U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Transitioning to a Sustainable Circular Economy for Plastics: Workshop Report

June 8–9, 2023
Seattle, Washington

Disclaimer

Acknowledgments

This report was prepared by Michelle Seitz, Coralie Backlund, Kelsey Sinclair, Kate Peretti, and Jay Fitzgerald. Alexandra Davies, Tristanne Martini, Grayson Shor, and Alan Jacobson gave valuable feedback on workshop design and suggestions for participants. The workshop was made possible by the participation of the attendees and presenters.

List of Acronyms

AMMTO	Advanced Materials and Manufacturing Technologies Office
BETO	Bioenergy Technologies Office
BFNUF	Biomass Feedstock National User Facility
BOTTLE	Bio-Optimized Technologies to keep Thermoplastics out of Landfills and the Environment
DOE	U.S. Department of Energy
EMF	Ellen MacArthur Foundation
EOL	end of life
EPR	extended producer responsibility
GHG	greenhouse gas
LCA	life cycle analysis
MRF	material recovery facility
NREL	National Renewable Energy Laboratory
PCR	post-consumer recycled content
PET	polyethylene terephthalate
PLA	polylactic acid
REMADE	Reducing EMbodied-energy And Decreasing Emissions
SPI	Strategy for Plastics Innovation

Executive Summary

The "Transitioning to a Sustainable, Circular Economy for Plastics" workshop, coordinated by the Bioenergy Technologies Office (BETO) and the Advanced Materials and Manufacturing Technologies Office (AMMTO) in collaboration with The Climate Pledge, brought together a diverse group of stakeholders to discuss the current challenges and opportunities in transitioning to a sustainable, circular economy for plastics in the United States. Input from the workshop will be used to ensure the U.S. Department of Energy's (DOE) Strategy for Plastics Innovation (SPI)[1] evolves with the rapidly changing landscape. Presentations, panel discussions, and breakout sessions provided a framework for sharing information and building direct connections among stakeholders across the value chain. This document summarizes the content discussed at the workshop to provide an update on the state of plastic sustainability in the United States.

The technological, regulatory, and economic landscape related to plastic use and recycling is rapidly changing. The focus of this workshop was to understand which metrics are being used to inform decisions related to plastic sustainability and circularity, as well as what technological gaps exist along the supply chain that would facilitate a more rapid transition to a more circular plastic economy. Key themes are discussed and may be used to identify opportunities where investments in research and development can most rapidly and substantially lead to decarbonization.

The workshop was structured in three sessions focusing on the current plastic landscape, how it is changing, and plastics in the future. A common framework for discussion was established by the plenary sessions' presentations and panels, followed by breakout sessions, which were a forum for participants to discuss challenges and opportunities. Breakout sessions further enabled cross-pollination between stakeholders from industry, academia, national labs, nonprofit organizations, and other organizations and helped to gather broad stakeholder input to identify overarching themes.

The workshop discussions highlighted numerous challenges and opportunities for increased plastic sustainability and circularity. Several overarching themes emerged, including:

- **Harmonization:** Inconsistent policies create a complex landscape for investment and alignment. The current variety of materials, product design, and recycling infrastructure limits the ability to recycle safely and economically.
- **Improved data, insight, and tools for assessing impact:** There is a need for open data and metrics that are understandable, credible, actionable, and comparable to assess the impacts on human health and the environment. Sensitivity analysis should be included to verify whether options perceived as more sustainable align with real-world outcomes.

[1] U.S. Department of Energy. 2023. *Strategy for Plastics Innovation*. https://www.energy.gov/sites/default/files/2023-01/DOE-strat-for-plastics-innova_1-19-23.pdf.

- **Expanded feedstock amount and quality:** There is a need to increase recycling access, engage consumers, expand infrastructure, and explore novel collection solutions to increase plastic recycling. Improved sortation would benefit both mechanical and advanced recycling by better matching feedstocks with recycling technologies.
- **New business models:** Innovations to expand reuse and refill as alternative to single-use applications, including insights into consumer acceptance, have potential to increase plastic circularity and reduce the demand for virgin material.
- **Material and recycling technology innovation:** New recycling technologies and material developments (bio-based, recyclable, and biodegradable plastics) are needed to address currently unrecycled plastics.
- **Collaboration as a key enabler:** Advancing technologies from small-scale demonstration through pilot scale and market implementation can be accelerated by partnerships between stakeholders across industry, academia, and government. The alignment of industry coalitions and pre-competitive collaborations around product design and systems development will facilitate the acceleration of innovations at scale. Additionally, direct insight from municipalities (rural and urban) should interface with research and policy development to support rapid adoption and integration.

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Introduction

Challenge

The technological, regulatory, and economic landscape related to plastic use and recycling is rapidly changing. Increased use of plastics and stagnated recycling rates are driving concern about pollution, but these challenges also present an opportunity to valorize these waste streams and drive decarbonization of the U.S. economy.

Worldwide attention on plastic pollution is leading to a changing regulatory environment for plastics. Ongoing initiatives include the United Nations plastic pollution treaty negotiations,[2] the introduction of recycled content requirements and enactment of extended producer responsibility[3] (EPR), and the U.S. Environmental Protection Agency's National Recycling Strategy.[4] Recent advances in recycling processes from sorting to innovative recycling technologies are being launched at pilot and commercial scales. In the wake of China implementing its Operation National Sword policy in 2018,[5] the export value of recyclables collapsed overnight, decreasing the United States' plastic recycling rates and increasing the amount of plastic being landfilled.[6,7] Shifting U.S. markets for recycled plastics are creating a demand for technology advances. Additionally, many companies have announced climate goals that include targets related to recycled content, plastic sustainability, and greenhouse gas (GHG) emissions, which are driving changes in this dynamic landscape.

These societal and technological changes will impact material selection, product design, and end of life (EOL) for plastics. The huge variety of potential feedstocks, plastics, applications, and EOL pathways (different recycling technologies, composting, biodegradation, and landfilling) makes the transition from a linear economy to a circular economy for plastics particularly challenging.

U.S. Department of Energy Strategy for Plastics Innovation

As part of the U.S. Department of Energy (DOE) Plastics Innovation Challenge, the Bioenergy Technologies Office (BETO) and Advanced Manufacturing Office hosted the "Plastics for a

[2] U.N. Environment Programme. 2023. "Intergovernmental Negotiating Committee on Plastic Pollution." Accessed Nov. 2, 2023. https://www.unep.org/inc-plastic-pollution.
[3] Organisation for Economic Co-operation and Development. 2023. "Extended Producer Responsibility." Accessed Nov. 2, 2023. https://www.oecd.org/environment/extended-producer-responsibility.htm.
[4] U.S. Environmental Protection Agency. 2023. "National Recycling Strategy." Last updated Oct. 25, 2023. https://www.epa.gov/circulareconomy/national-recycling-strategy.
[5] Cheryl Katz. 2019. "Piling Up: How China's Ban on Importing Waste Has Stalled Global Recycling." *Yale Environment 360*, March 7, 2019. https://e360.yale.edu/features/piling-up-how-chinas-ban-on-importing-waste-has-stalled-global-recycling.
[6] J. Heiges and K. O'Neill. 2022. "A Recycling Reckoning: How Operation National Sword catalyzed a transition in the U.S. plastics recycling system." *Journal of Cleaner Production* 378: 134367. https://doi.org/10.1016/j.jclepro.2022.134367.
[7] Jared Paben. 2023. "U.S. fiber and plastic exports continued to fall in 2022." *Resource Recycling*, Feb. 21, 2023. https://resource-recycling.com/recycling/2023/02/21/u-s-fiber-and-plastic-exports-continued-to-fall-in-2022/.

Circular Economy" workshop in December 2019,[8] which discussed technology solutions for addressing plastic waste, summarized in the workshop report.[9] Input from this workshop and other stakeholder engagement informed several BETO and Advanced Manufacturing Office funding opportunities related to plastic circularity. Portfolio and project summaries are available on the BETO 2023 Project Peer Review website.[10] DOE-funded consortia and centers relevant to plastic circularity are shown in Table 1.

In January 2023, the Strategy for Plastics Innovation (SPI)[11] was released, which focuses on resources from across DOE to create a comprehensive program to accelerate innovations that will dramatically reduce plastic waste in oceans and landfills. This initiative will position the United States as a global leader in advanced plastics recycling technologies and in the manufacturing of new plastics that are recyclable by design.

Vision: The United States leads the world in developing and deploying technologies that minimize plastic waste and promote energy-efficient and economical plastic and bioplastic design, production, reuse, and recycling.

Mission: To deliver transformative science and technology solutions that will reduce plastic waste and lower the energy impacts of plastic production and reuse.

Strategic goals:

1. **Deconstruction**: Create new chemical, thermal, and biological/hybrid pathways to deconstruct plastics efficiently into useful chemical intermediates.
2. **Upcycling**: Advance the scientific and technological foundations that will underpin new technologies for upcycling chemical intermediates from plastic waste into high-value products.
3. **Recyclable by design**: Design new and renewable plastics and bioplastics that have the properties of today's plastics, are easily upcycled, and can be manufactured at scale domestically.
4. **Scale and deploy**: Support an energy- and material-efficient domestic plastics supply chain by helping companies scale and deploy new technologies in domestic and global markets, while improving existing recycling technologies such as collection, sorting, and mechanical recycling.

The SPI has developed quantitative objectives and metrics to measure progress toward its strategic goals. These metrics will help ensure that funding opportunities associated with the SPI

[8] Bioenergy Technologies Office. 2023. "Plastics for a Circular Economy Workshop." Accessed Nov. 2, 2023. https://www.energy.gov/eere/bioenergy/events/plastics-circular-economy-workshop.
[9] U.S. Department of Energy. 2020. *Plastics for a Circular Economy Workshop: Summary Report*. DOE/EE-2074. https://www.energy.gov/sites/default/files/2020/08/f77/beto-amo-mars-plastics-wksp-rpt-final.pdf.
[10] Bioenergy Technologies Office. 2023. "Plastics Deconstruction and Redesign." Accessed Nov. 2, 2023. https://www.energy.gov/eere/bioenergy/plastics-deconstruction-and-redesign.
[11] U.S. Department of Energy. 2023. *Strategy for Plastics Innovation.*

are cost-effective and clearly emphasize GHG emissions reductions, energy efficiency, carbon efficiency, and material retention:

- Develop technologies to address EOL fate for >90% of plastic materials.
- Provide ≥50% energy savings relative to virgin material production.
- Achieve ≥75% carbon utilization from waste plastics to encourage material-efficient processes.
- Design recycling strategies that mitigate ≥50% GHG emissions relative to virgin resin or plastic intermediate production.
- Develop recyclable-by-design plastic solutions and recycling processes that are cost-competitive with incumbent plastic materials and processes.

Table 1. Description of DOE-Funded Consortia and Centers Relevant to Plastic Circularity

Consortia and Centers	Description
Bio-Optimized Technologies to keep Thermoplastics out of Landfills and the Environment (BOTTLE™) consortium (bottle.org)	BOTTLE is a DOE multi-organization consortium focused on developing new chemical upcycling strategies for today's plastics and redesigning tomorrow's plastics to be recyclable by design.
Reducing EMbodied-energy And Decreasing Emissions (REMADE) Institute (remadeinstitute.org)	In partnership with industry, academia, and DOE national labs, the REMADE Institute will enable the early-stage applied research and development of key industrial platform technologies that could dramatically reduce the embodied energy and carbon emissions associated with industrial-scale materials production and processing.
Chemical Upcycling of Waste Plastics (CUWP) (cuwp.org)	CUWP is a multi-university center funded by DOE to provide technical, environmental, and economic information on chemical recycling of plastic wastes. CUWP consists of six universities, more than 15 industrial partners, one national laboratory, and one industry association.
Institute for Cooperative Upcycling of Plastics (iCOUP) (ameslab.gov/institute-for-cooperative-upcycling-of-plastics-icoup)	iCOUP, led by DOE's Ames Laboratory, is an Energy Frontier Research Center. The scientists at iCOUP are discovering new chemical pathways to transform used plastics into a resource through recycling and upcycling.
Center for Plastics Innovation (CPI) (cpi.udel.edu)	CPI seizes the unique opportunity to integrate a data- and systems-driven approach with molecular-level understanding; synthesis of novel, multiscale catalytic materials; new processing schemes; and functionalization approaches toward new polymers. The goal is to reconstruct the current polymer plastic waste paradigm to positively impact the U.S. and global economy via efficient and environmentally benign pathways.

Consortia and Centers	Description
Biomass Feedstock National User Facility (BFNUF) (bfnuf.inl.gov)	BFNUF is the lead national research institution for material handling and mechanical processing. A $15-million upgrade was completed in 2023 to enhance biomass feedstock quality through expanded preprocessing capabilities, intelligent automation, and tools to advance fundamental knowledge of feedstock variability and material handling.

Transitioning to a Sustainable, Circular Economy for Plastics Workshop

BETO and the Advanced Materials and Manufacturing Technologies Office (AMMTO), in collaboration with the Climate Pledge, hosted the "Transitioning to a Sustainable, Circular Economy for Plastics" workshop on June 8–9, 2023, in Seattle, Washington.[12] The objective was to convene a diverse group of stakeholders to discuss the current challenges and opportunities in transitioning to a sustainable, circular economy for plastics in the United States.

The workshop goals were to:

- Assess the current landscape of plastic sustainability and circularity in the United States.
- Identify metrics that companies are using to assess plastic sustainability and circularity, along with selection drivers.
- Establish supply chain and technology gaps currently limiting the transition to a circular plastic economy.
- Identify opportunities for decarbonization with respect to plastics and pathways to achieve them.
- Facilitate collaboration across the entire value chain to accelerate transition to a more sustainable, circular economy for plastics.

The desired outcomes of the workshop were:

- Direct connections between stakeholders across the value chain to facilitate collaborations to accelerate innovation toward our collective decarbonization and circular economy goals.
- A publicly available, DOE-issued workshop report recording the discussed problems, research ideas, and industry feedback.
- Input to ensure the SPI evolves with the rapidly changing landscape to reflect current needs and challenges related to plastic sustainability and circularity.

[12] Bioenergy Technologies Office. 2023. "Workshop: Transitioning to a Sustainable, Circular Economy for Plastics." Accessed Nov. 2, 2023. https://www.energy.gov/eere/bioenergy/events/workshop-transitioning-sustainable-circular-economy-plastics.

BETO Mission

The Bioenergy Technologies Office (energy.gov/eere/bioenergy/bioenergy-technologies-office) within DOE's Office of Energy Efficiency and Renewable Energy supports the research, development, and demonstration of technologies aimed at mobilizing domestic renewable carbon resources for the reduction of GHG emissions across the U.S. economy.

AMMTO Mission

The Advanced Materials and Manufacturing Technologies Office (energy.gov/eere/ammto/advanced-materials-manufacturing-technologies-office) supports a globally competitive U.S. manufacturing sector that accelerates the adoption of innovative materials and manufacturing technologies in support of a clean, decarbonized economy. We do this through our mission: to inspire people and drive innovation to transform materials and manufacturing for America's energy future.

The Climate Pledge Mission

The Climate Pledge is a private-sector-focused climate action coalition initiated by Amazon and Global Optimism in 2019. Signatories of the pledge commit to achieve net-zero carbon emissions by 2040, a decade ahead of the Paris Agreement's goals. Signatories agree to measure and publicly report their emissions regularly and implement decarbonization strategies that are aligned with the Paris Agreement. The pledge organizes and manages a multitude of projects that help signatories collectively decarbonize their operations while supporting a just energy transition and circular economy. The pledge has more than 435 signatories based in 38 countries working across 56 industries with 9.7 million employees.

Workshop Structure

The workshop was organized in three plenary sessions, each followed by a breakout session with four parallel topics, as shown in Table 2. A full agenda can be found in Appendix A.5.

Table 2. Overview of Workshop Agenda

Session	Plenary Focus	Breakout Focus	Breakout Discussion Topics
1	Sustainability and Circularity for Plastics	Landscape of Plastics	1.1: How do we guide good policy and measure progress?
			1.2: What role do industry pledges, coalitions, and working groups have in the successful implementation of plastics recycling?
			1.3: What influences investments in recycling infrastructure?
			1.4: What are the tools for understanding plastic environmental impacts (e.g., life cycle analysis [LCA]), and how do we harmonize them?
2	Plastic Recycling – A Changing Landscape	Supply Chain Challenges	2.1: What are the challenges and opportunities related to incorporating recycled plastics in products and packaging?
			2.2: What are the challenges in sourcing and reprocessing recycled content?
			2.3: How do we make recycling more straightforward to increase quantity and quality of material?
			2.4: Which technology and business model approaches move us toward plastics circularity?
3	Plastics in the Future – Material Selection	Sustainability: From Challenges to Solutions	3.1: What are the challenges we anticipate for future recycling systems?
			3.2: What is the role of plastic packaging in the future?
			3.3: How can we redesign products and business models to enable reuse?
			3.4: How do we maximize sustainability benefits of bio-based plastics?

Each session ran for approximately half a day and started with presentations and panels to set the scene and provide background and perspectives. Presenters and panelists came from federal and state government agencies, academia, national laboratories, industry, trade associations, and nonprofit organizations. Biographies from speakers who chose to submit them are included in Appendix A.3. Presentations are available on the Transitioning to a Sustainable, Circular Economy for Plastics Workshop Presentations webpage.[13] Breakout room moderators are noted in the agenda. Prior to the workshop, panel moderators were provided with suggested guiding questions for the panels (included in Appendix A.2).

[13] Bioenergy Technologies Office. 2023. "Transitioning to a Sustainable, Circular Economy for Plastics Workshop Presentations." Accessed Nov. 2, 2023. https://www.energy.gov/eere/bioenergy/transitioning-sustainable-circular-economy-plastics-workshop-presentations.

Sessions ended with four parallel breakout discussions, with participants self-selecting which to attend. Each breakout discussion had a moderator, and participants formed groups of up to 10 to discuss with a notetaker. In addition to the questions emailed to participants prior to the workshop (included in Appendix A.1), each session was asked to consider how research, analysis, and collaborations can drive improvement and potential benefits or challenges related to environmental justice. The room moderator collected input from each table at the end of the discussion and then shared a readout when the entire workshop reconvened.

Workshop Attendance and Speakers

Strong interest was expressed in the workshop, with 150 registrations and a waitlist of 31. The 132 workshop participants represented a wide range of stakeholder groups as shown in Figure 1. While many of the attendees represented companies or trade organizations, a substantial fraction came from the research community (academia and national labs), and there were also participants from nonprofit organizations, government agencies, consulting agencies, and financial institutions. Attendees with affiliation are given in Appendix A.4.

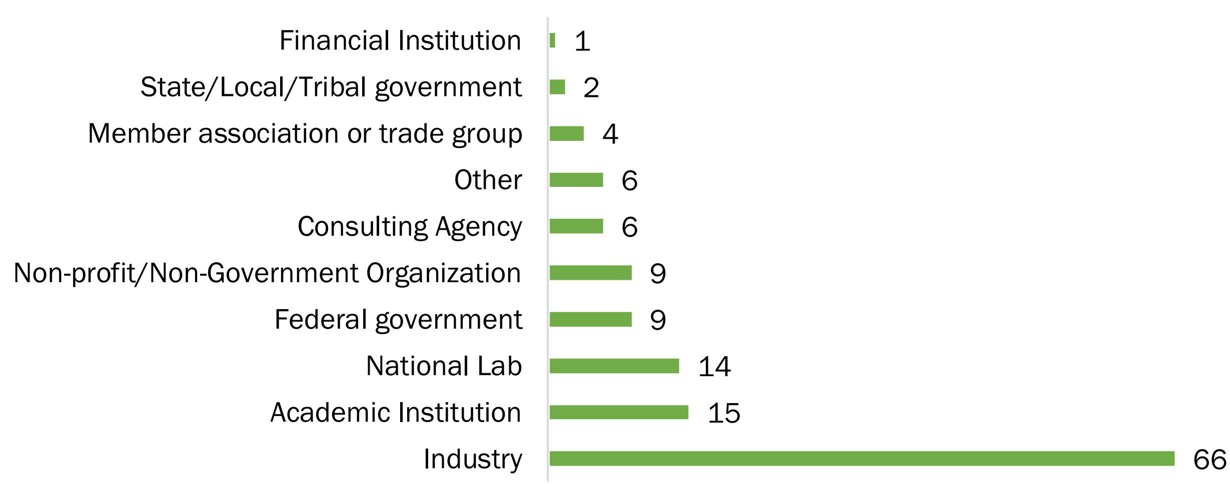

Figure 1. Workshop attendees by affiliation

Workshop Report Organization

This report provides summaries of the presentations, panels, and breakout discussions from the workshop. Content is provided in the same order as presented at the workshop. It concludes with a high-level summary of input received.

Plenary Session 1: Sustainability and Circularity for Plastics

The plenary session was structured to provide a survey of the current landscape of plastic sustainability and circularity to provide participants with a shared foundation moving into the breakout discussions.

Trade-Offs between Carbon Reduction and Circularity

Kathryn Peretti from AMMTO provided a backdrop on DOE's interest in promoting plastic circularity. Looking at the life cycle of plastics, DOE sees several opportunities in diverting plastic waste that currently ends up in landfills or the environment. Collection and use of these discarded plastics would allow for the retention of economic value, reduced embodied energy and emissions associated with recycled plastic production, and improved environmental and health impacts associated with plastic waste. This is an urgent problem—plastic production is projected to continue to increase at a steady rate, and the plastic recycling rate has been plateauing since about 2010.[14] In response to this important challenge, DOE developed the SPI,[15] meant to guide our efforts in addressing the technological barriers to plastic circularity. After introducing the vision and metrics of the SPI, the BOTTLE consortium[16] and REMADE Institute[17] were highlighted as ongoing efforts that offer opportunities for engagement. This workshop is the most recent effort to inform and guide the plastics-related programs at DOE by stakeholder feedback and engagement.

Figure 2. Forward-looking vision for the SPI.

Source: Kathryn Peretti, AMMTO

[14] U.S. Environmental Protection Agency. 2023. "Plastics: Material-Specific Data." Last updated April 21, 2023. https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data.
[15] U.S. Department of Energy. 2023. "Strategy for Plastics Innovation." Accessed Nov. 2, 2023. https://www.energy.gov/strategy-for-plastics-innovation.
[16] U.S. Department of Energy Office of Energy Efficiency and Renewable Energy. 2023. "Bottle." Accessed Nov. 2, 2023. https://www.bottle.org/.
[17] REMADE Institute. 2023. "The REMADE Institute." Accessed Nov. 2, 2023. https://remadeinstitute.org/.

Changing Landscape for Plastics: International Policy Perspective

Erica Nuñez from The Ocean Foundation provided an overview of the evolving landscape of international policy related to plastics. Much of the policy is being driven by increasing understanding of the impacts of plastic production, use, and disposal on wildlife, ecosystem, and human health.[18] The evolving mandate on marine litter and plastic pollution from the United Nations Environment Assembly led to the start of negotiations on a global treaty.[19] Insights were shared from the second of five Intergovernmental Negotiating Committee meetings, which concluded the week before this workshop. The Ocean Foundation summarized support for various elements from the written member state submissions. Potential elements with the strongest support in member state submissions include human health and plastic pollution in the environment. Many submissions included control measures as core obligations such as restricting toxic chemicals, under-an-acre pollution prevention plans, and waste management. For implementation, submissions showed strong support for national action plans, financial mechanisms, and national reporting. The presentation concluded by highlighting that the policy footprint related to plastics is expanding.

Ambitions and Challenges in Delivering on Plastics and Waste Commitments

Nicholas Vijverman from the Ellen MacArthur Foundation (EMF) explained that EMF's mission is to accelerate the transition to a circular economy. In 2018, EMF and the U.N. Environment Programme launched the New Plastics Economy Global Commitment.[20] The vision is to eliminate the plastics we don't need; innovate to ensure that the plastics we do need are reusable, recyclable, or compostable; and circulate all the plastic items we use to keep them in the economy and out of the environment. A progress report with lessons learned since 2018 was released in Oct. 2023.[21] EMF identified focus areas in transitioning to a circular economy for plastics as reuse models to reduce the need for plastic; well-designed, mandatory EPR; and defining a pathway to deal with flexible packaging. Eliminating plastic pollution may require letting go of the traditional packaging supply chain.

Panel Discussion: Circularity and Climate Trade-Offs for Materials

Moderator: Michelle Tulac (EMF); Panel: Anne Bedarf (Colgate) and Clinton Smith (Pregis)

This panel explored potential trade-offs between circularity and climate impact, how organizations navigate them, and challenges and innovation opportunities for research, development, and policy. The discussion is summarized below.

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[18] Philip J. Landrigan et al. 2023. "The Minderoo-Monaco commission on plastics and human health." *Annals of Global Health* 89 (1). https://doi.org/10.5334/aogh.4056.
[19] U.N. Environment Programme. 2023. "Intergovernmental Negotiating Committee on Plastic Pollution."
[20] U.N. Environment Programme. 2023. "The New Plastics Economy Global Commitment." Accessed Nov. 2, 2023. https://www.unep.org/new-plastics-economy-global-commitment.
[21] Ellen MacArthur Foundation. 2023. "The Global Commitment 2022 Progress Report." https://emf.thirdlight.com/link/f6oxost9xeso-nsjoqe/@/#id=2

It was noted that an EMF report[22] estimated the energy transition could tackle 55% of global emissions, but addressing product production and use is needed to reduce the other 45%. While net zero doesn't necessarily mean a circular economy, increased circularity is needed to reach net zero.

Panelists commented that they actively measure emissions, including manufacturing and transportation. They noted that most of their emissions are Scope 3 during the consumer use phase, so consumer behavior education (e.g., washing with cold water, turning off the tap while brushing) is an important piece. Additional activities around sustainability include working with the supply chain to introduce post-consumer recycled content (PCR), as well as thinking about locating facilities near users and sourcing renewable energy. When thinking about e-commerce, the product inside the packaging represents the majority of the footprint, and so it is critical that the packaging effectively protects the product.

There is an inherent tension between high material efficiency, emissions, and EOL challenges. One example is flexible packaging, which may be more preferrable from an emissions and material reduction perspective, but brings more EOL management challenges. The EMF project was noted for their efforts to address flexible packaging.[23] While mono-material solutions are being pursued to improve recyclability of flexibles, there is still a question of whether they will be collected and recycled. Compostable packaging needs infrastructure and acceptance. Concerns about the potential for product waste issues for reuse and refill systems were also voiced.

Depending on the application, fiber packaging may be a good solution, while in others flexible plastics have lower impact. Incorporating PCR requires working with the supply chain to hit performance metrics. In cases where performance differences with PCR are challenging (e.g., smell from PCR can affect pet food), bio-based alternatives can be used as a drop-in replacement with lower footprint (e.g., bio-based polyethylene). The challenge of navigating transitions in recycling technology and package design was noted. For example, high-density polyethylene tubes can be sorted in some material recovery facilities (MRFs) but not all. Dynamic labeling approaches may help with transitions and regional differences.

The need to engage people and keep all people in mind as we transition to a circular economy was noted. How we interact with things is a learned behavior, so engaging people is critical and an opportunity.

A need for a level, harmonized playing field for industry was voiced—for example, harmonized EPR (both globally and within the United States) that is inclusive of all materials including composition with eco-modulation, considering the impact of specific design decisions such as

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[22] Ellen MacArthur Foundation. 2021. *Completing the Picture: How the circular economy tackles climate change*. https://emf.thirdlight.com/file/24/cDm30tVcDDexwg2cD1ZEcZjU51g/Completing%20the%20Picture%20-%20How%20the%20circular%20economy%20tackles%20climate%20change.pdf.

[23] Ellen MacArthur Foundation. 2023. "Flexible packaging: The urgent actions needed to deliver circular economy solutions." Accessed Nov. 2, 2023. https://ellenmacarthurfoundation.org/flexible-packaging/overview.

adhesives and labels, in addition to main packaging materials. The example of the Consumer Goods Forum's view on optimal EPR[24] was mentioned. Ensuring that money collected via EPR is used to build infrastructure, as well as a desire from industry to have access to the material they pay to help collect, was discussed. Pre-competitive collaboration to define what optimal EPR looks like and help avoid competitive disadvantage was identified as an opportunity.

Challenges identified: Scaling from small demonstrations to market implementation and the associated investments. Understanding if consumers will accept reusable or refillable products and how to scale collection infrastructure. Balancing efficiency during use and collection/EOL.

[24] The Consumer Goods Forum. 2020. *Building a Circular Economy for Packaging: A View from the Consumer Goods Industry on Optimal Extended Producer Responsibility*. https://www.theconsumergoodsforum.com/wp-content/uploads/Building-a-Circular-Economy-for-Packaging-Dec-2022.pdf.

Breakout Session 1: Landscape of Plastics

Following the plenary session, participants moved into four breakout sessions to discuss the landscape of plastics. The discussion and input from these sessions are summarized next.

Session 1.1: How Do We Guide Good Policy and Measure Progress?

The goal of this session was to discuss what is driving decision-making, how to balance GHG emissions and other environmental factors if circularity should be the goal, and the lessons learned from other countries.

A variety of factors were identified as driving decision-making, including increased public awareness of plastic pollution due to media coverage, citizen science initiatives, company sustainability goals and pledges, increased data collection, and work of environmental nongovernmental organizations. The emotional aspect of the discussion around plastics and concerns around uninformed decision-making were raised. For example, there is potential for increased water and energy impacts when switching from plastic to paper.

While many potential metrics were raised, the focus on GHG emissions was viewed as being easiest for consumers to understand. The need for systems thinking broadly about carbon or full-system circularity rather than narrowly defining material circularity was highlighted. Divergent definitions, policies, and infrastructure were noted as challenges. However, there is also a need to be flexible to reflect regional differences in resources (e.g., water and infrastructure).

Lessons learned from other countries include the importance of culture in consumer behavior, bottle return schemes, acceptance of mass balance allocation for advanced recycling, and enactment of EPR policies. Other countries rely on multi-stream recycling, where consumers sort materials, rather than the predominantly single-stream system in the United States.

Opportunities: Education of public and policymakers. Harmonization of terminology and impact assessment.

Challenges: Quantifying the full impact—not only at the material level, but also at the system level, including impacts on human health and communities. Capturing cost and impacts in a way consumers can understand, and alignment on which indicators to include.

Collaborations: Consistency and harmonization in terminology, policy approaches (e.g., EPR), and between federal agencies. Ensuring all components of the waste management supply chain see benefits. Collaboration was seen as key to driving critical mass to drive system change.

Session 1.2: What Role Do Industry Pledges, Coalitions, and Working Groups Have in Successful Implementation of Plastics Recycling?

The goal of this session was to explore what drives decision-making, what voluntary goals have been set, whether the pledges are being met, and what research or further collaborations could enhance these efforts.

Business risks and opportunities, public pressure, and regulations were viewed as driving industry pledges around plastic recycling. Economics are key in decision-making; one participant noted, “you can’t have a sustainable system without a sustainable economic model.” Regulations are shifting the cost/benefit analysis around choices made by companies.

Many voluntary goals call for 100% recyclable, reusable, or compostable packing and the use of 30% recycled content. However, there is no standard guidelines for how the “recyclable” parameter is defined. Some viewed voluntary pledges as helping align industry around common metrics and as a vehicle for industry to inform what good policy could look like. A need for transparency around who is developing and participating in the pledges was voiced.

Participants felt that there was mixed progress toward pledges, depending on the company and the metric. Others felt that it was too early to measure progress. Challenges toward meeting pledges were identified as the lack of recycling collection in many communities, realities of the current supply chains and market conditions (recycler capacity, quality, and supply-and-demand imbalance), lack of common definitions, need for local infrastructure and workforce investment, and lack of harmonization of policy across states. It was noted that environmental, social, and governance politicization may disincentivize organizations from making pledges. Creative financing structures were cited as helpful in meeting pledges. The ongoing U.N. plastic treaty negotiations, as well as industry groups, were seen as forums to work toward harmonization.

Research opportunities: Understanding how best to engage consumers with research on consumer behavior and how to advance behavior change needed.

Analysis opportunities: Participants felt analysis of different approaches from states and countries would be helpful in understanding potential impacts (e.g., case studies of bottle return systems, differentiated bin systems). Some participants voiced a desire for trusted, non-industry institutions to collect, manage, and communicate data such as LCAs for certain materials.

Collaborations: Collaborations were viewed as critical to reaching harmonization of policies such as EPR, definitions, and recycling systems needed to increase plastic recycling. Participants felt that working directly with municipalities when crafting policy and research would be beneficial because they are on the front lines of waste management. A need for collaboration between industry and research was identified.

Potential benefits or challenges related to environmental justice: Participants felt that increased plastic recycling would have a positive effect because it would reduce the quantity of waste going to frontline communities and therefore the associated burdens. The challenge in balancing potential economic benefits such as jobs with burdens related to waste management/recycling for local, often disadvantaged communities was identified. Additionally, access to recycling varies between communities, and expectations and access must take local context into consideration.

Session 1.3: What Influences Investments in Recycling Infrastructure?

This session discussed non-monetary hurdles to upgrading infrastructure; trends in investment; where investments could have the largest impact; and how research, analysis, and collaboration could have impact.

The discussion identified many challenges related to recycling. Recycling infrastructure in the United States was not designed for the diversity of materials and stream composition fluctuations associated with today's recycled content. Many parts of the country, especially rural communities, lack access to recycling options. In areas with commingled recycling, conventional sorting is labor-intensive, making it expensive for the sorting facilities and challenging to retain skilled workers. Additives provide an extra layer of complexity, making it time-consuming and adding expense to qualify materials, negatively impacting the scrap value. Once the material is sorted, often space is constrained near recycling collection for storage or related processing facilities. The volatility in the price of scrap material has led to inefficiency in the market for recycled plastics.

Flexibles are a current focus with pilots and investment. For example, the Materials Recovery for the Future[25] project demonstrated optical sorting of flexibles at an MRF, The Recycling Partnership has the Film & Flexibles Recycling Coalition,[26] and Dow and WM announced a curbside film pilot.[27] Additionally, producers are looking at mono-material designs. Concerns about the introduction of new materials potentially negatively affecting current recycling processes were raised.

The relative cost of collection for recycling versus landfill fees was noted as a key driver. Waste management companies are becoming vertically integrated through mergers, which may influence the consistency of recyclables. For example, Republic Services Inc. and Ravago Group have formed Blue Polymers LLC.[28] Additionally, nontraditional sources of investments are coming into the recycling space such as the Amazon Climate Pledge Fund[29] and Closed Loop Partners.

Challenges: Material variability and lack of insight into composition/additives. Multi-material products. Lack of design for recycling. Inefficient polymer recycling marketplace.

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[25] Susan Graff. 2023. "MRFF Final Project Report." https://www.americanchemistry.com/content/download/14438/file/2023-MRFF-Final-Project-Report.pdf

[26] The Recycling Partnership. 2023. "Film and Flexibles Coalition." Accessed Nov. 2, 2023. https://recyclingpartnership.org/film-and-flexibles/.

[27] Dow. 2022. "WM and Dow Rollout First Major Residential Plastic Film Recycling Program in the U.S." Press release, Nov. 15, 2022. https://corporate.dow.com/en-us/news/press-releases/first-major-residential-plastic-film-recycling.html.

[28] Blue Polymers. 2023. "Blue Polymers." Accessed Nov. 2, 2023. https://bluepolymers.com/.

[29] Climate Pledge Fund. 2023. "The Climate Pledge Fund." Accessed Nov. 2, 2023. https://fund.theclimatepledge.com/.

Opportunities: Development of low-cost sorting methods to reduce dependence on manual sorting. Expanding recycling access for rural communities, including "dirty"[30] MRFs. Harmonization of material composition and format. Nontraditional investment in recycling infrastructure.

Analysis: Measurement of effectiveness of different recycling strategies. Better monitoring and sharing of actual recycling rates. Leverage modeling to give direction on largest impact and as faster/cheaper alternative to piloting. Evaluate pathways to introduce more sustainable materials while minimizing disruption to existing waste streams.

Collaborations: Alliances to de-risk investments, consensus-building around product design and recycling infrastructure, including the full value chain.

Session 1.4: What Are the Tools for Understanding Plastic Environmental Impacts, and How Do We Harmonize Them?

This session focused on understanding tools used to make decisions on circularity and environmental impact, whether solutions promoted as circular are identified by LCA as being optimal solutions, how research or collaboration can drive harmonization, and how to incentivize data sharing.

Different communities (national labs, academia, industry, and the public) have different needs relating to tools, data, and information for making decisions on environmental impact and circularity. Participants agreed there is a lack of standardization and transparency around evaluating impacts. Developing core, easily understood metrics to help consumers, policymakers, and companies make decisions was desired. While LCAs were widely used, concerns related to appropriate boundaries and varied data and metrics were raised. An LCA typically evaluates energy, GHG, and water impacts, and typically does not assess toxicity, impacts of extraction, and EOL/leakage issues. Tension between expanding LCA impact metrics and ease of use were raised. Some felt risk assessment is a more appropriate tool for toxicity evaluation than LCA. Streamlined tools to support at the design level provided by a neutral party such as a government agency rather than a single company were desired.

Participants emphasized that decisions related to perceived circularity may not be supported by data. For example, consumers with a negative perception of plastic may select an aluminum cup that has a larger environmental impact.

Many participants highlighted the need for easily accessible, up-to-date, and unbiased data to inform analysis. Concerns were raised about the recycling rate figures reported by the U.S. Environmental Protection Agency due to lack of inclusion of imported materials and issues with comparability across materials. Additionally, enthusiasm was expressed for tools that give insight into supply chains, such as digital product passports.

[30] "Dirty" MRFs are facilities that recover recyclables from an unsorted municipal solid waste stream.

Needs: Universal tools for sharing data and metrics. Inclusion of sensitivity analysis with LCAs. Expand LCA to include social impacts, or develop alternative tools to assess impacts on human health and the environment. Harmonization across impact categories and data.

Data: Data need to be up to date, unbiased, and easily accessible. Updated recycling rates and comparability across different materials.

Opportunities: Digital product passports to trace materials through the supply chain. Tools that are easy to use and understand to assess impacts. Expansion to evaluate social impacts in addition to environmental.

Plenary Session 2: Plastic Recycling – A Changing Landscape

This session was structured around how plastic recycling is changing. Presenters and panelists gave insight into current recycling rates, emerging technologies and innovations, state perspectives, and challenges related to sourcing PCR.

Current State of U.S. Plastic Recycling

Nina Bellucci Butler of Stina Inc. shared the latest figures on U.S. plastic recycling. Growth is needed in recycling across all categories, but especially material suitable for food grade. In 2021, 5,084.1 million pounds of post-consumer plastic material sourced in the United States was recovered for recycling in the categories of bottles, non-bottle rigids, film, and other plastics (excluding foam). Post-consumer plastic recovered for recycling was up overall by 280.3 million pounds, compared to a decline of 290 million pounds from 2019 to 2020. Most major categories of plastic recovered for recycling had an increase in total pounds reported in 2021 compared to 2020. For context, according to Chemical Market Analytics, more than 5 billion pounds of polyethylene (not including other resins) was produced just in March 2023. The findings in the *2021 U.S. Post-Consumer Recycling Data Report*[31] show some growth in recycling, but the U.S. volume of material collected for recycling has not yet returned to its peak seen in 2016, nor is the growth in the same scale as growth in virgin resin production. While a smaller percentage of scrap plastic is moving to export markets, an increasing amount of virgin resin is produced for the export market. Barriers to widespread use of PCR, historical scrap plastic pricing to illustrate impacts from major events, the need for full cost accounting of the production and disposal of plastics (and other materials), and the growing delta between virgin resin production and reclamation capacity were covered. Actions needed to catalyze the transition from our linear economy to a circular one for plastics were discussed.

[31] The Association of Plastic Recyclers. 2023. "2021 Plastic Recycling Data." Accessed Nov. 3, 2023. https://circularityinaction.com/2021PlasticRecyclingData.

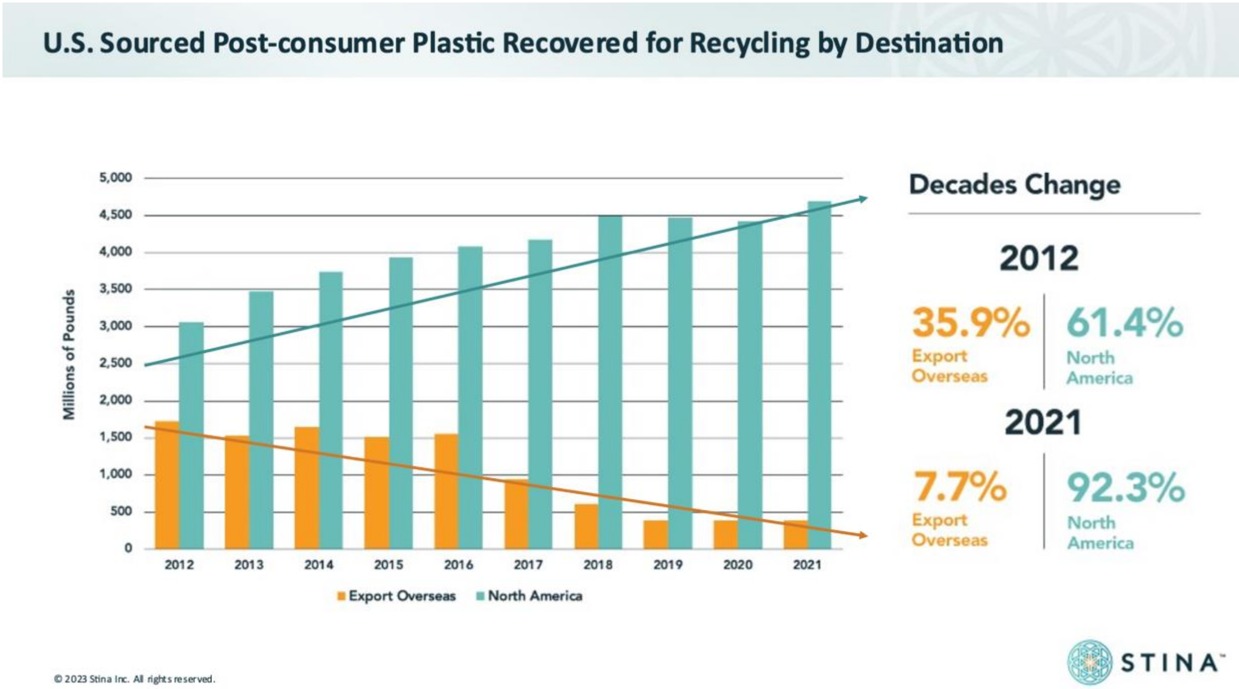

Figure 3. Trends in U.S. post-consumer plastic recycling by destination.

Source: Nina Bellucci Butler, Stina Inc.

BFNUF Capabilities for Plastic Processing and Recycling

Vicki Thompson from Idaho National Laboratory presented an overview of the BFNUF capabilities and challenges related to sorting. Plastic recycling in the United States is hindered by the difficulty and expense of current sorting technologies, low profit margins, contaminated materials, and the lack of access to curbside recycling in many areas. Idaho National Laboratory recently underwent a BETO-funded $15-million upgrade to its BFNUF.[32] This upgrade included new comminution equipment, mechanical sieving and sorting technologies, and air classifiers, as well as state-of-the-art, artificial-intelligence-trained sorting systems with near-infrared, mid-infrared, X-ray fluorescence, visible, and 3D sensors. Unlike current MRFs whose designs are static and not optimized for plastic sorting, the BFNUF is reconfigurable and can be utilized to explore different designs and maximize separations. The BFNUF also has the ability to explore nontraditional separations that are not currently utilized. Finally, the BFNUF is examining small modular MRF systems as a potential solution to rural waste generation. Examples of work at BFNUF were shared and include investigation of thermal treatment to remediate chlorine content

[32] U.S. Department of Energy. 2023. "DOE Launches New Energy Earthshot to Decarbonize Transportation and Industrial Sectors." May 24, 2023. https://www.energy.gov/articles/doe-launches-new-energy-earthshot-decarbonize-transportation-and-industrial-sectors.

in wastes,[33] decontamination studies,[34] rural waste, and work with the Defense Advanced Research Projects Agency ReSource program.[35]

Figure 4. Overview of BFNUF capabilities relevant to multilayer package recycling.

Source: Vicki Thompson, Idaho National Laboratory

Advanced Recycling Technologies

Bridget Croke of Closed Loop Partners gave an overview of different molecular recycling approaches. Molecular recycling, also referred to as chemical recycling or advanced recycling, is a diverse sector that uses a variety of technologies to break down plastics to create polymers, monomers, oligomers, or hydrocarbon products. Closed Loop Partners released a report in 2021 assessing molecular recycling technologies in the United States and Canada.[36] The complexity of plastic recycling was highlighted by showing how different plastic wastes can flow into different recycling technologies (mechanical, purification, depolymerization, or conversion), resulting in various outputs including polymers, monomers, and hydrocarbon chemicals. The system-level impacts for different technology categories were compared, and it was highlighted that in

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[33] S. Kolapkar et al. 2022. "Integrated torrefaction-extrusion system for solid fuel pellet production from mixed fiber-plastic wastes: Techno-economic analysis and life cycle assessment." *Fuel Processing Technology* 226: 107094. https://doi.org/10.1016/j.fuproc.2021.107094.

[34] R. M. Brown et al. 2022. "Decontamination of mixed paper and plastic municipal solid waste increases low and high temperature conversion yields." *Frontiers in Energy Research* 10: 834832. https://doi.org/10.3389/fenrg.2022.834832.

[35] Paul Menser. 2022. "Battle-ready recycling: DARPA ReSource project enlists INL research team." Idaho National Laboratory, Feb. 2, 2022. https://inl.gov/integrated-energy/battle-ready-recycling-darpa-resource-project-enlists-inl-research-team/.

[36] Closed Loop Partners. 2022. *Transitioning to a Circular System for Plastics: Assessing Molecular Recycling Technologies in the United States and Canada*. https://www.closedlooppartners.com/wp-content/uploads/2022/09/Molecular-Recycling-Report_FINAL.pdf.

addition to energy and emissions, the mass yield of the supply chain and the chemical inputs and processes avoided should be measured.

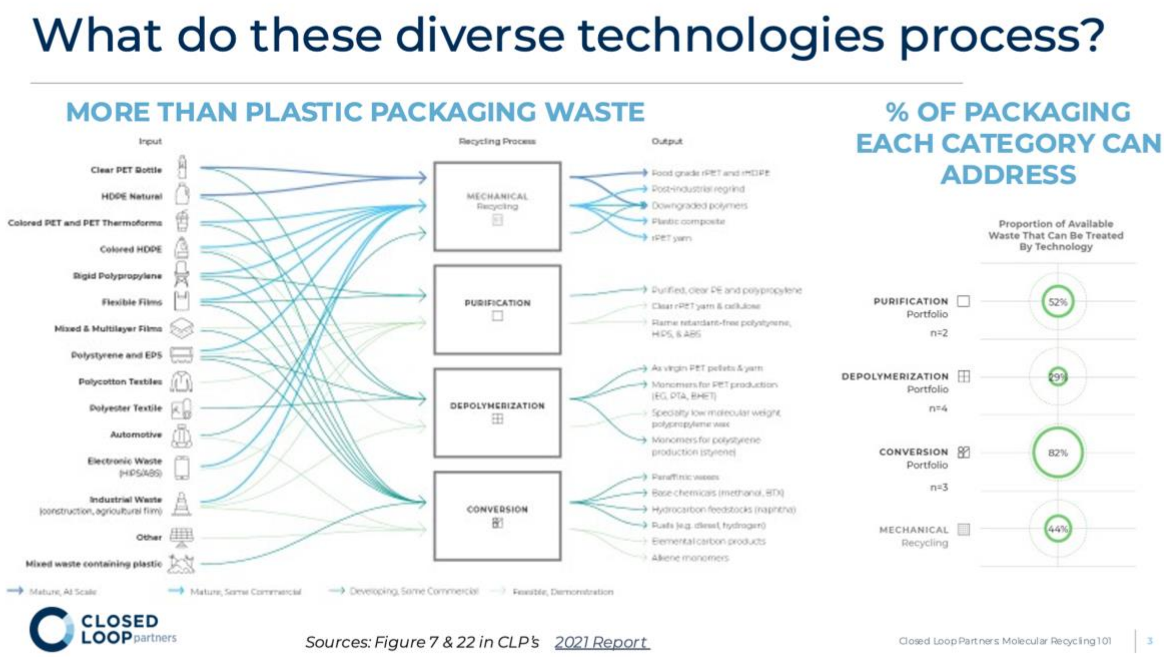

Figure 5. Plastic streams flowing into different recycling technologies and products.

Source: Bridget Croke, Closed Loop Partners

Benefits and Challenges in Scaling New Recycling Technologies

Gregg Beckham from the National Renewable Energy Laboratory (NREL) introduced the BOTTLE consortium, jointly funded by AMMTO and BETO, which focuses on developing scalable recycling technologies to enable cost-effective plastics recycling and redesign. A resource assessment for spatially dependent plastic waste availability in the United States[37] was presented alongside benchmark supply chain analysis for energy and GHG emissions for today's plastics manufacturing.[38] Techno-economic analysis and LCA results were shown for closed-loop polyethylene terephthalate (PET) recycling with enzymatic strategies[39] as an illustrative case that highlights the importance of identifying the most critical process areas to further develop toward efficient scale-up. Work from the BOTTLE consortium that focused on a

[37] A. Milbrandt et al. 2022. "Quantification and evaluation of plastic waste in the United States." *Resources, Conservation and Recycling* 183: 106363. https://doi.org/10.1016/j.resconrec.2022.106363.
[38] S. R. Nicholson et al. 2021. "Manufacturing energy and greenhouse gas emissions associated with plastics consumption." *Joule* 5 (3): 673–686. https://doi.org/10.1016/j.joule.2020.12.027.
[39] A. Singh et al. 2021. "Techno-economic, life-cycle, and socioeconomic impact analysis of enzymatic recycling of poly(ethylene terephthalate)." *Joule* 5 (9): 2479–2503. https://doi.org/10.1016/j.joule.2021.06.015; T. Uekert et al. 2022. "Life cycle assessment of enzymatic poly(ethylene terephthalate) recycling." *Green Chemistry* 24 (17): 6531–6543. https://doi.org/10.1039/D2GC02162E.

detailed comparison of existing and emerging closed-loop recycling methods was reviewed,[40] which offers a decision tree for selection among recycling options based on the feedstock and primary objectives in recycling. Lastly, a new, open-loop chemical recycling method[41] was highlighted that is able to connect today's plastics waste to the production of new, circular polymers that can achieve similar performance to many of today's thermoplastics.[42]

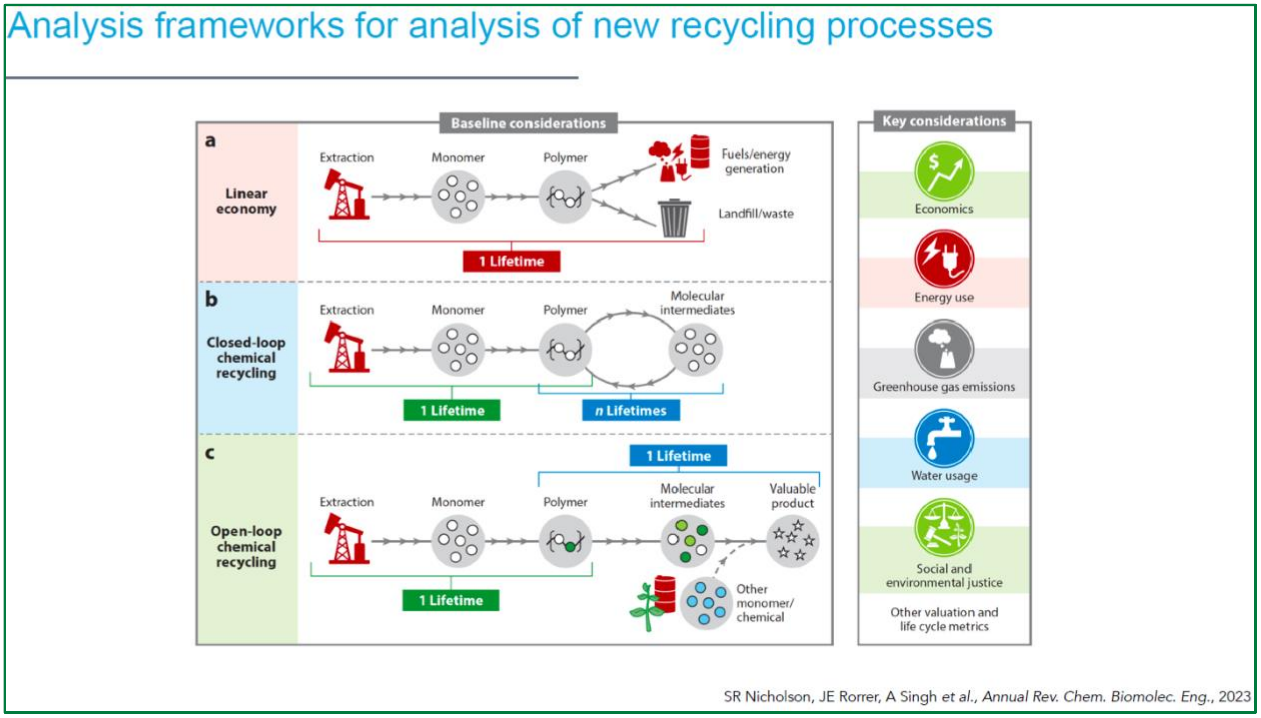

Figure 6. Analysis frameworks for new recycling processes.[43]

Source: Gregg Beckham, NREL/BOTTLE

Plastic Recycling Challenges and Improvements

David Allaway from Oregon's Department of Environmental Quality provided a state government perspective on recycling challenges. The recycling of post-consumer materials (including plastics) from Oregon was significantly disrupted by the contraction of export markets resulting from China's Operation National Sword policy. The resulting disruption revealed significant limitations in the state's policy framework, which had been designed several decades earlier when the waste stream, collection systems, processing infrastructure, and end markets

[40] T. Uekert et al. 2023. "Technical, economic, and environmental comparison of closed-loop recycling technologies for common plastics." *ACS Sustainable Chemistry & Engineering* 11 (3): 965–978. https://doi.org/10.1021/acssuschemeng.2c05497.
[41] K. P. Sullivan et al. 2022. "Mixed plastics waste valorization through tandem chemical oxidation and biological funneling." *Science* 378 (6616): 207–211. https://doi.org/10.1126/science.abo4626.
[42] E.C. Quinn et al. 2023. "Mono-material product design with bio-based, circular, and biodegradable polymers." *One Earth* 6 (6): 582–586. https://doi.org/10.1016/j.oneear.2023.05.019.
[43] S.R. Nicholson et al. 2022. "The Critical Role of Process Analysis in Chemical Recycling and Upcycling of Waste Plastics." *Annual Review of Chemical and Biomolecular Engineering* 13: 301–324. https://doi.org/10.1146/annurev-chembioeng-100521-085846.

were all very different. Current challenges include a high degree of public confusion[44] and unfavorable economic fundamentals,[45] which are worsened further as a consequence of contamination. Contamination—especially when exported—also creates potential for significant environmental harm. Emerging concerns involving exports, microplastics, and chemical contamination are also creating headwinds. Initiatives cloaked in the mantle of a "circular economy" often oversimplify conditions and lead to programs and policies—such as preferring materials based on physical attributes as opposed to environmental impacts[46]—that are ripe with potential for unintended consequences. Recycling done well can deliver environmental benefits, but state policy in the United States often results in either an underinvestment in recycling or forms and modes of recycling that are not optimized for environmental outcomes. Oregon's Plastic Pollution and Recycling Modernization Act (2021) aims to navigate between those two extremes and contribute to an economy that is both more circular and more sustainable. The act requires surgically targeted improvements to specific elements of Oregon's recycling system, while requiring producers, through a "shared responsibility" version of EPR, to support both financial and operational outcomes. Expected outcomes of implementation include improvements in both the quantity and quality of materials recycled, a much stronger emphasis on ensuring environmental and social outcomes (including environmental justice) through a "responsible end markets" requirement, improvements in public confidence, and reductions in environmental impacts.

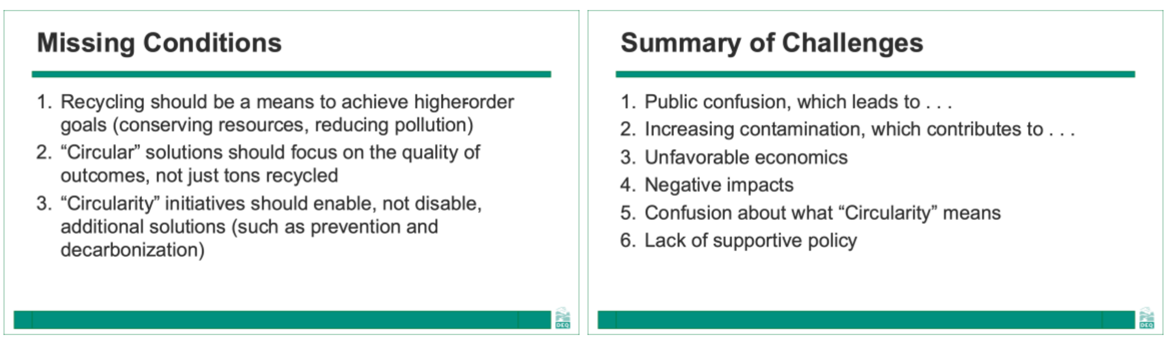

Figure 7. Missing conditions from a circularity-only focus and recycling challenges.

Source: David Allaway, Oregon Department of Environmental Quality

[44] DHM Research. "Metro Recycling Resident Survey." September 2018. https://www.oregonmetro.gov/sites/default/files/2019/03/28/Recycling-Survey-Report-2018.pdf.

[45] Oregon Department of Environmental Quality. 2023. "Plastics Recovery Assessment Project." Accessed Nov. 2, 2023. https://www.oregon.gov/deq/recycling/Pages/Plastics-Recovery.aspx; Oregon Department of Environmental Quality. 2023. "Recycling Material Acceptance Lists." Accessed Nov. 2, 2023. https://www.oregon.gov/deq/recycling/Pages/Material-Lists.aspx.

[46] Oregon Department of Environmental Quality. 2023. "Popular Packaging Attributes." Accessed Nov. 2, 2023. https://www.oregon.gov/deq/mm/production/Pages/Materials-Attributes.aspx.

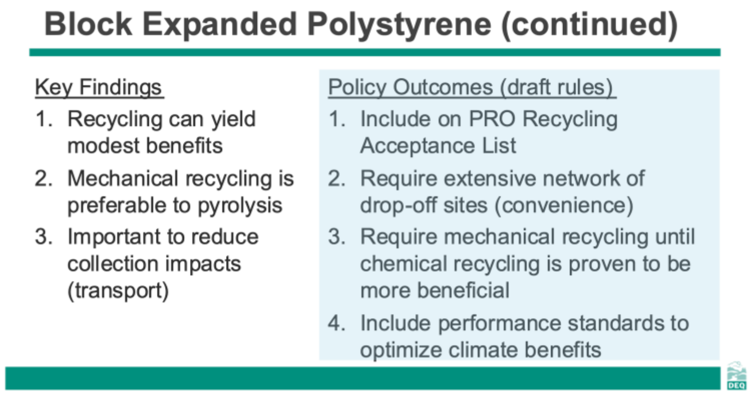

Figure 8. Key findings and policy outcomes from analysis for expanded polystyrene.[47]

Source: David Allaway, Oregon Department of Environmental Quality

Panel Discussion: The Recycled Content Challenge

Moderator: Vicki Thompson (Idaho National Laboratory); Panel: Bill Cooper (Cyclyx), Chris Wirth (AMP Robotics), and Fei Wang (Procter & Gamble)

This panel discussed the current state of play, barriers to sourcing at the right quality at volume, what is needed to address quality and quantity limitations, and whether advanced sorting is sufficient to address these issues. Points raised in the discussion are summarized below.

Achieving consistent quality of material at competitive price from responsibly sourced feedstock is difficult. Current challenges for producing and sourcing recycled content include finding feedstock at the needed specification to go into the recycling processes (especially for food-grade applications), producing PCR that is price-competitive, and the cost of sortation. Advanced recycling was viewed as complementing, rather than displacing, mechanical recycling and as needed to hit targets for PCR. Mechanical recycling cannot meet all performance or volume needs.

Key barriers discussed included qualifying feedstocks for different recycling pathways and increasing collection by addressing recycling deserts and consumer education. It was noted that post-industrial waste streams are cleaner than post-consumer streams and should be considered.

While advances in sortation were viewed as having potential positive impact, several considerations were raised. The opportunities, cost, and challenges for improving sorting will be different for retrofitting existing infrastructure versus incorporation into new facilities. Robotics coupled with data management is needed for maximum impact. In addition to the ability to sort, the sorted materials must be viewed as a valuable commodity rather than contamination (e.g., films). Increased data can help create standards and support end markets.

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[47] Oregon Department of Environmental Quality. 2022. “Comparative Life Cycle Assessment of Expanded Polystyrene Dispositions (Updated).” Material Lists Technical Workgroup Meeting #4, July 19, 2022. https://www.oregon.gov/deq/recycling/Documents/PyrolysisResults071122.pdf.

Opportunities identified: Partnership and collaboration to drive scale. Producer responsibility organizations and coalitions need to match the speed of PCR commitments. Feedstock supply chain at scale for advanced recycling. Simplify the aggregation processes and educate consumers so they understand and participate. Collaboration across the value chain on packaging design to reduce pressure on downstream recovery.

Technology development needed: Sortation technology for different waste streams and qualification of feedstock for different recycling processes.

Breakout Session 2: Supply Chain Challenge

Following the plenary session, participants divided into four breakout sessions to discuss supply chain challenges. The discussion and input from these sessions are summarized next.

Session 2.1: What Are the Challenges and Opportunities Related to Incorporating Recycled Plastics in Products and Packaging?

The goal of the session was to explore challenges with recycled content quality and quantity, matching recycled materials with end applications, differences between packaging and durable goods, manufacturing with recycled feedstock, and research or collaborations needed to overcome them.

Several challenges in matching recycled materials with end applications were identified. These included consistency of recycled materials; reliability of PCR supply; concerns related to degradation, color, smell, and toxic additives; difficulty in reaching the desired performance at high PCR amounts; and resistance to changing product design or specifications.

Challenges with the quantity of recycled materials were identified as being related to challenges with collection and mixed streams. Many felt the issue was achieving the right quality at the right price. Chemical recycling was mentioned to overcome quality concerns and to recycle lower-quality feedstocks than mechanical recycling can accept. Digital watermarks and smart barcodes were identified as technologies that may help with quality and quantity by improving sorting. The HolyGrail 2.0 pilot[48] on digital watermarks in Europe, as well as the Recycle Check program,[49] which integrates with How2Recycle[50] and SmartLabel,[51] were also mentioned.

In comparing packaging and durable goods, participants noted most of the goals and attention were focused on packaging; product use times are vastly different, and durables may be harder to recycle because they may contain mixed materials. There is potential for more durable packaging to enable reuse if concerns related to cross-contamination can be overcome via dispensing technology.

Manufacturing challenges related to using recycled feedstock were identified, including scale and consistency of material, the need to optimize processing parameters, determining appropriate specifications, and the need for long-term relationships with manufacturers (e.g., offtake agreements). Strategies that have been successful included the redesign of bottles to include a separate layer that minimizes product contact with PCR, chain extenders to help alleviate degradation in molecular weight, and blending with virgin resin. Polyester (PET) was identified as a success due to the solid supply chain.

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[48] AIM. 2023. "Pioneering Digital Watermarks." Accessed Nov. 3, 2023. https://www.digitalwatermarks.eu/.
[49] The Recycling Partnership. 2023. "Recycle Check: Solving consumer confusion with dynamic local information." Accessed Nov. 3, 2023. https://recyclingpartnership.org/recyclecheck/.
[50] How2Recycle. 2023. "How2Recycle." Accessed Nov. 3, 2023. https://how2recycle.info/.
[51] Consumer Brands Association. 2023. "SmartLabel." Accessed Nov. 3, 2023. https://smartlabel.org/.

Collaborations: Participants agreed that a holistic approach is needed that encompasses the entire supply chain and engages with consumers. As one noted, "to make it a reality, we have to work with literally everyone." Mapping dependencies across the supply chain would be helpful. A need for a better structure for defining and setting standards around different types of recycling and global harmonization was noted. Collaborations between academia, industry, and government were called for, as well as across the supply chain. An example of a footwear collective, where collaboration for incorporating PCR is shifting supply chains for the industry, was mentioned. Additionally, alliances for education to help change consumer behavior were cited.

Opportunities: Consumer engagement and education related to collection. Outreach to change consumer expectation/acceptance related to packaging (e.g., color). Dispensing technologies to reduce contamination concerns for packaging refill. Digital tools to improve sortation.

Session 2.2: What Are the Challenges in Sourcing Feedstock and Producing Recycled Content?

This session explored challenges with matching recovered materials with different recycling options, strategies for durable and consumable applications, and innovation and technology development needed.

Participants noted the need to invest in technology development and invest in infrastructure to allow sorting systems to direct materials to their highest value/best use, whether mechanical or advanced recycling. There are pilot programs looking at different waste stream compositions to generate more data and analysis on matching waste streams to recycling processes.

Removing barriers to participation is important—particularly for rural and multifamily housing—to expand feedstock available. Improved recycling access benefits other materials as well. Opportunities for increased recycling of personal protective equipment and medical plastics exist if regulatory issues related to biohazards are overcome. A lack of attention to some plastics (e.g., nylon, ethylene vinyl alcohol, rubbers) and challenges in film collection and aggregation systems were noted. Confusion and collection challenges are increased because one product category (e.g., yogurt cups) are not all made from the same material, and the material used can change over time.

Participants noted the variety of different durable goods, and that the collection system is different than for packaging (you don't recycle your car via a curbside bin). Infrastructure is currently lacking for accepting durables or removing targeted components from complex products for recycling. The value of metal, rather than plastic, is a driver for some durable goods recycling. For plastics used in electronics, concerns about legacy flame retardants were raised.

Innovations with the most potential impact were identified as improved sorting (artificial intelligence, optical, mobile sorting, methods for resin and fabric identification, QR codes) and contamination reduction in recycling plants (washing and grinding). Some participants called for a ban on materials that can't be recycled (e.g., resin codes 4, 5, and 6) because there are no current markets. For recycling that requires pre-washing, economically viable water recycling and filtration systems were identified as useful. This could address water usage, reduce the cost of current systems, and address microplastic runoff.

Opportunities: Recycling medical plastic if regulatory challenges can be overcome. Methods development for recovery of fibers from fabrics (e.g., reverse weaving). Reusing water in recycling systems and improved filtration to remove microplastics. Mobile sorting and access in rural areas.

Session 2.3: What Are the Challenges We Anticipate for Future Recycling Systems?

This session discussed effectiveness and improvements needed for current design guidelines for recyclability; challenges and potential for different waste streams; how much system redesign is being handled by MRFs; and disruptive research and collaboration to make recycling more effective.

Participants identified a tension with design guidelines between focusing on today's recycling system and design for future systems. They also noted that there are many guides available, which may create confusion. Some felt the guidelines were helpful and impactful, while others dissented. The largest issue with design guidelines was the regional variability in infrastructure and regulation. Development of a national standard for MRFs and infrastructure, along with legislation and regulation for the future system, were identified as needs.

Continued need for either new materials or recycling technologies for multilayered packaging was noted. Additionally, concerns related to unintended consequences of mixing post-industrial with post-consumer feedstocks were flagged—how to design a system so bad actors are not incentivized to create industrial waste to convert into PCR.

Participants noted that there is a lack of data about waste sources other than municipal solid waste, and improved data would help prioritize efforts. While some MRFs were viewed as state of the art, these were noted as limited. Putting the burden on MRFs to make the system profitable was seen as not viable, and the need for the wider ecosystem to play a role was noted—for example, via contracts to enable investment in MRFs or by testing product design in MRFs before they are put on the market. Regional secondary sortation centers were noted as an interesting emerging business model, where material would initially flow through an MRF and secondary sortation can occur elsewhere.

Challenges: Transition between current and future system. Scaling new materials and products without negatively affecting the system.

Collaborations: Producers and waste companies need to test products for successful sortation in MRFs in multiple regions.

Opportunities: Public data/research project on waste data to drive decisions. Digital traceability of material assets from cradle to grave via blockchain recording. Leverage reverse logistics of brands already delivering to homes. Regional secondary sortation.

Session 2.4: How Much Can Current Technology and Business Model Approaches Move Us toward Plastics Circularity?

This session discussed whether introducing new plastics could reduce plastic waste, whether an ideal system has fewer types of plastics or more with better-matched uses, what extent current business models incorporate circularity, and what research and collaboration could help scale the best approaches.

The need for a pathway for the material transition in analogy to the energy transition was raised. Participants were of mixed opinion whether an ideal system should have fewer or more types of plastics. It was noted that perhaps it is not fewer materials needed, but fewer chemistries. One participant noted "one chemistry to rule them all" with the ability to tune properties to meet application needs but recycle together. Some had concerns that reducing the number of materials is a risk to innovation, but simplification was generally viewed as beneficial for recycling.

There was general agreement that optimal EOL fate is dependent on the product and application and that there should be consideration toward designing benign degradation in the case of leakage into the environment. The potential for expanding reuse and refill was also noted. Some participants expressed support for banning materials with health or toxicity concerns or that encourage marine debris. There was strong support for considering EOL during material development and design.

Examples of business models incorporating plastic circularity raised in discussion included products as service models (e.g., toys or clothing), reusable food service ware, refill on the go or at home, bottle return schemes, maintenance and diagnostics of plastic equipment to extend lifetimes (e.g., drone assessment of infrastructure), consumer drop-off films that become feedstock for advanced recycling, carpet recycling in which installs remove and collect old carpet, and traditional recycling.

Collaborations were viewed as critical to getting to scale. Opportunities for municipalities to help enable business models—for example, building codes requiring compost use—can unlock investment in composting facilities. There was also strong support for funding to scale new technology, as well as collaboration for innovation and technology development.

Opportunities: Roadmap for material transition, collaboration with municipalities. Material innovation with EOL in mind. Technology to recycle multiple materials together. Reuse business models. Access to pilot-scale facilities to accelerate innovation.

Plenary Session 3: Plastics in the Future – Material Selection

This session focused on plastics in the future with an emphasis on material selection and development. Panels explored whether there was tension between recyclable and compostable plastics and discussed current developments in bio-based and biodegradable materials. A series of short flash talks provided perspectives from polymer scientists.

Panel Discussion: Recyclable vs. Compostable Plastics

Moderator: Taylor Uekert (NREL); Panel: Paul Darby (Novamont), Anindya Mukherjee (Go!PHA), and Derek Atkinson (Total Corbion)

This panel discussed current compostable plastics and innovations in the pipeline, whether there is a dichotomy between recyclable and compostable plastics, how composting and recycling should be compared as EOL routes, and potential for and mitigation of unintended consequences related to expanding compostable plastics. Points raised in the discussion are summarized below.

Current compostable plastics are mostly copolyesters such as polybutylene adipate terephthalate, polylactic acid (PLA), polyhydroxyalkanoate, and polybutylene succinate. They represent approximately 0.3% of global plastic production, tend to be higher in cost than traditional plastics, and can be either fossil- or bio-based. Major applications are related to food packaging. There are innovations looking at using materials for more durable goods such as shoe soles, as well as coatings for paper cups to allow them to be both recyclable and compostable.

There were mixed views on whether composting and recycling were complementary or in competition. Some compostable materials can be mechanically or chemically recycled. Recycling routes using monomer recovery may be more favorable due to the lower bond energy in materials such as PLA. Composting could be viewed as lower on the waste hierarchy than mechanical recycling because the goal should be to keep carbon-carbon bonds together for as long as possible. Recyclable and compostable materials can compete for the same applications, and they are processed on the same equipment.

Compostable plastics may help to divert organic waste currently disposed of in landfills; thus, having different EOL options for plastics may bring benefits for other waste streams. Milan was cited as an example where high organic waste diversion was achieved by leveraging compostable plastics. If compostable material isn't composted due to a lack of infrastructure, much of the sustainability benefit may be lost. Composting infrastructure will be driven by food waste, not packaging materials. Some compositing facilities also do not want compostable packaging.[52]

[52] Oregon Department of Environmental Quality. n.d. "A Message from Composters Serving Oregon: Why We Don't Want Compostable Packaging and Serviceware." https://www.oregon.gov/deq/mm/Documents/MessagefromComposter-En.pdf.

While there are many different certifications for compostable plastics, there is no equivalent for composting facilities. Thus, the performance of a material in facilities is difficult to know due to different operating conditions.

Given the currently low volume of compostable plastics, some viewed contamination of the recycling stream as not an issue, while others raised it as a concern. Contamination may be mitigated with near-infrared sorting of PET vs. PLA or regulations to require specific colors for compostable materials. Policy and regulation were viewed as critical for addressing contamination.

Challenges: Lack of composting infrastructure and acceptance. Lack of standards for composting facility operation. Contamination of recycling and composting streams.

Actions that would have biggest positive impact in this space were identified as introducing standards for compost facilities, simplifying compostable material certification, EPR to support composting, and utilizing policy related to compostable materials to improve food waste diversion.

Panel Discussion: Bio-Based and Biodegradable Plastics

Moderator: Jay Fitzgerald (BETO); Panel: Leah Ford (Nature Works), Jeanette Hanna (BASF), and Lauren Scott (CJ Biomaterials)

This panel discussed current bio-based and biodegradable plastics, sourcing and production challenges, sustainability opportunities and challenges, and which applications are currently most successful for these materials. Points raised in the discussion are summarized below.

The increased attention on plastics and plastic waste, along with the evolving policy landscape, are viewed as changing the landscape for these materials, which currently make up only about 1% of the market.

Opportunities for bio-based and biodegradable polymers identified were using biomass balance to integrate biomass into their portfolio leveraging existing manufacturing facilities, bio-based polymers for paper coating as an alternative to per- and polyfluoroalkyl substances (PFAS), blending PLA with polyhydroxyalkanoate or polybutylene adipate terephthalate to overcome brittleness and unlock barrier films, and applications related to food waste diversion (coffee capsules, food service ware). Not all applications are due to being bio-based or biodegradable; some, like 3D printing of PLA, depend on the differentiated material performance. Success in applications also depends on working with converters to understand how to optimize processing for these bio-based materials without sacrificing throughput.

Several challenges related to production and feedstocks were identified. Feedstocks that could be used for plastics are being diverted to other applications such as fuel. The full supply system needs to be in place. There is a perception that bio-based materials may compete with food, but in the United States, field corn is mostly used for cattle feed, fuel, and paper. Identifying crops with multiple applications is important to drive agricultural sustainability. Local feedstocks that can be grown sustainably keep GHGs and similar impacts low.

There is skepticism around data and estimates of environmental impact, energy, and land usage for bio-based polymers. Scaling production will lead to optimization and reduce cost and emissions. Improvements in sustainability can also come from electrification of processes. The need for industry collaboration and trade associations to engage with policymakers was noted.

Flash Talks: Perspectives from Polymer Scientists

The plenary session concluded with five flash talks, in which scientists gave 10-minute presentations exploring an aspect of material selection for future plastics.

A "Working Backwards" Approach to Plastics

Alan Jacobsen from Amazon discussed strategies for innovations in polymer design and recycling strategies. The physical properties, ease of processing, and low production cost of today's plastics has led to their broad use in a variety of different applications, but today's plastics also have environmental issues that need to be addressed. These issues include being made from fossil fuel feedstocks, complex recycling rules, poor quality of recycled material, and persistence in the environment. To address these issues, Amazon has been working with the BOTTLE consortium to develop a new recycling technology for bio-based, biodegradable, polyester-based plastics. This technology will enable recycling of a mixed waste stream of these materials and serve as a platform for introducing new plastics that are both recyclable and biodegradable without requiring a separate recycling stream to be developed. Amazon sees this work as an important step in achieving a longer-term vision where all plastics are made from renewable feedstock and are biodegradable, while also being readily recycled.

What Polymers Are Best for Packaging from a Holistic Sustainability Perspective, and What Technologies Are Needed to Scale Them?

Jun Wang from Colgate discussed polymers for packaging from a holistic perspective. Plastic is facing two global environmental challenges: from its EOL side it pollutes the world, and from its origin-of-life side, its production emits a significant amount of GHGs and depends heavily on fossil fuels. Current solutions to the plastic crisis include plastic recycling, bio-based plastic, and biodegradable plastic, all of which address only one aspect of its dual problems. On the contrary, after millions of years of evolution, nature forms a truly closed loop on its materials, resulting in carbon circularity. This can be mimicked through the use of natural polymers to replace single-use plastics and designing better ways to produce and digest materials, enabling convenience and circularity. There is still significant research to be done to better understand the pathways and properties of sustainable materials like polyhydroxyalkanoates, natural rubber, polysaccharides, proteins, and lignin. Colgate would like to promote this exploration through the formation of a consortium of industry, academia, and nongovernmental organizations that builds on investment, knowledge, creativity, and boldness to promote the study and applications of natural polymers.

The Confusion around Biodegradability

Jason Locklin from the University of Georgia discussed the confusion around biodegradability, beginning by offering some definitions for degradable plastic, biodegradable, compostable, and oxo-degradable or bio-oxo-degradable.

Degradable plastic: A material that will undergo a substantial change in chemical structure under certain specific environmental conditions, resulting in a change in the material properties such as fragmentation, thermomechanical properties, and/or discoloration. Degradable plastics are not necessarily biodegradable or compostable. The process is better described as *micronization*.

Biodegradable: a degradable plastic in which the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi, and algae. The process of biodegradation depends on the surrounding environment (moisture, temperature, inoculum, microbial load) and on the material itself.

Compostable: a plastic that undergoes degradation by biological processes during composting to yield CO_2, water, inorganic compounds, and biomass at a rate consistent with other known compostable materials and leaves no visible, distinguishable or toxic residue.

Oxodegradable or **Biooxodegradable:** substances added to conventional plastics with the intention of promoting oxidation. Oxidation brittles and fragments the material, accelerating the *micronization* process.

Figure 9. Definitions of terms related to polymer degradation.

Source: Jason Locklin, University of Georgia

Composability certifications vary around the world and depend on the environment. The University of Georgia houses the Bioseniatic Laboratory,[53] which has the capability to test actual products or packaging, not just powders or films, in both laboratory and field settings. It is important not only to look at the time for degradation, but also whether toxic residues or micro- and nano-sized particles are left behind.

Benefits and Risks of New Polymers in the Current and Future Recycling System

Taylor Uekert from NREL discussed the benefits and risks of introducing new polymers into current and future recycling systems from an analysis perspective. Several questions must be considered when thinking about recycling of new types of plastics: Will the new material be collected? How will the new material be sorted at an MRF? How will the new polymer behave in either mechanical or chemical recycling?

For mechanical recycling of PET, polyethylene, and polypropylene, the contamination tolerance is 1%–12%, but the average PET and high-density polyethylene PCR bale contamination is 14%.[54] As new polymers are scaled up and introduced into the waste management system, the contamination challenge could be exacerbated. To mitigate contamination, collection can be

[53] University of Georgia. 2023. "The Bioseniatic℠ Laboratory." Accessed Nov. 16, 2023. https://newmaterials.uga.edu/the-bioseniatic%E2%84%A0-laboratory/.

[54] T. Uekert et al. 2023. "Technical, economic, and environmental comparison of closed-loop recycling technologies for common plastics." *ACS Sustainable Chemistry & Engineering* 11 (3): 965–978. https://doi.org/10.1021/acssuschemeng.2c05497.

improved via behavioral interventions such as cart tagging.[55] Thinking toward future recycling, preliminary analysis of solvolysis, which depolymerizes polymer back into monomers, may benefit from introducing new polyesters in terms of emissions and revenue. This could mitigate some of the challenges to the introduction of new biodegradable plastics into the recycling system.

Which Plastics Can Easily/Reasonably Be Replaced with Biodegradable Plastics?

Andrea Kasko from the University of California, Los Angeles, pointed out that the environment will influence degradation and that normally increased degradation is linked with lower thermal stability. Therefore, degradation can often conflict with performance requirements. This is illustrated by the desire for a material to exhibit high stability from chemical manufacturers, converters, brand owners, consumers, and collectors, followed by an inflection point where rapid biodegradation is desired.[56] It is also important to consider that there can be a significant mismatch between product lifetime and degradability. Biodegradation and/or compositing are most desired when there is contamination with food waste; it is likely to end up in organic waste collection and unlikely to be effectively mechanically recycled, and redesign is not possible for reusable solutions. Some potential applications include biowaste bags, tea bags, or catering items.[57] Most current biodegradable plastics are sourced from or inspired by natural materials.[58] Professor Kasko concluded by pointing out that lignin is underutilized as a source for monomers and materials because only 2% of the 50 million tons of lignin isolated from pulping in 2010 was used in specialty products.[59]

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[55] J. Walzberg, S. Sethuraman, T. Ghosh, T. Uekert, and A. Carpenter. 2023. "Think before you throw! An analysis of behavioral interventions targeting PET bottle recycling in the United States." *Energy Research & Social Science* 100: 103116. https://doi.org/10.1016/j.erss.2023.103116.

[56] K. Ghosh and B. H. Jones. 2021. "Roadmap to biodegradable plastics—current state and research needs." *ACS Sustainable Chemistry & Engineering* 9 (18): 6170–6187. https://doi.org/10.1021/acssuschemeng.1c00801.

[57] European Bioplastics. 2019. "EUBP proposes criteria and product examples for preferable use of compostable plastics." Sept. 26, 2019. https://www.european-bioplastics.org/eubp-proposes-criteria-and-product-examples-for-preferable-use-of-compostable-plastics/.

[58] J.-G. Rosenboom, R. Langer, and G. Traverso. 2022. "Bioplastics for a circular economy." *Nature Reviews Materials* 7: 117–137. https://www.nature.com/articles/s41578-021-00407-8.

[59] J.-Y. Kim, S.-Y. Park, J. J. Lee, I.-G. Choi, and J. W. Choi. 2017. "Sequential solvent fractionation of lignin for selective production of monoaromatics by Ru catalyzed ethanolysis." *RSC Advances* 7: 53117–53125. https://doi.org/10.1039/C7RA11541E.

Breakout Session 3: Sustainability from Challenges to Solutions

Following the plenary session, participants broke into four breakout sessions to discuss sustainability from challenges to solutions. The discussion and input from these sessions are summarized next.

Topic 3.1: What Are the Challenges We Anticipate for Future Recycling Systems?

This session explored current successes in plastic recycling and how to translate these into future systems, introducing new materials without disruption to existing systems, integrating data and smart manufacturing, challenges with transitioning from current to future systems, and what innovations, research, analysis, and funding could better prepare for future recycling systems.

Participants noted several successes and innovations in plastics recycling including developments related to using supercritical water for plastic recycling;[60] high-energy plasma developments; progress on chemical recycling; improvements in cameras, artificial intelligence, robotics, and falling costs enabling better sorting (including for films) and data; increased supply chain collaboration; mining of landfills for materials; increased willingness to use backhauling; and increased investment and research in polymer recycling.

The need to balance transport and potential for facility collocation were raised. Distributed processes for advanced recycling (such as gasifiers) were viewed as interesting, but questions around whether it makes more sense to transport plastic than potentially hazardous chemicals were raised. Transportation may not be a significant contribution to GHG emissions but can be a large cost driver. Mobile recycling and opportunities to create mixed pathways for recycling moving beyond mechanical to chemical and future options were posed as potential solutions. Some viewed chemical recycling as a bridge toward a future system, while others commented on environmental and health concerns.

Data and smart manufacturing were viewed as opportunities to improve plastic recycling. Improved data on feedstocks can reduce contamination (especially halogens) concerns and reduce downtime. Increased insight into facility and material location via geospatial data can improve system optimization and logistics. Data to understand LCA and techno-economic analysis, as well as emerging social and environmental justice aspects, are necessary.

Several challenges related to transitioning to a future system were identified. These include challenges related to financing and the low cost of virgin plastic, as well as addressing environmental justice when considering facility location so as not to burden already disadvantaged communities. Participants also noted the need to consider labor and working

[60] University of Birmingham. 2022. "A new 'supercritical water' approach to recycling plastic packaging waste." Feb. 9, 2022. https://www.birmingham.ac.uk/news/2022/a-new-supercritical-water-approach-to-recycling-plastic-packaging-waste.

conditions in the supply chain, as well as environmental justice aspects beyond human health and social impacts.

Participants noted potential for collaborations across the value chains to create more known feedstock streams (e.g., takeback of specific products such as astroturf or carpet). Dynamic covalent bonds were suggested as an avenue to replace current thermosets.

Opportunities: Reduction in backhaul inefficiencies, recycling process intensification and electrification, mobile units, collocation of facilities, data and technologies to track and eliminate chlorine from feedstock for advanced recycling, and geospatial data for MRFs, recyclers, and materials. Recycling of tires and composites. Incentivizing disassembly of plastic car parts before shredding. Utilization of plastics in shredder residue.

Topic 3.2: What Is the Role of Plastic Packaging in the Future?

This session discussed what innovations could reduce the demand for packaging, whether future packaging needs new materials and how to assess risks, what solutions can reduce the impact of plastic use, and what research or tools are needed to decide if plastic packaging could be replaced for an application.

A participant noted that packaging has a dual role of containment/protection and marketing and asked how we can shift this balance. Another suggested asking “where is packaging not required” in addition to what material should be used and how it can be optimized. Shifting some applications to reuse, improving packaging design (e.g., rightsizing, mono-material), and designing for recycling were seen as options to reduce the amount of plastics needed and to improve recycling.

A need for new materials was seen but not viewed as the whole solution. Potential innovations identified include water-soluble materials based on naturally occurring materials such as seaweed, eliminating the need for toxic additives through new material development, and new barrier materials as alternatives to ethylene vinyl alcohol and polyvinylidene chloride.

Plastics were viewed as required for many applications, including in the medical field and for durable goods. Additionally, it was noted in many applications that plastics may have lower impacts than alternative materials. Some felt addressing carbon emissions and circularity is needed to keep the social license to continue to use plastic materials. Options to reduce the impact of plastics in these applications include reuse and efficiency/optimization, design for recycling, and additional collection strategies. Easy-to-use tools to help make decisions on material and design to minimize impacts were desired.

Several tools and research needs identified for deciding if plastic packaging can be replaced for an application included a multicriteria assessment tool considering multiple metrics (carbon, circularity, performance, and customer convenience), standardization for LCAs to compare different options including sensitivity analysis, and additional analysis to compare the impacts of different recycling processes.

Topic 3.3: How Can We Redesign Products and Business Models to Enable Reuse?

This session discussed strategies to keep the most carbon circulating with the smallest impact, what is needed to make that happen, what products make the most sense for a reuse model, and research and collaborations that could help scale the best technology and business model approaches.

Strategies to keep carbon circulating with the smallest impact identified include reuse, sharing/rental, use of PCR, design for repair/modularity, “product as service,” and right to repair. It was noted that reuse will only reduce impacts if consumers actually reuse the product; thus, there is a large component for consumer behavior and acceptance. Understanding which products are suitable for reuse and how to do collections (e.g., store drop-off, mail back, home pickup) need development. Reuse in a business-to-business context was viewed as simpler in terms of acceptance. Reuse models are typically highly local, and it is unclear how they will work in rural settings. Participants also noted that there can be a tension between design for durability/reuse and customer expectations (e.g., lightweight electronics, pristine packaging). When considering new business models and approaches, equity and access need to be considered to ensure some are not excluded from this transition.

To enable these strategies to be successful, several needs were identified. Coalitions between brands to create common packaging for reuse, as has occurred in Europe, would facilitate reuse/refill. Digital labeling and tracking can enable reuse, especially for food-safe applications. Collaboration is needed to build out reverse logistics, as are innovations to allow standardization of reusable containers while allowing for customized branding. Another strategy identified was tweaking aesthetics of products to account for reuse or recycled components. There is a need to change societal norms to unlock these new strategies; as one participant put it, “make used cool.” Local infrastructure needs to be developed, and costs should be compared with setting up additional recycling/waste management infrastructure. There is a need to design for modularity to allow component reuse across product lines.

Products identified as potentially suitable for reuse include packing (although that can depend on contents), clothing, pallets, modular and upgradable products, and infrequently used items such as tools.

Opportunities: Product finish innovation to be more tolerant of recycled/reused material (e.g., dots to obscure defects), adjustable branding on standardized containers (inks/shrink-wraps), central washing facilities, public-private-partnerships involving cities and industry, research into consumer behavior and adoption, industry coalitions for container standardization, and analysis to understand the most impactful items to standardize.

Topic 3.4: How Do We Maximize Sustainability Benefits of Bio-Based Plastics?

This session discussed opportunities and challenges for expanding feedstocks for bio-based plastics, whether recyclability is a must for EOL of bio-based plastics, how to ensure biomass is used in the must sustainable way given competing sectors, and whether there should be harmonized sustainability criteria for all bio-based plastics or their feedstocks.

Participants noted a need to expand feedstocks and match them with the most appropriate application. Full crop utilization is need for supply chain optimization and economics. Feedstock opportunities identified include using byproducts that are currently landfilled (paper mill sludge), algae, food waste, biogas and flue gas, and mycelium. Challenges include convincing growers to switch from current crops, costs or cost perceptions, process standardization, quality control, scaling from early stage, achieving functional parity with current plastics, and skilled labor availability. The goal should be to match biomass with its best use, but this is not simple.

Participants felt that recyclability is desirable for bio-based plastics, and EOL must be considered for the development of any plastic. Some raised toxicity concerns related to bio-based plastics. For biodegradable materials, applications with high leakage rates of microplastics such as tires and textiles were identified as priority applications.

To consider sustainability criteria for bioplastic plastics and feedstocks, participants raised the need to consider how to account for biogenic carbon and toxicity, how to quantify biodiversity impacts of monoculture crops, and who is impacted by the supply chain (social justice). Participants identified a need for a harmonized way to communicate benefits of bio-based plastics. Others noted that bio-based may not be the lowest-emission option.

Conclusions

The Transitioning to a Sustainable, Circular Economy for Plastics workshop brought together stakeholders from industry, academia, national laboratories, and nonprofits to discuss the current challenges and opportunities in transitioning to a sustainable, circular economy for plastics in the United States. The workshop featured 12 breakout sessions with robust discussion between participants. While numerous challenges and opportunities were outlined in the previous sections relating both to policy and technology needs, several overarching themes emerged, which inform future research needs and collaboration opportunities:

- Harmonization:
  - Inconsistent development of policies and subsequent application of regulations, both domestically and internationally (e.g., EPR, definition of recycling, impact assessment), create a complex landscape for investment and alignment.
  - Material diversity, variation in compositions, and contamination reduce the ability to recycle safely and economically. Harmonization of design, materials, and recycling infrastructure is necessary to keep plastics out of landfills.
- Improved data, insight, and tools for assessing impact:
  - Easily accessible, up-to-date, and unbiased data to inform analysis on material flows and regionally accurate recycling rates in the United States are needed.
  - There is a need for metrics that are understandable, credible, actionable, and comparable to assess the impacts on human health and the environment. Rigorous sensitivity analysis should be conducted in conjunction with LCAs to verify whether options perceived as more sustainable align with real-world outcomes.
  - Leveraging informatics such as digital product passports, watermarks, or smart labels is an opportunity to gain insight into consumer behavior and improve sortation.
- Expanded feedstock amount and quality:
  - To increase the amount of plastic reused and recycled, there is a need to increase access to collection (rural areas, multifamily units), engage consumers, expand infrastructure, and explore novel collection solutions such as mobile sortation.
  - Improved sortation via leveraging data and robotics would benefit both mechanical and advanced recycling by better matching feedstocks with recycling technologies. Leveraging and optimizing reverse logistics can improve economics.
- New business models:
  - Innovations to expand reuse and refill as alternative to single-use applications, including insights into consumer acceptance, have potential to increase plastic circularity and reduce demand raw material.

- Material and recycling technology innovation:
    - New material developments will improve sustainability such as the development of bio-based, recyclable, and biodegradable plastics. There is a need for alternative high-barrier materials to replace multilayer packaging with recyclable mono-material options.
    - Recycling technologies and material developments to address multilayer films and flexibles, durable goods, thermosets, and plastics other than currently recycled materials are needed. This includes the ability to process mixed input streams economically either by greater contamination robustness or improved separations.
    - There is a need for a mechanism to introduce new, more sustainable materials and technologies in a way that avoids negatively impacting the current system. This will require collaboration across the entire value chain.
- Collaboration as key enabler:
    - Scaling from small-scale demonstration to pilot and market implementation can be accelerated by partnerships, including between industry, academia, and government.
    - Industry coalitions and pre-competitive collaboration to align around product design and harmonization can accelerate innovations at scale.
    - Involving a range of municipalities (rural and urban) in research and policy development can incorporate on-the-ground insights.

DOE would like to thank workshop participants for their time and input. DOE will consider workshop feedback when developing programmatic plans in support of the SPI and the circular economy.

Appendix

A.1 Questions for Breakout Discussions

Session 1.1: How do we guide good policy and measure progress?

- What is driving decision-making (public pressure, regulations, recycled content pledges)?
- How do we balance GHG emissions vs. other environmental factors?
- Is upcycling or downcycling enough, or do we need to strive for circularity?
- What are the lessons learned from other countries?

Session 1.2: What role do industry pledges, coalitions, and working groups have in the successful implementation of plastics recycling?

- What is driving decision-making (public pressure, regulations, recycled content pledges)?
- What are the main voluntary goals that have been set?
    - Are there overlaps/duplications or gaps?
        - Is having a range of voluntary pledges beneficial or divisive?
- Are the pledges being met? Why or why not?
- What research or further collaborations could enhance these efforts?

Session 1.3: What influences investments in recycling infrastructure?

- What non-monetary hurdles are there to upgrading recycling infrastructure?
- What are the big trends in recycling/plastics investment space?
    - What are the main gaps they aim to address?
- Is plastics recycling broken?
    - If so, where could investments have the biggest impact?
- How can research, analysis, and collaborations contribute to wider-scale impactful investment?

Session 1.4: What are the tools for understanding plastic environmental impacts (e.g., LCA), and how do we harmonize them?

- Are you making choices on circularity, environmental impact, or both?
    - What tools are you using to make these choices?
    - What data/tools do you need to do this better?
- In your experience, are solutions promoted as “circular” typically identified by LCA as being optimal/desirable solutions?

    - If not, how do you reconcile conflict when a "circular" solution isn't the lower-impact solution?
- What research/collaborations could drive harmonization of policy frameworks/objectives?
- How do we harmonize data sets and methodologies used?
    - How can we incentivize participation in databases and sharing of data?

Session 2.1: What are the challenges and opportunities related to incorporating recycled plastics in products and packaging?

- After material is recycled, are there challenges in matching this with end applications (cost of qualifying material, differences in performance, resistance to change product design)?
- Which is the bigger challenge: recycled quality or quantity?
    - What are ways to improve the amount of recycled content recovered?
- How do challenges compare for packaging versus durable goods?
- What are the key manufacturing challenges posed by using recycled/upcycled feedstocks?
    - What have been successful strategies?
- What research or further collaborations are needed?

Session 2.2: What are the challenges in sourcing feedstock and producing recycled content?

- What are the challenges with matching recovered material with different recycling options?
- Should recycling strategies for durable applications vs. consumable applications be considered differently?
- What innovations would most impact cost, quality, or quantity of recycled content?
    - What technology development is needed?
- What approaches exist for improving the quality of mechanically recycled plastics?
- What advances are still needed?

Session 2.3: What are the challenges we anticipate for future recycling systems?

- How effective (or not) are current recommendations for design for recyclability?
    - What is needed to improve?

- What are the current challenges and future potential of different waste streams such as municipal solid waste, industrial, construction, rural, multifamily housing, or commercial?
- To what extent is system redesign already being handled by MRFs?
- What are disruptive research/collaboration ideas to make recycling more effective?

Session 2.4: How much can current technology and business model approaches move us toward plastics circularity?

- Do you agree with the premise that introducing new EOL plastics could reduce plastic waste? Why or why not?
- In an ideal system, are there fewer types of plastics or more with better-matched uses?
- What are examples of current business models that are incorporating plastics circularity?
- What research/collaborations could help scale the best technology/business model approaches?

Session 3.1: What are the challenges we anticipate for future recycling systems?

- What are the current successes in plastic recycling?
  - How will these translate into future recycling systems?
- Can new plastics be effectively introduced without disruption to existing systems?
  - If not, what needs to be done to enable this?
- Will data and smart manufacturing help overcome future recycling challenges?
  - If so, how?
  - What is needed to ensure this happens?
- What are the challenges of transitioning from our current recycling systems to future systems?
- What innovations, research, analysis, or funding could better prepare for future recycling systems?

Session 3.2: What is the role of plastic packaging in the future?

- What innovations could dramatically reduce the demand for packaging in the future (both product design and package design)?
- Does future plastics packaging need new materials? If yes, how do we assess the risks and challenges of these new plastics?
- Where plastics are still required, what are the solutions to reduce impact?

- What research/tools are needed to decide if plastic packaging could be replaced for an application?

Session 3.3: How can we redesign products and business models to enable reuse?

- What are strategies to keep the most carbon circulating in the economy with the smallest environmental impact?
- What is needed to make this happen (e.g., investment, infrastructure, consumer education/engagement)?
- What products make the most sense for a reuse model? Which don't?
- What research/collaborations could help scale the best technology or business model approaches?

Session 3.4: How do we maximize sustainability benefits of bio-based plastics?

- What are the opportunities and challenges of expanding feedstocks for bio-based plastics?
- What type of requirements should be in place for EOL of bio-based plastics?
    - Is recyclability a must or not with bio-based carbon content?
- There are many sectors that could possibly compete in the same raw material pools (e.g., food, feed, road fuels, aviation, chemicals, plastics). How do we ensure the biomass is used in the most sustainable way, or can there be enough for all?
- Should there be some harmonized sustainability criteria for all bio-based plastics or their feedstocks?
    - What tools are needed to accomplish this?

A.2 Prompts for Panels

Prompts for panel on Circularity and Climate Trade-Offs for Materials:

1. Are there trade-offs that need to be made to balance circularity and climate impact?
2. How does your organization navigate these trade-offs?
3. How do you balance material performance and carbon emissions?
4. How does this influence material selection? What drives the shift between plastic and alternatives?
5. What would have the biggest positive impact in this space?

Prompts for panel on The Recycled Content Challenge:

1. What is the current state of play for producing and sourcing recycled content?

2. What are the key barriers to sourcing recycled content at the right quality at volume?
3. What is needed to address both the quality and quantity limitations for recycled content?
4. Will advances in sorting be sufficient to address this issue? If not, what other interventions are needed?
5. What would have the biggest positive impact in this space?

Prompts for panel on Recyclable vs. Compostable Plastics:

1. What is the current state of play for compostable plastics? What innovations are in the pipeline?
2. Is there a dichotomy between recyclable and compostable plastics?
3. How should we compare the impacts of compostable versus recyclable EOL routes?
4. Are there potential unintended consequences of expanding compostable plastics, and how might these be mitigated?
5. What would have the biggest positive impact in this space?

Prompts for panel on Bio-Based and Biodegradable Plastics:

1. What is the current state of play for bio-based and biodegradable plastics?
2. What are the sourcing and production challenges current? What advances are in development?
3. What are the sustainability opportunities and challenges for bio-based and biodegradable plastics?
4. Which applications are currently most successful with these approaches?

A.3 Speaker Biographies

All speakers were invited to submit biographies; however, not all chose to do so. Those received are provide below.

David Allaway works as a senior policy analyst at the Oregon Department of Environmental Quality. He has pioneered several applications of life cycle assessment in program and policy development, including the first subnational (state-level) estimate of consumption-based GHG emissions in the United States and a groundbreaking meta-analysis that compared popular packaging attributes (recyclable, compostable, recycled content, and bio-based) against environmental outcomes. David served as an invited science advisor to the Walmart Packaging Sustainable Value Network and the *New York Times* bestseller *Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming*. In 2019–2020 David co-chaired and led the staff team that supported Oregon's Recycling Steering Committee, then played a key role in the development, negotiation, and early implementation of Oregon's Plastic Pollution and Recycling Modernization Act, including leading the project to identify initial recycling acceptance lists for the state. A recipient of awards from the American Center for Life Cycle Assessment and the U.S. Environmental Protection Agency, David has a B.A. (physics, with honors) and a concentration in science, technology, and public policy from Carleton College.

Gregg Beckham is a senior research fellow and group leader at NREL. Gregg works with and leads an interdisciplinary research group focused on biomass conversion and plastics recycling. He also leads the DOE-funded BOTTLE consortium, which is a 10-institution research consortium focused on developing new approaches for plastics recycling and redesign.

Nina Bellucci Butler, CEO of Stina Inc., believes in delivering unbiased guidance in navigating the role plastics play in sustainability. She has testified before the U.S. Congress, served as a subject matter expert for XPrize, and presented to the OPEC Secretariat and other global events such as the World Bank and United Nations events. Her team conducts critical research such as the Annual Plastic Recycling Study, develops online resources such as the Drop-Off Directory on bagandfilmrecycling.org, and leads multistakeholder initiatives such as the Plastic Squeeze Tube Recycling Project, working to navigate the journey to recyclability. Nina has volunteered on several expeditions including the Ocean Plastics Recovery Project: Katmai Cleanup.

Bridget Croke is a managing director at Closed Loop Partners, an investment and innovation firm working to accelerate a more circular economy. Bridget has spent the last 20 years building movements to help drive a more sustainable economy—from the local food movement to the circular economy. This work has included a national campaign to improve quality of life with less consumption; building and executing campaign tools to move consumers to Buy Fresh, Buy Local; a startup turned growth company incentivizing consumers to recycle right; and Purpose, a consultancy and incubator leveraging the tools of movement building to solve global challenges.

Alan Jacobsen currently leads the science and innovation team within the Net Zero Operations organization at Amazon. In the nearly 5 years he has been with Amazon, he has held various roles focused on the science, innovation, and sustainability of products and packaging. Dr. Jacobsen has a wealth of experience in early-stage innovation, including cofounding two startup companies and building a portfolio of more than 100 issued patents in his 20-year career, mostly related to materials innovations for the automotive, aerospace, energy, and consumer products sectors. Dr. Jacobsen is currently leading Amazon's effort to fundamentally rethink the solutions and technologies needed to address the issues with today's plastics. He holds a Ph.D. from the University of Southern California, M.S. from Northwestern University, and B.S. from New Mexico State University.

Erica Nuñez is the program officer for The Ocean Foundation's Plastics Initiative, where she leads the management and strategic development of the organization's scientific and policy activities related to combating plastic pollution. She leads the organization's engagement within the U.N. Environment Assembly and U.N. Environment Programme, including the current negotiations for an international legally binding instrument to end plastic pollution; the development of a science policy panel to contribute further to the sound management of chemicals, waste, and pollution; and the Basel Convention, among other international work. Erica has nearly 20 years of experience working to protect and conserve the environment and served 14 of those years with the U.S. federal government before moving on to the nongovernmental organization sector.

Vicki Thompson is the manager of the Bioenergy Feedstock Technologies department at Idaho National Laboratory, as well as a distinguished staff engineer. She is currently the node lead for recycling and recovery within the DOE-AMMTO-funded REMADE Institute. Dr. Thompson joined Idaho National Laboratory in 1996 after receiving her B.S. and Ph.D. in chemical engineering from the University of Iowa and Michigan State University, respectively. Her research currently focuses on applying chemical engineering principles to biological problems. She is currently working to identify and characterize low-cost waste feedstocks, develop feedstock/waste blends that meet DOE targets, and develop decontamination methods for waste materials. She participates in research projects in the Critical Materials Institute on recovery of critical metals and development of techno-economic analysis/LCA of these processes; in REMADE providing expertise on processes for sorting waste, as well as models of these processes; and in BETO developing methods to process and decontaminate waste streams. She was also part of the team that redesigned the BFNUF for processing a variety of waste streams. Upgrades include artificial intelligence sorting systems, enhanced waste characterization, and size reduction and decontamination systems. Other interests include rapid, sensitive biological detection methods of environmental contaminants and toxins with emphasis on antibody- and enzyme-based assays; isolation and characterization of extremophilic microorganisms for waste treatment; and purification and characterization of novel proteins and enzymes. Her interests also include applications in forensics, food quality control, environmental evaluation, agriculture, medical diagnostics, and biological warfare agents.

Nicholas Vijverman is a program manager in the Plastics Initiative at EMF, closely working with the network to achieve their ambitious goals toward 2025 and beyond. Before arriving at EMF, Nicholas worked as a management consultant at McKinsey & Company and as a researcher at Vlerick Business School. With a background in business engineering, he firmly believes that the circular economy holds the key to addressing the pressing environmental challenges of our generation.

Jun Wang currently works as the packaging material subject matter expert in packaging innovation for the Global Design and Packaging group at Colgate-Palmolive Company. Dr. Wang owns a Ph.D. in polymer chemistry and has more than 30 years of experience in polymers. Between 2014 and 2020, he led the development of the first-of-its-kind recyclable plastic tube, which received recognitions from the recycling industry, including the Association of Plastic Recyclers and Plastics Recyclers Europe. Currently, Dr. Wang is working with Dow and the ACS Green Chemistry Institute to form an industry-academia-nongovernmental organization consortium on natural polymers. The goal is to seek an alternative solution to address plastic pollution from the underexplored natural polymers area.

A.4 Attendees

The following is a list of participants who elected to share their contact information in these proceedings:

Attendee	Affiliation
Marisa Adler	RRS
David Allaway	Oregon Dept. of Environmental Quality
Derek Atkinson	TotalEnergies Corbion BV
Coralie Backlund	Department of Energy
Gregg Beckham	NREL
Anne Bedarf	Colgate-Palmolive
Pahola Thathiana Benavides	Argonne National Laboratory
Mike Berg	University of Delaware
Bryan Bhark	Brooks Sports
Clay Bunyard	Kimberly-Clark
Nina Butler	Stina Inc
Alberta Carpenter	NREL
Utkarsh Chaudhari	Michigan Technological University
Peter Chauvel	X, the moonshot factory
William Cooper	Cyclyx International
Bridget Croke	Closed Loop Partners
Sarah Crooks	INDEED Innovation
Edward Daniels	REMADE
Paul Darby	Novamont North America Inc
Alexandra Davies	Amazon
Jillaine Dellis	Henkel Corporation
Sarai Demien	LyondellBasell - Houston, TX
Patricia Drake	Lyondellbasell
Bethany Edwards	WBCSD
Nancy Eisenmenger	Nike
Muthu Elen	Pacific Northwest National Laboratory
Dan Falla	Shell Polymers
Scott Farling	Google X

Attendee	Affiliation
Jay Fitzgerald	DOE-BETO
Leah Ford	NatureWorks
Brandon Fortino	NewType Group, Inc.
Jay Gaillard	Savannah River National Laboratory
Yan Gao	Philips
Jamaica Gayle	Plant Based Products Council
Ulises Gracida Alvarez	Argonne National Laboratory
Jeanette Hanna	BASF
Logan Harvey	Recology
Troy Hawkins	Argonne National Laboratory
Bryce Hesterman	RRS/NextCycle
Katherine Hofmann	Eastman
Amy Hu	Brooks Sports Inc
Mounir Izallalen	Eastman
Shari Jackson	American Chemistry Council
Alan Jacobsen	Amazon
Yinghua Jin	RockyTech, Ltd.
Joe Johnson	Cisco
Jim Johnson	Plastics News/Crain Communications
Andrea Kasko	University of California, Los Angeles
Dave Kemp	Brooks Running
Robert Kennedy	Aeternal Upcycling
Michael Kent	Sandia National Laboratories
Jordan Klinger	Idaho National Laboratory
Vinod Konaganti	Amazon
Helene Lanctuit	Eunomia Research & Consulting
Kwan-Soo Lee	Los Alamos National Laboratory
Ashley Leidolf	Dow
Thorsten Leopold	Henkel AG & Co. KGaA
Houqian Li	University of Wisconsin-Madison
Tony Li	Microsoft

Attendee	Affiliation
Hongfei Lin	Washington State University
Jason Locklin	University of Georgia
Taylor Maddalene	University of Georgia
Ofei Mante	Amazon
John Martin	DTG Recycle
Michael Martin	r.Cup
Tristanne Martini	Amazon
Gabriel Mens	Brooks Running
Daniel Merkel	Pacific Northwest National Laboratory
Kalman Migler	NIST
Steve Moddemeyer	CollinsWoerman
Anindya Mukherjee	Global Organization for PHA (GO!PHA)
Edgard Ngaboyamahina	RTI International
Kelly Nguyen	Lindahl Reed
John Opsteen	Amazon
Michael Pantelides	American Chemistry Council
Mahesh Parit	RiKarbon Inc
Kathryn Peretti	Department of Energy
Jessica Phillips	BGS
Joshua Pins	Rubicon
Yunqiao Pu	Oak Ridge National Laboratory
Jason Puracal	ZILA BioWorks
Shruti Rattan	3D Printing industry
Ronald Rau	PureCycle
Sandra Rojas	Kimberly Clark Corporation
Jennifer Ronk	Dow, Inc.
Julie Rorrer	University of Washington
Eleftheria Roumeli	University of Washington
Aaron Sadow	Iowa State University
Michelle Salim	ExxonMobil Product Solutions
lauren scott	CJ Biomaterials

Attendee	Affiliation
Christopher Seely	Microsoft
Michelle Seitz	
Gerhard Seizer	INDEED Innovation
John Shane	Amazon
Kathleen Shannon	University of Rhode Island
Katherine Shayne	CIRT
Elizabeth Sheaffer	ITW/Hi-Cone
Ronald Sherga	Cyclyx
David Shonnard	Michigan Technological University
Grayson Shor	The Climate Pledge, Amazon
Ryan Simkovsky	Algenesis Materials
Clint Smith	Pregis LLC
Jake Smith	Microsoft
Natalie Stirling-Sanders	Alliance to End Plastic Waste
Adrian Tan	King County Solid Waste Division
Vicki Thompson	Idaho National Laboratory
John Torkelson	Northwestern University
Parker Townley	Amazon
Heather Trim	Zero Waste Washington
Michelle Tulac	Ellen MacArthur Foundation
Taylor Uekert	NREL
Nicholas Vijverman	Ellen MacArthur Foundation
Michael Waggoner	Corumat, Inc.
Fei Wang	P&G
Jun Wang	Colgate-Palmolive Company
Phoebe Wang	Amazon Climate Pledge Fund
Madeleine Watson	Department of Energy
Matthew White	EWI
Christopher Wirth	AMP Robotics
Bin Yang	Washington State University
Jinwen Zhang	Washington State University

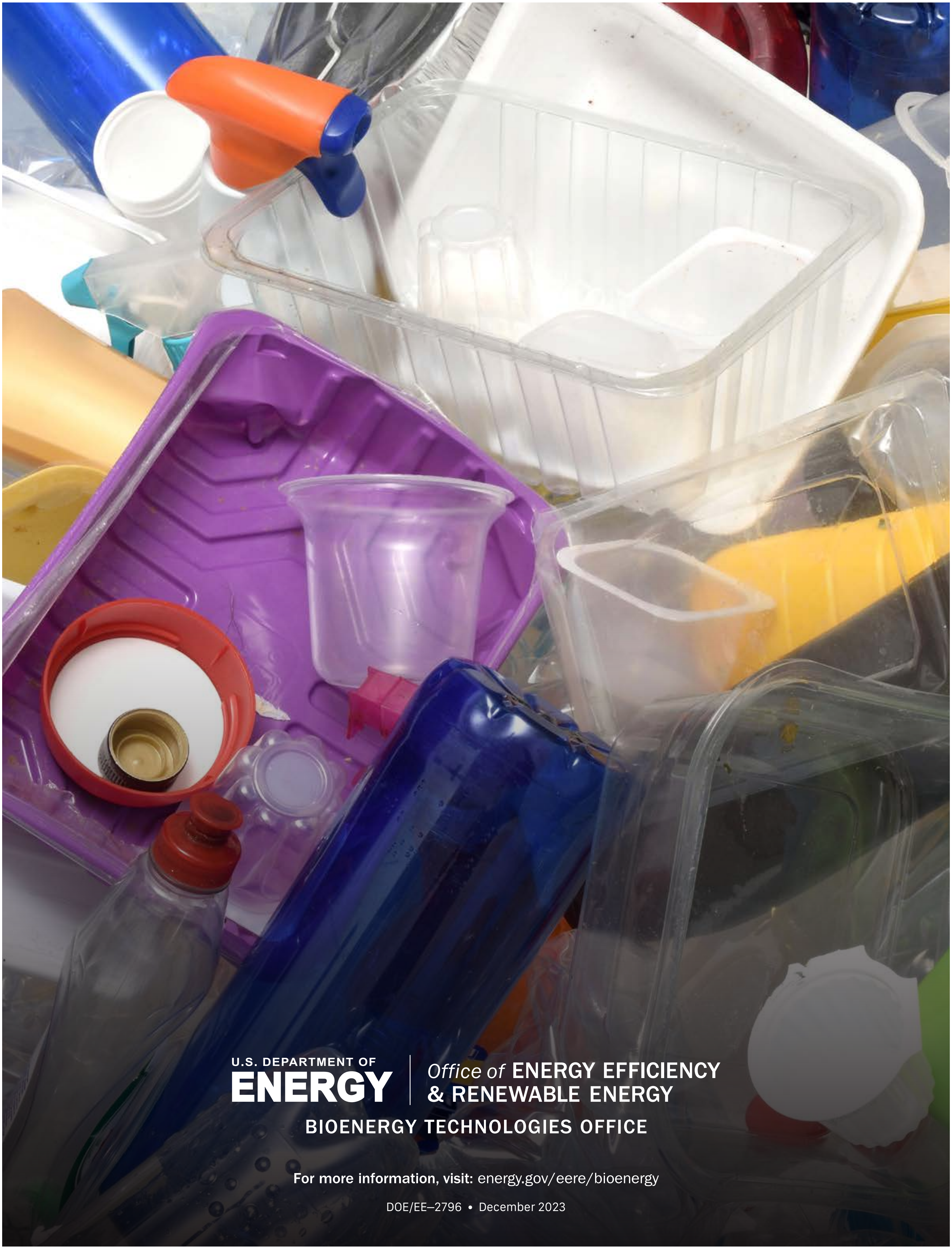
Attendee	Affiliation
Xianhui Zhao	Oak Ridge National Laboratory
Rachel Zipperian	Procter & Gamble

A.5 Workshop Agenda

Agenda: Transitioning to a Sustainable, Circular Economy for Plastics Workshop		
DAY 1 (June 8, 2023) **Opening Session: Introductions/Opening Remarks**		
Time (PT)	**Agenda Item**	**Speaker**
8:00–9:00 a.m.	Registration	
9:00–9:10 a.m.	Welcome and Workshop Introductions	Coralie Backlund – DOE BETO
Session 1: Sustainability & Circularity for Plastics (9:10–10:45 a.m.)		
Time (PT)	**Agenda Item**	**Speaker**
9:10–9:30 a.m.	Department of Energy's Evolving Interests in Plastic Circularity	Kathryn Peretti – DOE AMMTO
9:30–9:50 a.m.	Changing Landscape for Plastics: International Policy Perspective	Erica Nuñez – The Ocean Foundation
9:50–10:10 a.m.	Ambitions and Challenges in Delivering on Plastics and Waste Commitments	Nicholas Vijverman– Ellen MacArthur Foundation
10:10–10:35 a.m.	Panel Discussion: Circularity and Climate Trade-Offs for Materials	**Moderator:** Michelle Tulac – Ellen MacArthur Foundation **Panel:** Anne Bedarf – Colgate Clinton Smith – Pregis
10:35–10:45 a.m.	Moderated Q&A	
Break (10:45–11:00 a.m.)		
Breakout Session: Landscape of Plastics – 11:00 a.m.–12:20 p.m.		
Time (PT)	**Agenda Item**	**Discussion Facilitator**
11:00 a.m.–12:00 p.m.	Topic 1: How do we guide good policy and measure progress?	Erica Nuñez – The Ocean Foundation
11:00 a.m.–12:00 p.m.	Topic 2: What role do industry pledges, coalitions and working groups have in successful implementation of plastics recycling?	Nicholas Vijverman – Ellen MacArthur Foundation
11:00 a.m.–12:00 p.m.	Topic 3: What influences investments in recycling infrastructure?	Kathryn Peretti – DOE AMMTO
11:00 a.m.–12:00 p.m.	Topic 4: What are the tools for understanding plastic environmental impacts (e.g., LCA) and how do we harmonize them?	David Allaway – Oregon DEQ
12:00–12:20 p.m.	Report out from Breakout Discussion	
Lunch (12:20–1:20 p.m.)		

Session 2: Plastic Recycling – A Changing Landscape (1:20–3:30 p.m.)		
Time (PT)	**Agenda Item**	**Speaker**
1:20–1:40 p.m.	Current State of Plastic Recycling in the U.S.	Nina Bellucci Butler – Stina
1:40–2:00 p.m.	Biomass Feedstock National User Facility Capabilities for Plastic Processing and Recycling	Vicki Thompson – Biomass Feedstock National User Facility
2:00–2:20 p.m.	Molecular Recycling	Bridget Croke – Closed Loop Partners
2:20–2:40 p.m.	Plastics recycling and design in the BOTTLE consortium	Gregg Beckham – NREL/BOTTLE
2:40–3:10 p.m.	Plastic Recycling Challenges and Improvements – talks from the field	David Allaway – Oregon DEQ
3:10–3:20 p.m.	Panel Discussion: The Recycled Content Challenge	**Moderator:** Vicki Thompson – Idaho National Laboratory **Panel:** Bill Cooper – Cyclyx Chris Wirth – AMP Robotics Fei Wang – Procter & Gamble
3:30–3:40 p.m.	Moderated Q&A	
Break (3:40–4:00 p.m.)		
Breakout Sessions: Supply Chain Challenges (4:00–5:30 p.m.)		
Time (PT)	**Agenda Item**	**Discussion Facilitator**
4:00–5:00 p.m.	Topic 1: What are the challenges and opportunities related to incorporating recycled plastics in products and packaging?	Justine Mahler – Amazon
4:00–5:00 p.m.	Topic 2: What are the challenges in sourcing and reprocessing recycled content?	Ron Sherga – Cyclyx
4:00–5:00 p.m.	Topic 3: How do we make recycling more straightforward to increase quantity and quality of material?	Katherine Shayne – UGA
4:00–5:00 p.m.	Topic 4: Which technology and business model approaches move us towards plastics circularity?	Jennifer Ronk – Dow
5:00–5:20 p.m.	Report out from Breakout Discussion	
5:20–5:30 p.m.	Closing of Day 1	

DAY 2 (June 9, 2023) Opening Remarks/Housekeeping		
Time (PT)	**Agenda Item**	**Speaker**
8:00–8:30 a.m.	Registration	
8:30–8:40 a.m.	Introductions and Housekeeping Day 2	
Session 3: Plastics in the Future – Material Selection (8:40–9:45 a.m.)		
Time (PT)	**Agenda Item**	**Speaker**
8:40–9:10 a.m.	Panel Discussion: Recyclable vs. Compostable Plastics	**Moderator:** Taylor Uekert – NREL **Panel:** Paul Darby – Novamont Anindya Mukherjee – Go!PHA Derek Atkinson – Total Corbion
9:10–9:40 a.m.	Panel Discussion: Bio-Based and Biodegradable Plastics	**Moderator:** Jay Fitzgerald – BETO **Panel:** Leah Ford – Nature Works Jeanette Hanna – BASF Lauren Scott – CJ Biomaterials
9:40–10:30 a.m.	Flash Talks: Perspectives from Polymer Scientists	
	A Working Backwards Approach to Plastics	Alan Jacobsen – Amazon
	What polymers are best for packaging from a holistic sustainability perspective and technologies are needed to scale them?	Jun Wang – Colgate
	The confusion around biodegradability	Jason Locklin – University of Georgia
	Benefits and risks of new polymers in the current and future recycling system	Taylor Uekert – NREL
	Which plastics can easily/reasonably be replaced with biodegradable plastics?	Andrea Kasko – University of California, Los Angeles
Break (10:30–10:45 a.m.)		
Breakout Sessions: Sustainability from Challenges to Solutions (10:45 am – 12:00 pm)		
Time (PT)	**Agenda Item**	**Discussion Facilitator**
10:45–11:45 a.m.	Topic 1 - What are the challenges we anticipate for future recycling systems?	Kathryn Peretti – DOE AMMTO
10:45–11:45 a.m.	Topic 2 - What is the role of plastic packaging in the future?	Alan Jacobsen – Amazon
10:45–11:45 a.m.	Topic 3 - How can we redesign products and business models to enable reuse?	Michael Martin – R.cup
10:45–11:45 a.m.	Topic 4 - How do we maximize sustainability benefits of bio-based plastics?	Omar Terrie – Neste
11:45 a.m.–12:00 p.m.	Report out from Breakout Discussions	
Closing Session – What's Next? (12:00–12:30 p.m.)		



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