulation § 23.103.

impacts), then consumers may not be willing to pay higher prices for more sustainable products.

In addition to market incentives that encourage firms to produce more sustainable products, government entities can, when appropriate, take actions such as subsidies, award programs, or tax credits, or limits, bans, and taxes. Governments may also provide environmental and health-related information to help guide the choices of consumers, workers, downstream users, and investors. For new markets and investments to be realized, sufficient information is needed on the environmental damage and health hazards that can be associated with some chemicals and the possibilities that exist to develop alternatives that overcome these challenges.

Stakeholders Vary in How They Define and Assess the Sustainability of Chemical Processes and Products

In February 2018, we reported that stakeholders vary in (1) how they define sustainable chemistry, (2) how they assess sustainability, and (3) which environmental and health factors they considered most important.[13] Most companies that responded to our survey agreed that a standardized set of factors for assessing sustainability would be useful.

Definitions of Sustainable Chemistry

Stakeholders do not agree on a single definition of sustainable chemistry. In total, we asked 71 representatives of stakeholder organizations how they or their organization defines sustainable chemistry.[14] The most common response we received was that sustainable chemistry includes minimizing the use of non-renewable resources. Other concepts that stakeholders commonly associated with sustainable chemistry included minimizing the use of toxic or hazardous chemicals, considering trade-offs between various factors during each phase of the life cycle, minimizing energy and water use, and increasing biodegradability or recyclability. Based on a review of the literature and stakeholder

[13] GAO-18-307.

[14] Stakeholders we interviewed included federal and state officials, chemical companies, industry and professional organizations, academics and educational institutions, NGOs, and others.

interviews, we identified several common themes underlying what sustainable chemistry strives to achieve, including:

- improve the efficiency with which natural resources—including energy, water, and materials—are used to meet human needs for chemical products while avoiding environmental harm;
- reduce or eliminate the use or generation of hazardous substances in the design, manufacture, and use of chemical products;
- protect and benefit the economy, people, and the environment using innovative chemical transformations;
- consider all life cycle stages including manufacture, use, and disposal (see fig. 1) when evaluating the environmental impact of a product; and
- minimize the use of non-renewable resources.

Approaches for Assessing Sustainability

Stakeholders such as chemical companies, federal agencies, and others use many different approaches for assessing the sustainability of chemical processes and products. While the varying approaches provide flexibility to meet the priorities of the user, the lack of a standardized approach makes it very difficult for customers, decision makers, and others to compare the sustainability of various products to make informed decisions.

Some companies and organizations design their own approaches for assessing chemical sustainability and use those approaches to make internal decisions on product design and processing, while others use metrics, chemical selection guides, or third-party certifications and assessment tools that are common to their industry. For example, chemical companies use several established metrics to measure their efficiency in using materials to generate products.[15] The variety of metrics used—and variation in the underlying factors included in their calculation—hinders the ability of companies and others to compare the sustainability of chemical processes or products.

[15]Such metrics include process mass efficiency, solvent intensity, and wastewater intensity, among others. See F. Roschangar, R. A. Sheldon, and C.H. Senanayake, “Overcoming Barriers to Green Chemistry in the Pharmaceutical Industry – the Green Aspiration Level Concept,” *Green Chemistry*, vol. 17, no. 2 (2015).

In addition to common metrics, some sectors have developed guides that companies and others can use to compare the sustainability of materials used in chemical processes, including solvent selection guides and reagent guides. Solvent selection guides assess solvents based on a variety of sustainability criteria, such as environmental, health, and safety impacts; recyclability; and regulatory concerns. One pharmaceutical company reported a 50 percent decrease in the use of certain hazardous solvents after the introduction of a solvent selection guide.

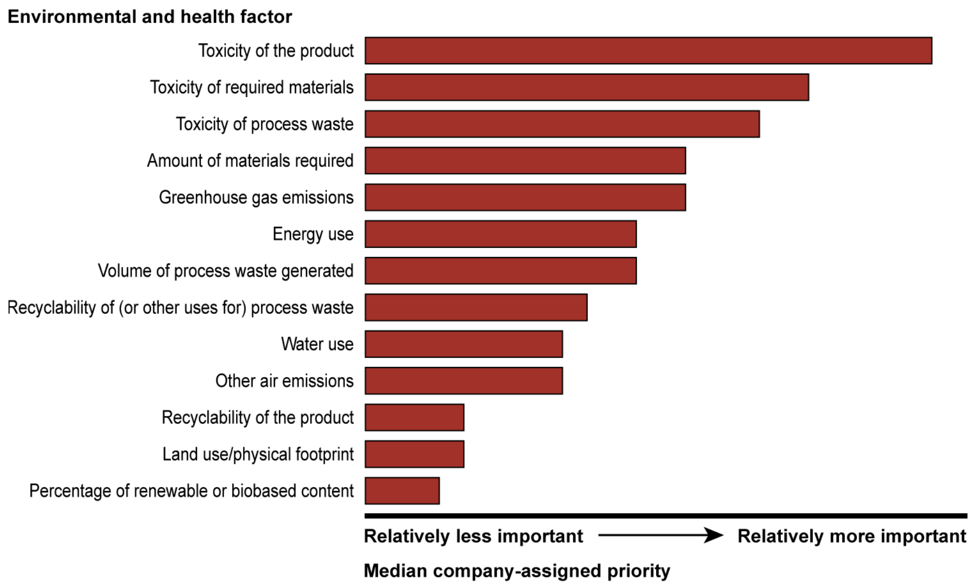
NGOs, federal agencies, and professional associations are also developing product certification programs and assessment tools. Certification programs set minimum criteria that products must meet to be certified, such as biodegradability, toxicity, performance, or water usage. Certifying bodies make databases of certified products publicly available and allow manufacturers to affix certification labels or logos to their products.

Environmental and Health Factors Considered Most Important

Companies prioritize various environmental and health factors differently when assessing sustainability, according to our survey of 27 companies. We asked respondents to indicate the relative importance their company gives to each of 13 environmental and health factors by comparing a pair of factors and selecting the factor they considered more important to optimize, even if that benefit came at the expense of the other factor. For example, a company might compare “energy use” with “water use” and determine that it was more important to their company to maximize the sustainability benefit relative to the “energy use” of a process even if it resulted in less sustainable use of water. We found that, overall, “toxicity of the product” was the most important factor for the companies surveyed and “percentage of renewable or biobased content” was the least important factor when making trade-offs (see fig. 2). However, there were sizable differences between companies and sectors regarding which factors they considered most important to optimize. For a more detailed description of our analysis, see our report *Chemical Innovation: Technologies to Make Processes and Products More Sustainable*.[16]

[16]GAO-18-307.

Figure 2: Relative Importance of Environmental and Health Factors to Surveyed Chemical Companies



Source: GAO analysis of survey data. | GAO-19-660T

The Importance of a Standard Definition and Metrics for Sustainability

The literature and the results of our interviews and survey indicate that the lack of a standard definition for sustainable chemistry, combined with the lack of standard ways of measuring or assessing sustainability, hinder the development and adoption of more sustainable chemistry technologies. It is difficult for consumers, purchasers, policymakers, and even manufacturers to compare the sustainability of one process or product with another when such processes and products are assessed using different metrics that incorporate different factors. In addition, while there were sizable differences between the companies that responded to our survey with regard to which environmental and health factors they considered most important to prioritize, most agreed that it would be useful to have a standardized set of factors for assessing sustainability across their industry sector and (to a lesser degree) across the entire industry.

Technologies Can Make Chemical Processes and Products More Sustainable

There are many technologies available and in development that can improve chemical sustainability at each stage of the chemical life cycle. Our February 2018 report focused on three categories: catalysts, solvents, and continuous processing.[17] Because each chemical process or product has unique requirements, there is no one-size-fits-all solution to sustainability concerns.

Catalysts

Catalysts are used to make chemical processes run faster or use less material. One common application is the catalytic converter in an automobile, where the catalyst converts pollutant gases in the exhaust into harmless chemicals. Without catalysts, many everyday items such as medicines, fibers, fuels, and paints could not be produced in sufficient quantities to meet demand. Unfortunately, the most common catalysts—including those used in automobile catalytic converters—are rare, nonrenewable metals such as platinum and palladium. Researchers are working to replace such metals with alternatives, including abundant metals (e.g., iron and nickel) and metal-free catalysts (such as biocatalysts) where possible.

For example, in 2016, Newlight Technologies won a Presidential Green Chemistry Challenge Award for developing and commercializing a biocatalyst technology that captures methane (a potent greenhouse gas) and combines it with air to create a material that matches the performance of petroleum-based plastics at a lower cost. Several companies are now using this material to make a range of products, including packaging, cell phone cases, and furniture.

Solvents

Solvents are key components in chemical reactions. They are used to dissolve other substances so reactions can occur, to separate and purify chemicals, and to clean the equipment used in chemical processes, among other uses. Solvents constitute a large portion of the total volume of chemicals used in industrial chemical processes. However, many conventional solvents are considered hazardous, both to the environment and to human health. There are a variety of alternatives that can be used in some situations, including biobased solvents, less hazardous solvents

[17] GAO-18-307.

such as water or ethanol, and solvent-free or reduced-solvent technologies.

For example, biobased solvents called citrus terpenes, which are extracted from citrus peel waste, can be used as flavoring agents or fragrances in cleaning products. According to a representative from Florida Chemical, citrus terpenes may be a low-toxicity alternative compared to traditionally used petroleum-based products for the hydraulic fracturing industry's concerns about contamination of source and groundwater. However, the regionality and seasonality of the citrus supply can present a challenge to production.

Continuous Processing

Historically, industrial chemicals have been produced mainly using an approach known as batch processing, where the starting materials are combined in a closed vessel or vat and allowed to react, then transferred to the next vat for the next stage of processing while the first vat is cleaned, and the process is repeated with the next batch. This approach can use significant amounts of solvents for cleaning the vats between batches, consume considerable energy, result in potentially long wait times, and create safety risks. An alternative to batch processing is continuous processing, which allows chemical reactions to occur as the reaction mixture is pumped through a series of pipes or tubes where reactions take place continuously. This approach can improve product yield, product quality, reaction time, and process safety while reducing waste and costs.

For example, researchers developed a process for manufacturing the active ingredient in medications including Benadryl® and Tylenol® PM using microreactors that minimized waste, reduced the number of purification steps, and reduced production times compared to traditional batch processing.[18]

[18]D. R. Snead and T. F. Jamison, "End-to-End Continuous Flow Synthesis and Purification of Diphenhydramine Hydrochloride Featuring Atom Economy, In-line Separation, and Flow of Molten Ammonium Salts," *Chemical Science,* vol. 4 (2013).

Roles of the Federal Government and Other Stakeholders in Supporting the Development and Use of More Sustainable Chemical Processes and Products

The federal government and other stakeholders play a number of roles, sometimes in collaboration, to advance the development and use of more sustainable chemical processes and products. Federal programs support research on the impacts of chemicals on human and environmental health, support the development of more sustainable chemical processes and their commercialization, and aid the expansion of markets for products manufactured with more sustainable chemicals and processes. Other stakeholders play similar roles and some additional roles that contribute to the development and use of more sustainable chemical processes and products.

Federal Programs Support Research on the Impacts of Chemicals on Human and Environmental Health

Federal programs conduct and fund basic research on the characteristics and biological effects of chemicals, which underpins the development and use of more sustainable chemistry products and processes. Decision makers must have a scientific understanding of the potential harmful impacts of exposure to chemicals in order to effectively minimize the harmful effects of chemicals through regulations and other means, and to assess the regulated community's compliance with them. Industry needs this information to make informed decisions about the selection, design, and use of more sustainable chemicals in their products and processes, including their impact on workers.

Federal programs fund and study the impacts of chemicals on human health and the environment, develop new methodologies for testing and predicting these effects, award grants for research on chemicals and new methodologies, identify more sustainable chemical alternatives, and evaluate the risks of chemicals. (See table 1.)

Table 1: Selected Federal Programs and Offices Support Research on the Impacts of Chemicals on Human and Environmental Health, February 2018

Federal program or office	Selected activities related to sustainable chemistry
National Toxicology Program (NTP) - Department of Health and Human Services	Conducts toxicology research on the potential health effects of chemicals.
Toxicology in the 21st Century (Tox21) program - Department of Health and Human Services / Environmental Protection Agency	Seeks to improve how scientists predict the safety of chemicals by developing new testing methodologies.
Chemical Safety for Sustainability (CSS) program - Environmental Protection Agency	Conducts research on the properties of chemicals and generates hazard, exposure, and risk assessment data.
Science to Achieve Results (STAR) grant program - Environmental Protection Agency	Funds academic research on new methodologies for testing and understanding chemicals and the effects of exposure.
National Institute for Environmental Health Sciences (NIEHS) - Department of Health and Human Services	Funds research on the impacts of chemicals on human health.
Significant New Alternatives Policy (SNAP) program - Environmental Protection Agency	Evaluates alternatives for ozone-depleting substances to help industry identify acceptable alternatives in order to comply with Clean Air Act regulations.
Chemical and Material Risk Management Program - Department of Defense	Identifies and seeks to manage the risks associated with hazardous chemicals and materials.

Source: GAO analysis of agency documentation. | GAO-19-660T

Note: Additional examples from the National Science Foundation and Department of Energy can be found in: GAO, Chemical Innovation: Technologies to Make Processes and Products More Sustainable, GAO-18-307 (Washington, D.C.: Feb. 8, 2018).

Federal Programs Support the Development and Commercialization of More Sustainable Chemistry Technologies

Federal programs also seek to support the development and facilitate the commercialization of new, more sustainable chemistry processes by conducting and funding basic and applied research to develop more sustainable processes and products; providing loan guarantees, grants, and technical assistance to researchers and companies; and recognizing innovative technologies through an award program, among other programs. (See table 2.)

Table 2: Selected Federal Programs and Offices That Support the Development and Commercialization of More Sustainable Chemicals and Chemical Processes, February 2018

Federal Program or Office	Selected Activities Related to Sustainable Chemistry
Sustainable Chemistry, Engineering, and Materials (SusChEM) - National Science Foundation	Funds research to develop clean, safe, and economical alternatives to traditional chemical products and practices. This program ended as planned in 2017.
Centers for Chemical Innovation - National Science Foundation	Funds research centers focused on fundamental chemical research challenges.
Agricultural Research Service (ARS) National Program on Biorefining - Department of Agriculture	Conducts research on feedstocks and commercially-viable technologies to convert agricultural material into biochemicals and other byproducts.
Advanced Manufacturing Office (AMO) - Department of Energy	Supports the development of materials and technologies that reduce the energy intensity of sustainable chemistry technologies.
Manufacturing USA – Rapid Advancement in Process Intensification Deployment (RAPID) institute - Department of Energy	Researches, develops, and demonstrates new chemical processes that save energy and reduce waste.
National Laboratories - Department of Energy	Conduct research and provide unique scientific capabilities on sustainable chemistry technologies and support the commercialization of processes.
Small Business and Innovation Research (SBIR) and Small Business Technology Transfer (STTR) grant programs - Multiple Agencies	Fund sustainable chemistry technological innovation and increase commercialization of innovations.
National Institute of Standards and Technologies - Department of Commerce	Develops methodologies and standards for measuring and evaluating the sustainability of chemicals and chemistry technologies.
Green Chemistry Challenge Awards - Environmental Protection Agency	Recognizes chemical technologies that incorporate the principles of green chemistry into chemical design, manufacture, and use.
Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP) - Department of Defense	Funds research on contaminants of concern to the DOD and for the validation and demonstration of new, more sustainable products.

Source: GAO analysis of agency documentation. | GAO-19-660T

Note: Additional examples from the National Science Foundation, Environmental Protection Agency, Department of Agriculture, and Department of Energy can be found in: GAO, Chemical Innovation: Technologies to Make Processes and Products More Sustainable, GAO-18-307 (Washington, D.C.: Feb. 8, 2018).

Federal Programs Aid Market Growth for Products Made with Sustainable Chemicals and Processes

Federal programs also aid market growth for products made with sustainable chemicals and processes by informing consumers about these products and by facilitating their purchase by federal offices. It can be challenging for consumers seeking out more sustainably manufactured products to identify them or verify company claims. Federal programs can help companies seeking to manufacture more sustainable products strive to ensure that their products are differentiated from less sustainable products in order to reach these consumers. For example, federal programs conduct evaluations of the chemical content of products, manage product certification and labeling programs, provide information to consumers and federal purchasers on the chemical content of products, and develop purchasing and sustainability plans to support agency purchase and use of more sustainable products. EPA's Safer Choice voluntary certification and labeling program helps consumers make informed purchasing decisions and incentivizes manufacturers to select more sustainable chemical alternatives so they can differentiate their products in the market.

Industry, Academic Institutions, States, Companies, and Other Stakeholders Support More Sustainable Chemistry

Other stakeholders—such as the chemical manufacturing industry, companies and retailers, state governments, academic institutions, and NGOs—also seek to influence the development and use of more sustainable chemistry processes and products through activities such as supporting workforce development and developing tools and resources for industry. These stakeholders may work on collaborative efforts, such as sustainability initiatives and developing industry-specific standards. The chemical industry conducts and supports research into more sustainable chemistry technologies and other activities. Companies and retailers, such as Kaiser Permanente and Target, create demand for more sustainable products from their suppliers by setting sustainability criteria for purchases. Academic institutions conduct research on the impacts of chemicals and sustainable chemistry technologies and train the next generation of chemists and engineers. States seek to protect public health by regulating chemicals in products. NGOs also play a diverse range of roles such as supporting workforce development, facilitating collaboration between other stakeholders, and developing tools and resources for industry.

Strategic Implications in the Field of Sustainable Chemistry

Sustainable chemistry is an emerging field within the chemical sciences that has the potential to inspire new products and processes, create jobs, and enhance benefits to human health and the environment. Stakeholders offered a range of potential options to realize the full potential of these technologies. However, there are a number of challenges to implementing more sustainable chemistry technologies, including technological, business, and industry-wide and sector-specific challenges.

Opportunities

The field of sustainable chemistry has the potential to inspire new products and processes, create jobs, and enhance benefits to human health and the environment. Stakeholders noted that much more work is needed to realize its full promise and offered a range of potential options to realize the full potential of these technologies, including the following:

- Breakthrough technologies in sustainable chemistry and a new conceptual framework could transform how the industry thinks about performance, function, and synthesis.
- An industry consortium, working in partnership with a key supporter at the federal level, could help make sustainable chemistry a priority and lead to an effective national initiative or strategy.
- Integrating sustainable chemistry principles into educational programs could bolster a new generation of chemists, encourage innovation, and advance achievement in the field.
- A national initiative that considers sustainable chemistry in a systematic manner could encourage collaborations among industry, academia, and the government, similar to the National Nanotechnology Initiative.[19]
- There are opportunities for the federal government to address industry-wide challenges such as developing standard tools for assessment and a robust definition of sustainable chemistry. Federal agencies can also play a role in demonstrating, piloting, and de-risking some technology development efforts.

Challenges

Stakeholders noted that there are a number of challenges to implementing more sustainable chemistry technologies, including (1) technological and business challenges, (2) industry-wide and sector-specific challenges, and (3) challenges with coordination between stakeholders. One example of a technological challenge is the fact that alternatives to current solvent use can sometimes pose the same inherent toxicity and volatility risks as their conventional counterparts. Alternatives can also vary in supply and quality and can be expensive. Less toxic solvents, such as water, may require specialized equipment, greater energy input, or elevated pressure, and they can be difficult to scale up for industrial use.

[19]The National Nanotechnology Initiative is a U.S. government R&D initiative involving 20 departments and independent agencies working on science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers; a nanometer is one billionth of a meter.

Companies told us they face many business challenges in implementing sustainable chemistry technologies, including the need to prioritize product performance; weigh sustainability trade-offs between various technologies; risk disruptions to the supply chain when switching to a more sustainable option; and consider regulatory challenges, among others. Stakeholders also noted the challenge of overturning proven conventional practices and acknowledged that existing capital investments in current technologies can create barriers for new companies to enter a field full of well-established players.

Our survey and interviews also found that there are several industry-wide and sector-specific challenges to implementing more sustainable chemistry technologies, such as the lack of a standard definition for sustainable chemistry and lack of agreement on standard ways of measuring or assessing it. Without a standard definition that captures the full range of activities within sustainable chemistry, it is difficult to define the universe of relevant players. Without agreement on how to measure the sustainability of chemical processes and products, companies may be hesitant to invest in innovation they cannot effectively quantify, and end users are unable to make meaningful comparisons that allow them to select appropriate chemical products and processes.

There is no mechanism for coordinating a standardized set of sustainability factors across the diverse range of stakeholders at present, despite the motivation of some specific sectors to do so. Moreover, although the federal government has worked with stakeholders through its research support, technical assistance, certification programs, and other efforts, there are still gaps in understanding. Many stakeholders told us that without such basic information as a standardized approach for assessing the sustainability of chemical processes and products, better information on product content throughout the supply chain, and more complete data on the health and environmental impacts of chemicals throughout their life cycle, they cannot make informed decisions that compare the sustainability of various products. Sector-specific challenges exist as well. For example, pharmaceutical sector representatives told us that changing the manufacturing process for an already marketed drug triggers a new FDA review, which can result in delays and additional costs—thus discouraging innovation that could make their chemical processes more sustainable.

In conclusion, according to stakeholders, transitioning toward the use of more sustainable chemistry technologies requires that industry, government, and other stakeholders work together. As they and others noted, there is a need for new processes that make more efficient use of the resources that are available, reuse products or their components during manufacturing, and account for impacts across the entire life cycle of chemical processes and products. Furthermore, they highlight the importance of disseminating environmental and health-related information to help guide the choices of consumers, chemists, workers, downstream users, and investors to facilitate further progress. They also indicated that momentum in this field will require national leadership in order to realize the full potential of sustainable chemistry technologies.

Chairwoman Stevens, Ranking Member Baird, and Members of the Committee, this completes my prepared statement. I would be pleased to respond to any questions that you may have at this time.

GAO Contact and Staff Acknowledgments

If you or your staff have any questions about this testimony, please contact me at 202-512-6412 or personst@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this statement. GAO staff who made key contributions to this testimony include Karen Howard (Assistant Director), Diane Raynes (Assistant Director), Katrina Pekar-Carpenter (Analyst-in-Charge), Patrick Harner, Summer Lingard-Smith, Krista Mantsch, Anika McMillon, Rebecca Parkhurst, and Ben Shouse. Other staff who made key contributions to the report cited in the testimony are identified in that report.

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