Fair Plastics:
Advancing Industrial Decarbonization through Equitable Social Innovations

Workshop Report
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VIRGINIA TECH

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EXECUTIVE SUMMARY

The Fair Plastics workshop brought together a group of experts and stakeholders to discuss the challenging problem of decarbonizing ethylene production. It consisted of a half-day discussion of the significant obstacles and potential pathways for reducing greenhouse gas (GHG) emissions in the chemical industry, particularly focusing on ethylene, the most extensively produced organic chemical. The chemical industry is the largest industrial CO_2 emitter in the United States, contributing 20% of industrial energy-related emissions.

Key decarbonization strategies discussed include carbon capture, utilization, and storage (CCUS), low-carbon combustion fuels, electrification of process heat, novel electrochemical synthesis, and using non-fossil feedstocks. However, these options face challenges such as high costs, infrastructure needs, and the potential for carbon lock-in, where existing technical and social systems hinder the adoption of more sustainable technologies.

The report highlights the necessity of innovative approaches, including the use of hydrogen and biomass feedstocks, and stresses the importance of electrifying ethylene production processes using renewable energy. The workshop participants comprised industry representatives, researchers, and environmental and community groups.

Industry representatives focused on technical pathways to ethylene decarbonization. While requesting infrastructure for electricity, hydrogen, and CO_2, they emphasized the need for regulatory standards, carbon pricing, and government intervention to support the transition to decarbonization.

Government and academic researchers assessed the existing pathways and highlighted carbon contributors other than ethylene, such as the steel and cement industries. The group also highlighted the economic challenges of the entire plastics lifecycle, noting the difficulty in reducing reliance on low-cost natural gas and the lack of replacement materials for ethylene-derived products.

Environmental and community groups stressed the importance of addressing the entire lifecycle of plastic production, including upstream and downstream activities, to mitigate environmental and health impacts. They advocated for source reduction and greater industry accountability to ensure environmental justice for communities affected by petrochemical pollution.

The report concludes that achieving ethylene decarbonization requires coordinated efforts across technical, social, and policy dimensions, with a focus on sustainability, innovation, and equity for affected communities.

The Challenge of Decarbonizing Ethylene Production

Industrial decarbonization is an absolute and immediate requirement in the context of global climate change. Producing the basic materials that constitute the infrastructure of our modern societies (e.g. steel, cement, plastics) is the most significant source of industrial GHG emissions. Despite the clear scientific mandate to reduce GHG emissions, our decarbonization policies continue to fall short of their intended goals, both in scope and speed (IPCC 2023). Compared to areas such as electricity generation and ground transportation, where clear technological solutions for decarbonization have emerged, decarbonizing industry may follow any number of potential pathways.

In the United States, the chemical industry is the largest industrial carbon dioxide (CO_2) emitter and is responsible for 20% of U.S. industrial energy-related greenhouse gas (GHG) emissions (EIA 2023). Complicating decarbonization efforts even further is the fact that reported emissions from the chemical industry grew by 18% from 2010 to 2019 (calculations based on EPA [2022]). Producing plastics and their constituent monomers generates significant economic value for the U.S. chemical industry ($230 billion in 2020; American Chemistry Council 2021). These production activities require considerable amounts of energy for both feedstock and combustion purposes. Despite efforts to reduce the demand for plastics, particularly single-use consumer applications, these efforts may be swamped by more powerful forces generating greater demand: population growth, urbanization, and rising standards of living in the developing world.

More ethylene is produced than any other organic chemical (De Luna et al. 2019) and the rapid expansion of unconventional natural gas production has enabled domestic ethylene production to more than double since 2010 (EIA 2022). The high temperature requirement and large energy intensity of steam crackers, as well as ethylene's ubiquitous use in consumer goods, embody the greatest challenges and opportunities for industrial decarbonization. Additionally, the communities surrounding ethylene cracking facilities face the immediate environmental burdens of air pollution from ethylene production (Johnson et al. 2023).

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The plastics industry embodies the great challenges of decarbonization because of the technical nature of its production processes and its ubiquitous use. Producing the most widely-used plastics currently requires fossil fuels (oil or natural gas) as feedstock material and to generate high-temperature process heat. As a result, decarbonization options include carbon capture, utilization, and storage (CCUS); low-carbon combustion fuels; electrification of process heat;

novel electrochemical synthesis; low-carbon feedstocks; and demand reduction. Many decarbonization options face significant challenges because they are radical innovations for an industry characterized by highly optimized and integrated systems that are improved incrementally (Janipour et al. 2020) and focused on short-term economic payback (Wesseling et al. 2022).

The U.S. Department of Energy's Industrial Decarbonization Roadmap identifies priority approaches for the chemical industry that include shifting production routes from conventional feedstocks to alternative processes based on hydrogen, either produced from low-carbon energy sources or produced with CCUS (U.S. Department of Energy 2022). Specific strategies that are directly related to ethylene production include the use of biomass feedstocks for polyethylene.

Although there are significant technical challenges to decarbonizing plastics, the greater, yet less widely studied concern is the potential for carbon lock-in (Bauer and Fontenit 2021). The theory of carbon lock-in captures the idea that interactions between technical systems and social institutions can prevent the adoption of more environmentally advantageous technologies (Unruh, 2000). Decarbonization policies that are not designed to overcome carbon lock-in may not only fail to achieve the requisite emissions reductions, but also perpetuate existing environmental injustices, negating a just energy transition.

Fair Plastics: A Participatory Workshop

The Fair Plastics workshop was designed with the recognition that progress toward a viable decarbonization strategy for this industry requires participation of multiple voices and consideration of the full range of environmental impacts of plastics across the product life cycle.

We designed the workshop along the following principles:

- **Participation of multiple stakeholder groups.** The lack of a preferred path to ethylene decarbonization has some benefits. It means that we are at a stage of thinking about this problem that is open to a wide range of concerns and can take into account the diverse set of perspectives and interests involved in this industry.
- **Socio-technical systems.** Ethylene production, and the entire plastics supply chain, is a socio-technical system. This means that it is composed of a range of components, including not only technologies but social components as well. The technologies do not function without a set of social practices, organizations, regulations, market relations, or other components of the system. Therefore, the question of decarbonization is not purely a matter of technology adoption. It requires changes to many features of the system, and the involvement of a range of actors.
- **Consideration of the broader impacts.** Any pursuit of decarbonization of this industry should consider the full range of environmental impacts it generates across the entire life cycle of products. In addition to greenhouse gases, petrochemical production generates other pollutants that threaten the quality of air and water. As the greenhouse gas emissions of this industry should be considered jointly with the other impacts, measures to reduce those emissions may also help reduce other kinds of pollution from plastics production, use, and disposal.

The Participants

We identified potential participants based on their direct experience with ethylene production and its impacts. We aimed for representation from industry, environmental organizations, frontline community groups, academic research, and government agencies. For the workshop's purposes, these were reduced to three sectors: Industry, Government and Academic Research, and Community and Environmental organizations. This was not a random sample, since those who agreed to participate were self-selected based on their interest in the discussion. This resulted in a set of voices that were both knowledgeable and intensely engaged.

Industry

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Community and Environmental

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Hilary O'Toole, Executive Director, Beaver County Marcellus Awareness Community

Carrie Schoeneberger, Industrial & Hydrogen Analyst, National Resources Defense Council

Organization of the Workshop

The workshop was held virtually using the Zoom Webinar format. Registration was open to the public and discussions were conducted under the Chatham House Rule. The workshop consisted of three 90-minute sessions. The first, a "Getting Acquainted" session, began with a keynote by Dr. Clemens Schneider, who provided an overview of issues and debates around ethylene decarbonization. Each of the participants then took a few minutes to introduce themselves and provide their perspective in response to one of the following pre-circulated questions:

1. How high a priority should decarbonizing ethylene production be?
2. What is the best path to net-zero carbon ethylene production?
3. What do you see as the challenge(s) to decarbonizing ethylene production?
4. How can you or your organization contribute to decarbonizing ethylene production?
5. What is your target year for achieving net-zero ethylene production?

The second session, "Compatible Visions?," began with breakout rooms for each of the three sector groups. For 45 minutes, each group conducted a moderated discussion of their priorities and visions for transitioning the plastics industry and ethylene production in particular. During the final 45 minutes, each group reported back to the full workshop.

The third session, "Decarbonized and Fair? Bringing it all Together," was designed to maximize interaction among the participants and with the audience. The moderator introduced a series of themes, allowing the participants to offer their outlook, ask questions of others, and reflect on the day's

discussion. Roughly half of this session was devoted to questions from the broader audience.

The rest of this report will summarize the discussion, including the range of proposals and perspectives voiced.

Workshop Discussion Summary

Session 1: Getting Acquainted

The workshop's first session focused on strategies and challenges for achieving ethylene decarbonization. Participants from every group identified and discussed various challenges and approaches, including electrification with renewable energy, improving energy efficiency, blue hydrogen, carbon capture, recycling plastic to feedstock, and the circular economy.

Electrification with renewable energy was highlighted as a key solution by industry representatives, though the cracking furnace's high temperature and energy demand present significant challenges. In the United States, most petrochemical industries rely on natural gas or other fossil fuels, making the shift to reliable, non-fossil fuel energy sources a critical issue. Several representatives suggested blue hydrogen or small-scale nuclear plants as pathways to net-zero ethylene production.

> The problem isn't chemistry. The problem is energy.
>
> - Industry representative

Industry representatives noted that infrastructure for electricity and hydrogen is not yet in place. Current power grids, built for fossil fuel sources, may need rearranging to support renewable energy like solar and wind. Similarly, pipeline networks are needed to support hydrogen transmission. Some representatives urged government intervention to help sustain the current infrastructure and install new systems. Additionally, recycling plastic waste and capturing carbon dioxide back to feedstock were mentioned as effective ways to reduce carbon emissions.

> I will try to insist that we also talk not only about decarbonization, but de-fossilization, and that it's really about plastics. And not only about ethylene.
>
> - Environmental researcher

The discussion also addressed retrofitting old assets. Representatives highlighted that upgrading older ethylene crackers, particularly those built 40 to 50 years ago, could significantly reduce carbon emissions. Upgrading exchangeable parts of cracking furnaces can help meet decarbonization goals at a lower cost than building new facilities. Companies expressed a preference for integrating solutions into existing plants to avoid major overhauls. They also called for government intervention to set standards, develop policies, and incentivize investment in low or net-zero CO_2 products markets. Some companies lean towards net-zero emissions rather than full decarbonization.

Similar to members of the industry group, the research and government participants with chemical engineering backgrounds focused primarily on the importance of innovation. They raised many possible technological solutions to the net carbon emissions of the plastics industry. However, they voiced much uncertainty about which technological pathway was the most realistic.

The views of the community and environmental group on the challenges of decarbonizing ethylene production overlapped somewhat with the other two

groups. One technology that was also highlighted by the group was using an electric cracker to produce ethylene. However, it was considered to be in an early stage of development and faces economic challenges due to the major capital costs needed for further development, as well as the energy costs for electricity.

Another overlapping view was the importance of taking a life cycle perspective of plastics production overall: from the production of feedstocks used to make ethylene to the downstream use of plastics and their disposal. For the community and environmental group, however, this framing also focused on the environmental health and environmental justice challenges of these upstream and downstream activities. These activities were seen as inseparable from the challenges of decarbonizing ethylene production itself. In this view, the production of ethylene was tied to natural gas fracking in a region that was identified as the birthplace of both oil production and petrochemical production. The potential use of carbon capture and storage (CCS) on ethylene crackers was met with skepticism that the technology would ultimately be a way to continue extracting natural gas, locking the area into fossil fuel production for decades longer.

> Carbon capture associated with plastic production in our area will largely be used for fracking well stimulation and keep us locked into fossil fuel production in our area for decades.
>
> - Community and environmental representative

Unlike the two other groups, the community and environmental group extensively identified source reduction (i.e., using less plastic) in the United States and globally as a means of addressing the origin of many of the problems with plastics, or as an option to reduce life cycle impacts from ethylene production. The group also mentioned the power imbalance that can exist between small counties and multi-national petrochemical producers to influence legislation and leaders when siting new ethylene crackers.

There was concern that there is no easily implemented ethylene decarbonization solution available now. Not only that, but the communities that are facing the impacts of ethylene production now lack the time for identified solutions to be put into place.

Session 2: Compatible Visions?

The industry group summarized their breakout session discussion as covering five topics: priority, best pathway, efforts, challenges, and target year. Decarbonizing ethylene production is a top priority for the petrochemical industry, as it is one of the largest emitters. Industry representatives identified promising options for net-zero ethylene production, including electrification, blue hydrogen, carbon capture, and recycling plastic waste. Some technologies are ready now but may not be viable long-term. The rollout of different technologies will depend on factors such as new technology development, infrastructure, and cost.

All participating companies recognize the importance of ethylene decarbonization and are actively addressing it, but several challenges

remain. High costs and capital intensity for new technologies pose significant challenges. Other challenges include the need for a carbon price and ensuring the availability of renewable energy sources. Most companies aim to achieve significant reductions by 2035, with a target of net zero by 2050. There is also a consensus on the need for regulatory standards to ensure a level playing field for zero or low-carbon emission products. Additionally, several industry representatives emphasized the necessity of a carbon tax for expensive low-carbon technologies to compete with existing pathways and the importance of scalability for significant impact. Several representatives emphasized the importance of established frameworks for calculating a product's carbon footprint, including emissions from feedstocks.

All participating companies recognize the importance of ethylene decarbonization and are actively addressing it, but several challenges remain. High costs and capital intensity for new technologies pose significant challenges.

Accounting for upstream carbon emissions is crucial. Companies stressed the need for aggressive decarbonization targets for upstream businesses as well. Discussions included substituting feedstocks for ethylene production with biodiesels, recycled oils, and recycled plastics. Decarbonizing ethylene production requires net-zero targets for both production and upstream processes. Practical short-term solutions include process electrification with renewable energy or using blue hydrogen.

Other participants raised questions about infrastructure demands, including the potential for on-site hydrogen production to avoid supply chain issues. Long-term reliance on electricity and hydrogen infrastructures is vital for the petrochemical industry. Ideally, consumption sites should be near generation sites to reduce transportation costs and maintain pipeline integrity. However, on-site generation is impractical for most companies, and only large-scale corporations can afford to build facilities for generating and transporting electricity and hydrogen. The discussion on infrastructure extended to technology options, highlighting the challenges of balancing current portfolios with emerging technologies and the critical role of scalability and cost in adopting new technologies.

Some representatives from consulting firms stressed rethinking the logic behind ethylene production. They emphasized the urgency of transitioning from a linear to a circular model, redesigning recycling processes, and maximizing the value and lifespan of materials. Moreover, they encouraged petrochemical companies to adopt a comprehensive approach across the value chain to minimize fossil fuel input. For most industries, plastics are an inseparable part of society, and ethylene production will remain central to the petrochemical industry in the near future.

> We have to really take the total value chain. Put the molecules to the highest use, extend the life of the material so that we don't really consume that much. So, all these things have to go hand in hand to minimize the input from the fossil fuel type of environment. So, I think, it is not purely a one-piece problem. It's the whole value chains which need to be addressed going from a linear model to a circular model.
>
> - Industry representative

The research and government group placed a lot of emphasis on the steam cracking process, which is still needed for any high-volume production of ethylene. The biggest sustainability concern here is the high heat needed for this process, usually attained through fossil fuel combustion. One approach would be decarbonizing this process by using electric crackers, ideally supplied from renewable generation sources. Electrification could eliminate nearly all on-site emissions from cracking plants. However, it is not a comprehensive solution, as it leaves the problem of tail gas emissions, as well as facing high-cost barriers. Those in the breakout session agreed that electrification "is not a silver bullet."

The group had mixed opinions on the use of carbon capture and storage for residual emissions. Due to the need for infrastructure to capture, transport, and utilize CO_2, as well as the costs to build required infrastructure and for operations, the potential for CCS and CCUS can be considered site-specific. There was agreement that CCS might be a last resort unless a viable way of recycling carbon can be developed.

Members of the research and government group displayed a deep understanding and concern for the economics of the entire production process, as well as the impacts of the entire life cycle of plastics. They noted that the low cost of natural gas meant it would be difficult to reduce the reliance on this input, as both a feedstock and energy source. One member of the group mentioned the difficulty of moving away from ethylene due to the lack of replacement materials for plastic end-use products. While researchers were focused primarily on technological innovation, they articulated a need to consider the entire plastics value chain.

The community and environmental group stressed that it was not possible to separate ethylene decarbonization from the GHG emissions that occur upstream and downstream from production. They were interested in hearing from industry representatives about how companies were accounting for upstream emissions, specifically in their decarbonization plans.

Like other groups, the community and environmental group highlighted the uncertainty around many decarbonization technologies. For this group, however, uncertainty was tied to the need to decarbonize within time constraints.

Related to technological uncertainty, the group also discussed the political landscape and its uncertain and dynamic nature. They identified regulatory and enforcement challenges for decarbonization at federal and state levels. At a federal level, regulations may change with administrations, swinging between regulation and deregulation. Regulations may vary between states, as well as the willingness to enforce regulations.

Session 3: Decarbonized and Fair? Bringing it all Together.

In the last session of the workshop, the discussion turned to the technological and environmental impacts of decarbonization. Many representatives expressed their opinions on ethylene decarbonization's human and ecological dimensions. Opinions within the industry group, particularly between companies and consultants, varied.

The facilitator began by asking about industry and government partnerships to address the human dimension and ensure responsible actions across different regions. Concerns were raised about differing regulations and their impact on communities worldwide. Environmental and community organization representatives highlighted the broader impacts on the supply chain, human communities, and the environment, emphasizing equity for frontline communities affected by industry pollution.

Consulting firm representatives agreed with these concerns and highlighted the industry's historical lack of awareness about environmental impacts. They stressed the need for increased accountability and support for sustainability policies. The petrochemical industry, responding to consumer demand, is obligated to act responsibly and sustainably toward minority groups and frontline communities. Consulting firms also discussed the need to price externalities like climate change into the system through carbon pricing or direct regulation, considering differential impacts on various communities.

Researchers echoed some of the industry voices by emphasizing de-fossilization in contrast to decarbonization. De-fossilization refers to the continued use of hydrocarbons as both feedstock and heat source for plastics production but obtaining these hydrocarbons from sources other than fossil natural gas. One possibility mentioned by several of the researchers is to recycle the tail gas from steam crackers for the CO_2 feedstock. One of the researchers mentioned that government assistance would be needed to develop and scale up this approach, "but I see it as a possible solution to foster de-fossilization."

De-fossilization refers to the continued use of hydrocarbons as both feedstock and heat source for plastics production but obtaining these hydrocarbons from sources other than fossil natural gas.

Questions about the petrochemical industry's environmental impacts were raised, particularly regarding plastic waste and its relation to the industry's climate impact and carbon emissions. Consulting firm representatives framed climate change and plastic waste as consequences of carbon leakage. Achieving net-zero goals requires considering the entire carbon leakage equation, including circularity and end-of-life product management.

For community and environmental organizations, it is critical to approach ethylene decarbonization from a life cycle perspective (i.e., from natural gas extraction to production to product end-of-life). In particular, community and environmental organizations again stressed the high priority of reducing the

use of plastics. They recognized that certain uses, such as for medical devices, may not have an acceptable alternative material. However, in one member's view, single-use plastics should be eliminated. Several pilot projects were noted in grocery stores, schools, and care facilities where single-use plastics either have been or will be eliminated, saving organizations money and providing additional benefits. Adopting plastics recycling approaches that may increase pollution in their neighboring communities, such as chemical recycling, would create new frontline communities.

The facilitator asked participants what types of carbon pricing policies might benefit local communities and what effective partnerships between industry, government agencies, and communities might look like. Consulting firms suggested that government regulation should ensure carbon pricing revenues support those adversely impacted and establish a revenue distribution process. They emphasized that decarbonization strategies—including technologies, policies, and economic instruments—must involve all stakeholders and adopt a neutral, science- and economics-based approach that includes social justice considerations.

Environmental organization representatives pointed out the difference between asking for community input and providing community services, emphasizing the need for meaningful dialogue.

Petrochemical companies highlighted community engagement projects, such as "Teaching Tables," used to foster communication and collaboration. One representative mentioned a partnership with local communities involving plastic waste donation at an advanced recycling facility. Community and environmental organization representatives pointed out the difference between asking for community input and providing community services, emphasizing the need for meaningful dialogue. They stressed the importance of enforcement alongside a regulatory framework, noting inconsistent enforcement in high-production states, and highlighted the need for corporations to communicate how they improve residents' lives.

Members of the research and government sector, however, were largely absent from this discussion. This is partially a function of the professional roles and areas of expertise of the four representatives of this sector. However, it raises the question of whether engineers devoted to developing new technologies see the downstream impacts of the industry as among their considerations when identifying promising technologies. However, changes in policy may be influencing the outlook of technical experts. One of the chemical engineers, employed in the U.S. Department of Energy, did mention the department's initiatives to focus benefits on underserved minority communities, to require community benefit plans in grant applications and as a criterion for awards, and stakeholder engagement in the siting of a bio-refinery.

To conclude the workshop, the facilitator asked each representative about their preferred pathways, urgent

next steps, and priorities. Petrochemical companies highlighted steps toward electrification and hydrogen use to meet the 2030 carbon emission reduction goal, emphasizing innovations that maximize product output from less feedstock. They also mentioned decarbonization roadmaps for all facilities and the need for policy support to develop low-carbon solutions. Policy instruments, like the cap-and-trade program under the Clean Air Act, have the potential to effectively reduce GHG emissions.

Consulting firms underlined the uncertainty of long-term solutions and the need to develop scenarios for 2050, emphasizing the importance of choosing paths that minimize risk and align with the 1.5-degree target of the Paris Agreement. They further stressed the importance of carbon pricing for rational market decisions and cost-effective CO_2 reduction. This carbon pricing market should not only drive decisions about decarbonization technologies but also facilitate protection for vulnerable populations.

Conclusions

The global climate change emergency urges the petrochemical industry to develop pathways toward decarbonization, de-fossilization, or net-zero emissions. As a key stage of the plastic industry, ethylene production involves not only technical components—steam crackers, utility facilities, and transportation infrastructure—but also social dimensions: consumer markets, industry policies, and environmental impacts. Every aspect of the current and future ethylene system needs consideration to achieve decarbonization. Our workshop's discussion of ethylene decarbonization epitomizes the sociotechnical system perspective of ethylene production. Viewing ethylene production as a sociotechnical system highlights opportunities and restrictions based on existing knowledge and resources.

Other approaches do not decarbonize the production process, but de-fossilize by relying on non-fossil sources of fuels, such as recycled tail gases. Members of the research and policy community strongly supported additional investment in these "circular economy" solutions.

Technical challenges and opportunities for decarbonization approaches were frequently emphasized in the workshop. Participants discussed various methods to decarbonize ethylene production. There are a number of technological pathways, each with advantages and limitations, with no clear preferred option:

- Upgrading old steam crackers focuses on optimizing existing units to reduce CO_2 emissions, offering companies a quicker and more accessible solution than implementing a new technology.
- Another approach for reducing emissions is to change the energy source of steam crackers by switching to alternatives like blue hydrogen and renewable electricity. At a time when increasing demands are made on the electricity grid, there are questions about the ability of our infrastructure to accommodate

the massive new loads this would entail.

- CCS is being actively pursued by the industry, since it allows them to continue to draw value from their existing assets. This option still has strong cost limitations and does not eliminate carbon emissions from combustion or fugitive methane.
- Other approaches do not decarbonize the production process, but de-fossilize by relying on non-fossil sources of fuels, such as recycled tail gases. Members of the research and policy community strongly supported additional investment in these "circular economy" solutions.

However, the technical dimension is only one aspect of ethylene decarbonization. Social interventions, such as source reduction—reducing the overall demand for plastic products—were discussed much less often than technical solutions. Additionally, it was most often the community and environmental group that discussed source reduction as a decarbonization option.

Other dimensions of ethylene production, including standards, markets, and policies, were frequently mentioned during the discussion, highlighting the need for actors beyond the petrochemical industry. Electrification, blue hydrogen, and CCUS require infrastructure for electricity transmission, hydrogen, and CO_2 transportation. While some companies can build their own power grids, hydrogen, or CO_2 pipelines, most can only invest in limited projects. Thus, the key question for all advocates of decarbonization pathways is how to build, manage, and sustain a network of electricity, hydrogen, and CO_2 to support ethylene decarbonization. This task often requires external help, such as infrastructure or energy policy support.

Incentivized policies were specifically mentioned during the discussion. Carbon tax credits or subsidies for companies investing in ethylene decarbonization can enhance their competitiveness against companies not engaged in decarbonization. However, environmental organizations question whether carbon pricing benefits frontline communities. While it does not need to be a fully government-led project, industry and environmental organizations expect some government intervention. The industry also expects the government to set standards for valuing low-carbon or zero-carbon petrochemical products to facilitate a broader transition to decarbonization. In short, ethylene decarbonization requires both technical and social dimensions.

Addressing the technical and social dimensions of the petrochemical sociotechnical system highlights ethylene decarbonization's challenges and opportunities. However, this system also has the potential to lock us into options that do not decarbonize the entire life cycle of ethylene. The technical and social dimensions serve as instruments or resources for achieving the goal, but economic and environmental impacts on local communities are often overlooked. Environmental impacts on communities near petrochemical plants, natural gas wells, or plastics recycling facilities are contentious and require industry-community partnerships. While the industry views plastics as essential,

environmental groups advocate reducing plastic use as another pathway toward decarbonization. In other words, participants who represented community and environmental organizations highlighted the community, environmental, and economic impacts of ethylene decarbonization that were underemphasized or missing from the perspectives of other participating groups.

Further steps

The conclusions of this workshop encourage participants in ethylene decarbonization to take a broad set of concerns (technological and social) and build them into the policy-making process. Participants from industry and community and environmental groups call for policy instruments (e.g., subsidies, revenue redistribution, and carbon pricing) to support the decarbonization agenda.

Without identifying a preferred pathway, even among a participant group, the workshop brought out some important principles that can structure a fruitful policy process.

The discussion also highlighted the risks of a suboptimal solution under current policies. In this environment, the petrochemical industry has a strong incentive to get maximum value from current assets by maintaining existing technologies—based on the use and combustion of fossil hydrocarbons—and taking moderate steps to reduce or offset emissions. Policies are needed to direct investment into restructuring the production process itself. But policies that simply provide incentives and "de-risking" for investment in non-carbon emitting technologies will probably be insufficient from an environmental and justice perspective. Workshop participants were supportive of incentive policies that simultaneously target reductions in impacts on local communities caused by the petrochemical industry as well as the entire life-cycle of plastics.

Above all, the workshop demonstrated the importance of including a wide range of experts and stakeholders while research and policy are at an early stage. The next steps should be equally participatory.

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“Once you talk to people you realize, ‘hey, we're all in this, [we] have a lot of the same opinions,’ and until you can get [around] the table together, you don't know that.”

– Industry representative