Advancing Sustainability and Circularity in Durable Plastic Markets

An Industry Roadmap

American Chemistry Council | Plastics Division

December 2023

About this Report

The American Chemistry Council (ACC) Plastics Division led the development of this report, guided by the Durable Goods Leadership Team (DGLT) under the leadership of Gina Oliver, Senior Director, ACC Plastics Division. Vital contributions were made by the DGLT members and experts from the plastics, automotive, building & construction, electronics, infrastructure, and medical communities. Nexight Group provided stakeholder engagement and report development support to ACC and prepared this document.

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Durable plastic goods are **critical to modern society** and the **safe and effective operation** of virtually all **major economic and market sectors**.

We are **taking action *now*** to **advance end-of-life and circularity solutions** for these essential goods.

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Building & Construction

Electronics

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Introduction to Durable Plastic Circularity and End-of-Life Sustainability

Plastics are essential to modern society.

From the devices in our pockets to the homes, workplaces, and vehicles in which we spend our days, and even the infrastructure that supports our communities, like hospitals, utilities, and roads, plastics are involved throughout 21st century life.

What's more is that plastics play a major role in making technological advancements possible. Whether they are being used to create more durable fiber optic cables to bring connectivity to new areas, helping increase fuel efficiency in lighter-weight cars, or serving as essential materials in wind turbines and other clean energy systems fighting climate change, the value of plastics to the world of the future is undeniable. **The durable plastics that make up our world provide performance, design flexibility, affordability, and longevity vital to meeting society's needs.**

As critical as durable plastics are to daily life and future innovation, end-of-life (EOL) challenges persist. The plastics industry recognizes these issues and is working hard toward eliminating plastic waste in the environment. Consumers and supply chain partners are also demanding recycling and circularity solutions, and regulations across the country and around the world are shaping requirements for durable plastics manufacturing and use. In the United States, two major legislative acts geared toward promoting a circular economy—the Protecting Communities from Plastics Act* and the Infrastructure Investment and Jobs Act**—have signaled growing interest from Congress in plastics' sustainability. In the European Union, legislation curbing single-use plastic packaging is being debated, and if passed could be "the largest driver of plastic waste reduction."[3]

Across a wide range of market sectors, the plastics industry is already working to implement changes that demonstrate their commitment toward a more circular economy, and in doing so, is creating significant value for consumers and the economy. **By 2030, the value of the circular economy could be upwards of $4.5 trillion,[4] and by 2040, the economic benefits of plastics circularity in the United States could generate $200 billion in savings annually**.[5]

Plastics producers are embracing the push toward a circular economy. Shareholders are pushing for more recycled plastic use[6] and companies are forming industry partnerships and investing in technology development aimed at improving the recovery, reuse, and recyclability of plastics. Companies that have preemptively managed environmental concerns over a 15-year time period have seen better long-term stock market performance compared with others.[7]

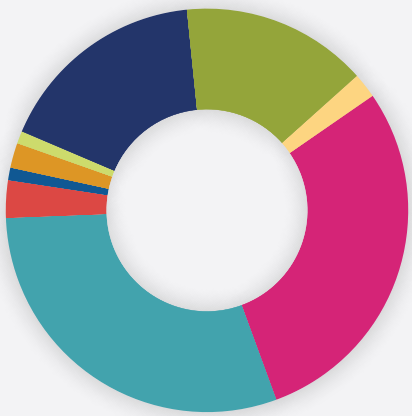
But before we can achieve circularity, we need to recognize that not all plastics are the same. Durable plastics, unlike their single-use counterparts, are meant to last for years, sometimes decades—even a lifetime. This makes durable plastics well suited for applications where

*While it did not pass, the Protecting Communities from Plastics Act was introduced in Congress in December 2022. It sought to establish a moratorium on the issuance of federal and state agency-administered Clean Air Act and Clean Water Act permits for new plastic facilities and petrochemical plants. The only planned exceptions were for material recovery facilities, mechanical recycling facilities, and composting facilities.[1]

**The Infrastructure Investment and Jobs Act reinstated Superfund Excise Taxes on July 1, 2022. The bill reinstates an excise tax to certain chemicals, and it is likely to affect plastics resins, increasing the cost for manufacturers that use those chemicals and resins of the products produced with those materials.[2]

strength and safety are essential, like vehicles, drinking and wastewater pipes, medical implants, and buildings.[8,9] But durable plastics are not only durable. Used extensively in technologically advanced applications, some durable plastics are also approved for use in essential medical devices, strong enough to withstand the highly demanding performance requirements of commercial vehicles, and still aesthetically pleasing when used in consumer electronics.[10,11,12]

Durable plastics make up a significant portion of the plastics market[13]

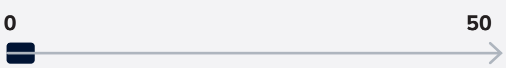


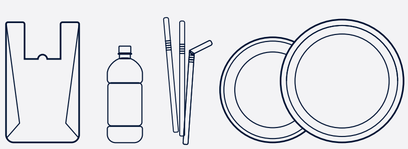
30%	Packaging
29%	Exports
17%	Consumer & Institutional
15%	Building & Construction
3%	Electrical/Electronic
2%	Transportation
2%	All Others
1%	Furniture/Furnishings
1%	Industrial/Machinery

Single-use and durable goods plastics serve different purposes and markets

Single-Use & Packaging Plastics

Used in the same year to < 3 years[14]

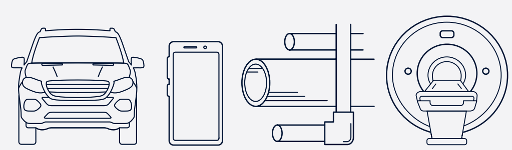




Plastic plates and cups, trash bags, disposable diapers, clothing, footwear, plastic wrap, food containers[15]

Durable Goods Plastics

Used for 3-50+ years[16,17]



Major and small appliances, furniture, carpets, consumer electronics, building materials, vehicles, medical equipment[18]

Because durable plastic goods are designed for consistent long-term use, they must withstand typical wear and tear and not break down easily, making their path to sustainability and circularity unique.

To achieve circularity, a material or product must not become waste and instead must be able to be reused or recycled while saving energy, labor, and raw materials. This means products must be repairable or recyclable or must be able to be repurposed for continued use. But sustainability and circularity cannot only be considered at the end of a product's life; the product and supply chain must be designed to encourage it.

While there are some shared circular practices with non-durable plastic applications such as packaging (e.g., certain advanced recycling technologies, recycled materials feedstock), durable plastic goods serve several distinct market sectors with varying methods for processing materials at EOL that differ from typical municipal waste and recycling programs for plastics used for most single-use and packaging products. For example, the larger size of and demolition practices for some durable goods, such as automobiles, building materials, and large-scale electronics (e.g., heating and cooling systems, electrical grid components), presents unique collection and sorting opportunities and challenges. Certain durable plastic use cases—such as the electronics or medical fields—produce contaminants requiring treatment.

The plastics industry is working hard to help eliminate plastic waste in the environment, regardless of application. Recognizing the unique challenges and opportunities for durable market applications, our industry has come together in partnership with the automotive, building and construction, electronics, infrastructure, and medical market sectors. Together we are identifying and implementing solutions and pathways for advancing EOL sustainability and circularity.

Together we are identifying and implementing solutions and pathways for advancing end-of-life sustainability and circularity.

2

Durable Plastics: A Market-Based Approach for Advancing Circularity

While the automotive, building and construction, electronics, infrastructure, and medical market sectors all rely on durable plastics, each has their own unique challenges and opportunities to advancing EOL sustainability and circularity. The following section outlines market-based approaches for each of the five sectors that reflect these differences.

Automotive Sector

Plastics are essential to virtually every part, assembly, and system in today's vehicles and are a critical enabler of future advances in mobility. Modern plastics deliver unique design flexibility for manufacturers and enable lighter-weight vehicles that produce fewer carbon emissions while helping meet or exceed the industry’s rigorous safety standards.

Plastics have revolutionized the automotive industry.

Today's vehicles on average are 50% plastics by materials volume, but those plastics only contribute 10% of the total weight of the vehicle.[19] By often giving automakers the ability to significantly cut vehicle weight while delivering superior strength and safety, plastics have been found to increase vehicle fuel efficiency by 6-8%[20] and enable low-carbon vehicles by dramatically improving electric vehicle (EV) and hybrid electric vehicle (HEV) range and performance.[21] In doing so, plastics have enabled significant reductions in automotive emissions and helped automakers in efforts to meet their sustainability goals.

Plastics also make possible the multitude of advanced electronics now standard in most vehicles. Their uniquely tailored and flexible properties are essential to the manufacture and seamless integration of the sensors, cameras, and radar necessary for automated driver-assist safety features and improved pedestrian protection.

As demand for EVs and HEVs increases and automakers strive for even greater fuel efficiency, lightweight plastics are well positioned to drive innovation that can meet the needs of U.S. drivers. Plastics' durability and flexibility is enabling the development of modern transportation infrastructure such as charging stations and increased connectivity, and are integral to the customized interiors and functionality required by autonomous vehicles.

Plastics will be integral in creating value and evolving mobility as the automotive sector becomes increasingly circular. By 2030, the growing circular economy is expected to create $400 to $600 billion in economic value to the automotive sector.[22]

Example durable plastic applications

Interior finishing and electronic content

Enables instrument panel designs and lighting for improved readability as well as the seamless integration of high-value electronic content[23]

Innovative, multi-configurable seating

Creates durable, stain-resistant upholstery and fabrics that retain a high-quality look and feel while enabling design flexibility

Communication with modern infrastructure

Enables vehicles to communicate with emerging smart infrastructure and other vehicles to help maintain safety and traffic flow[24]

EV/HEV battery packs and enclosures

Provides high strength-to-weight ratio for battery housing to reduce vehicle weight without sacrificing safety, increasing range per charge[25]

Roofs, frames, and other body components

Fiber-reinforced composites absorb four times the crash energy of steel[26] to reduce vehicle baseline weight while exceeding NHTSA crash requirements[27]

Automated driver assist safety innovations

Enables sensors, cameras, radar, and LiDAR to improve the safety of drivers and pedestrians

Advancing durable plastics sustainability and circularity

Business Opportunity

The **recycling market for vehicles** is projected to grow by 15.2% annually from 2022 to 2028:[28]

2022 **$72B**

2028 **$160B**

Using **recycled plastics can reduce emissions** and help automakers meet their environmental sustainability goals; compared with fossil fuel-based plastics, recycled plastics can result in up to

89% **lower carbon footprint**[29]

Of the **64% of surveyed consumers** who consider themselves "**sustainability-minded drivers**":[30]

97%

are **willing to change their vehicle brand** to switch to a more sustainable brand[31]

60%

are **willing to pay over a 6% premium** for a sustainable vehicle[32]

Legislative Drivers

EU Vehicle Circularity Requirements

New EU circularity requirements are mandating a **25% minimum recycled plastics content in vehicle manufacturing** and requiring **25% of the recycled content come from end-of-life vehicles**.[33] This international push affects all vehicle manufacturers who wish to sell their products in the EU, a market of over US$415 billion.[34] Failure to follow these directives could cost billions in revenues to automotive companies and decrease international competitiveness.

U.S Legislative Efforts

Domestically, ongoing debates in Congress have led to the **introduction of legislation with the potential to stall plastics manufacturing**. For example, some efforts have aimed to halt or limit new or expanded permits for plastics manufacturing facilities.[35]

Unique Challenges to Address

Recycled-content plastics often do not meet automotive performance requirements as expressed in existing materials standards

Post-consumer recycled (PCR) and post-industrial recycled (PIR) plastics are not “drop-in replacements” offering one-for-one alternatives to non-recycled plastics. Properties and costs can vary significantly, complicating incorporation of recycled content into automotive components. Clear definitions of allowed recycled materials and acceptable mass balance accounting methods are needed, as are updated standards and regulations that support the use of recycled materials in automotive manufacturing.

There is no common certification process/ standard for traceability of recycled durable plastic content

Third-party certification (e.g., ISCC Plus, UL, RSB, REDcert[2], and others), which is used extensively in other industries for advanced recycling and renewables, is not currently recognized within the automotive industry. Certifications that are emerging have different requirements and compliance processes which are not well harmonized, creating inconsistency across OEMs and potential for confusion in the marketplace.

OEMs lack clear insight into the EOL recycling process and demands for EOL recycling for vehicles

The supply chain for North American OEMs ends at delivery of the assembled vehicle, and they have limited insight into the plastics lifecycle and consumer interest in EOL automotive recycling. This has left some OEMs having greater demand than the current recycling methods can support, while others see issues in single-stream plastics recycling and assume consumer engagement there portends limited consumer interest in plastics recycling within the automotive sector.

The use of multiple plastics in automotive components and systems makes recycling difficult

Multiple types of durable plastics (i.e., meshes, webs, foams, adhesives) are used together in automotive components and systems like seats or display consoles. Further, plastic resins are reinforced with glass and carbon fibers to create strong, durable composite materials for modern automobiles. At the vehicle’s end of life, separating and purifying these multi-material systems into individual material streams suitable for effective, efficient recycling is a technical and economic challenge.

Recycling programs and infrastructure are not consistent

Across the United States and around the world, different recycling needs, resources, regulations, and interest levels increase complexities for global automakers and durable plastics producers. Sustainable economic models to support durable automotive plastics recycling programs have not yet emerged. As a result, the market has not been willing to finance a collection and sorting infrastructure for EOL durable automotive plastics.

Industry priorities for advancing circularity of durable plastics: Automotive

Develop business model supports that allow durable automotive plastics to be recycled economically and responsibly and results in a reliable supply stream for recycled resins

Possible business model supports include:

Fair and feasible producer responsibility paradigms (i.e., extended producer responsibility [EPR]) requiring producers to pay for the collection, sorting, and recycling of end-of-life durable automotive plastics.

Federal and state-level initiatives to stimulate investment in national durable plastics recycling infrastructure for collecting, separating, sorting, and processing EOL automotive plastics.

Tax incentives/rebates for vehicles incorporating recycled content.

Establish graduated minimum recycled content standards/ legislation (including both PCR and PIR resins) for durable automotive plastics to add market predictability, increase the value of recycled plastics, and support consistent feedstock quality for product developers

Automotive OEMs should include recycled content standards as part of their material certification process, informed by automotive market analysis to define segments that place premium value on recycled content.

Such standards should provide allowances for certain additives and other trace chemicals in durable goods that can be recycled to provide a policy "on-ramp" for durable automotive plastics recycling components.

Demonstrate EOL durable automotive plastic separation methods that facilitate optimum physical and chemical recycling approaches and minimize durable plastic waste from the automotive sector

Successful approaches in near term will likely require intermediary physical separations of key components during disassembly, prior to shredding; economic trade-off studies are needed to identify for which components disassembly does and does not make business sense in the recycling scheme. Longer term, new technologies and business models will be needed to automatically separate automotive shredder residue (ASR) material best suited to physical and chemical recycling methods to facilitate optimum automotive recycling approaches, including the ability to separate fibers from resins for automotive composites. Such approaches require strong chain-of-custody solutions and life-cycle analyses of chemical recycling processes to ensure the methods have lower environmental impact than alternatives.

Support the implementation of right-to-repair legislation to increase the acceptance of reused and refurbished parts from end-of-life vehicles

Right-to-repair legislation could offer a beneficial alternative to recycling by making it easier for consumers to remanufacture, refurbish, and reuse durable automotive plastics. It would provide consumers with access to diagnostic tools for assessing defective components, repair information for safe disassembly and separation, and spare automotive replacement parts. Increasing the repairability of automotive components could improve the sustainability and circularity of durable plastics and ultimately lead to greater acceptance of reused and refurbished parts at the end of their useful lifespans.

Establish standardized "design for disassembly and recyclability" methods to provide an automotive design framework for recovering durable plastics

Recycling automotive components today is often complicated by the multi-material nature of automotive components such as seats, doors, instrument panels, or headliners, because they include adhesives, webs, foams and other materials.

Establish independent, regional durable plastics recycling and compounding centers to facilitate the collection, separation, cleaning, and mechanical/chemical recycling of durable automotive plastics

Such centers may be able to accommodate durable plastics from other market sectors to further enhance economics. The EU model for end-of-life management has proven to be effective and offers motivation to establish a sub-economy for dismantling.

Ensure automotive recycling approaches pursued in North America align with global standards

The automotive industry is highly global in nature; existing EOL vehicle requirements in the EU will drive global automotive standards and practices. Such global regulations should be a basis for U.S.-based requirements.

EU requirements are driving the development of tools and data sources to comply (e.g., the automotive industry's International Material Data System [IMDS][36]). Leveraging this investment to inform North American regulations will benefit the automotive industry and durable plastics suppliers by driving consistency for these global companies.

Progress Toward Circularity: Automotive Sector Highlights

Design for disassembly/recyclability

In the design of its i Vision Circular concept vehicle, **BMW** made deliberate choices with end-of-life disassembly and recyclability in mind. The **vehicle interior incorporates monomaterials joined without bonding** to facilitate dismantling and grade purity. The components and materials are manufactured to fit precisely and minimize scrap and offcuts, enabled in part by 3D printing.[37] In addition, the **display and control surface** integrates functions such as window buttons, door openers, and sunroof operation into a singular **electronic component in the doors that can simply be removed and separated by type** when the doors are disassembled.[38]

Advances in chemical recycling

Audi has partnered with the **Karlsruhe Institute for Technology** to create a **chemical recycling process** capable of **converting mixed EOL automotive plastics into pyrolysis oil**.[39] The resulting pyrolysis oil can then be used in the production of plastic automotive components.[40]

Advanced sorting: Sieve and wind sifting

Belgium-based **Ad Rem NV** began shipping their "Scavenger" system to a heavy media separation site in Greece in 2022.[41] The "Scavenger" is a technology system **designed to sort and clean mixed plastics and metals from shredded end-of-life vehicles** at a rate of 10 metric tons per hour.[42] The compact machine combines sieves and wind sifting systems to sort materials while simultaneously washing the sieves and separating materials from contaminants.[43]

Using bioplastics

Toyota Motor Corporation employs **bioplastics** in various uses in its cars. The **seat cushions** in the Toyota Prius, Corolla, and RAV4 and the Lexus RX 350 contain fully or partially derived plastics from plant matter.[44] **Door panel insulation**, **floor silencers**, and **floor mats** are also made from post-industrial cotton and synthetic fibers in garment clippings.[45]

DSM produces EcoPaXX®, a **bio-based thermoplastic** for "under the hood" automotive applications, building and construction, and electronics.[46] It is derived from 70% castor beans and is 100% carbon neutral.[47]

BASF has commercialized **door handles for Mercedes** vehicles in the EU that are made of a mix of chemically recycled and renewable feedstock.[48] The **mass-balanced Ultramid®** features the same properties as prime quality plastic and can help BASF's customers meet their sustainability goals by using REDcert^{2} independent certification to verify the quantities of pyrolysis oil from recycled tires and biomethane from organic waste to replace fossil raw materials for the end product.[49]

Using recycled plastics

An increasing number of automakers have been using recycled plastics throughout their vehicles. **GM** has used over **17 million pounds of recycled EOL plastics** in its vehicles.[50] **Nissan** uses recycled plastic in many parts of its Leaf car, including recycled plastic bottles for **seat and armrest fabric**, recycled bumpers to make new **bumpers**, and other recycled plastics to create **fabrics for floor insulation**.[51] **BMW Group's thermoplastic components** contain **100% recycled plastic**[52] and **Audi** has been using polypropylene from LyondellBasell's chemically recycled feedstock for **plastic, seatbelt-buckle covers** in their cars.[53]

Japanese motorcycle manufacturer **Yamaha** announced in April 2023 plans to use **recycled polypropylene (PP) for the exterior of its bikes**.[54] Although the company has used recycled PP before, this is the first time it will be produced in commercial products for customers. According to Yamaha, the recycled PP offers greater strength and improved appearance compared to other conventional recycled materials.[55]

Borealis AG and **TOMRA AS** opened an advanced mechanical demonstration plant in Lahnstein, Germany in 2021 that processes both rigid and flexible plastic waste from households.[56] The recycled polymers it produces are capable of being used in many applications across the value chain, including **automotive and consumer products**.[57]

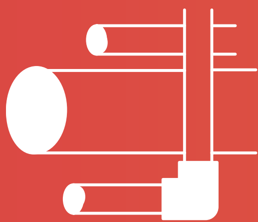
Building collection and recycling infrastructure

Li-Cycle collects a range of lithium-ion batteries, including from electric vehicles, at its "spoke" facilities, where it processes them in a water-based solution.[58] This process recovers 95% of the battery's resources, including plastics, which are separated, rinsed, dried, and packaged for shipping to recyclers.[59]

ACC and Oak Ridge National Laboratory signed a five-year memorandum of understanding to advance end-of-life and circularity solutions for durable automotive plastics. The partnership plans **a pilot-scale separation line** that reclaims durable plastic through efficient sorting, separation, and advanced recycling to make new high-performance plastics for reuse.[60]

Part reuse

LKQ Corp. operates 170 dismantling facilities worldwide where they harvest vehicle components for reuse in vehicle repair from over 700,000 used vehicles annually.[61] Once the parts are harvested, they remove the remaining valuable materials and use them in the manufacture of new basic materials, such as plastic.[62] Overall, LKQ Corp. diverts nearly 90% of all materials from total loss and EOL vehicles from landfills.[63]



Building & Construction Sector

Durable plastics improve modern buildings from floor to ceiling—and many components in between. Today's plastics and polymers are incredibly durable, helping buildings last longer and withstand the harshest elements. They are valued for being lightweight, convenient, and helping lower costs—not just in the production of the materials, but in shipping and installation. Plastics can also help improve energy efficiency, which reduces energy costs for tenants.

Durable plastics make sustainable buildings possible.

Plastics help increase the energy efficiency of buildings while extending their lifespan and improving quality of life for their occupants. Plastics contribute to improved temperature regulation and decreased heat transfer when used in insulation and window framing and films.[64] They also support sound absorption, creating quieter, more comfortable environments.[65,66] Because plastics are extremely durable and resistant to corrosion, they are also sought after for piping, having been shown to increase the lifespan of some pipe systems by at least 25 years.[67]

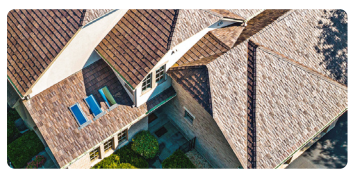
But plastics are not only used in these major applications. Plastics are lightweight yet strong, and offer flexibility of design, making them useful for small, essential building components like hinges and latches. They have minimal electric conductivity and are water-resistant, making them valued for wire coverings and electrical fixtures. And plastics offer a range of aesthetic options, making them preferable for use in flooring and décor.

All these qualities make durable plastics high-demand materials in modern building and construction. The market value of plastics in building and construction was $130.16 billion in 2021 and is estimated to grow at a rate of 7% per year through 2030, reaching a value of $239.29 billion.[68]

Example durable plastic applications

Insulation

Creates a heat transfer barrier with minimum thickness and maximum energy efficiency[69]

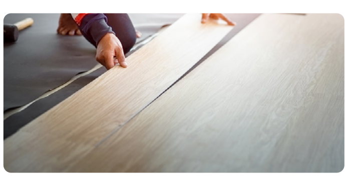


Roofing

Protects buildings from damage while remaining formable and lightweight[70,71]

Window glazing

Extends longevity of windows while aiding temperature regulation inside buildings[72]



Flooring

Provides water-resistant, durable, and easy to clean floors while offering a variety of patterns, colors, and textures for consumer preferences[73]

Pipes

Reduces the number of joints needed, decreasing potential for leaks and creating higher flow rates;[74] long-lasting (sometimes for an estimated 100 years) while maintaining leak and corrosion resistance[75]

Seals & Gaskets

Protective membranes, seals, and adhesives are resistant to deformation and weathering while retaining elasticity[76]

Advancing durable plastics sustainability and circularity

Business Opportunity

The **recycling market for all construction waste** is projected to grow by 5.4% annually from 2022 to 2030:[77]

2022 **$28B**

2030 **$41B**

According to a 2021 American National Association of Homebuyers survey:

More than 50% of responding homebuyers are **willing to pay more upfront for their house** for energy savings[80]

78% of responding homebuyers are **concerned about the environmental impact of their home**[81]

In the 2022 Simon-Kucher & Partners' Global Sustainability Study:

39% of respondents placed **higher value on sustainable goods in home construction**[83]

Using circular practices can provide a **6%** overall **decrease in acquisition and maintenance costs** compared to a standard building[82]

Using **post-consumer plastic lumber can help builders achieve third-party green certification for their buildings**.[84] Compared with office buildings without certifications, **third-party green certification for office buildings has shown to increase value:**

25 to 77% higher value per square foot[85]

Legislative Drivers

Inflation Reduction Act of 2022

The signing of the Inflation Reduction Act included the appropriation of more than $2 billion to the General Services Administration to use low embodied carbon materials in the construction and renovation of federal buildings.[78] In support of the Act, the U.S. Environmental Protection Agency (EPA) established the Reducing Embodied Greenhouse Gas Emissions for Construction Materials program. This program makes available $100 million in grants to businesses that manufacture, remanufacture, and refurbish construction materials who can demonstrate that they offer lower carbon footprint options through the development of Environmental Product Declarations (EPDs).[79]

Unique Challenges to Address

It is easier to comingle materials and landfill them, particularly on job sites

Waste materials are not typically sorted on job sites, and even if it were done, there is a general lack of collection and recycling infrastructure to support the process. Waste and scrap materials represent an opportunity to improve circularity. As much as 15% of material at a construction job site becomes "waste,"[86] though it has not reached the end of its lifecycle. A lack of incentives and recycling infrastructure often results in these materials being landfilled rather than repurposed.

Many building and construction standards for materials performance have not evolved to account for recycled material composition

Some building standards specify material composition as a proxy for performance. Recycled plastics can have more variability in composition but are still able to meet performance requirements. These standards limit the ability to use recycled plastics even though recycled plastics can meet performance requirements.

EPA's Toxic Substances Control Act (TSCA) regulations may affect the ability to recycle or reuse materials currently in use

If a chemical in a material or product is banned or limited by EPA TSCA risk management plans, the entire material or product class could be limited or banned in its ability to be recycled or reused based on its chemical content. This is true even for whole classes of materials with new formulations that do not include the limited or banned chemical as it is not easy to identify material content during demolition/deconstruction. Additionally, materials designed for particular performance characteristics (e.g., impact resistance, UV resistance, fire performance, thermal resistance) require various additives that can be difficult to separate with mechanical recycling processes.

There is no definitive information on EOL durable plastics available for recycling in this sector

Without detailed information on what materials are available, in what quantities, and at what locations and purity levels, it is difficult for manufacturers to commit to making investments required to remove and recycle durable plastics from the waste stream.

It is often difficult to recover long-term installed materials used underground (e.g., piping systems, synthetic liners, moisture barriers)

Removal from long-term applications, especially those installed underground, is currently inefficient and often requires removal of other materials necessary for installation and long-term use (e.g., adhesives, insulation, fasteners) that make separation and recycling challenging.

The building and construction sector lacks clarity on who along the supply chain is responsible for recycling

Given the fragmentation within the sector and the average lifespan of new buildings (50+ years),[87] it is unclear who the EOL recyclers along the supply chain are. There is also no adequate mechanism in place to encourage building contractors/owners to engage in collection, sorting, and disposal practices.

Multilayer construction applications (e.g., laminated floorboards, painted materials, glass- and carbon-fiber reinforced composites) make separation and recycling more complicated

If these materials cannot be reasonably separated, it can compromise the recyclability of these products. Consistency of materials is particularly vital in building and construction because of the required durability and lifespan of the manufactured products.

EOL recycling goals and regulations for building and construction can change before a building has reached the end of its life

The long lifespan of building and construction products means they will outlive most regulations. In some cases, materials that were acceptable for use when the building was constructed could be subject to restrictive regulations decades later at end-of-life, making it difficult to recycle those materials. Materials and methods will also change many times over the course of a building's life, making it difficult to predict with certainty the recyclability of building and construction durable plastics.

Industry priorities for advancing circularity of durable plastics: Buildings & Construction

Develop and pilot building-site deconstruction and sorting methods that enable rapid separation of EOL durable plastics by composition and quality to allow sorted plastic to be diverted to the proper recycling stream and reduce contamination across durable materials present in construction and deconstruction projects

Multilayer construction is commonly used in building and construction applications such as painted profiles and laminated deck boards. These components typically contain polymeric materials that are hard to separate and, if not separated well, compromise the performance of the recycled materials. Where practical recovery is possible (e.g., building foam plastic insulation), the products can still be contaminated with other construction materials/debris (e.g., adhesives, fasteners) that make sorting and recycling more difficult. Sensing technologies may be needed to identify material composition and contaminants, allowing those components to be appropriately separated. Pilot programs can engage local and regional deconstruction companies with hands-on learning opportunities essential to educating workers on the importance and viability of circularity approaches.

Use modular and on-site design techniques in building and construction to incorporate a circular mindset from onset to reduce waste and enable easier EOL reuse and recycling of durable plastics

Industrializing building construction such that buildings can be manufactured on- or off-site and rapidly assembled onsite will bring a factory-like assembly line to building and construction and better control waste. Building and construction companies should use:

Modularity in building design to facilitate reduction in materials, material reuse, and recycling by implementing design for assembly and disassembly, reducing landfill waste and mix-material demolition.

Building data collection by type to learn and estimate the typical amount of materials used.

Encourage other circularity methods beyond recycling in building and construction applications

Remanufacturing, refurbishment, and reuse can provide beneficial alternatives to recycling and should be explored for building & construction applications. In addition, research on the design of bio-based materials for use in buildings and construction applications has the potential to improve circularity of the sector.

Research and develop economically and environmentally sound recycling techniques to enable large-scale mechanical and advanced recycling of plastics found in building and construction applications

Plastics found in building and construction applications often have chloride in their chemical structure, which is more difficult to recycle. While mechanical recycling can often be done through partnership with the construction and demolition recyclers, research and development of advanced chemical technologies that are less energy-intensive and more robust is needed to bridge the technical gap and improve economically and environmentally feasible large-scale use.

Educate the sector on and/or incentivize participation in circularity and sustainable building and construction practices for durable plastics

Educate designers and contractors on plastics products to inform better decision making regarding performance, cost, longevity, and recyclability.

Build new academic programming to teach design for disassembly and recycling techniques within existing engineering curricula.

Train building subcontractors on durable plastic recycling practices.

Incentivize building owners to specify that their renovation contractors will collect materials at EOL, which will help place value on EOL materials being collected for recycling or reuse and incentivize designers and contractors to include those extra costs in their project bids.

Partner with standards development organizations to develop standards across the building and construction supply chain to establish practical, science-based recycled content standards for durable plastics

Standards should accommodate more variability in composition for materials that perform the same when tested. For example, bale specs should be reviewed and updated in partnership with the Institute of Scrap Recycling Industries. Mass balance accounting methods should also be considered as part of such standards.

Progress Toward Circularity: Buildings & Construction Sector Highlights

Using recycled materials

Ecotile, a UK floor tile manufacturing company, **uses recycled plastics in the production of its interlocking floor tiles**, which at EOL, the company says can be 100% recycled.[88]

Aspire by BRAVA Pavers, based in the US, uses **95% post-consumer recycled content, including plastics, in their pavers** to create strong and durable synthetic pavers.[89] Their manufacturing process also reduces energy usage and $C0_2$ emissions compared to many conventional pavers.[90] **BRAVA rooftile**, the owner of Aspire, also uses **recycled and recyclable materials to create their durable roofing**.[91]

Manufacturer members of the Chemical Fabrics and Film Association's Vinyl Roofing Division collectively recycled 758 thousand pounds of vinyl roofing membranes by 2021.[92] These recycled materials were then used to create new roofing membranes or other products such as flooring.

In Taiwan, **MINIWIZ** is **upcycling local waste** as a substitute for raw materials. MINIWIZ **uses reclaimed textile waste and post-consumer water bottles**[93] to create architectural products, furniture, and modular building construction systems at scale.[94]

EcoDomum collects plastic materials to recycle into **low-cost housing** in Mexico. The company can **build a house with the recycled plastic in less than a week**. With this strategy, EcoDomum is reducing plastic waste in the environment and creating affordable housing for low-income families in Mexico.[95]

Azek is **incorporating over 500 million pounds of waste and scrap into its exterior polymer products**, which the company says are also **designed to be recyclable** at the end of life.[96]

Design for disassembly/recyclability

Skanska, a multinational construction and development company, uses **modular construction** to deliver high quality, sustainable building solutions.[97] By building key components remotely, Skanska can **provide quick assembly and more efficient delivery** of their construction projects.

UK-based **BAM Construction** has focused efforts on sustainability and circularity. By designing their products with the entire lifecycle in mind, their materials are more likely to end up back in the supply chain rather than in a landfill. By 2030, BAM plans to **reduce their waste by 75%** compared to 2015.[98]

Recycling infrastructure

In 2022, **CRDC Global** with support from the Alliance to End Plastic Waste, opened in York, Pennsylvania the **first-ever U.S. facility to transform any type of plastic waste (resins 1-7) into RESIN8**, an additive that enhances the integrity of concrete and asphalt.[99] The facility can transform plastic waste into RESIN8 at a rate of approximately one ton of plastic per hour for use in numerous applications—including concrete blocks and pavers, pre-cast concrete, ready-mix concrete, mortars, and even hot mix asphalt.[100] Incorporating RESIN8 can reportedly make the resultant material **up to 15% lighter or stronger depending on its usage, with up to 20% better insulation properties** than traditional concrete.[101]

Recycling service company **Firstar Fiber** established an **integrated plastic-to-lumber recycling complex** alongside its existing materials recovery facility in Omaha, Nebraska through a partnership with the **Alliance to End Plastic waste**.[102] Launched in February 2023, Firstar's plastic-to-lumber operation receives recyclables through Omaha's curbside recycling program, which participates in the **Hefty ReNew program** that asks residents to bag hard-to-recycle plastics separately.[103] The contents of the ReNew bags are manually inspected and sorted before being sent to a shredder or granulator where the material is flaked and extruded into the final composite lumber product for use in building materials, including lumber for decking.[104]

Advanced recycling

Canadian-based **GREENMANTRA** is developing **catalytic depolymerization** technology to **transform single-use personal protective equipment from hospitals into specialty waxes and polymers for use in the construction industry**.[105] These polymers and waxes are used as additives in asphalt, roofing, drainage pipes, and extruded plastic lumber.[106]

Using bioplastics

Researchers at **Oak Ridge National Laboratory** and the **University of Maine** are successfully utilizing **bamboo with polyactic acid, or PLA**—a bioderived and biodegradable thermoplastic polyester—to manufacture **more recyclable homes** while also providing a solution to Maine's affordable housing crisis.[107]

BASF has developed the **first greenhouse gas neutral aromatic isocyanate**, Lupranat® ZERO, for use in the production of **polyisocyanurate panels and rigid polyurethane foam** for thermal insulation.[108] Renewable raw materials are used at the beginning of the chemical production chain and allocated via a mass balance process to achieve neutral emissions.[109]

Electronics Sector

Consumer electronics must be elegantly designed, durable, and safe—qualities made possible through the use of modern durable plastics. These qualities also make durable plastics critical to cutting-edge innovations across the electronics sector.

Plastics are a key component of most everyday electronics.

Consumer electronics must be elegantly designed, durable, and safe, all of which today's durable plastics help to provide.

Plastics have a high electrical resistance, making them highly valued for insulation and casing.[110] They offer unique design flexibility while withstanding significant wear and tear, making them suitable for many internal and external electronics components. And because durable plastics are lightweight, they are well suited for personal and portable electronics.

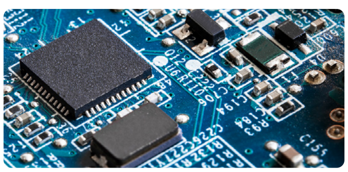
Plastics are vital to innovation in personal electronics. The modern microchip is made possible by plastics, which allow the technology to withstand extreme temperatures and harsh environments. This makes it possible for device manufacturers to push the limits on what can be made "smart" and how personal electronics can be more integrated into everyday life.

In particular, wearable electronic devices—from smart watches to fitness trackers to health monitoring technology—rely on durable plastics to make them small, lightweight, and affordable, opening up personalized health and fitness options to a much wider audience. Plastics make it possible for manufacturers to develop paper-thin polymers that fit a user like a second skin and sturdy casings that can withstand aggressive impacts.

The durability of plastics is a key selling point for many consumers. Consumers want products that last—60% of consumers are replacing their gadgets less frequently, with 55% opting to repair their devices rather than rush to replace them—and durable plastics permit consumers to make those decisions while also focusing on device quality.[111]

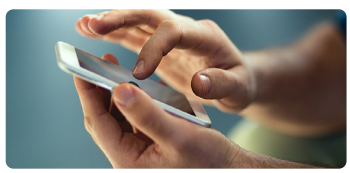
Plastics for consumer electronics are expected to be a $7.7 billion market by 2028.[112] But consumer demand for recycled and recyclable plastics is growing, too. The global market for electronics recycling is estimated to reach $110.6 billion by 2030, a significant portion of which will be for recycled durable plastics.[113]

Example durable plastic applications



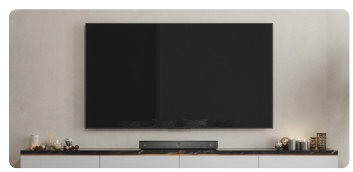
Semiconductors

Provides heat resistance, conductivity, insulating, and shielding properties for inclusion in products and the equipment used to manufacture them[114]



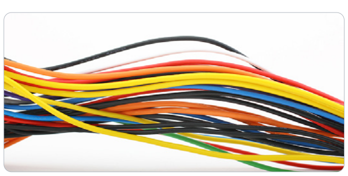
5G Compatibility

Enable high transparency in devices for 5G frequencies, reducing signal loss and improving velocity and transfer speeds[115]



Audio & Visual

Thermoplastics used in AV casings can be formed into a desired shape then set to provide the properties needed for proper function of the device[116]

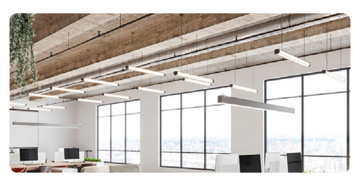


Cables and wires

Provides an effective, long-lasting protective barrier between electrical parts and humans while retaining flexibility and flame-retardant capabilities[117]

Personal Computing & Cellular Communication Devices

Enables shatter- and scratch-resistance for long-term durability combined with improved reception due to lack of interference with internal antennae[118]



Lighting Systems

Increases the energy efficiency of bulbs and systems and offers lightweight and flexible options with customizable design[119]

Advancing durable plastics sustainability and circularity

Business Opportunity

The **global market for electronics recycling** is projected to grow by 13.6% annually from 2022 to 2030:[120]

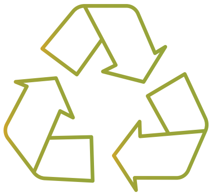
$39B 2022

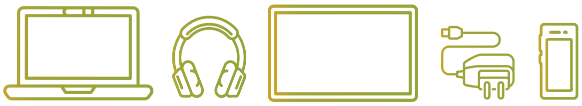
$110B 2030

The **market for electronics plastics recycling** is projected to grow by 12.4% annually from 2022 to 2030:[121]

$8B 2022

$20B 2030





According to a 2020 Morgan Stanley survey:

54%

of consumer respondents **recycled their electronic devices**, more than double the number in 2018[122]

40%

of consumer respondents said they **are buying refurbished electronics** rather than new ones[123]

$150 billion of smartphones enter the US market each year[124]

When they are discarded, that value is lost.

If these phones were instead recycled,

$11.5B of value could be retained[125]

Legislative Drivers

U.S Legislative Efforts

Ongoing debates in Congress have led to the introduction of legislation that signals increased attention on the ways electronic waste is handled. For example, some efforts have aimed to limit the export of electronics waste.[126] This changing atmosphere could signal future legislation that could be disruptive to the electronics market if further steps toward circularity and EOL sustainability are not taken sooner.

Unique Challenges to Address

Electronic Product Environmental Assessment Tool (EPEAT) can be useful for promoting electronics containing recycled plastics, but its usage remains limited

Where the EPEAT system is used and advertised, it can help promote electronics made with post-consumer recycled plastics.

Domestic and international regulations that restrict movement of waste products can create barriers to electronics circularity

Durable plastics recycling infrastructure is underdeveloped in most regions, necessitating the movement of recyclable materials for proper processing. Some regulations and laws restrict the shipping of certain electronics waste materials to encourage domestic recycling (e.g., the Basel Convention), which can make recycling and reuse efforts of the durable plastics used in this sector challenging.

Flammability standards for electronics materials make developing a clean plastic recycling stream challenging

With strong standards around flammability for consumer electronics, most products use additives or composites that are difficult to separate during post-consumer recycling. Innovation in recycling technologies is needed to address this challenge.

Electronics OEMs are not incentivized to make their products easy to disassemble

Products are designed to be lighter and more aesthetically pleasing, goals that often run counter to the needs of easy disassembly. Additionally, electronics manufacturers prioritize proprietary design elements over the more limited options that would make disassembly simpler.

Recycling of consumer electronics requires not only better infrastructure for durable plastics recycling, but increased recycling capabilities for metal, glass, and other composites

The plastics industry can help support electronics recycling but a system that results in true circularity would require buy-in from multiple materials industries to recycle all materials used in electronics.

Consumers do not value sustainability/recyclability as much in consumer electronics as they do in other markets

In addition to consumers not having information about the recyclability of their devices, sustainability of materials used in electronic devices is rarely considered in consumers' purchasing decisions.

- **Consumer-friendly recycling programs are lacking for personal electronics**. Consumers are not as willing to take the extra steps needed to recycle personal electronics. Developing more consumer-friendly recycling infrastructure puts the burden of additional cost on municipalities and/or manufacturers.
- **Many consumer electronics are used to store personal information, and there is no consistent or reliable process for effective data wiping**. Devices, particularly small electronics (i.e., smart watches), that contain personal data are more likely to be shredded and landfilled rather than disassembled for wiping and recycling. Further, disassembly of small consumer electronics does not yield sufficient materials to justify the cost of their recycling at present.

Industry priorities for advancing circularity of durable plastics: Electronics

Support industry-government collaboration to develop and improve product-specific standards and certifications promoting recycling and recycled content in durable plastic components used in electronics

Harmonize recycling circularity standards across electronics supply chains to track and verify recycled content

The electronics industry can do this by adding more specific plastics processing requirements through R2 and e-Stewards standards. Expanding R2 standards may require additional support globally given 530 facilities use R2 standards in 21 countries worldwide.

Government incentives to use and support purchase of electronics with greater recycled durable plastic content can help drive greater market acceptance and uptake of more circular products.

Communicate the benefit of advanced recycling to the electronics industry and consumers

This includes the ability to achieve properties similar to original materials, through customer showcases (e.g., Microsoft Ocean Plastics Mouse[127]), success stories on electronics recycling and its impact on sustainability, and outreach efforts that educate consumers about environmental benefits of recycling durable plastics. Life-cycle analyses quantifying the environmental benefits of PCR resins in electronics can inform messaging.

Establish consumer-accessible electronics collection facilities in partnership with OEMs to enable electronics collection and alleviate data management security concerns

Incentive programs similar to “bottle buy-back” programs could help further encourage consumer participation.

Pursue funding opportunities and incentives to expand research and development into durable electronic plastics recycling technologies

This includes sorting and advanced manufacturing to expand processing of both high-value electronics plastics and small-volume, less-easily recycled plastics found in electronics, such as television frames. Additional research is also needed to understand any performance degradation associated with the recycling of durable plastics in electronics, given the faster pace of turnover in electronics compared to longer-lived applications.

Embrace fair and feasible EPR paradigms requiring producers to pay for the collection, sorting, and recycling of end-of-life durable plastics in electronics

In Canada, industry-led (regulated) EPR approaches for electronics have provided revenue required for effective collection and processing of devices and the resulting materials, including plastics. In these programs, environmental handling fees agreed upon by electronics firms and retailers provides revenue to support collection and recycling efforts. Developing models for the United States that build on these successes will accelerate circularity of durable plastics in this sector.

Support voluntary and/or required "Right-to-Repair" programs and/or legislation to encourage EOL design requirements for electronics, supported by new designs that encourage and enable upgradeability to extend the overall product lifespan

Five states have already passed "Right-to-Repair" legislation with over 20 bills submitted in states to add "Right-to-Repair." These programs and laws make it more accessible and economical for consumers to repair and upgrade their products, including repair options not involving the original equipment manufacturer, thereby lengthening the lifespan of electronics while reducing the number of new materials required by allowing individual components to be replaced rather than the whole product.

Progress Toward Circularity: Electronics Sector Highlights

Building collection and sorting infrastructure

In 2021, **LG** announced new initiatives to **take back and recycle electronic waste in over 52 countries**.[128] LG set a goal to nearly double its collection and recycling from 4.5 million metric tons (its 2006 figure) to over 8 million metric tons by 2030.[129] The company currently has over 1,000 collection sites in the United States and provides pre-paid shipping labels to return any brand electronics via mail.[130]

Panasonic recently launched their "Take Back for Tomorrow" program, which aims to **promote and increase recycling of consumer electronic devices**, such as shavers and trimmers. Panasonic will **cover the cost of shipping** EOL consumer electronic devices via a pre-paid label for consumers to ship their device for recycling.

Lenovo offers **Asset Recovery Services to businesses** by taking back equipment, destroying data, and offering refurbishment and recycling services. Lenovo's **trade-in program allows consumers to return their electronic devices**, which Lenovo will recycle, and receive payment for doing so.[131]

Sweden-based **Renova**, a waste management company, **operates a collection center for electronic waste** on behalf of Sweden's national recycling program.[132]

Using bioplastics

In 2021, **Dell** announced the development of its first **PCs made with reclaimed materials**: the Latitude 5000 series and the Precision 2560.[133] Parts of the PCs are created with bioplastics made from tree waste. The device's lids contain 21% bioplastic and a total of 71% recycled or renewable materials. The lid of the device is the second heaviest part of the PC. Focusing on such a large PC part has enabled Dell to make a larger impact on sustainability and its resource footprints.

Advanced recycling

One type of advanced chemical recycling is seen in a 2021 project by the **University of Massachusetts** and the **REMADE Institute** showed promising potential of **solvent-based recycling processes to produce secondary plastics materials from e-waste** while also **saving 25-60% of the embodied energy** used to manufacture plastics used in electronics.[134]

Design for disassembly

Microsoft designed its **Surface Hub 2S** with modular components to allow for repairs and upgrades.[135] Not only could this make it easier to disassemble in the future, but it also reduces how quickly a customer may need to purchase a new product and dispose of their old one.

Cisco designs its **Unified Computing System servers** to be quickly and easily assembled and disassembled. The company utilizes modularity and removable components to optimize reuse, repair, and recyclability.[136]

The **Fairphone 4** was created to fight the "make-use-dispose" trend in electronics by using a modular design that enables users to easily replace or upgrade components, including the camera.[137] By **using a modular approach**, Fairphone can extend the life of their products and reduce emissions linked to global warming.[138]

Dell and **Covestro** are working together to **use old Dell notebooks as feedstock for new ones**. Using these materials in a closed loop design, Dell and Covestro were able to extend the lifespan of notebook components from 3-8 years to 12-32 years.[139]

Using recycled materials

Epson, one of the world's largest manufacturers of computer printers, **aims to become "underground resource free" by 2050**. As part of this initiative, Epson is using recycled plastics in high-capacity ink tank printers.[140]

LG Electronics plans to **use nearly 600,000 tonnes of recycled plastics** in its products by 2030. As of 2021, LG used recycled plastics within its products, such as within TVs, monitors, washing machines, etc. However, LG announced it will **expand its use of recycled plastics** to also the exterior of products.[141]

Samsung is on track to reach its 2030 goal of using over half a billion pounds of recycled plastics in its products. Since 2009, Samsung **has used 310,291 tons of recycled plastics in its products**. Recycled materials end up in their Galaxy products including their Buds, Book, Watch, and Phones.[142]

Infrastructure Sector

The needs of 21st century infrastructure could not be met without the inclusion of durable plastics. Every major element of modern infrastructure relies on some form of plastics. From waterlines and roadways to green power infrastructure, plastics keep the world moving forward.

Durable plastics are prized in infrastructure applications because of their durability and longevity.

Pipelines and water mains that use plastic piping have been found to operate effectively for more than 100 years.[143] By incorporating plastics into the paving materials used for roadways, the lifespan of the road can be extended by more than 30 years—and it can limit the number of repairs needed to keep the road functional.[144] Meanwhile, the use of plastics in the construction of bridges helps those bridges withstand heavier loads for longer. Not only can plastics make a bridge last longer—sometimes as long as 50 years, due to their resistance against corrosion,[145] mold, moisture, and UV rays[146]—but it can support heavier loads with lighter materials.[147] To support a 70-ton tank, for example, a wooden bridge would typically need to weigh nearly three times the amount of a bridge built with plastic.[148]

But infrastructure is more than bridges and roads. Electrical and power systems—including those used to power the automobiles that travel those roadways—are also critical infrastructure systems. Durable plastics and composites are used in the construction of solar panels and wind turbines, as well as in the EV charging stations that are spreading across the country as EV adoption increases.

Further, plastics are in the fiber optic cables and the 5G cellular systems that deliver the wireless internet and cellphone connectivity that make modern life possible.[149]

Through all these applications, durable plastics help secure the supply chain for the materials used in infrastructure and can lower the costs of those materials. And as infrastructure moves toward a more circular plastics economy, the supply chain will become even more resilient.[150]

Example durable plastic applications

Wind turbines

Provides lightweight strength that allows blades to spin more quickly and last longer[151]

Solar panels

Used in insulation panels to decrease internal humidity and increase durability[152]

Roads and bridges

Resists temperature swings and provides water resistance for longevity and durability[153]

EV charging and hydrogen refueling stations

Provides EV stations with high resistance to weathering and tailorable electrical insulation properties;[154] strengthens hydrogen tanks to keep hydrogen contained and shielded from the surrounding environment[155]

Modernized transportation infrastructure

Enables durable infrastructure that can communicate with vehicles to maintain safety and traffic flow (e.g., charging stations, traffic flow monitors, lane-diversion signals)[156]

Fiber optic cable and 5G

Flexibility allows cables to be routed through tight areas and cut to length on site;[157] improves antenna performance for 5G creating, higher speeds, lower latency, and better transmission[158]

Advancing durable plastics sustainability and circularity

Business Opportunity

According to an estimate from Transparency Market Research, the market size for **solar panel recycling is expected to grow by 37% annually** from 2021 to 2031:[159]

$78M
2021

$1.8B
2031

The **onshore wind turbine scrapping and recycling market is projected to grow at a rate of 37.2%** from 2022 to 2029:[160]

$30M
2022

$275M
2029

Due to the simplicity of installing plastic fiber optic cable, the **overall cost of plastic fiber optics** is about

1/5 the cost

of comparable fiber optic cables[161]

Manufacturing **recycled plastic asphalt** reduced British manufacturer MacRebur's costs by

$100,000 per 100,000 tons of asphalt[163]

Plastic applications in bridge abutments can cost

30-50% less

than traditionally designed bridges while decreasing building time and increasing resiliency of the bridge.[164]

Legislative Drivers

Inflation Reduction Act of 2022

The signing of the Inflation Reduction Act will lead to investment of almost $400 billion of federal money into climate initiatives, the majority of which will go to funding clean energy projects.[162] The plastics industry, through wind turbines, solar panels, and more, will play a direct role in building up this clean infrastructure, making now a prime opportunity to consider and incorporate sustainable end-of-life and circular approaches.

Unique Challenges to Address

The lifespan of infrastructure elements is significantly longer than in many other plastics applications

Some types of infrastructure must last 10 to 50+ years, often making EOL recycling standards moot by time the product reaches the end of its useful life and the material is ready to be recycled.

Mandates for non-plastic materials make use of recycled plastics impossible in some infrastructure applications

Standards and regulations vary across countries, states, and municipalities and have not evolved to support the use of modern durable plastics in certain infrastructure applications (i.e., iron is often mandated for ductile pipes).

Durable plastics are often not recycled into the same application as their original use, further complicating the incentive structure for infrastructure developers

Because plastics typically get recycled into new materials (i.e., plastic EOL pipes into asphalt), developers do not receive the same incentives of their use of recycled alternate materials.

Infrastructure does not have the same consumer as other markets, making it difficult to encourage the end user to value recycled materials over non-recycled plastics

The "consumer" in the infrastructure market is often the engineer, who is frequently more familiar with specific materials (i.e., iron, steel) and less willing to consider alternatives. Any awareness campaign about the benefits of recycled plastics, then, needs to target a much more niche consumer audience to be effective (e.g., state departments of transportation who have not yet seen plastics and plastic composites as "proven" in the same way other materials used in infrastructure are).

Structured programs to retire, recover, and reclaim material from end-of-life infrastructure (e.g., wind turbine blades) do not exist

Such programs are needed to standardize end-of-life management, create market clarity that incentivizes end-of-life management of these components.

Infrastructure developers must enter competitive bids for work, and the lack of consistent information about the supply of recycled plastics can hinder preparation of an accurate, reliable bid

If a developer cannot ensure availability and price of materials for new infrastructure projects, the developer is likely to bid with only consistently available non-recycled materials.

Inconsistent standards and regulations for recycling and use of recycled materials hinders reliance on recycled materials

Without consistent and standard information about the supply of recycled materials and their use in infrastructure applications, it is difficult to encourage the use of recycled materials.

EPR fees are viewed by many as a "stealth tax"

Currently, it is cheaper—in many instances—to landfill plastic waste from infrastructure than to recycle. Instead of additional fees for recycling, the infrastructure market would benefit from tax incentives to encourage effective EOL management of durable plastics.

Education of infrastructure professionals does not include sufficient coverage of plastics

Colleges and trade schools that produce infrastructure professionals continue to focus on traditional materials (i.e., steel, concrete), while durable plastics are rarely covered.

Industry Priorities for Advancing Circularity of Durable Plastics: Infrastructure

Establish "Design for Inspectability and Reuse" methods and standards to extend the life of durable plastics in infrastructure applications by improving the ease of repair and/or replacement of durable plastic components

Re-certification and quality control protocols may enable reuse of durable plastic components, further extending their useful lifetime and advancing circularity goals in infrastructure applications.

Increase public perceptions and awareness of the benefits of durable plastics in infrastructure by partnering with non-government organizations to document and publicize case studies

For example, work with water conservation groups to explain how durable plastics can prevent water loss in piping infrastructure.

Prioritize infrastructure applications that can effectively use durable plastics (especially plastics with recycled content) for early success stories

Examples include wastewater treatment facilities (where material requirements typically encompass greater variety), chemical processing industry equipment which already uses plastics and composites extensively due to their chemical resistance, and composite bridge replacements that offer compelling societal benefits on a life-cycle analysis basis.

Progress Toward Circularity: Infrastructure Sector Highlights

Using recycled materials

Interest is growing in **adding recycled plastic to asphalt** for paving roads and parking lots.[165] **LyondellBasell** and **Plastics Industry Association (PLASTICS)** are piloting a project to build parking lots with **asphalt fortified with recycled polyethylene film**.[166] In addition, **Dow** and its global partners are working to construct polymer-modified asphalt roads with post-consumer recycled plastic.[167] This asphalt can be torn up and used again and again.

Pact Group has produced and installed **noise barrier panels** along the Mordialloc Freeway in Victoria, Australia, using **75% recycled plastic materials as feedstock**.[168] The project created 32,000 square meters of panels from around 570 metric tons of hard-to-recycle plastic.[169] According to Pact Group, the panels are easy to install, low maintenance, and color fast for 30 years.[170] In addition, the new panels are said to have a lifespan of 40 years and be recyclable at end of life.[171]

In collaboration with **Prysmian Group**, the **Climate Change Company** is taking **EOL fiber optic cable to create Littar, a product used to create asphalt**.[172] Using Littar reduces weight, transportation emissions, and cost compared to a number of more conventional asphalt mixtures.[173]

EVBox, the EV charging station manufacturer, has teamed up with **Covestro** to **use more sustainable plastics in the production of their charging stations**. These components will enable EVBox to produce charging stations more sustainably and to comply with industry regulations.[174]

Platio is using hard-to-recycle plastics in their solar paver solutions as the base for the paver. The plastics in the base **provide the hardness properties of concrete but with a longer lifespan**. The solar pavers are load bearing allowing people to walk on them while collecting solar energy to power buildings and electronics.[175]

European bus company, **Dancer**, has created a **public transportation option** that is made with a large portion of recycled plastic.[176]

CMI is working to **improve the sustainability of shorelines and waterways infrastructure** by **using at least 90% recycled materials** in many of their product solutions.[177] The company works with components of their supply chain to develop policies and relationships that optimize the life cycle of their solutions. They also reportedly recycle 2% of the polyvinyl chloride (PVC) generated in the U.S. and Canada and recycle PVC into the same product—such as **vinyl sea walls**—up to seven times, creating a more sustainable way of preparing communities for climate change adaptation.[178]

Design for disassembly/recyclability

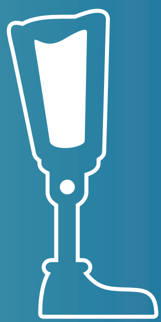
By 2040, **Siemens Gamesa Renewable Energy** aims to make all of its **wind turbines** fully recyclable. The company is already integrating fully recyclable blades into its land-based and offshore turbines.[179]

Using bioplastics

SABIC is enabling **Charge Amps** to manufacture **electric vehicle chargers with a housing made from certified renewable polycarbonate**, a first for the industry.[180]

Recycling infrastructure

PacifiCorp and **MidAmerican** are transporting EOL wind turbine blades to **Carbon Rivers, LLC** in Knoxville, Tennessee to be **recycled into new composites** that can be used in vehicles, other renewable energy system components, and more.[181]



Medical Sector

Durable plastics make modern lifesaving medical devices possible. From institutional medical devices—like CT scanners and in-room monitors—to at-home equipment—such as respirators and personal EKG readers—plastics help patients receive superior medical care when and where they need it.

Lightweight and flexible while maintaining strength and durability, plastics are well-suited for major medical devices—like MRI machines and hospital beds.

But today's plastics are also valued for biocompatibility with the human body, making them often used for more personalized medical devices—such as implants and wearable devices. Durable plastics are also able to be sterilized, allowing them to be safely used and reused, contributing not only to better health but also less waste and improved environmental sustainability.

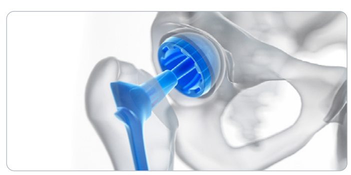
Plastics also allow for increased innovation across the medical sector. The design flexibility of plastic permits allows for functional and aesthetic improvements in everyday medical devices—such as eyeglasses, dental implants, and prosthetic limbs—that make them more comfortable and convenient for users. Durable plastics also encourage the creation of entirely new medical options. Needle-free injection systems made of modern polymers, for example, are gentler on the patient and can offer a more reliable supply chain than traditional needles and syringes.[182] New pharmaceutical-grade durable plastics also make implantable drug delivery devices possible, allowing for sustained delivery of needed medications without continual trips to the doctor or need for a patient to alter their daily life to meet their medication schedule.[183]

The global medical plastic market was worth $28 billion in 2021 and is expected to reach $57 billion by 2030.[184] But medical device and plastics manufacturers are already responding to the increasing demand for greener medical plastics, too. New medical-grade plastics are being created using recycled plastic bottles, lowering greenhouse gas emissions and energy use during the manufacturing process, and manufacturers are developing advanced recycling processes to help give other out-of-use plastic products new life.[185] The market for reprocessed medical devices—which includes a significant amount of plastic—was over $2 billion in 2022 and is estimated to grow at an annual rate of 16.9% between 2023 and 2032.[186]

Example durable plastic applications

Surgical equipment

Offers chemical and heating resistance for sterilization and compatible with imaging systems such as X-rays and MRIs[187]



Medical devices

Provides biocompatibility and has a similar modulus to that of bone[188,189]

Mobility aids

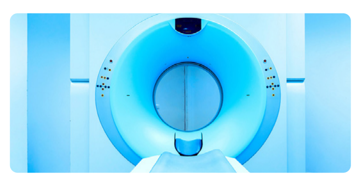
Allows people to recognize how much pressure they are applying while also offering lightweight alternatives for comfort and increased mobility[190]

Eyeglasses

Contains lightweight material that reduces facial soreness[191] while also providing variety in color and lens availability, e.g., tinted or transition lenses[192]

Dental equipment

Provides comfort for long wear[193] while also being moisture resistant and having good chemical resistance[194]



Medical imaging machines

Allow for more accurate imaging by not interfering with radiofrequency of certain machines;[195] provides shielding components against x-ray and gamma radiation[196]

Advancing durable plastics sustainability and circularity

Business Opportunity

The **market for reprocessed medical devices** is projected to grow by 16.2% annually from 2023 to **2032:**[197]

The Mayo Clinic's internal recycling initiative in Rochester, NY has **saved the organization**

$2M

KAISER PERMANENTE®

Kaiser Permanente's Northern California Region (NCAL) established a trade-in and bulk buy agreement with the supplier of the installed base of stress test systems.[198] When the supplier delivers new machines, it picks up the old machines to be re-sold, used for spare parts or recycled responsibly regardless of working condition.

Participating in this device trade-in program to replace 19 systems saved NCAL

$58,000

Legislative Drivers

Green New Deal for Health

Introduced in the House of Representatives in 2023, the Green New Deal for Health would direct the U.S. Department of Health and Human Services to develop policies for mandatory public disclosure of emission and climate risk[199] in an effort to create a more transparent and green medical supply chain.[200] Focusing on advancing sustainable and circular practices in the medical sector now can position the plastics industry to aid the market in navigating more stringent environmental policies in the future.

Right-to-Repair Acts

Right to repair acts are gaining steam across the country and the globe, including the right to repair medical devices. If right-to-repair is applied to this market, it may become illegal for original equipment manufacturers to design devices that preclude reprocessing.[201] Moreover, if right-to-repair is passed for medical devices in more states, there is a value-driven opportunity to get ahead of the curve on setting up systems and technologies capable of reprocessing durable plastic medical devices.

Unique Challenges to Address

It is difficult to gain regulatory approval for recycled or reused durable plastics in medical devices and other applications

The approval of new medical devices using recycled plastics can be a major roadblock for device manufacturers. Standards and regulation for medical devices require proof of consistent purity and quality of materials used. Additionally, plastics used in previous medical applications are often considered contaminated medical waste, preventing them from being recycled for future use.

Reusing medical devices through reprocessing or refurbishing creates liability for the reprocessor/refurbisher

When a device is reused or repurposed, the reprocessor becomes the "manufacturer" of the device and must assume risks associated with manufacturing a new device. Given the unique nature of risks and liability in the medical sector, this creates a significant barrier to this aspect of durable plastic circularity in the medical sector.

The economic benefits of recycling durable plastics from medical applications are unclear

The volume of materials recovered from recycled durable medical devices is not sufficiently large to support industry needs or provide sufficient economic benefit to manufacturers to justify investments in recycling systems.

Standards around the sterilization of medical devices for reuse and recycling are centered on metal devices and do not often account for plastics sterilization methods and practices

While standards are beginning to evolve to support plastics sterilization and cleaning, they are not yet widely used or accepted across the medical sector.

There is no existing recycling system that can capture and recycle durable plastics used in medical applications

While it is possible for hospitals and other medical institutions to develop their own durable plastic recycling streams, there is no known system in place that would permit consumers to easily recycle medical-use durable plastics.

There is a negative perception of the use of recycled materials in medical applications

The medical device market is much more conservative than other plastics markets, with medical professionals and consumer end-users viewing recycled materials as riskier than non-recycled materials in medical applications. This presents a market challenge for medical device manufacturers that want to introduce products made with recycled materials.

Industry Priorities for Advancing Circularity of Durable Plastics: Medical

Support graduated minimum recycled content standards for durable medical plastics to add market predictability and increase the value of recycled plastics

Recycled content standards must be realistic to medical applications and specificities of use. For example, recycled content in non-sensitive contact applications may be the best starting point.

Establish accelerated routes to screen and qualify durable plastics with recycled content in the medical sector.

Characterize the medical market's durable plastics EOL material streams and how they will integrate with other EOL durable plastics to form feedstock needed to sustain recycling processes and demand for recycled content

Sourcing of feedstock is one of the biggest challenges in the recycling value chain.

However, there have been some successful efforts to recycle single-use plastic bio-medical devices, such as IV bags, syringes, needles, and oxygen masks for use in other products.[202,203] Such existing medical recycling programs could be leveraged and evaluated as potential feedstock streams for recycled medical durable plastic applications.

Given the unique requirements of many medical applications, a closed-loop circular approach to medical sector may not be viable.

Understanding how the medical sector can fit into a broader circular economy (vs. a circular industry) can offer more feasible pathways to eliminating durable plastic waste from medical.

Partner with the medical device industry to develop a refurbishment and reuse program that properly recognizes the unique liability considerations of the medical sector

Such a program could allow for greater circularity of durable plastics in medical applications in a sector-appropriate context.

Conduct a recycling pilot program with participation from medical plastics value chain participants to inform the safety and effectiveness of circularity approaches to durable plastics in medical applications

The medical sector is especially sensitive to risk and liability concerns, so reluctance to introduce new materials, processes, and practices is higher than many other sectors. Pilot programs that provide incentives to gather needed information can catalyze more progress towards durables circularity in the medical sector.

Conduct a deep-dive analysis on the value creation possible with durable plastics circularity in the medical sector, with extensive input from medical value chain participants

Value in medical applications are less driven by environmental, social, and corporate governance (ESG) factors. "Consumers" in this sector are typically device manufacturers making material selection and recycled content decisions, but patients must also be considered.

Standards and regulations that advance circularity (e.g., by minimizing the number of different durable plastics used in medical applications) must be cautious not to compromise medical science, device functionality, or patient outcomes.

Progress Toward Circularity: Medical Sector Highlights

Advanced chemical recycling

The **Brightmark Energy** and the **Cleveland Clinic** are working to build a partnership that will use Brightmark's pyrolysis process to convert mixed waste, including **pre-surgical healthcare plastics**, into fuel.[204] Brightmark is nearing completion of a plant in Ashley, Indiana that will be the largest advanced plastics renewal facility in the world when it is completed.[205] The company aims to develop its technology to support a 100% plastic-to-plastic manufacturing model by 2025.[206]

Building collection and recycling infrastructure

The **Association of Medical Device Reprocessors (AMDR) reprocesses medical devices** like blood pressure cuffs, ultrasonic scalpels, and diagnostic catheters to keep them in circulation.[207] Hospitals send their used devices to one of eight facilities throughout the United States so the devices can be disassembled, cleaned, put back together, tested, inspected, and repackaged in accordance with U.S. Food and Drug Administration standards.[208] **Hospitals can then buy back devices at a savings** from what new devices would cost.[209]

Using recycled materials

Eastman is using **recycled plastics from Warby Parker demo glasses** to create their Eastman Acetate Renew, a product that is **60% bio-based and 40% certified recycled content**.[210] Currently, eyeglasses frames make up about 5,000 metric tons of waste across the globe annually.[211] By recycling some of this content, Warby Parker and Eastman are working to reduce this impact on the environment.

SABIC upcycles post-consumer plastic bottles into a strong, high-quality resin for use in healthcare applications.[212] Using this upcycled material results in the same tough material for these products while lowering greenhouse gas emissions and energy use as compared to plastics made from first-use materials.

Refurbishing EOL durable goods

Philips, an electronics and health technology company, **offers “Circular Edition” versions of their medical equipment**. This equipment has been carefully selected and gone through rigorous refurbishment, **offering same-as-new quality and savings and reducing waste** by extending the life of products.[213]

Didage, a medical and surgical equipment sales company, **purchases old medical equipment**, including, operating room tables, imaging equipment, patient monitors, etc., to be refurbished for reuse at another hospital or surgery center. Their products undergo quality control inspection and data cleansing process.[214]

Recycling infrastructure

Oak Creek, Wisconsin, is home to **GE Healthcare’s** largest recycling center. The facility takes in about **10 million pounds of recyclable medical equipment** every year and keeps more than 8 million pounds of medical equipment out of landfills annually.[215]

Using bioplastics

Swedish MedTech company **Wellspect Healthcare** is working with suppliers **LyondellBasell** and **Neste** to use a mass balance approach to **incorporate bio-based raw materials into its urinary catheter**.[216]

3

Durable Plastics: A Multimarket Approach for Advancing Circularity

While there are many ways individual market sectors can advance durable plastics' EOL sustainability and circularity, there are some initiatives that would benefit from a cross-sector approach. Coordination across markets in areas such as life cycle assessment (LCA) methodologies, regional recycling infrastructure, and others will limit redundancy while helping to maximize the potential impact of these crosscutting areas.

Industry Priorities for Advancing Circularity of Durable Plastics: Multimarket

Expand pilot programs that inform the technical and economic viability of regional separation, sorting, recycling, and compounding approaches for durable plastics

To encourage sustained progress toward the circularity of durable plastics, companies must have confidence in the technical and economic viability of durable plastics recycling practices. Yet, establishing the nationwide recycling infrastructure needed to achieve circularity will require significant investment from both industry and government—investment that is difficult to justify without demonstrating viability. Pilot programs for the collection, sorting, cleaning, and mechanical and chemical recycling of EOL durable plastics would build the business case for and lower the overall risk of national-scale investment by:

- Establishing and sharing best practices (with protection for proprietary data as appropriate);
- Demonstrating regional approaches for distinct circularity resources and needs; and
- Identifying and solving key technical and/or logistical challenges.

Develop recycled material and component performance standards and part certification processes that support greater acceptance of recycled content in durable plastics

While components made using recycled-content sources may be able to reliably meet performance requirements, the relevant material specifications and standards may not allow recycled content use because of how the standards were created. Engineers or designers who attempt to use materials that are not accepted by standards risk increased liability exposure, often offsetting the potential benefit of using the “off-spec” material.

Updated or new standards and certifications that are more accommodating of recycled content without compromising material quality or component performance could:

- Reduce perceived and actual risk of using recycled content in durable plastics;
- Lower market risk and support consistent quality in recycled feedstocks;
- Help build a stable, predictable market for recycled durable plastic goods;
- Indicate the value of recycled content in durable plastics, which is essential for creating sustainable business models for durable plastics circularity; and
- Recognize other sustainability benefits of recycled durable goods, including potential for carbon footprint reduction and conservation of fossil fuel resources through displacement with chemically recycled and renewable feedstocks.

Develop separation solutions and technologies for EOL durable plastics that can distinguish chemical composition and quality and operate cost-effectively at scale

The volume and abundance of durable plastics reaching the end of their service lifetimes is sufficient to create a large, reliable feedstock of recycled plastics for use in new products. However, current practices often lead to the disposal or incineration of EOL durable plastics. This occurs in part because cost-effective separation and sorting methods specifically designed for durable plastics cannot accurately sort materials by chemical composition or differentiate products that contain contaminants (and thus require further processing). In addition, these methods cannot cost-effectively separate or sort at the speeds and volumes needed to manage the EOL durable plastics material stream at scale.

Improved, cost-effective sorting technologies that can separate durable plastics accurately and at high speeds (such as infrared-based methods) will improve the economics of waste sorting, enable greater recycling rates, and increase recycled feedstock available for new products.

Accelerate the research, development, and demonstration of scalable advanced chemical recycling technologies that can be part of a national circularity infrastructure for durable plastic goods

Advanced chemical recycling technologies are needed to complement mechanical recycling methods and achieve widespread circularity for all plastics, but especially for the complex compositions typically found in durable plastic goods. While advanced recycling methods are currently being researched and developed, further technology advances are needed to improve cost-effectiveness and scale of advanced chemical recycling methods. The durable plastics industry should:

- Work with leading research universities with expertise in selective synthesis of polymers, including selectively polymerizing block co-polymers with complex architectures. These capabilities can be applied in reverse to define novel pathways for depolymerizing durable plastics in ways that yield useful building blocks for new durable plastic goods.
- Focus ongoing research and demonstrations to accelerate and scale individual pilot projects to a series of of regional advanced recycling facilities that are part of a national infrastructure for durable plastics recycling.
- Prioritize near-term efforts to identify the largest-volume durable plastic goods among end-of-life products that will enter recycling streams. This data will inform investments in advanced recycling R&D programs and early commercial deployments most likely to succeed both technically and economically.
- Promote acceptance of mass balance methods for accounting for sustainable content in plastics.

Industry Priorities for Advancing Circularity of Durable Plastics: Multimarket

Advocate for requirements establishing design for durable plastics components and systems that facilitate circularity approaches at end of life

Many durable plastic goods are not currently recycled because of the complex composition of the plastic materials , as well as the difficulty of disassembling and separating durable plastics from other materials at end of life in products such as vehicles, electronics, or medical devices. These challenges can be mitigated by designing future durable plastics and components for disassembly and recyclability. To support circularity through designing for disassembly, the various markets should:

- Research to discover novel polymer and composite chemistries that meet performance requirements while increasing recyclability;
- Use new tools like AI-powered computational materials discovery to help suppliers optimize design of materials with ease of separation and recycling as a performance criterion; and
- Incorporate new design tools that consider the recyclability of the materials themselves and disassembly and separation of durable plastics from other materials—other plastics, metals, ceramics, glasses, fabrics, and electronic materials.

The insights gained through this work can be packaged into updated design guidelines for designers and product engineers. At a minimum, such tools should allow designers to make the most recycling-friendly choices possible without compromising cost or performance.

Conduct and compile a database of market-specific standardized lifecycle and technoeconomic assessments to measure the benefits of durable plastic goods

Durable plastics are widely used in many applications throughout our economy because they deliver a combination of cost and performance that many other materials cannot match. As the plastics industry and its customers pursue durable plastics circularity to achieve sustainability goals, thorough LCAs tailored to durable plastic goods and alternatives must inform trade-off decisions that otherwise may lead to worse overall environmental performance.

Effective LCAs must consider myriad environmental factors, including:

- Greenhouse gas and other emissions created during material extraction and processing into final form
- Contributions to relative environmental performance during the material use phase (e.g., vehicle lightweighting, building envelope sealing, component durability, etc.)
- Other end-of-service-life factors (e.g., remanufacturing and reuse potential, landfill diversion opportunities, and upcycling/recycling/downcycling pathways).

Such LCAs can help to define where environmental benefits and economic value are created and therefore available to capture during the recovery, reuse, and recycling process for durable plastics. Capturing value throughout this circular value chain is essential to build the viable business models needed to create greater circularity becomes standard business practice.

Educate industry stakeholders and the public about available and emerging recycling technologies to help eliminate plastic waste out of the environment

Defining and communicating the environmental, social, and performance benefits of recycling durable plastics is essential for building consumer demand for recycled content.

Today, most consumers do not have information regarding the recyclability or recycled content in the products they buy featuring durable plastics, such as vehicles or electronics. Most consumers also do not appreciate that large volumes of single-use plastics are recycled into durable plastic goods, where they continue to provide value to society for many years. Providing this information in ways suited to mass markets will allow consumers to make more informed choices that may consider circularity.

Similarly, downstream value chain partners in automotive, building and construction, infrastructure, electronics, medical, and other industries need current information on durable plastics with recycled content to make informed choices regarding their use. Industry stakeholders would benefit from consistent education on design tools and LCAs to improve recycling capabilities.

Influence and advocate for pro-circularity policies that enable our industry's ability to continue providing the essential modern-day innovations to meet societal needs in a more sustainable way

Ultimately, market pull for recycled content in durable plastic goods is needed to establish sustainable businesses dedicated to recycling these materials. Pro-circularity policies can establish clearer market demand by making circular and sustainable choices commonplace. Advocating for pro-circular policies established by the government, such as remanufacturing or recycled content targets or mandates in government procurement, would create incentives for companies to provide more circular durable plastic goods to meet that new demand. Policies could include incentives to allow circular measures to become more economically feasible and enable commonalities across industries that use durable plastics.

Progress Toward Circularity: Multimarket Highlights

Purification technologies

Agilyx and Technip Energies have partnered to launch the TruStyrenyx™ brand. The TruStyrenyx™ brand utilizes Agilyx's depolymerization with Technip Energies Purification technology.[217] Through this purification process, the companies can yield a **high purity of a recycled styrene monomer—reportedly around 99.8 wt%**.[218] The styrene monomer is used in many plastics and polymers, including automotive parts, medical equipment, and building and construction applications.[219]

Polycycl's purification process uses non-hazardous solvents to dissolve isolated resins into a homogenized solution from which additives, colorants, odorants, and other non-plastic contaminants are removed using a series of physical separation and chemical-assisted steps.[220] This leaves behind a dissolved purified plastic that can be made into new plastic for use in manufacturing new products.[221]

The PYROMAX™ technology patented by **APChemi** uses **pyrolysis technology** to recycle dirty and mixed plastic waste into high quality pyrolysis oil that can be used to create new products.[222] The ability to recycle combined mixed and contaminated plastics decreases the need for rigorous sorting practices and facilities.[223] The company also partnered with **Technip Energies** to help further close the loop by **converting the pyrolysis oil to polyolefin building blocks** using its ethylene furnace and steam cracker design expertise along with its preparation and purification technologies.[224]

Advanced recycling

PureCycle Technologies has a patented solvent-driven purification recycling technology developed by **Procter & Gamble** that is designed to transform polypropylene (no. 5) waste into a renewable resource.[225] This **purification technology can remove odors, colors, and other contaminants from the feedstock** to create an ultra-pure recycled (UPR) resin. PureCycle is close to completing its first purification plant in Ironton, Ohio, and broke ground on a second facility in Augusta, Georgia in early 2022.[226]

Chemical company **BASF**, along with partners, developed their trademarked project known as ChemCycling™, a **pyrolysis-based chemical recycling process**.[227] Once plastic waste is turned into pyrolysis oil, BASF allocates it via a mass balance approach to products manufactured in their integrated chemical production network (Verbund).[228] The resulting products have the same properties as products made from fossil fuel resources and can be used by BASF's customers in **applications with high demands on quality, hygiene, and performance**, including medical applications and safety-relevant automotive parts.[229]

Eastman Chemical utilizes their Polyester Renewal Technology to continually recycle polyester-based products, including carpets and textiles. Eastman's chemical recycling has a 20-30% reduction in greenhouse gas emissions compared to fossil fuels.[230] In 2022, Eastman announced they would be investing up to $1 billion for a methanolysis-based recycling plant in France to break down and recycle polyethylene terephthalate (PET).[231]

Durable plastics collection and recycling infrastructure

Cyclx International, **ExxonMobil Corp.**, and **LyondellBasell** signed an agreement to advance development of a **first-of-its-kind plastic waste sorting and processing facility** in Houston, Texas.[232] The facility aims to connect community recycling programs to advanced recycling technologies that have the potential to take a much wider variety of plastic materials. It will produce feedstock for both mechanical and advanced recycling—an estimated 150,000 metric tons of plastic feedstock per year—and commercial start-up is expected in 2024.[233]

Pyrowave Inc. and **Michelin Ventures** agreed in late 2020 to a joint development project focused on developing the **first industrial-scale plant converting polystyrene waste into low carbon styrene monomer**,[234] an industrial chemical typically used in making various plastics and synthetic rubbers.[235] The joint venture has led to a growth in demand from chemical companies interested in introducing the low carbon styrene monomer into their products.[236]

Mura Technology, in partnership with **Dow Chemical**, **LG Chem**, **Igus**, and **Chevron Phillips Chemical**, opened a **commercial-scale HydroPRS advanced plastic recycling site** in Tesside, England in October 2023.[237] The facility can efficiently recycle postconsumer flexible, rigid, and multilayered plastics into high-quality, recycled liquid hydrocarbons and aims to have a recycling capacity of 600,000 tonnes of aggregated recycling by 2030.[238,239]

SABIC has teamed up with **Plastic Energy** to build the **world's first commercial recycling plant for polymer recycling**.[240] Once fully operational, the plant will utilize **thermal depolymerization technologies** and has an anticipated capacity of up to 20,000 metric tons per year of circular chemicals.[241] This facility is part of SABIC's planned scale-up of production of bio-based and chemically and mechanically derived chemicals to 1 million metrics tons per year by 2030.[242]

SK geo centric and **PureCycle** made a joint investment in October 2022 to build **Asia's first polypropylene recycling plant** in South Korea.[243] Expected to be completed in 2025 with an estimated capacity of up to 60,000 tons, the plant will be designed to convert contaminated plastic feedstock into an "**ultra-pure recycled (UPR) resin**."[244] In addition, PureCycle has already started building two other facilities in the United States.[245]

Source One Plastics—a joint venture between **LyondellBasell** and **23 Oaks Investments**—plans to build an **energy efficient, advanced plastic waste sorting and recycling facility** in Germany that will be powered by renewable energy from wind and biomass.[246] The facility is designed to process the amount of plastic packaging waste generated by 1.3 million German citizens annually.[247]

Advanced sorting technologies

ZEISS, a manufacturing company, and technology company **Polysecure** are working to advance a **tracer-based sorting (TBS) detector** that will be used at an industrial sorting line in Germany.[248] After trials, the companies plan to commercialize the technology for in-house recycling and post-production recycling projects in the first phase of commercialization.[249]

Green Machine—a manufacturer and designer of waste recycling equipment—developed an **automated hyperspectral optical and robotic sorting platform** capable of separating a broad range of post-consumer plastics, including PET, PET Thermoforms, high-density polyethylene (HDPE) Natural, HDPE Colored, Polypropylene, and other no. 3-7 plastics.[250,251] Each system can reportedly be trained to sort material at a 95% or better accuracy rate.[252]

Tomra, a manufacturer of sensor-based sorting systems, has developed **add-on laser sensors to enable detection of the black plastics** often found in electronics and other durable goods.[253] Its Autosort technology combines multiple technologies in one sorting machine—including near-infrared (NIR) spectroscopy, laser, electromagnetic, and AI-based camera sensors.[254]

Recycleye developed an **AI-powered computer vision system** that works in conjunction with robotic sorting technologies at material recovery facilities to sort a variety items—including black plastics—into pure material waste streams.[255]

Recycling equipment manufacturer **Bollegraaf** developed an **AI-driven, NIR sensing, and robotic sorting system** for use at a range of recycling facilities, including construction and demolition debris facilities and electronics recycling facilities.[256] The company recently partnered with **Clariter**, **BioBTX**, and **N+P** to develop what may be Europe's largest plastic waste sorting plant for the chemical recycling industry in the Netherlands, slated to begin operations in 2025.[257]

Nine brand owners—including **Michelin** and **Procter & Gamble**—as well as an independent test and research center and two universities recently launched **The Perfect Sorting Consortium**. The Consortium aims to collaborate over the next two years to develop and test an AI decision model.[258]

Using recycled materials and feedstocks to produce durable goods

As part of the pilot phase of its ChemCycling™ project, **BASF** used the resulting pyrolysis oil as feedstock for its own production of recycled polymers, including Ultramid.[259] BASF's customers were able to use these polymers in their products, which have high demands on quality, hygiene, and performance. For example, **Jaguar Land Rover** used Ultramid to develop a **plastic front-end carrier** prototype for its first electric SUV and **Schneider Electric** used it to manufacture a **circuit breaker**.[260]

Bioplastics and renewable feedstocks

LANXESS created Adiprene Green, a **renewable, bio-based polyether prepolymer**.[261] This prepolymer can be used to replace existing fossil fuel-based polyether prepolymers to manufacture **highly durable polyurethane elastomers**.[262] Depending on the polyurethane processor, a 20-30% reduction of CO_2 compared with fossil-based prepolymers is reportedly possible.[263]

LANXESS also partnered with **BP** to use **sustainable raw materials in the production of high-tech plastics**.[264] Starting at the end of 2021, BP began supplying LANXESS with more sustainably produced cyclohexane, which LANXESS uses as a precursor in the production of **polyamide 6**, a high-performance plastic used primarily in the automotive industry as well as the electrical and consumer goods industries.[265]

A **renewable plastics supply chain** is in development thanks to collaboration between **Neste**, **Idemitsu Kosan**, **CHIMEI** and **Mitsubishi Corp**. Neste RE, a biobased hydrocarbon created from waste and residues, will be used to produce styrene monomer and its mass balanced renewable plastics derivatives, including **acrylonitrile butadiene styrene (ABS)**, a thermoplastic polymer with impact resistance, toughness, and rigidity that is used across sectors, including automotive and electronics.[266]

SABIC launched the industry's **first polycarbonate derived from certified renewable feedstock** which customers can use on their existing equipment under identical processing conditions. The renewable polycarbonate resins have the potential to reduce CO_2 emissions by half and reduce fossil depletion by up to 35%.[267]

BASF has introduced its versatile range of **Ultramid® molding compounds** with a lower carbon footprint thanks to its **use of certified renewable feedstock** in lieu of fossil resources at the beginning of the production process. [268]Ultramid® offers tailorable characteristics for many applications including automotive, building and construction, and electronics.[269]

Designing for disassembly and recyclability

Many plastic makers—including **Dow** and **ExxonMobil**—are **offering customers specialty polyolefin elastomers (POEs) and polyolefin plastomers (POPs)** to enable them to compatibilize mixed streams of polymers for improved recycling.[270] While initially POEs and POPs were added to plastics to boost properties such as impact and tensile strength, as compatibilizers they allow incompatible plastics to mix and melt together.[271] This reduces the need for plastics separation while still enabling manufacturers to use recycled plastics to produce high-quality goods.[272]

Cisco designs its **Unified Computing System servers** to be quickly and easily assembled and disassembled. The company utilizes modularity and removable components to optimize reuse, repair, and recyclability.[273]

Philips Engineering Solutions created a **Disassembly Map modeling method**. This method can be used to identify key design features hindering disassembly in the early stages of the design process and has been applied to consumer products (e.g., vacuums, electronics), medical devices and equipment, and surgical devices.[274]

4

Call to Action

As plastics continue to enable durable goods markets to reach their next frontiers, the opportunity to deliver and capture business value through advances in EOL sustainability and circularity has never been greater.

Investing *now* in the implementation of systems and practices that minimize waste, promote reuse, and improve coordination across the value chain has the potential to maximize durable goods' share of the $4.5 trillion in economic value the circular economy could bring. The plastics industry is ready to work with the automotive, buildings and construction, electronics, infrastructure, and medical sectors to realize this potential and transition toward more sustainable and circular durable plastic goods.

The scope of this transition and the priority initiatives it will take to achieve it will require coordination both within and across the durable goods market sectors. Participation from the stakeholders within each market sector's respective value chain—including plastics producers, part and product manufacturers, end users, and dismantlers and recyclers—as well as government agencies, researchers, and non-profit organizations will help ensure that individual markets are progressing in the ways that make the most sense for their businesses. At the same time, information sharing and collaboration across the sectors will drive advances that will benefit all sectors. ACC and its member companies are committed to stewarding the implementation of this roadmap but will rely on the active leadership and engagement of this wide range of stakeholders to coordinate independently to progress durable goods sustainability and circularity at scale.

The commitment and expertise of these stakeholders is essential to the realization of circular durable goods. Together we can unleash plastics' potential to continue to revolutionize these markets while creating a more sustainable world for us all.

We need **your help** to realize the EOL sustainabilty and circularity of durable plastic goods. To get involved in the priority initiatives outlined in this roadmap, contact Gina Oliver at Gina-Marie_Oliver@americanchemistry.com.

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Appendix B. Acronyms

ABS	acrylonitrile butadiene styrene
ACC	American Chemsitry Council
AMDR	Association of Medical Device Reprocessors
ASR	automotive shredder residue
DGLT	Durable Goods Leadership Team
EOL	end of life
EPA	U.S. Environmental Protection Agency
EPD	Environmental Product Declaration
EPEAT	Electronic Product Environmental Assessment Tool
EPR	extended producer responsibility
ESG	environmental, social, and corporate governance
EV	electric vehicle
HDPE	high-density polyethylene
HEV	hybrid electric vehicle
IMDS	International Material Data System
LCA	life cycle assessment
LiDAR	light detection and ranging
NCAL	Northern California Region
NHTSA	National Highway Traffic Safety Administration
NIR	near-infrared
OEM	original equipment manufacturer
PCR	post-consumer recycled
PET	polyethylene terephthalate
PIR	post-industrial recycled
PLA	polylactic acid
POE	polyolefin elastomers
POP	polyolefin plastomers
PP	polypropylene
PVC	polyvinyl chloride
TBS	tracer-based sorting
TSCA	Toxic Substances Control Act
UPR	ultra-pure recycled
Wt%	percentage by weight

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