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INDUSTRIAL EFFICIENCY & DECARBONIZATION OFFICE

Sustainable Chemistry in RD&D to Transform the Chemicals Sector Roundtable

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Disclaimer

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List of Acronyms

ACS	American Chemical Society
BTX	Benzene/Toluene/Xylene
DOE	U.S. Department of Energy
EJ	Environmental Justice
EPA	Environmental Protection Agency
CO_2	Carbon Dioxide
CO_2e	CO_2-Equivalent
GC3	Green Chemistry & Commerce Council
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HAZOP	Hazard and Operability Study
IEDO	Industrial Efficiency and Decarbonization Office
MMT	Million Metric Ton
NAS	National Academy of Sciences
PHA	Polyhydroxyalkanoate
RD&D	Research, Development, and Demonstration
TRL	Technology Readiness Level
TSCA	Toxic Substance Control Act

Executive Summary

The U.S. Department of Energy (DOE) Industrial Efficiency and Decarbonization Office (IEDO) and Change Chemistry (formerly the Green Chemistry & Commerce Council, GC3) co-hosted the Sustainable Chemistry in RD&D [research, development, and demonstration] to Transform the Chemicals Sector Roundtable on March 7, 2023. The event brought together about 50 participants—from industry, national laboratories, small businesses, startups, non-profits, and government—to gather input on how to effectively leverage sustainable chemistry to advance industrial decarbonization, industrial efficiency, and environmental justice (EJ) goals. This report is a summary of the views expressed by individual participants during the roundtable; it is not intended to represent DOE's views or programmatic priorities.

Context

As reducing industrial carbon emissions is a key goal of IEDO, the Office recognizes the imperative to decarbonize the chemicals sector. This strategy is key to addressing the climate crisis and achieving economy-wide net-zero emissions by 2050. However, the challenge is particularly complex, as industrial efficiency and decarbonization, sustainable chemistry, and environmental justice (EJ) are intrinsically linked.

Low-income communities and communities of color have borne a greater share of environmental and health impacts associated with chemicals manufacturing and product-related pollution. In his keynote address, Matthew Tejada, Deputy Assistant Administrator for Environmental Justice, U.S. Environmental Protection Agency, provided a historical perspective of the discriminatory practices that have contributed to this inequity. It is important that individual researchers and decision makers in industry and government understand the history of redlining, which segregated minority communities into highly industrial sections of U.S. cities in the 1930s. This historically significant practice contributed to nearly 100 years of cumulative and disproportionate burden on the environment and human health of redlined communities. Decreasing toxic air and water emissions of chemicals production is an important step that can help to decrease the cumulative burdens on communities. Sustainable chemistry must focus on designing products and processes that reduce not only energy use and emissions but also human health hazards, particularly in disadvantaged communities. As such, sustainable chemistry innovations can help achieve multiple sustainability goals.

Challenges

For companies with a sustainable chemistry solution or product, identifying potential markets can be a challenge. Incumbent technologies and processes are well-entrenched within the industry. The chemicals sector has been historically dominated by a few high-volume, low-margin commodity petrochemicals such as ethylene, propylene, and benzene/toluene/xylene (BTX). The incumbent manufacturing processes are capital-intensive and are optimized for cost, energy efficiency, and integration into the supply chain.

When a new product has been identified, challenges will likely emerge across the supply chain. New products rarely lead to "drop-in" replacements of existing chemical products. There are usually slight differences in properties that do not integrate perfectly with the rest of the value chain. Therefore, downstream users may have to make substantial capital investments to accommodate the new renewable product, and then expose themselves to additional supply chain risk by sourcing from a single sustainable supplier.

Because scaling up a new process involves many such challenges, the costs of technology commercialization are both high and uncertain. The finance community has a culture of low risk tolerance that limits capital investments in sustainable chemistry solutions.

In addition, there are many different dimensions to sustainability, and making informed, consistent decisions requires complex analysis across a product's life cycle, as well as standardized and transparent sustainability metrics. The private sector does not have ready access to the data, tools, and expertise needed to evaluate sustainability of commercialized and new products. Companies are forced to balance competing priorities when it comes to sustainable chemistry; very few options are collectively net-zero, non-toxic, and environmentally just.

With all these complications, a variety of strategies will be required to accelerate the application of sustainable chemistry principles in the U.S. chemicals sector. The most important strategies identified from this roundtable are shown in Figure ES-1.

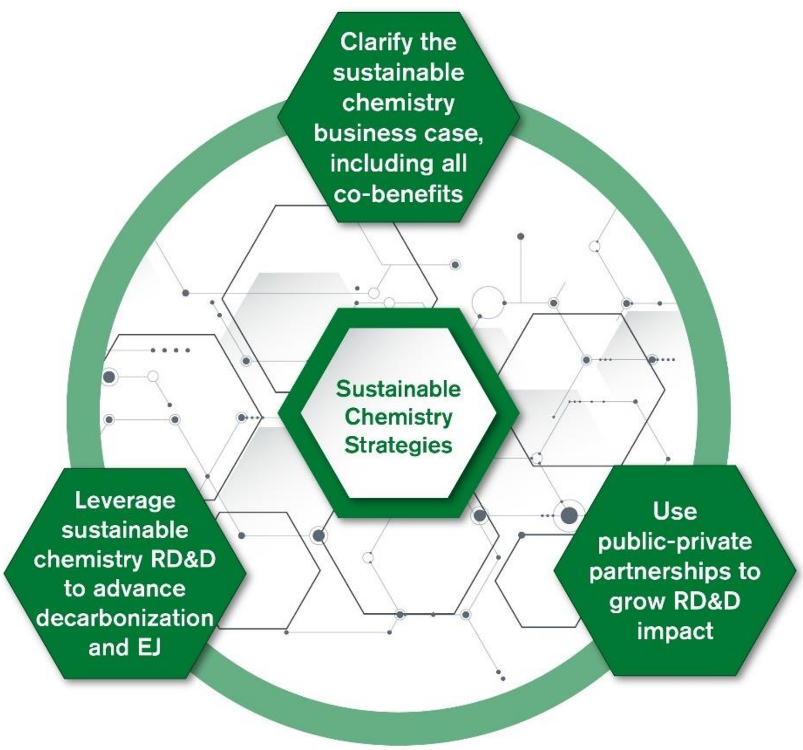

Figure ES-1. Sustainable chemistry strategies

Sustainable Chemistry Strategies to Advance Environmental Justice and Industrial Efficiency and Decarbonization

Clarify the sustainable chemistry business case; include co-benefits in efficiency, decarbonization, and environmental justice

The business proposition for investment in sustainable chemistry includes not only decarbonization benefits but also those associated with eliminating chemicals of concern and finding safer alternatives (also referred to as “detoxification”). Such investments may lower cost and financial and reputational risk, increase government compliance, create new market value, avoid regrettable substitutions, and support corporate sustainability targets. Making a strong business case—that sustainable chemistry investments solve multiple challenges and have improved life cycle costs—is critical for market success.

Incumbent technologies and processes are well-established within the industry and value chain, so sustainable chemistry solution providers must find new uses for high-value materials and gradually increase their market impacts. This often involves targeting new applications or areas of the market that may be better served with sustainable solutions over incumbent products or processes, rather than just replacing incumbents. These “beachhead” applications can serve as a starting point leading to greater market adoption.

Sustainable chemistry solution providers can position themselves more strongly in the market by identifying customers and developing sustainable products that have higher quality and improved properties compared to incumbent products. This requires conducting independent validations of the products and demonstrating that they are lower-impact and perform as well as, or better than, the incumbents.

Challenges remain for new sustainable drop-in replacements of existing chemical products. Slight differences in properties can result in a product that does not integrate perfectly with the rest of the value chain. Therefore, downstream users and customers may have to make substantial capital investments to accommodate the new sustainable product and then expose themselves to additional supply chain risk by sourcing from a single sustainable supplier. Sustainable chemistry solution providers must address these market risks in their interactions with potential customers.

Leverage sustainable chemistry RD&D to advance efficiency, decarbonization, and environmental justice goals

Assessments of new chemistries, manufacturing processes, and chemical products should consider EJ-related aspects across the full value chain and life cycle of a product. Considering only the life cycle impacts of chemical products, even if analyzed from cradle to grave, is insufficient to address the hazards of chemical exposures to workers in manufacturing facilities, risks to consumers using the products, and release of chemicals into neighboring communities and the environment.

The chemicals sector should measure all co-benefits and cumulative impacts of a sustainable product or process. Some examples include increased material efficiency, reduced natural resource extraction, reduced water and air pollution, reduced chemical exposure at work and within communities, and reduced life cycle impacts. Consolidation of these co-benefits into a single "environmental metric" would be an oversimplification, since metrics would be situational for specific geographic areas, communities, and chemical processes.

The benefits of connecting sustainable chemistry, decarbonization, and EJ should be felt in local communities through improved public health metrics, such as reduced cancer rates and higher life expectancies. The public health community and EJ leaders should be involved early in technology commercialization processes and work with startups and chemical companies to improve EJ outcomes for customers, employees, and surrounding communities.

Equitable access to sustainable products for all consumer demographics ensures all populations have access to safer and more sustainable chemical alternatives when manufacturing and deploying sustainable products. There is an opportunity for manufacturers to examine whether the populations that consume their products reflect the demographics of the communities that produce their products.

Use public–private partnerships and integrate environmental justice considerations to grow sustainable chemistry RD&D impact

The recent growth in commitment to and investments in efficiency, decarbonization, and EJ across the chemicals sector provides a significant opportunity for public- and private-sector investments in sustainable chemistry innovation. Such widescale interest and investment will not only reduce the adverse impacts of chemical processes and products but also provide benefits to historically disadvantaged communities.

Methods are needed to incorporate EJ considerations into sustainable chemistry RD&D. Specific metrics include community disease burdens or toxic chemical releases. The development of these methods should involve fence line communities and public health experts.

Coordinated public–private RD&D partnerships are also needed to address industry challenges and drive and accelerate timeframes for commercialization and adoption of innovative technologies and approaches in a market historically dominated by high-volume, low-margin incumbents. For example, investments in distributed manufacturing approaches may achieve multiple goals. These partnerships could manifest themselves as application-focused research and development practices so that research can deliver new chemical and materials solutions to address application gaps in industry. In addition, the federal government could help to scale sustainable chemistry solutions through increased support of pilot-phase facilities. The federal government—working with the private sector and investment community—can ultimately play a critical role in both de-risking and creating a level playing field for innovative sustainable chemistry processes and products that demonstrably achieve efficiency, decarbonization, and EJ goals.

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1 Introduction

1.1 Roundtable Overview

The U.S. Department of Energy (DOE) Industrial Efficiency and Decarbonization Office (IEDO) and Change Chemistry (formerly GC3) co-hosted the Sustainable Chemistry in RD&D [research, development, and demonstration] to Transform the Chemicals Sector Roundtable on March 7th, 2023. The events brought together 51 participants, comprising a broad mix of stakeholders from industry, government, national laboratories, small businesses, and non-profits. IEDO and Change Chemistry sought specific engagement with potential partners who demonstrate a focus on sustainability, an ability to advance breakthrough innovations, and an understanding of the unique challenges that face sustainable chemistry adoption in industry.

> Roundtable motivation
> *Understand the opportunities and challenges to leveraging sustainable chemistry practices in manufacturing to promote industrial efficiency and decarbonization, along with environmental justice*

During the roundtable, participants shared perspectives on opportunities to leverage sustainable chemistry to achieve industrial efficiency and decarbonization and to align those goals with environmental justice (EJ). Attendees explored the following topics in facilitated discussion groups:

- Opportunities and barriers to sustainable chemical manufacturing
- Priority RD&D goals and metrics that link sustainable chemistry to efficiency, decarbonization, and EJ
- Public- and private-sector needs and incentives, including required technical assistance to accelerate RD&D and advance EJ concepts in sustainable chemistry

1.2 Context

Reducing industrial carbon emissions and energy input is a key goal of DOE IEDO. The Change Chemistry mission is to drive commercial adoption of sustainable chemistry and bridge the supply chain to connect technology needs of end users and brands with the new technologies that chemical producers (including innovative startups) can provide. Change Chemistry envisions a global economy in which all chemicals, materials, and products are safe and sustainable from creation through disposal or reuse.

> Sustainable chemistry, defined
> *The design, development, and use of chemicals and materials that have lower energy consumption and emissions; are less toxic to human health and the environment; have reduced natural resource impacts; and are designed for reduced waste and increased recycling capability across the product life cycle*

Through previous stakeholder discussions organized by DOE, Change Chemistry, and the U.S. Environmental Protection Agency (EPA), it became clear that industrial efficiency and decarbonization, sustainable chemistry, and EJ are intrinsically linked. Sustainable chemistry must focus on designing products and processes that not only reduce energy use and emissions but also lower natural resource impacts, reduce human health hazards, decrease waste, and increase recycling capability across the product life cycle. As such, sustainable chemistry innovations can help achieve multiple sustainability goals.

Many chemical manufacturing processes used in industrial facilities consume significant amounts of energy, generate greenhouse gas (GHG) emissions, and produce air and water pollutants, with harmful impacts on the health and well-being of surrounding communities. In the United States, racial and ethnic minority communities and lower-income groups are disproportionately exposed to elevated levels of air pollution, water pollution, and hazardous waste and, consequently, experience higher rates of adverse health impacts compared to the general population. Addressing pollution from chemicals manufacturing is an integral step toward achieving EJ by remediating social, economic, and health burdens on those disproportionately harmed by industrial sector emissions. Assessing community-level impacts and prioritizing EJ helps ensure the benefits of industrial decarbonization are realized across all U.S. communities. Such a focus is consistent with current Administration priorities for investments in low-carbon technologies that create opportunities and lower impacts in EJ communities.

The motivation for hosting this roundtable was to understand the opportunities and challenges for leveraging sustainable chemistry practices in the chemicals sector to promote efficiency, decarbonization, and EJ. There is currently market demand for more sustainable manufacturing practices in the chemical industry for both consumer and commercial products, inducing an opportunity to realize these goals while creating significant value for U.S. manufacturing and maintaining global competitiveness. By developing safer chemicals and manufacturing processes that have low toxicity and low carbon emissions, we can reduce impacts on the environment and human health while ensuring a secure and competitive U.S. chemicals sector.

1.3 Prior Roundtable

The Sustainable Chemistry in RD&D to Transform the Chemicals Sector Roundtable is the second stakeholder engagement event on the topic of sustainable chemistry co-hosted by DOE industrial programs and Change Chemistry. On November 17, 2020, the DOE Advanced Manufacturing Office and Change Chemistry (then known as GC3) co-hosted a roundtable on Sustainable Chemistry in Manufacturing Processes to collect industry stakeholders' perspectives on incorporating sustainable chemistry manufacturing practices into the production of consumer and commercial products. Discussion focused on technology and commercialization barriers to sustainable chemistry and the research, development and demonstration (RD&D) needs to incorporate sustainable chemistry practices into the manufacturing of consumer and commercial products. Five themes were identified: scalability, information-sharing and collaboration, technoeconomic and life cycle analyses, supply chain, and chemical manufacturing processes. Specific RD&D opportunities identified were summarized into two broad categories: ***materials*** (e.g., material and feedstock substitution and innovation in platform molecules) and ***processes and practices*** (e.g., electrification, process intensification, and shared burden, such as platform molecule/derivative chemical libraries and shared pilot facilities). The 2023 roundtable built on these foundations to further understand barriers, needs, and opportunities to leverage sustainable chemistry innovations to advance efficiency, decarbonization, and EJ goals.

SECTION

2

Introductory Remarks

Industrial Efficiency and Decarbonization Office: Mission and Strategy

Industrial Decarbonization of the Chemicals Sector

Introductory Remarks by Change Chemistry

2 Introductory Remarks

2.1 Industrial Efficiency and Decarbonization Office: Mission and Strategy

Avi Shultz, Director, IEDO

Avi Shultz emphasized the roundtable objective to facilitate conversation and collaboration with stakeholder groups to inform future IEDO program planning. IEDO's mission is to accelerate the innovation and adoption of new industrial technologies to reach net-zero by 2050. Industrial emissions account for approximately one-third of total U.S. emissions. IEDO is focused on reducing emissions and increasing efficiency in the industrial sector while enhancing U.S. competitiveness, maintaining profitability, and fostering workforce development. This means thinking critically about the commercialization pathway of any funded technology and engaging with other DOE offices, as well as the industrial community, to develop public-facing frameworks for evaluating manufacturing readiness of researched technologies. The IEDO strategy is informed by the DOE Industrial Decarbonization Roadmap, which identifies four key technological pathways (pillars) to reduce industrial emissions through innovation in U.S. manufacturing: energy efficiency; industrial electrification; low-carbon fuels, feedstocks, and energy sources; and carbon capture, utilization, and storage. IEDO also considers the manufacturing technology innovation needed to achieve industrial efficiency and decarbonization.

The DOE Energy Earthshot initiatives are also well-aligned with chemicals and refining sector interests. The Hydrogen Shot is accelerating innovation and spurring demand for clean hydrogen by reducing the cost by 80%, to $1 per 1 kilogram of clean hydrogen within 1 decade ("1 1 1"). The Industrial Heat Shot set targets to develop cost-competitive industrial heat decarbonization technologies with at least 85% lower GHG emissions by 2035. The recently announced Clean Fuels & Products Shot focuses on decarbonizing the fuel and chemical industry through alternative sources of carbon to advance cost-effective technologies with a minimum of 85% lower GHG emissions by 2035.

DOE is equally committed to ensuring that EJ principles are applied to all DOE programs, policies, and activities. The Justice40 Initiative directs that 40% of the overall benefits of certain federal investments flow to disadvantaged communities. The investment categories include clean energy and energy efficiency, clean transit, affordable and sustainable housing, training and workforce development, the remediation and reduction of legacy pollution, and the development of clean water infrastructure. These overburdened communities must be included in the decarbonization future and be reflected in IEDO program planning and funding decisions. This roundtable presented an opportunity to strategize how to decrease the impacts of the chemicals sector on human health and the environment through innovations in sustainable chemistry.

The participants at this roundtable represent a cross-functional team of government, industry, national laboratories, and academia. Such cross-sector collaboration is crucial to collective success. Working together will facilitate development of safer chemicals and processes that reduce environmental impacts and lead to a more just and competitive U.S. chemicals sector.

2.2 Industrial Decarbonization of the Chemicals Sector

Felicia Lucci, Technology Manager, DOE IEDO

Decarbonization of the chemicals sector is key to addressing the climate crisis and achieving economy-wide net-zero emissions by 2050. The chemicals sector is a capital-intensive industry contributing to 25% of U.S. gross domestic product (GDP) and expected to continue growing over the coming decades. However, decarbonization of this sector is especially challenging because of the heterogeneity of products and processes. With more than 70,000 products, 11,000 manufacturers, and deep supply chain interconnections, the U.S. chemical sector is very diverse. It is the largest energy user in the U.S. manufacturing sector, when considering feedstocks, heat, and power. Overall, the GHG emissions footprint for U.S. chemicals manufacturing in 2018 was 332 million metric tons (MMT) of carbon dioxide equivalent (CO_2e).

The IEDO chemical portfolio aims to accelerate innovations in transformative low-carbon unit operations and processes to decarbonize the full value chain of high-volume and energy- and emissions-intensive chemicals, including basic organics and inorganics, petrochemicals, nitrogenous fertilizers, and plastic materials and resins. The broad portfolio addresses the diversity of chemical products and associated applications, the complexity of a highly integrated capital-intensive sector, and the environmental impacts of chemical products necessary in a modern global society. These priority areas will be accomplished through investments in applied RD&D and first-of-a-kind pilot demonstrations to accelerate the commercial readiness of decarbonization technologies. The focus is on technologies and pathways that, when broadly deployed, are capable of ambitious (>50%) emissions reductions. The goal is to create commercialization pathways for promising technologies across DOE. To properly evaluate the merits of emerging technologies and pathways, it is critical to consider not only technical performance metrics but also technology impacts on supply chains, economic markets, and communities.

Sustainable chemistry and decarbonization are intrinsically linked in the IEDO chemicals portfolio. Sustainable chemistry innovation represents a possible solution to replace legacy, carbon-intensive processes with innovations that have reduced adverse impacts on human health and the environment. It is important to focus on de-risking technologies, processes, and products that can have the biggest impacts and associated benefits in advancing efficiency, decarbonization, and EJ goals; for example, innovative building block chemicals will have far greater impacts than applications targeting niche, small-scale markets.

As IEDO considers investing in these innovations, it is essential to include EJ concepts, such as toxicity and possible environmental leakage, in RD&D and project evaluation. Requirements for Community Benefits Plans for new funding is a good first step. This is a growth opportunity for IEDO, and input from stakeholders within the sustainable chemistry and EJ communities is necessary for IEDO to develop EJ expertise. The 2020 Sustainable Chemistry in Manufacturing Processes Roundtable developed pillars that are well-aligned with industrial efficiency, decarbonization, and EJ priorities, including reducing toxicity, lowering energy and emissions footprints, reducing natural resource impacts, reducing waste, and increasing reuse/recycling of chemicals and materials across product life cycles.

2.3 Introductory Remarks by Change Chemistry

Joel Tickner, Executive Director, Change Chemistry

Change Chemistry focuses on accelerating the commercialization, adoption, and scale of safer, more sustainable chemicals, processes, and products through value chain collaboration and market activation. It will be difficult to eliminate chemicals and processes of concern without adequate supply of high-performing, safer, and more sustainable solutions. The Sustainable Chemistry Roundtable in 2020 focused on the technologies needed to scale safer, more sustainable chemistry. Moving forward, “better chemistry” is enabled by identifying the barriers to deployment and matching industry needs (pain points) with more sustainable chemicals, materials, and processes. Disruptive concepts, such as new molecular structures, feedstocks, manufacturing processes, and product designs, are needed to reimagine the chemicals sector. There is a need for a clearer roadmap to transition the chemicals sector; an example is the European Commission’s Transition Pathway for the Chemical Industry.

The DOE Industrial Decarbonization Roadmap sets out a bold agenda to reduce emissions across the industrial sector, but the priorities of the private and public sectors must be aligned to reach 2050 goals. In the context of EJ, there must be parity between emissions reduction and pollution reduction. Populations living near major chemical and refining operations, such as along the Gulf Coast, are overwhelmingly low-income groups and communities of color; thus, they suffer disproportionate impacts from the cumulative effects that harmful chemicals have on human and environmental health. Importantly, the significant government, investment, and business interests around decarbonization and circularity may not fully address concerns about upstream and downstream impacts of production on communities. As such, it is crucial to monitor that, in achieving decarbonization or pollution reduction, burdens are eliminated, or at least mitigated, not simply shifted.

Sustainable transformation of the chemicals sector is challenging. Incumbent chemistries are cost-optimized, highly efficient, and well-integrated in the supply chain, and there is often a lack of demand or willingness to pay for replacement technologies. There is a clear need for greater specificity on sustainable chemistry enablers, technology metrics, and cost and risk tolerances for sustainable chemistries.

This roundtable aims to identify the opportunities and challenges for leveraging sustainable chemistry and EJ, as well as the chemicals, technologies, and applications that can be scaled to make significant impacts on the sector. The recent investments made by the federal government and engagement of sustainable chemistry stakeholders offer the potential to enable solutions to legacy chemical practices by addressing a major barrier: capital costs in the chemicals sector. Nonetheless, there is no short-term fix to these issues. Sustained investment and group commitment is critical to realize change in industry. This roundtable represents an opportunity for participants to reflect on how they can bring EJ considerations into their product development, manufacturing, and sourcing decisions and who should have a seat at the table when making decisions that affect community and environmental health. Engagement with the communities most adversely affected by the chemicals sector is necessary to identify not only what the largest challenges and needs are but also how sustainable chemistry solutions can benefit these communities.

SECTION 3

Keynote Speech: Equity and Justice Today at the U.S. Environmental Protection Agency

3 Keynote Speech: Equity and Justice Today at the U.S. Environmental Protection Agency

Matthew Tejada, Deputy Assistant Administrator for Environmental Justice, EPA National Program Office for Environmental Justice and External Civil Rights

Dr. Matthew Tejada gave an address titled "Equity and Justice Today at the EPA." His talk provided a history of EJ policy and science in the United States and how the EPA is addressing equity and justice today.

Dr. Tejada used the EPA's EJSCREEN tool[1] to show a map of Oakland, California, highlighting the historical significance and continued impacts of "redlining" policies dating to the 1930s. Redlining was the practice of using mortgage loan discrimination to segregate U.S. cities. Communities of color were purposefully co-located in industrial areas. At the time, surveyors talked about pollution, noise, and odors as indicators for where to situate minority communities. While redlining and the government-sanctioned racial segregation and discrimination against minority populations are no longer practiced, up to 90% of communities still adhere to the redlined boundaries that were drawn nearly 100 years ago. Redlining decisions are still affecting where communities of color are located, and those co-locations contribute to poorer health outcomes for those communities.

It is crucial that conversations about EJ be grounded in history and that decision makers recognize that these disadvantaged communities were purposefully created. The Biden/Harris Administration has given federal agencies the freedom to take action to remedy past harms and prioritize the needs of historically disadvantaged communities. This includes issues of housing, transportation, permitting, environmental regulation, civil rights laws, and environmental laws (e.g., Clean Water and Clean Air Acts).

Dr. Tejada emphasized our collective responsibility to take action to reverse historical inequities, as near-term decisions can have long-term consequences for the health outcomes of U.S. citizens. Entities involved in deploying new chemistries must comprehensively understand the effects on the environment and human health. The first step to planning a new manufacturing facility should be involving the community that will be impacted by that facility. These communities must be assured that they are not being harmed and understand how they will benefit from manufacturing. Industry and government must be authentic partners in both policy and project development to demonstrate that communities close to manufacturing sites are good places to live.

Furthermore, the federal government must consider the cumulative impacts and burden of industrial processes when permitting new operations. Permitting policy currently considers primarily impacts on an average individual by a single chemical from a single source.

[1] The EJSCREEN tool, which is publicly available, incorporates national datasets on traffic, air quality, and proximity to major manufacturing facilities. Race and low income are combined with the 13 EJ indices to show the potential burden on and vulnerability of these communities.

However, broad chemical pollution, such as is found along the Gulf Coast, is complex, and its impacts on nearby communities are complex and progressive. Better permitting practices are needed to protect already disadvantaged communities from shouldering more industrial burden, including burdens from state-of-the-art, decarbonized, or sustainable processes.

Over the coming decades, industrial development must intersect more effectively with EJ and civil rights to ensure that business decisions also consider land use, the environment, and impacted communities. Steps may then be taken to invest in and provide benefits to historically disadvantaged communities.

Sustainable chemistry and EJ have numerous touchpoints across a chemical's life cycle, from raw materials and feedstocks to waste disposal/recycling. Upstream impacts of extraction and production of feedstocks must be considered, and any impacted populations (e.g., local residents) must be identified. Chemicals production includes both building block chemicals production and secondary production of products and goods. Each of these involves exposing workers and the community to production-related hazards. The public must be informed of such risks. Workers in industries with high exposure to chemicals, such as beauty salons, painters, construction, manufacturing, and agriculture, should understand the risks of repeated exposure.

Sustainable chemistry benefits should be distributed equitably to all communities. Employee demographics of chemical manufacturers should be evaluated to determine whether these high-paying jobs are available to the communities and/or markets that the manufacturer serves. Communities located near manufacturing sites are not against manufacturing. They simply want manufacturing and products to be safe. Ideally, such co-location will also provide benefits in the form of job creation and economic opportunity. The accessibility of new green products is also important. In a market with alternative, safer, and sustainable products, decision makers must consider which communities can afford and/or have access to these safer alternatives, minimizing green premiums where possible.

Finally, sustainable chemistry products should be designed to reduce hazardous waste generation, regardless of whether these products are designed to be more easily recycled or designed for circularity. There is also the need to safely transport and store chemicals across the life cycle from raw materials to end of life.

SECTION 4

Panel and Lightning Presentation Sessions

Panel Discussion with Sustainable Chemistry Thought Leaders

Technology leader Perspectives – Lightning Presentations

4 Panel and Lightning Presentation Sessions

4.1 Panel Discussion with Sustainable Chemistry Thought Leaders

A panel of thought leaders was assembled to discuss how sustainable chemistry investments can effectively address industrial efficiency, decarbonization, and EJ goals. The panel included:

- Beverley Thorpe, Consulting Program Manager, Clean Production Action
- Darcy Prather, President of Kalion
- Adelina Voutchkova, Director of Sustainable Development, American Chemical Society (ACS); Lead, ACS Green Chemistry Institute
- Catherine Wise, Program Officer, Energy and Environmental Systems Board, National Academy of Sciences (NAS)

Prompt questions (see sidebar) were used to initiate discussion.

Discussion questions

- *How can leveraging sustainable chemistry practices in manufacturing promote environmental justice?*
- *How can we develop safer chemicals and manufacturing processes that are resilient, reduce impacts to the environment, and reduce use of natural resources?*
- *How can we reduce impacts to communities that are near manufacturing sites*?

The remainder of Section 4.1 provides a summary of general themes.

EJ role in facilitating safe and sustainable chemistry

Climate justice and EJ are similar concepts, yet impacts are felt by some more than others. The effects of climate change are becoming more apparent, and no community is immune. However, historically disadvantaged communities, such as low-income communities and communities of color, are often the first to be impacted. Communities along the Gulf Coast near chemicals and refining facilities are prime examples. In 2017, Hurricane Harvey caused massive environmental consequences from flaring, tank spillage, and other issues. Climate change impacts include such disruptive weather events, which are growing in number and intensity, thus exacerbating concerns about storm damage in vulnerable regions.

Sustainable chemistry can provide solutions for both climate and pollution crises, but solutions must focus on both EJ and decarbonization. A sole focus on lowering the carbon footprint of chemicals will not address global chemical pollution issues. For example, switching to bio-feedstocks to produce BTX does not lead to better outcomes for communities that are exposed to benzene pollution. Benzene is still a carcinogen, regardless of the feedstock.

Government agencies, private industry, and the investor community all play roles in reforming chemicals manufacturing through sustained public-sector investment in sustainable chemistry, EJ audits of existing chemicals manufacturing operations, and community engagement. The Louisville Charter for Safer Chemicals provides an EJ roadmap to transform the chemical industry.

Connecting sustainable chemistry RD&D to manufacturing and potential impacts

Education is critical to long-term sustainability. Younger generations must learn about EJ topics and sustainable chemistry at a foundational age to better understand the positive and negative impacts of chemistry on the world. ACS is responding by developing free fundamental courses on EJ, green chemistry, and sustainability.

There is also a deep need to connect academics with industry partners to understand whether the problems academics are trying to solve through RD&D at early technology readiness levels (TRLs) are relevant and translatable to commercial operations. Fostering pre-competitive collaboration between academia and chemical companies may accelerate commercialization of sustainable chemistry concepts. Collective public–private progress keeps those involved mindful of economics, environment, and human health, thereby minimizing finger-pointing and moving public perception of chemicals from being the cause of a problem to providing the solution.

The path toward local sustainable chemistry solutions is not always clear. A strategy for effectively communicating sustainable chemistry and EJ benefits is needed to maximize the impact of community engagement. This strategy may be developed by establishing partnerships across the sustainable chemistry RD&D landscape: early-TRL academia, mid-TRL DOE applied energy offices, policy advocates, and industry.

Including all science and technology needs for decarbonization

Many non-profit scientific organizations, such as NAS, provide evidence-based perspectives to the federal government on scientific topics. Current work includes projects on a wide variety of topics related to accelerating decarbonization of the U.S. economy; as a whole, the portfolio increasingly places equal emphasis on both technology and societal aspects related to decarbonization. This type of research necessitates convening stakeholders with broader-than-usual expertise, including social scientists, EJ experts, and RD&D scientists and engineers. Technical goals include energy efficiency and productivity; producing carbon-free electricity; electrification of energy services in transportation, buildings, and manufacturing; planning, permitting, and building critical infrastructure; increasing the use of sustainable feedstocks; and expanding the innovation toolkit. Follow-on studies broaden the scope to include more social and economic considerations, such as economic impact assessment, EJ, and cost-effectiveness. Policy recommendations can then be made to effect positive change for human health, reduce impacts of land use, and better define the role of federal, state, and local government.

Implementing sustainable chemistry and balancing competing goals as an organization

For companies with a sustainable chemistry solution or product, identifying potential markets can be a challenge. Incumbent technologies and processes are well-entrenched within the industry, so sustainable chemistry solution providers must find new uses for high-value materials and gradually increase their market impacts. This strategy often involves targeting new applications or areas of the market that may be better served with sustainable solutions over incumbent products or processes.

Decision makers within chemical companies must be more mindful of the impacts their operations have on the environment and human health, particularly in disadvantaged communities. Company executives generally do not live in communities burdened by chemical production. Therefore, it is crucial to connect their non-lived experience with the lived experience of members of impacted communities. Steps to be taken include engaging with the local community as well as public health experts to understand how people and the environment are impacted by the facilities. There must be robust dialogue between innovators and local leaders to find sustainable chemistry solutions that have positive technical, social, and economic impacts.

4.2 Technology Leader Perspectives – Lighting Presentations

The roundtable included a series of lightning talks from sustainable chemistry innovators. They presented their perspectives on needs for sustainable chemistry research and investments that can advance efficiency, decarbonization, and EJ goals, as well as how government can best address those needs.

Corey Tyree, Chief Executive Officer, Trillium Renewable Chemicals

Trillium is a startup company offering a sustainable nitrile solution. Nearly all acrylonitrile produced today is derived from propylene. Trillium offers an alternative pathway to acrylonitrile that does not require a market shift away from acrylonitrile or rely on the decarbonization of propylene. Glycerol is dehydrated, followed by an ammoxidation to produce two marketable products (acrylonitrile and acetonitrile), without producing hydrogen cyanide. Advantages include high conversion and scalability of unit processes. Success is driven by the strong demand for acrylonitrile and the drop-in readiness of acrylonitrile produced via this more sustainable pathway.

Startups can position themselves more strongly in the market by identifying buyers and developing sustainable products that have equivalent quality to incumbent products. However, the latter requires independent validation of the products and demonstration that the performance of end-use chemicals/products is similar to the incumbents.

The speaker emphasized that more federal support is needed not only for high-risk low- to mid-TRL technology development but also for third-party validation of the technology. Over its nearly ten-year history, Trillium has received support from DOE and venture capital firms, which has resulted in construction of a pilot plant and partnership with a major chemical company.

Sean Hunt, Chief Technology Officer, Solugen

Solugen is a sustainable chemicals company that leverages circular feedstocks; a simple, high-yield process combining enzymes and biocatalysts; and a local supply chain for decarbonized distribution. In 2019, Solugen received a new market tax credit to redevelop a brownfield site of a former polyethylene wax distillery that experienced an explosion in 2005. In October 2020, the company broke ground on “Bioforge 1.” It took 11 months to generate the first product. In 2023, Solugen first demonstrated 100 continuous hours on-stream, equating to over 70 tanker trucks of product and a >94% yield of product from feedstock.

The incumbent multi-billion-dollar chemicals sector faces very different hurdles from the sustainable chemistry industry. Traditional chemical companies invest small amounts of capital for low risk and low (but guaranteed) returns, while providers of sustainable chemistry solutions are taking much greater financial risk to produce higher-return products. Data and analysis can inform large companies of the consequences of making or not making certain investments. Finance executives must understand that certain decisions may have a high short-term financial burden with long-term payoff. The sustainable chemistry industry needs different types of investment and incentive structures. Sustainable chemistry RD&D requires tolerance of up to a 90% failure rate for investing in new technologies (more “shots on goal”) to drive future successes. Demonstration plants should be viewed not as commercial endeavors but rather as part of the RD&D chain, with substantial risk of failure.

Keith Edwards, Vice President of Business Development, Danimer Scientific

Danimer Scientific is a biotechnology company that produces polyhydroxyalkanoate (PHA) biopolymer. Danimer Scientific offers PHA as a biobased and sustainable material for single-use plastics that are approved for food contact in the United States. The biodegradable product is made from a renewable feedstock (canola oil) using microbes in a fermentation process. The company was founded in 2004 and has matured from startup to implementation through partnering with brands to co-fund RD&D that solves the partners’ specific challenges. However, purchasing the brownfield site of a former brewery to scale commercial production took almost a decade.

The sustainable chemistry community and policy makers must think holistically about plastics use. Single-use plastics are critical to food transportation, and wholesale bans of these products may be counterproductive to sustainability goals, push consumers to worse options, and disproportionally impact low-income communities. Biopolymer innovation should be embraced and be viewed as an alternative to bans of single-use plastics.

In addition, grant and loan programs need to incentivize biobased products over fossil-based products. There is precedent for this, as the government incentivizes production of biofuels over petroleum-based fuels.

More circular economic models require major and specific support at federal, state, and local levels. Policies should help drive diversion of organic materials from landfills to composting. These policies should also ease regulations for permitting composting sites, which are currently permitted as landfills. In addition, the Toxic Substance Control Act (TSCA) and food contact approvals should be streamlined to encourage innovation.

Renee Hackenmiller-Paradis, Director of the Chemistry Center of Excellence, Nike, Inc.

Nike is scaling sustainable chemistry in the apparel and footwear industry. Nike has been exploring sustainable solutions for its products since 1993, when shoes were used as secondary material for playground equipment. Today, Nike's water-repellant product lines are PFAS-free. The company is targeting net-zero emissions by 2050 and eliminating many chemicals of concern from its supply chain. In 2022, Nike released NIKE Forward, a new material whose manufacturing process has reduced carbon intensity by 60%.

Regulation is a major driver for sustainable chemistry. The business proposition for sustainable chemistry initiatives includes eliminating chemicals of concern and finding safer alternatives. Through these actions, one may lower cost, time, and risk (financial and reputational); increase government compliance; avoid regrettable substitutions; and support corporate sustainability targets. The business impacts include removing known problems from processes and accelerating adoption of safer chemistry and improved feedstocks for circularity.

Technical needs to further sustainable chemistry, EJ, and decarbonization include closing data gaps, including the lack of information disclosure. Nike suppliers do not disclose toxicity information on new chemicals. More data on manufacturing processes is needed across the supply chain.

Drop-in replacements are needed now, but circular materials are needed for the future. Life cycle thinking is critical, here to not only to account for energy and carbon impacts, but also to consider other sustainability concerns. There is a lack of understanding of the trade-offs with other impacts. For example, although recycled polyester is not a long-term solution, biobased materials may not truly be better. The two most-used materials in the apparel and footwear industry—cotton and leather—are both biobased, but their production is highly water- and carbon-intensive. Nonetheless, replacing these materials with ones whose production pollutes the environment is counterproductive. Industry needs better information on the impacts of new chemistries—at scale. Carbon and climate impacts do not always scale linearly. In addition, the environmental assessment tools currently in use focus on one impact at a time.

Governments can support sustainable chemistry goals by investing in end-of-life circular solutions that are safe and sustainable. This includes supporting a healthy, competitive industry for renewable monomers and continuing the dialogue with all parts of the value chain.



SECTION

5

Roundtable Facilitated Breakout Sessions

RD&D Opportunities to Leverage Sustainable Chemistry for a Carbon-Neutral Economy

Strategy for Linking Sustainable Chemistry, Decarbonization, and Environmental Justice

Public- and Private-Sector Needs and Incentives for Sustainable Chemistry

5 Roundtable Facilitated Breakout Sessions

During facilitated discussions, participants were separated into breakout groups to discuss pre-determined topics. The topic areas were:

- Opportunities and Challenges to Leverage Sustainable Chemistry for a Carbon-Neutral Economy by Reducing the Adverse Impacts of Chemicals on Human Health and the Environment
- Goals and Metrics to Link Sustainable Chemistry to Decarbonization and Environmental Justice
- Public- and Private-Sector Needs and Incentives for Sustainable Chemistry

5.1 RD&D Opportunities to Address Barriers to Leverage Sustainable Chemistry for a Carbon-Neutral Economy

Challenges and Barriers

During this opening breakout session, participants discussed financial, technical, and social barriers to developing and deploying sustainable chemistry practices and technologies in the chemicals sector. This section summarizes the outcomes of those discussions.

> Breakout 1 Discussion Questions
>
> 1) *What are the challenges and barriers to developing and deploying low-carbon, sustainable chemistry practices and technologies across the supply (value) chain?*
> 2) *What RD&D is needed to address challenges/barriers and enable adoption of innovative sustainable chemistry technologies and approaches?*

Advantages of incumbency. While the chemicals sector is made up of 10,000+ companies making 70,000+ products, the market is dominated by a few high-volume, low-margin commodity chemicals such as ethylene, propylene, and BTX. The advantages of these incumbents make them very difficult to replace. These platform chemicals have highly optimized supply chains, as well as energy- and capital-efficient, world-scale production processes. Without economies of scale, new chemical processes must be more efficient than the incumbents to compete effectively. Additionally, a large base of legacy assets and existing infrastructure gives large corporations an advantage over startups and small businesses, even if those assets are repurposed to produce new products. Finally, incumbent chemical properties have been optimized to support specific customer requests and expectations, adding pressure on new companies to replicate the incumbents rather than innovate. Other topics mentioned that can similarly favor incumbent products included intellectual property risks preventing substantial corporate R&D investment and strong customer preferences for existing products.

Lack of transparency and standardization in sustainable chemistry. Industry participants emphasized that the analysis to evaluate sustainability of new and existing products is very difficult. There are many dimensions to sustainability, and the tools are not available to help companies make informed, consistent decisions based on standardized and transparent metrics. Companies are forced to balance competing priorities when it comes to sustainable chemistry; very few options are collectively net-zero, non-toxic, and environmentally just. As more requirements are added to making a chemical “sustainable,” it becomes harder to find solutions. Data and tools are needed to better evaluate a range of sustainability attributes across the life cycle (including EJ), and to consider trade-offs when necessary. The public sector can lead in this area to help drive sustainable market behaviors and shape corporate RD&D efforts. The U.S. Department of Agriculture’s Biopreferred and EPA’s Safer Choice as “government stamp” programs could serve as models for sustainable chemistry standardization efforts.

Market barriers. Many participants noted that the costs of technology commercialization are both high and uncertain because of the unique challenges of scaling up a new process. This includes capital and operational expenditure risks, making it difficult to justify investment without a commitment from a specific buyer. As such, offtake agreements and other joint application research efforts are essential. These barriers are not restricted to the producers of sustainable chemicals, but are also concerns for downstream users and customers. New products rarely lead to “drop-in” replacements of existing chemical products, forcing stakeholders across the value chain to make substantial capital investments to accommodate the new product. Sometimes, this leads to additional supply chain risk if there aren’t multiple manufacturers to supply the market. Participants also mentioned that competing decarbonization time horizons can be a barrier to developing sustainable chemistry practices and technologies. Significant capital devoted to deployment of short-term decarbonization solutions limits the resources that can be allocated to long-term sustainability and decarbonization technologies, even though those innovations may have a greater impact in the long run.

Feedstock challenges. Many participants brought up challenges with transitioning chemical production from fossil fuel dependency to renewable feedstock sources. The volume of renewable feedstocks currently available cannot completely replace commodity chemicals such as ethylene, propylene, and BTX. One participant suggested that these feedstocks may be more optimized to directly replace downstream products (thermoplastics, rubbers, textiles, etc.); others agreed that this is a more feasible pathway for sustainable chemistry to gain market share than direct competition with platform chemicals. Industry participants emphasized that more sustainable feedstocks often come with a host of impurities, but early-stage RD&D efforts often focus on model compounds, which hinders progress toward technology commercialization. Finally, some small business participants thought that the RD&D timeline for producing sustainable feedstocks at a relevant manufacturing scale lags the development of new chemicals in the private sector. If a company is producing a new molecule, they cannot always wait for a sustainable feedstock and are often forced to use the petroleum-based options currently available.

Regulatory barriers. Participants mentioned that regulatory approval requirements for new chemicals, whether under TSCA or other statutes or standards, are barriers to deploying sustainable chemicals. Even if a new chemical is inherently less toxic/hazardous than the incumbent, there is a high data burden on the sustainable chemistry manufacturer to demonstrate the safety of the new chemical. These hurdles are costly and can be time-consuming, and sometimes they halt sustainable chemistry projects entirely. In contrast, it is more difficult for the EPA to use its TSCA authority to restrict hazardous commodity chemicals already on the market. Participants said that streamlined regulatory mechanisms to support sustainable chemistry technologies and processes would accelerate deployment.

RD&D Opportunities

After discussing the barriers to the adoption of sustainable chemistry processes and practices, the group brainstormed RD&D needs to address challenges and drive adoption in markets historically dominated by high-volume, low-margin incumbents.

Shared, flexible testbed/pilot-scale facilities that can produce industrially relevant quantities. Industry representatives said that scale-up science is always a challenge and that testbed facilities could be very valuable. However, current national laboratory facilities are often an order of magnitude smaller than what is needed to properly test new technologies. Startup participants stated that shared facilities with flexibility to produce different chemicals would be extremely valuable. Others noted that, in practice, such facilities would be very difficult to build because of the heterogeneity of chemical processes.

Application-focused RD&D practices. Participants agreed that current RD&D programs do not properly connect fundamental research with application gaps and pain points in industry, nor do they always connect core technology development with end-use product requirements. This is an area where government support for partnering and linking industry experts with sustainable chemistry innovators could be helpful. In addition, there is a need for more funding for product testing of promising new chemistries to help encourage market uptake. Also needed are opportunities to use computational power and analysis tools—e.g., computational fluid dynamics modeling and technoeconomic analysis—to accelerate technology scale-up (scale-up science).

Technology-specific RD&D. Participants highlighted specific technologies that leverage sustainable chemistry to advance decarbonization:

- Industrial electrification (electrification of boilers, integration of renewable utility supply with chemical processes)
- Separations and purification technologies to meet tight product purity specifications
- Increased focus on new molecular development and chemical formulations rather than biobased drop-ins to current formulations
- Development of processes that do not require excessively high temperatures and pressures

5.2 Strategy for Linking Sustainable Chemistry, Decarbonization, and Environmental Justice

Breakout 2 Discussion Questions

1) *What would be the primary goal(s) to work toward in linking sustainable chemistry to decarbonization and EJ?*
2) *What metrics could be used to quantify the benefits/impacts of sustainable chemistry on decarbonization and EJ?*

During this session, participants tackled the challenge of linking sustainable chemistry, decarbonization, and EJ. To begin, the groups discussed specific goals to work toward in tying together these three prongs of a secure, sustainable U.S. chemicals sector. Later, the participants brainstormed specific metrics that could be used to quantify the impact of sustainable chemistry on efficiency, decarbonization, and EJ. Both breakout groups mentioned that this topic was particularly challenging because of the heterogeneity of processes, communities, and impacts that need to be considered across the chemicals sector. Establishing metrics associated with industrial decarbonization and natural resource usage is feasible for chemicals sector researchers. However, metrics associated with health impacts and EJ will challenge the industry to include a broader set of stakeholders—including public health officials, community leaders, and others across the public and private sectors—to arrive at comprehensive solutions.

There was consensus across breakout groups that sustainable chemistry innovation is an area in which, without detailed consideration of specific impacts, it could be easy to create unintended negative consequences. Thus, most participants agreed that metrics would have to be site-specific, depending on the specific geographic area and chemical process. They acknowledged this level of specificity would necessitate performing a deep dive into issues impacting each community and forming metrics from those community interactions.

Map all co-benefits and cumulative impacts of products and processes. Participants mentioned that the chemicals sector should aim to measure all co-benefits and cumulative impacts of a sustainable product or process. Sustainable chemistry can lead to multiple benefits, including increased material efficiency, reduced natural resource extraction, reduced water and air pollution, reduced chemical exposure at work and within communities, and reduced life cycle impacts. One participant said that these co-benefits should be considered in federal program planning, while others agreed that some way of quantifying them was necessary to link sustainable chemistry to various incentives and investment opportunities. While some participants advocated for consolidating the various impact areas (air, water, carbon, waste potential) into an “environmental impact” metric, others noted that this would be an oversimplification of a complex issue. Perhaps the best synthesis of these two viewpoints came from a participant who suggested a “nutrition label” analogue for chemical products that includes carbon intensity, waste potential, end-of-life use, and human toxicity information. Another participant suggested a hazard-level-based system similar to the National Fire Protection Association diamond. Consumers and businesses could make better choices with more transparent/standardized data. Other ideas for quantitative metrics included:

- Property value change due to plant installation
- Asthma rates in local schools as a proxy for air quality
- Potential waste generated from proper and improper disposal
- Reduced risk of major incidents/spills through hazard and operability study (HAZOP)-type analysis, consequences of a major release
- Toxicity of products, wastes, and intermediates to humans and the environment

Improve quality of life in historically impacted areas through sustainable chemistry. One participant emphasized that the benefits of connecting these three topics should be felt in local communities through reduced cancer rates, higher life expectancies, and other public health metrics, as well as more high-paying jobs and enhanced economy opportunity. Others agreed that by working with both the public health community and local EJ leaders from the beginning of the technology commercialization cycle (early-stage RD&D), chemical companies can improve EJ outcomes for their customers, their employees, and the communities surrounding their operating footprints. One participant noted that there are three groups to consider when it comes to EJ impacts: employees working inside the fence line, communities living just outside the fence line, and consumers. While industry is generally good at identifying and mitigating risks to employees and consumers, industry is not good at doing the same where communities just outside the fence line are concerned. Some participants agreed that better communication between scientists, engineers, project managers, public health experts, and local EJ leaders could change this going forward.

Use EJ thinking for mid-TRL technology development. Both breakout groups recognized that identifying what to measure to quantify the EJ concerns or benefits of a decarbonization technology in the RD&D pipeline (Table 1) is a very difficult task. The metrics would have to be general enough to allow comparison of technology solutions, but specific enough to be measurable in a particular community or geographic area. To improve EJ outcomes, RD&D in the early- to mid-TRL range must consider impacts and risks at realistic manufacturing scales, including impacts on a fence line community. One of the other major challenges with integrating EJ thinking into mid-TRL research is that there is often no local community to consider; participants said this could be improved by better partnering between researchers and potential manufacturers.

The takeaways from this second breakout session are summarized in Table 1.

Table 1. Sustainable Chemistry and EJ Impacts and Considerations for Mid-TRL Technology Development

Impacts to assess during technology development	Potential actions or metrics for consideration
Energy and environmental impacts	• Increased material efficiency • Reduced natural resource extraction • Reduced water and air pollution • Reduced GHG emissions
Impacts on fence line communities	• Site-specific and community-driven metrics • Local community impacts, determined by partnering with manufacturers, as needed • Better communication with public health experts and local EJ leaders from the project conception • Cumulative burden, evaluated through local cancer rates, asthma rates, and life expectancies • Potential economic impacts, such as property value change due to plant installation
Impacts on employees and consumers	• Health risks from consistent, long-term exposure • Project scale-up risks, assessed through HAZOP analysis

5.3 Public- and Private-Sector Needs and Incentives for Sustainable Chemistry

During this session, participants discussed how the public and private sectors can work together to accelerate sustainable chemistry RD&D through federal program planning and resource-sharing. The participants further discussed what economic incentives would be needed to catalyze the commercialization of impactful sustainable chemistry technologies.

> Breakout 3 Discussion Questions
>
> *1) What types of public–private partnerships would be helpful to identify/accelerate sustainable chemistry RD&D and incorporate decarbonization and EJ concepts into sustainable chemistry?*
>
> *2) What types of economic drivers, policies, or other incentives might be needed to catalyze demonstration and deployment of impactful sustainable chemistry concepts and practices?*
>
> *3) Are there existing incentives that could be applied to sustainable chemistry concepts and practices?*

Partnership facilitation. Participants emphasized that cross-sectoral project teams—including national labs, industry, academia, and EJ leaders—can lead to new products and reach markets where the private sector alone could not. Some also mentioned that DOE can play a pivotal role as "matchmaker" to connect startups and other companies with national laboratories and other stakeholders as research partners. Such collaborations could lead to better research outcomes; national laboratories could provide computational tools and advanced pilot-scale facilities to industry project partners, who would then be able to harness those resources to solve commercially relevant challenges. Participants emphasized that better public–private partnerships could help technologies avoid the "valley of death" associated with commercialization. Other suggestions for improving public–private partnerships were mentioned:

- Grant programs to encourage collaborations between researchers and community EJ leaders
- Publicly accessible industry training resources on EJ
- Publicly accessible computational models of pilot-scale processes to accelerate technology commercialization
- Shared pilot, testbed, and analytical facilities to support new product testing
- Shared facilities, labor, and materials for solving specific technical problems relevant to multiple industry stakeholders

Accelerated RD&D funding timelines. Participants emphasized that the speed of public funding mechanisms does not match the speed of private-sector RD&D. Over the time scale of a typical federal RD&D funding process, a project's premise or development stage may change significantly. This discourages companies from seeking federal funding to support promising project ideas. For smaller companies, the labor intensity of writing full applications prevents many good ideas from receiving consideration, especially for startups that do not have the ability to dedicate full-time employees to proposal development. Novel strategies for RD&D funding could align with the speed of private-sector innovation (and market and regulatory timeframes for substitution) more closely. Suggestions included:

- Stage-gate funding mechanisms
- Large prizes for solving specific technical challenges
- Technology accelerators

Reduced market barriers. Participants emphasized that it will be a challenge for sustainable products to overcome economies of scale, mature supply chain integrations, and well-established product properties possessed by incumbent products. The public sector can help create a level playing field for sustainable chemistry innovations and accelerate the adoption of sustainable products. The government can use its buying power to encourage adoption of more sustainable products, incentivizing reuse of end-of-life consumer goods and encouraging competition to address supply chain risks of sustainable feedstocks.

SECTION

6

Conclusion: Strategy to Accelerate Sustainable Chemistry, Decarbonization, and Environmental Justic Considerations in RD&D

6 Conclusion: Strategy to Accelerate Sustainable Chemistry, Decarbonization, and Environmental Justice Considerations in RD&D

The Sustainable Chemistry in RD&D to Transform the Chemicals Sector Roundtable brought together participants from across sustainable chemicals stakeholder groups: academia, non-profits, government, national laboratories, startups, small businesses, and large corporations. The participants shared their perspectives on the opportunities and challenges of linking sustainable chemistry, EJ, and decarbonization. This section summarizes the key themes and takeaways that emerged.

Barriers to sustainable chemistry exist and need to be addressed. Sustainable chemistry includes the development of new molecular structures, feedstocks, and manufacturing processes. Participants noted that sustained investment in this "better chemistry" is needed to increase the demand for and supply of replacement technologies and to reimagine the chemicals sector. Feedstock availability is a major industry concern regarding sustainable alternatives to incumbent pathways. The volume of renewable feedstocks currently available cannot completely replace commodity chemicals such as ethylene, propylene, and BTX. It may be more feasible to optimize renewable feedstocks to directly replace downstream products (e.g., thermoplastics, rubbers, and textiles), rather than optimizing renewable feedstocks to produce commodity chemicals. Integration of new sustainable chemicals into existing supply chains is also a barrier to implementation.

Despite these barriers, sustainable chemistry is growing. The business proposition for sustainable chemistry initiatives is strong, including addressing decarbonization targets while eliminating chemicals of concern and finding safer alternatives. Through sustainable chemistry, one may lower cost, time, and financial and reputational risk; increase government compliance; avoid regrettable substitutions; and make tangible progress toward corporate sustainability targets. Companies are increasingly considering the life cycle and toxicity impacts of chemicals in their sourcing decisions.

Sustainable chemistry investments should link decarbonization and environmental justice. Sustainable chemistry innovations should not only address decarbonization or waste goals but also reduce chemical pollution and improve EJ outcomes. The benefits of connecting sustainable chemistry, decarbonization, and EJ could be felt in local communities through improved health and economic outcomes. The public health community and EJ leaders should be involved in early technology development commercialization, working with chemical companies to improve EJ outcomes from customers, employees, and surrounding communities.

Environmental justice considerations are needed for RD&D in sustainable chemistry. There must be robust dialogue between innovators and EJ leaders to find sustainable chemistry solutions that have positive technical, social, and economic impacts. Communities most affected by the chemicals industry need a seat at the table in manufacturing decisions. Engagement with the communities most adversely affected by the chemicals sector is necessary to identify not only the largest challenges and needs but also ways that sustainable chemistry solutions in development can benefit these communities. Qualitative and quantitative metrics to evaluate EJ impacts and benefits will be needed. Specific quantitative metrics from discussion include changes in property value due to plant installation, asthma rates in local schools as a proxy for air quality, potential waste generated from proper and improper disposal, reduced risk for major incidents/spills, consequences of a major release, and toxicity of products, wastes, and intermediates to humans and the environment. Developing these metrics would require the support of a broader community, including public health experts and fence line community groups.

Public–private partnerships can overcome barriers to sustainable chemistry to advance decarbonization and environmental justice. Coordinated public–private RD&D partnerships are needed to address industry challenges and drive commercialization and adoption of innovative technologies and approaches in a market historically dominated by high-volume, low-margin incumbents. For example, the government can support sustainable chemistry goals by investing in end-of-life circular economy solutions. There is a need to support a healthy, competitive industry for renewable monomers and platform chemicals and to continue the dialogue with all parts of the value chain. To overcome issues associated with sustainable drop-in replacements for incumbent chemicals, increased focus is needed on new chemical formulations, development of lower-temperature and lower-pressure processes, and protocols for third-party validation.

Appendix A. Agenda

Sustainable Chemistry in RD&D to Transform the Chemicals Sector Roundtable

Co-hosted by DOE/EERE's Industrial Efficiency and Decarbonization Office and Change Chemistry (formerly GC3)

DoubleTree by Hilton Hotel, Crystal City, Arlington, VA.

March 7th, 2023: 9:00 AM – 5:00 PM ET

AGENDA

Time EST	Activity
8:00 AM – 9:00 AM	**Arrival** • Coffee and Networking
9:00 AM – 9:20 AM	**Welcome, DOE** • Avi Shultz, Deputy Director, IEDO • Felicia Lucci, Technology Manager, IEDO
9:20 AM – 9:30 AM	**GC3 Welcome and Keynote Introduction** • Joel Tickner, Founder and Director, GC3
9:30 AM – 10:00 AM	**Environmental Justice (EJ) Keynote Speaker** • Matthew Tejada, EPA Deputy Assistant Administrator for Environmental Justice
10:05 AM – 11:05 AM	**Panel Discussion with Sustainable Chemistry Thought Leaders** • How can leveraging sustainable chemistry practices in manufacturing promote environmental justice? • How can we develop safer chemicals and manufacturing processes that are resilient, reduce impacts to the environment and reduce use of natural resources? • How can we reduce impacts to communities that are in close proximity to manufacturing sites? Panelists: Catherine Wise (NAS), Darcy Prather (Kalion), Adelina Voutchkova (ACS), Beverly Thorpe (Clean Production Action)
11:05 AM – 11:15 AM	**BREAK**
11:15 AM – 12:15 PM	**Technology Leaders - Lightning Round Presentations** Lightning round perspectives from technical leaders in sustainable chemistry on innovative technologies, research, technology and investment needs, challenges and how government could help address them. Presenters: Corey Tyree (Trillium), Sean Hunt (Solugen), Keith Edwards (Danimer Scientific), Renee Hackenmiller-Paradis (Nike)
12:15 PM – 1:00 PM	**LUNCH included with registration**

1:00 PM – 1:10 PM	**Roundtable Logistics and Facilitation** • Sam Gage, Energetics
1:10 PM – 2:30 PM	**Facilitated Discussion – Round 1** Opportunities and challenges to leverage sustainable chemistry for a carbon-neutral economy by reducing the adverse impacts of chemicals on human health and the environment
2:30 PM – 2:45 PM	**BREAK**
2:45 PM – 3:30 PM	**Facilitated Discussion – Round 2** Goals and metrics to link sustainable chemistry to decarbonization and environmental justice (EJ)
3:30 PM – 3:45 PM	**BREAK**
3:45 PM – 4:30 PM	**Facilitated Discussion – Round 3** Public- and private-sector needs and incentives for sustainable chemistry
4:30 PM – 4:45 PM	**Report-Outs, Next Steps, Closing Remarks, and Adjournment**
5:00 PM	**Reception**

Appendix B. List of Roundtable Participants

Name	Organization	Name	Organization
Ben Dunham*	Dunham Law & Policy	Adelina Voutchkova	ACS, GWU
Beverley Thorpe	Clean Production Action	Alex Ward	Origin Materials
Bikash Rajkarnikar	Henkel Corporation	Andrew Sumner*	DOE OCED
Brandon MacDonald	Via Separations	Aude Bechu*	Change Chemistry
Catherine Wise	NASM	Avi Shultz	DOE IEDO
Christian Lenges	IFF	Cameron Rylance	Bluestem Biosciences
Corey Tyree	Trillium	Christopher Straub	Novozymes
Diane Sellers*	Energetics	Daniel MacEachran	Braskem
Dionne Delli Gatti	EDF	Darcy Prather	Kalion, Inc.
Erik Spoerke	SNL	Drew Wong	LLNL
Ignasi Palou-Rivera	AIChE/RAPID	Felicia Lucci*	DOE IEDO
Joel Tickner*	Change Chemistry	Gretchen Baier	Dow Chemical
John Shaw	Itaconix Corporation	Jeffrey Weissman	PCI
Karin Calvinho	RenewCO2 Inc	Jennifer MacKellar*	Change Chemistry
Kathryn Peretti	DOE AMMTO	Karthikeyan Ramasamy	PNNL
Kristin Powell*	Energetics	Keith Edwards	Danimer Scientific
Lisa Guay	DOE BETO	Logan Guy*	Energetics
Mitrajit Mukherjee	Exelus Inc	Michael Stutelberg	AURI
Peter Ciesielski	NREL	Natalia Sharova	Air Company
Prem Patel	Ingevity	Nicholas Thornburg	NREL
Rebecca Erwin	DOE	Patrick Foley	P2 Science, Inc
Rob Hart	Shepherd Chemical	Renee Hackenmiller-Paradis	Nike
Rob Paxton	Shepherd Chemical	Samuel Gage*	Energetics
Sean Hunt	Solugen	Sharon Nolen	Eastman
Seth Snyder	INL	Steven Evans	BioMADE.org
Tomas Green	DOE HFTO		

** planning team and facilitators*

The information presented in this report includes the viewpoints of specific roundtable attendees that do not reflect consensus of all participants.

U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

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