We Can Cut Petrochemicals Use Today

Framing the Challenge and Opportunity

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Authors

Authors

Sasha Bylsma
T. J. Conway
Joseph Fallurin

Authors listed alphabetically. All authors from RMI unless otherwise noted.

Contacts

Joseph Fallurin, jfallurin@rmi.org
T. J. Conway, tconway@rmi.org

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About RMI

RMI is an independent nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing.

Executive Summary

The global petrochemicals supply chain emits an estimated **3%** of global greenhouse gas (GHG) emissions if only operational emissions are considered, or up to **10%** when the full life cycle of petrochemicals products is considered. This share is **projected to grow** over the next decade if demand continues along historical growth trends. RMI is carrying out an in-depth series on the opportunities to reduce petrochemicals demand and decarbonize the industry. Initial findings of the team's work include several key points:

- Global demand growth for fossil fuel-based petrochemicals must slow and reverse for the sector to align with the Paris Agreement. Without curtailment in demand, the industry will have little incentive to stop building or shut down production capacity. Supply restrictions in one country or jurisdiction will spur new production growth in other geographical areas, as long as demand continues to grow.

- While some petrochemicals are essential to modern industrial life, others are not. Reduction of excessive petrochemicals demand is key to achieving net-zero alignment.

- Petrochemicals intermediates are the basic building blocks of the industry. Plastic resins comprise about half of intermediate petrochemicals consumption, and offer the greatest opportunity to curb demand. Commodity plastics (resin codes 1-6) account for over 80% of plastics by weight. A review of commodity plastics demand points to three sectors with the greatest demand-reduction potential: packaging, buildings, and textiles.

- Certain petrochemicals pathways have outsized climate, health, and environmental justice impacts. Cutting demand and emissions in these cases should be a top priority.

- Food supply chain waste, natural gas supply leaks, and solid waste incineration can exceed total GHG emissions within petrochemicals plants when tracing specific petrochemicals' life cycles. Curtailing these practices can yield immediate economic, environmental, and community benefits.

Introduction

Understanding petrochemicals demand is key to identifying and implementing the full suite of sectoral decarbonization levers available. Yet successfully building this knowledge base has been elusive due to the sector's complexity, existence of co-products from many processes, numerous product and by-product flows, and lack of public data on petrochemicals supply and demand. Petrochemicals' complex value chain and vast array of end uses create a wide gulf between consumers and producers, muting demand-side pressure for emissions transparency and decarbonization.

The industry has been slow to respond and account for its GHG emissions, with some exceptions such as BASF, which started identifying product-level emissions in the first decade of the 2000s. Together for Sustainability, a chemicals industry group, is beginning to build a broader understanding of the sector's emissions, but there is a lot more work to do. Self-reporting has provided some data, but more direct measurements are needed to fully understand the GHG emissions associated with various chemicals products. Only with more granular emissions data will the various emissions-reduction opportunities become clear.

Understanding petrochemicals demand is key to identifying and implementing the full suite of sectoral decarbonization levers available.

Petrochemicals are used in over 100,000 different products — and a good number serve critical purposes in the economy and society. Medical products directly save lives, while paints and coatings make many durable goods last longer. Even petrochemicals-based textiles can be essential to prioritize food production on scarce land. Yet the societal costs paid to obtain these benefits cannot be ignored. Making, moving, and storing myriad petrochemicals along complex supply chains create health hazards to many who will never see a final product nor its benefits. Disposing of petrochemicals no longer needed can impose extra costs on others. Excess fertilizer runoff can create toxic algal blooms that disrupt entire fishing-dependent communities. Facilities that burn plastic waste can decrease air quality and increase hazardous solid waste disposal burdens on fence-line communities.

There are also many petrochemical products we can simply do without. Disposable packaging, cups, plates, and utensils top the list. We can also use products more efficiently and extend their useful lives. Supply-side emissions cuts are critical, but so are demand-side reductions.

We define and quantify intermediate petrochemicals as the basic building blocks for all petrochemicals products.

Mapping Petrochemical Production Flows

Given the vast array of products, petrochemicals demand can be difficult to understand, let alone analyze. We define and quantify intermediate petrochemicals as the basic building blocks for all petrochemicals products. Starting with intermediates to map petrochemicals production pathways — through to end use — brings helpful clarity to the analysis. Petrochemicals intermediates (shown on left side of Exhibit 1, next page) fall into three major buckets:

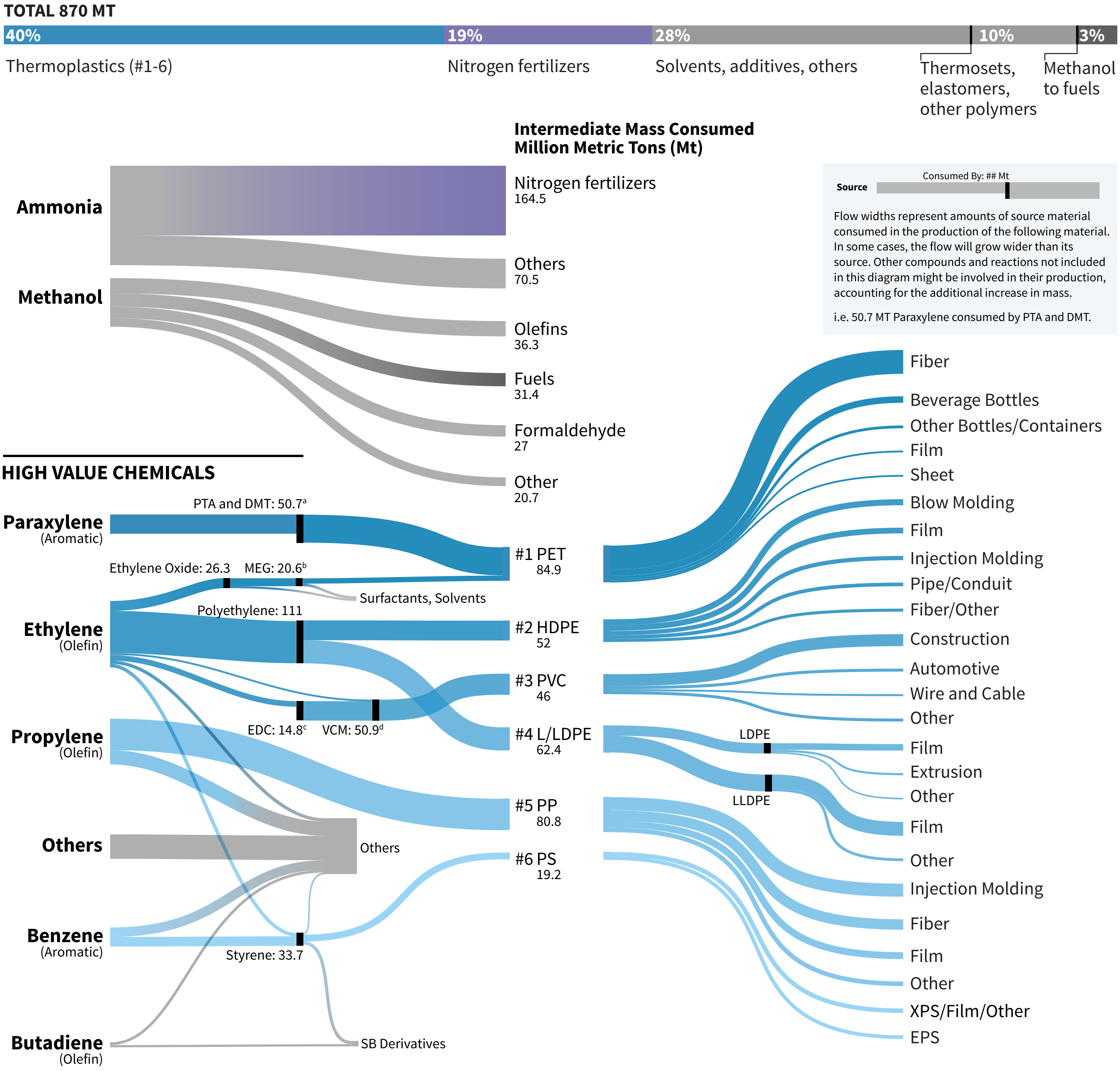
- **Ammonia** is an important stand-alone chemical and critical intermediate in fertilizer production. Production of synthetic plastic for textiles like nylon fibers and polyurethane for synthetic leather use ammonia. In smaller quantities, ammonia serves as a refrigerant. In the future, it may be central to developing a clean hydrogen economy.

- **Methanol** goes into many fuels, wood-based construction products, high-value chemicals (see next bullet), and more specialized petrochemicals.

- **High-value chemicals** (HVCs) encompass what most people tend to think of as petrochemicals and fall into two main categories: olefins (ethylene, propylene, and butadiene) and aromatics (benzene, toluene, and xylene). HVCs comprise commodity plastics, such as those used in films and flexible packaging; higher-performing plastics typically used to make durable products like appliance and car parts; and a host of specialty chemicals ranging from lubricants to paint.

One of the most significant — and most visible — groups of HVCs are the commodity plastics commonly used in packaging applications. Key commodity plastics are better known by their 1-6 resin classification: (1) PET (polyethylene terephthalate), (2) HDPE (high-density polyethylene), (3) PVC (polyvinyl chloride), (4) LDPE/LLDPE (low-density polyethylene and linear low-density polyethylene), (5) PP (polypropylene), and (6) PS (polystyrene). Other HVC subsegments, including materials that go into durable goods and construction, are also significant sources of demand.

Exhibit 1 Petrochemicals Consumption in 2021



Flow widths represent amounts of source material consumed in the production of the following material. In some cases, the flow will grow wider than its source. Other compounds and reactions not included in this diagram might be involved in their production, accounting for the additional increase in mass.

i.e. 50.7 MT Paraxylene consumed by PTA and DMT.

a. PTA = Terephthalic acid; DMT = Dimethyl Terephthalate
b. MEG: Monoethylene glycol
c. EDC: Ethylene dichloride
d. VCM: Vinyl chloride monomer

Source: Bloomberg Terminal, MMSA, University of Cambridge, and RMI analysis

Charting the Path through GHG Emissions Peaks

Different petrochemicals have different emissions profiles depending on how they are produced and used. Prioritizing demand cuts on those with the highest intensity can yield the most impact. Generally, a petrochemical that needs more processing steps will be more carbon intensive per pound of product. Petrochemicals made with more coal inputs, both for energy and feedstocks, also have outsized emissions across all major intermediate types.

Ammonia is the most produced petrochemical molecule and responsible for the most emissions across its life. Food system waste presents a major GHG reduction opportunity linked to ammonia demand. About one-third of food is wasted. **This amounts to about 9% of global GHG emissions** — higher than all countries except the United States and China. In the United States, food made up over 20% of municipal solid waste as of 2018. More than half of US food waste went to landfills, which is the third-largest source of methane emissions across economic sectors. **Methane is a greenhouse gas over 80 times more potent than CO_2 on a 20-year basis**. Nearly 12% of US food waste was incinerated for energy recovery in 2018. It is likely that other solid waste, including petrochemicals, was commingled and also incinerated. Reducing food waste and increasing the fraction composted can drastically reduce GHG emissions and ammonia-based nitrogen fertilizer demand.

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Most ammonia use outside of fertilizers finds its way into foam-filled furniture, building surface area, extra car seats, nylon and faux-leather clothes. Nitric and adipic acid production plants convert ammonia into an input for synthetic fibers like nylon. These plants are major emitters of nitrous oxide (N_2O) — a GHG nearly 300 times more powerful than CO_2 per ton — and **are on track to account for 1% of global non-CO_2 emissions in 2030**, according to the US Environmental Protection Agency. Reducing ammonia use in these consumer goods can have a smaller demand impact, but is among the potential near-term opportunities.

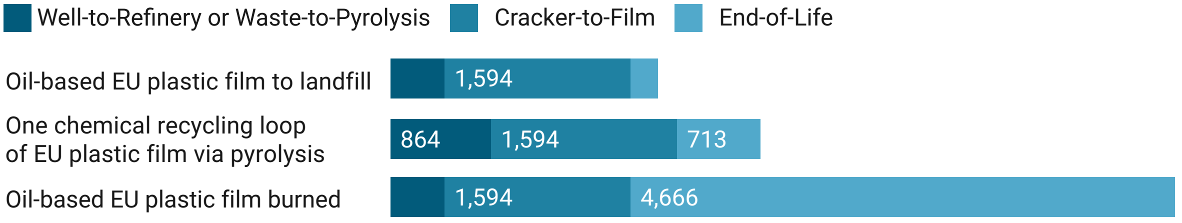
Farmers have room to cut fertilizer consumption as well. In the United States, N_2O emissions from using nitrogen fertilizers in agriculture are **over 10 times higher** than N_2O emissions from industry. Urea, the most used fertilizer, releases CO_2 as it decomposes in addition to N_2O during use. About **two-thirds of nitrogen fertilizer** life-cycle emissions are generated during the use phase. We can maximize the use of cleaner alternatives like compost, nitrogen-fixing bacteria, and **power-to-fertilizer systems**. We can also cut demand for gasoline blended with ethanol, which requires ammonia fertilizers as an input. Conventional bioethanol for gasoline blending **accounts for 3%–8% of US fertilizer demand** and likely results in more life-cycle emissions than oil-based gasoline due to land-use change emissions. An extended analysis of ammonia decarbonization pathways can be found through ***Making Net-Zero Ammonia Possible***, published by the Mission Possible Partnership, an RMI-affiliated coalition.

Methanol demand is shaped by three key applications. Conventional car and transport fuel demand, **mainly in China**, is the most emissions-intensive use of methanol. About 30% of methanol is converted to a fuel or fuel additive that is ultimately combusted, adding over 1.3 t CO_2e/t to methanol's life-cycle emissions. Car paints, fabrics, glues, and paneling all use methanol as an input. Buildings, household goods, and clothing drive methanol demand in most other parts of the world. Finally, a large portion of China's methanol is transformed into high-value chemicals (HVCs) and combined with imported bulk plastic pellets to meet global demand for finished plastic goods. Demand for imported single-use plastics in the United States alone is equal to **one-third** of China's net exports.

HVC demand is dominated by commodity plastics, but specialty applications can have an outsize GHG impact. Plastics that require a smaller share of simple HVC ingredients like PET, PVC, PS, and specialty plastics tend to have higher carbon footprints. There are also major GHG reduction opportunities in the disposal of products that drive HVC demand. Fluorinated gases (F-gases) like hydrofluorocarbons (HFCs) — as well as chlorofluorocarbons (CFCs), which were banned by the Montreal Protocol — are also made from HVCs. They are short-lived climate pollutants that have a global warming potential (GWP) thousands of times greater than CO_2 on a per-ton basis if improperly disposed of by venting. A recent **study** found that one-quarter of all plastic waste was incinerated worldwide in 2018. Incinerated plastic can produce more than twice the full life-cycle emissions of landfilled plastic, as shown in Exhibit 2. In contrast, mechanically recycled rigid plastics can have **less than one-third** of the GHG emissions of conventional plastics made from oil and gas.

Exhibit 2

The same consumer plastic film can have different GHG emissions



Note: EU = European Union. Credits for emissions avoided through energy recovery from incineration not included.

Source: **Consumer Goods Forum**

Respecting the Hazards to Health and Equity

Several petrochemicals applications improve health and equity at their intended primary use, yet their impacts across the rest of their life cycle must be accounted for. Certain petrochemicals for pharmaceuticals, vaccines, medical equipment, firefighting foams, and disinfectants are intended to save lives from acute risks. Food refrigerants, pesticides, water piping, water treatment chemicals, hygiene products, and key food packaging applications also have a major role in preventing disease across the world. Sufficient winter clothing, low-GWP space refrigerants, wood glues, and wiring insulation can provide low-carbon means for healthy personal climate control. For those who need them, eyewear, hearing aids, wheelchair tires, and diapers can provide more dignified and equitable livelihoods.

There are several ways in which the production and transport of petrochemicals lead to human health hazards. At the site of facilities synthesizing petrochemicals, emissions of known carcinogens such as benzene, butadiene, formaldehyde, styrene, and other volatile organic compounds occur during normal operation. All carcinogens regulated by the Occupational Safety and Health Administration (OSHA) and over 85% of substances with **no established recommended exposure limits** in the United States are petrochemicals. The harmful effects of this chronic pollution have been well documented by both epidemiological research and the lived experiences of local fence-line communities.

Ammonia, methanol, and aromatic HVCs all have acute health impacts as shown through permissible exposure limits defined by OSHA. Major health risks also prevail for intermediates of PVC — an important building material — and ethylene glycols used for textiles, detergents, and cosmetics. Communities far from production plants but near major transportation routes can still be exposed to major dangers. **Recently, a US train derailment of a carcinogenic input to PVC caused fires and evacuations** of multiple towns. Mismanaged storage of nitrogen fertilizers such as ammonium nitrate can result in deadly uncontrolled explosions **as seen in Beirut in 2020**.

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Human health concerns resulting from the use of petrochemicals products also have been widely studied, especially in household items such as cosmetics and cookware, two areas where we often encounter petrochemicals daily. Plasticizers such as phthalates are used to enhance flexibility, longevity, and stability of lotions, sprays, and fragrances. Phthalate exposure can be common for lower-income fence-line communities with some studies showing correlations to **reproductive health risks**. **Community groups** are spreading the word of potential risks while the Food and Drug Administration further evaluates the potential risk for end-use exposure through goods like **food containers**. Preservatives like parabens and surfactants such as sulfates are common ingredients in personal care products, and some of these additives have been identified as neurotoxins. The kitchen may also be an interface with petrochemicals in the form of PFAS (perfluoroalkyl and polyfluoroalkyl substances), dubbed “forever chemicals,” that **can be found in some** food packaging, tap water, carpets, floor waxes, and nonstick cookware.

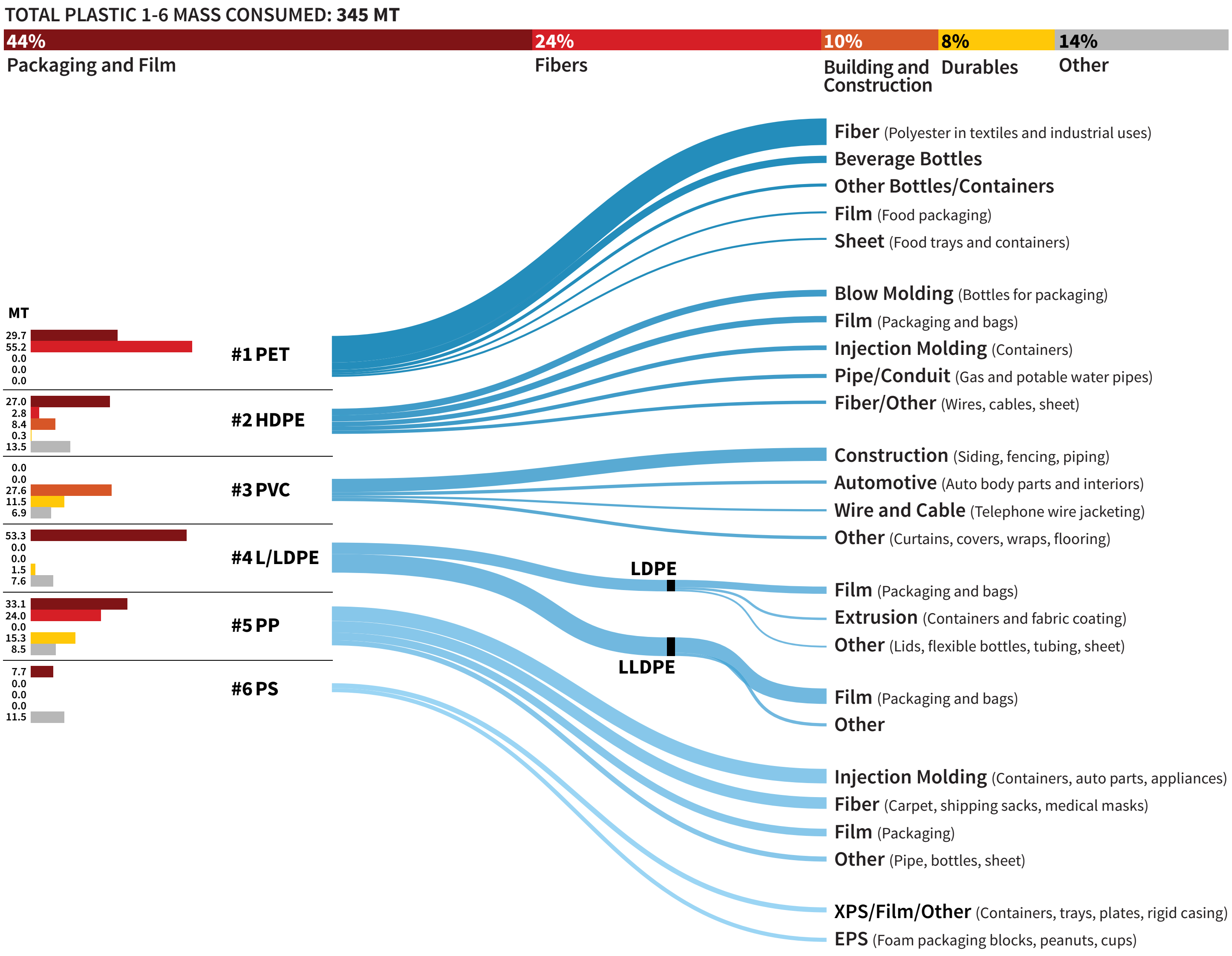
Although consumer goods industries are modifying their products to avoid these types of toxins, there is more work to do to align industry practice with evolving chemicals safety benchmarks. Even in cases where hazardous chemicals in consumer products have been removed, the replacement chemicals are often related to the original and lack the proper safety regulation. This is best documented in Teflon, a chemicals product that saw its input compound — the carcinogenic C8 perfluorooctanoic acid (PFOA) — phased out in nonstick cookware and waterproof clothing, **only to be replaced by C6**, a chemical in the same PFAS family that lacks toxicological data and safety standards.

The disposal of petrochemicals products like plastics often gets the most attention in public discourse because it is the externality that is the most visible and tangible. Properly landfilling plastic waste is almost certainly the least polluting method of final disposal. Although plastic pollution in the form of discarded or unmanaged litter remains of high concern for broader environmental stewardship, incineration of plastics arguably presents an even greater threat. Combusting petrochemicals products will not only emit the embodied carbon that poses a significant warming impact — as outlined above — but will also gasify the embodied chemical compounds, leading to the release of air toxins such as dioxins, although improved incineration techniques have greatly reduced this problem.

Navigating the Plastics Jungle

Plastics are one of the more widely understood and recognized groups of petrochemicals products, but the true extent of their applications and end uses goes underappreciated. This stems from several factors including the wide range of names plastic products take — think common consumer terms like microfiber, fiberglass, Styrofoam, nylon, vinyl, and acrylic. Misunderstanding also can emerge from combined material products where plastic is not directly visible — like a polyurethane foam mattress with a cotton exterior, or a synthetic rubber sole of a leather boot. The subset of plastics most recognized are those with resin code numbers 1 to 6. They are commonly called “commodity plastics” due to their large share of total plastic and HVCs — 80% and 66%, respectively. The left half of Exhibit 3, next page, maps these plastics to the materials and processes that use them, with common end-use examples in parentheses. The right half illustrates the aggregated demand of the commodity plastics across five end-use categories, along with each plastic’s contribution to the consumption in each category. In total, 2021 saw 345 million tons (Mt) of plastic resin consumed by the end uses of the six common commodity plastics.

Exhibit 3 Commodity Plastics Demand by End Use (left), and 2021 Total Plastic 1–6 Mass Consumed (right)



Source: Bloomberg Terminal, MMSA, University of Cambridge, and RMI analysis

A high-level overview of commodity plastics end uses follows.

Packaging and Film

Packaging and film end uses here generally refer to plastics of varying degrees of flexibility and thickness used to contain a food, beverage, or nonconsumable product. This wide range includes thin films used as bags, wrappers, and box liners as well as products molded to preforms like containers and bottles. This category exemplifies the linear model of plastic production, use, and disposal, because the protective service these products provide is finished once the product is unpackaged and consumed, with generally limited opportunity for circularity. Nearly all packaging and film plastics are discarded within one year of use, effectively creating a constant flow of these materials through the global economy.

Fibers

Synthetic plastic fibers have a variety of end uses in textiles, fabrics, carpeting, ropes, cables, and cords. Fiber derived from PET comprises most of this category, and this material is commonly known as polyester. Polyester comprises **over half** of the world's fiber market, primarily for use in textiles and apparel. The second most consumed form of plastic fiber is derived from polypropylene and has heat-retaining and nonabsorbent properties that see applications in upholstery, furnishings, carpeting, thermal wear, and nonwoven fabrics.

Buildings and Construction

Plastics with end uses in buildings and construction differ from plastics characterized by a rapid flow of production, use, and disposal due to longer use periods before disposal and a higher number of people served during its use period. PVC holds the primary share of plastic types in this end-use market through its widely adopted use in materials like exterior wall siding, fencing, flooring, and piping. HDPE has applications in this sector as material for pressure piping, drainage piping, and lumber substitutes.

Durables

Plastics intended for long-term use that have applications beyond buildings and construction can be classified as durables. PP is the primary feedstock for durable commodity plastics and often takes the form of large, molded items like crates, bins, dumpsters, and any other solid, rigid shape. PVC is the other common resin for durable commodity plastics products, where plasticizer additives can enable more flexibility to the plastic, allowing for varied end uses like automotive interior panels and upholstery, wire and cable insulation, and medical devices.

Other

About 14% of plastic products derived from the six commodity plastics have end uses we have not split out into the above four categories or have applications beyond the four largest categories discussed. These applications range from utensils to appliance and electronic parts to toys.

Opportunities to Curtail Petrochemical Demand

Reductions in superfluous plastics demand across several end-use markets described are necessary to minimize the climate impact of plastics. Some of these demand-reduction opportunities exist independent of the larger global energy landscape, such as increasing the lifetime of a plastic's use. Other solutions have synergies with reducing overall fossil-fuel demand, such as curbing the use of polystyrene due to decreased benzene supply from lower refining outputs.

We expect eight key demand-reduction levers shown in Exhibit 4 (next page) could cut demand roughly 20% if fully applied today. This reduction could be counteracted by growing demand for low-carbon methanol and ammonia fuels in a rapidly decarbonizing economy. Flattening total demand in the medium term can still be valuable in shifting demand and funding priorities in favor of reduced social costs. Reducing the use of ammonia-based nitrogen fertilizers now can cut near-term demand and emissions. Coalitions like the Mission Possible Partnership have developed robust frameworks for ammonia decarbonization, including demand-side reduction levers, in publications such as *Making Net-Zero Ammonia Possible*. Given extensive coverage elsewhere on decarbonizing the ammonia fertilizer chain — and curbing demand — we will not discuss them below or in our subsequent analysis in this series.

Most nonagriculture reduction opportunities are in the packaging, building, and textile (clothing) sectors — which account for two-thirds of commodity plastics demand. The lifetimes of products in these sectors vary from single use to long-lived capital stock. They also support basic human needs in the food supply chain, shelter, and temperature control while revealing other dimensions of petrochemicals demand.

Exhibit 4 **Eight Demand-Reduction Opportunities**

Demand-Reduction Levers	Relevant Petrochemicals*	Reduction Potential: Mass	Reduction Potential: Emissions
① **Cut low-value single-use plastics**	PE, PS, PET	High (>10 Mt/year)	Medium
② **Increase useful life and substitutes of durable consumer goods**	PP, SBR	Medium (5-10 Mt/year)	Low
③ **Increase useful life and substitutes of textiles, especially bio-based**	PET, PA, Acrylic Fibers	High (>10 Mt/year)	High
④ **Substitute building petrochemicals demand**	Methanol, PVC, PUR	Medium (5-10 Mt/year)	Medium
⑤ **Cut food waste without plastic packaging**	Ammonia	High (>10 Mt/year)	High
⑥ **Cut fertilizer application waste and use urea substitutes**	Ammonia	High (>10 Mt/year)	High
⑦ **Reduce overconsumption, meat consumption, and replace sugars with sweet proteins**	Ammonia	High (>10 Mt/year)	High
⑧ **Electrify road transport to displace alcohol fuels**	Ammonia, methanol	High (>10 Mt/year)	Medium

* HDPE = high-density polyethylene
LDPE = low-density polyethylene
LLDPE = linear low-density polyethylene
PA = polyamide
PET = polyethylene terephthalate
PP = polypropylene
PS = polystyrene
PUR = polyurethane
PVC = polyvinyl chloride
SBR = styrene-butadiene rubber

Source: RMI analysis

A look ahead

In upcoming briefs, we will analyze each of these three sectors in depth. It is clear from the outset that there are substantial opportunities for demand reduction. In packaging, polyethylene and polypropylene, the most widely produced plastics, are particularly ripe for demand destruction. More than two-thirds of these two materials are likely **discarded within one year of production**, accounting for more than half of plastics disposed of annually. Improving the actual used life of longer-lasting petrochemicals applications such as polyester textiles, ending “fast fashion,” and substituting with natural fibers where practical can reduce demand in this sector. In buildings, there are a variety of alternatives that can be used in place of higher-emissions materials used currently.