EXECUTIVE SUMMARY

The Sustainable Plastics Roadmap: Recycling, Bioplastics, and Alternatives

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Executive Summary

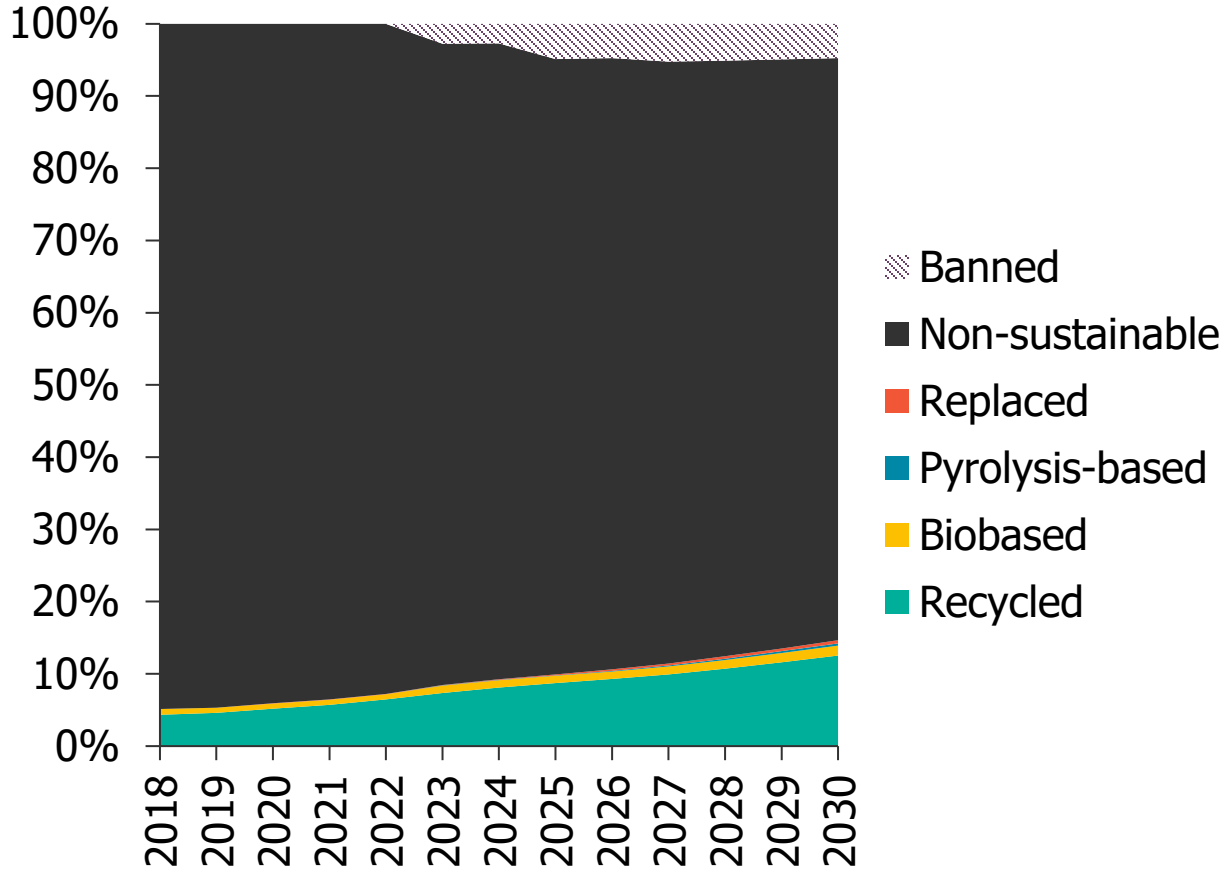
A combination of negative consumer sentiment, regulation, a global focus on sustainability has combined to push the issue of plastics sustainability to the fore.

In this report, we forecast the adoption of conventional and advanced recycling, bio-based plastics, and alternative materials and quantify the impact of bans and other regulations to predict the future of sustainable plastics.

In 2030, 15% of plastics #1 to #6 will be sustainable, fueled primarily by a tripling of global plastics recycling along with strong regulatory action that bans key waste generators. Chemicals companies will face stagnating demand for oil-derived plastics – even including pyrolysis oil – and must invest in recycling to find growth in the plastics space. There's still substantial uncertainty in our outlook, as regulations, the actions of consumer companies, and technology improvements could all dramatically change the economics and deployment of advanced recycling.

Sustainable plastics will make up 15% of production in 2030

Share of plastic #1 to #6 production



INTRODUCTION

The future of plastics is in doubt

The story of the post-World War II material economy has largely been the story of plastics. Plastics have reshaped nearly every industry – from consumer packaged goods (CPG) to automotive, from apparel to construction – and been a core component of the dramatic increase in quality of life for many over the course of the past 70 years. For all that success, there is now a credible combination of threats to the growth of primary plastic production.

- Concerns about the impact of plastic waste have grown – and been exacerbated by waste importation bans like China's National Sword policy, which has disrupted global trade.
- Anti-plastic consumer sentiment is growing due to both real and perceived concerns surrounding waste, safety, and the environment.
- Anti-plastic regulation is growing globally, including bans on specific types of plastic products and general regulations penalizing the use of plastics.
- A technology boom is occurring in advanced recycling and waste management techniques.
- Credible competitors to single-use plastics are emerging – both conventional (like aluminum cans) and novel (like advanced pulp products).

Single-use plastics are particularly in the crosshairs with consumers and regulators, though companies across a wide range of industries are trying to deploy sustainable solutions. Regardless, both companies that produce plastics and those that use them in their products need to understand the outlook for more sustainable plastics and alternatives in order to have their future strategy prepared.

METHODOLOGY

We combined multiple forecasts to build an overall view of sustainable plastics adoption

The first step in our modeling exercise was to forecast baseline demand for primary plastics from 2015 (when we last had comprehensive historical data) to 2030. We make two key simplifying assumptions here: that historical production of plastics is the same as demand, and that alternatives (like bioplastics and high-grade recycled plastics) have had such a small historical market share that they can be ignored in this baseline primary demand model. We then added forecasts of recycling capacity and bioplastics to assess their impact.

For production of primary plastics, we developed four possible growth trajectories for each material: high growth past 2020, medium growth, no growth, and shrinking production past 2025. For mechanical recycling, we forecast a baseline capacity growth based on our expectation of global capacity expansion. For advanced recycling technologies, we used an S-curve adoption model to forecast their capacity growth. For the bioplastics model, we used the analysis and projects discussed in the report "Biopolymer Vision 2020."

MODELS		OUTPUTS
Baseline primary plastic demand forecast Accounts for baseline demand growth and the macro impact of consumer perception and regulation	→	Baseline primary plastic demand
Recycling & pyrolysis capacity forecast Based on forecast investment in capacity	→	High-quality recycled plastics production Low-quality recycled plastics production Pyrolysis-derived plastics production
Bioplastics capacity forecast From our bioplastics outlook report	→	Bioplastics production

Which scenarios did we examine and why?

Our initial modeling effort focused on the four scenarios below. The goal of the first three scenarios is to model the impact of different assumptions and events in isolation, before combining them into a likely case scenario. The fourth scenario's goal is to test the limits of the model and possible expectations. The four cases we picked were:

- **Initial assumptions**: This reflects our starting set of assumptions about the future direction of sustainable plastics, as described on the previous slides.
- **Aggressive advanced recycling adoption:** In this scenario, advanced recycling is ramped up more quickly than in the baseline case. In addition, pyrolysis is adopted globally instead of just in the EU.
- **Disruptive bans and alternatives:** In this scenario, bans of different plastic products are implemented, and different alternatives begin to displace PET.
- **Toward plastic neutrality:** Here, we implement all the solutions from the previous scenarios in even more aggressive ways. We also alter the baseline assumptions for growth in plastic consumption. The goal is to see how close it's possible to get to a future in which all plastic use is either sustainable or eliminated.

What did we report and why?

Each scenario features six charts showing different facets of the plastics sustainability landscape. These are:

- **Recycling capacity**: The global volume of recycling capacity, including pyrolysis. Important for those concerned about waste treatment, including MRFs, governments, and brands.
- **Recycled plastic outputs**: As advanced recycling processes can have very different yields, we also report an output volume. For some processes that don't directly yield plastic (pyrolysis and depolymerization), we report a volume of plastic that can be made from that process assuming plastics 100% derived from that output (i.e., 100% pyrolysis oil-based plastic).
- **Material conversion capex spending**: The annual spend necessary to build new recycling capacity. Important for governments, chemical companies, and brands looking to underwrite this transition. Note, however, that this figure doesn't cover the costs of waste collection and sorting.
- **Oil-derived plastic demand**: The amount of plastic that will be made from oil sources, including pyrolysis oil. Important for chemicals companies.
- **Recycling capacity availability**: The ratio of plastic waste to recycling capacity. If 100% of recycling capacity is utilized, this figure is the same as the recycling rate, though real-world recycling rates will be lower.
- **Sustainable plastic breakdown**: The overall ratio of plastics production by source, including bio-based plastics and plastics alternatives.

LIKELY CASE SCENARIO

The likely case relies on a combination of bans and recycling to make modest gains in plastic sustainability

INTRODUCTION

Our likely case scenario mixes disruptive events that are quite close to the bans scenario with a rollout of depolymerization and pyrolysis that's between our initial assumptions and the aggressive case. There are a few areas of uncertainty: The fate of pyrolysis oil makes a major impact on the overall outlook. Our likely case is that the EU will crack pyrolysis oil, but the rest of the world won't, as the economics are too poor, even though broader adoption of cracking would substantially increase sustainable plastic output. Additionally, greater adoption of PET depolymerization is possible, but it requires a concerted effort on the part of textile companies (in both apparel and other sectors) to both substantially increase collection and ensure that depolymerization can work with blended PET garments.

KEY ASSUMPTIONS

Primary demand growth: Initial assumptions

Recycling infrastructure:

- PET depolymerization capacity two times greater than baseline
- HDPE solvent capacity same as initial assumptions
- Pyrolysis adopted to 50% of projected EU incineration capacity and 50% of China and Japan incineration capacity; pyrolysis oil is cracked in EU and used as fuel elsewhere

Disruptive events:

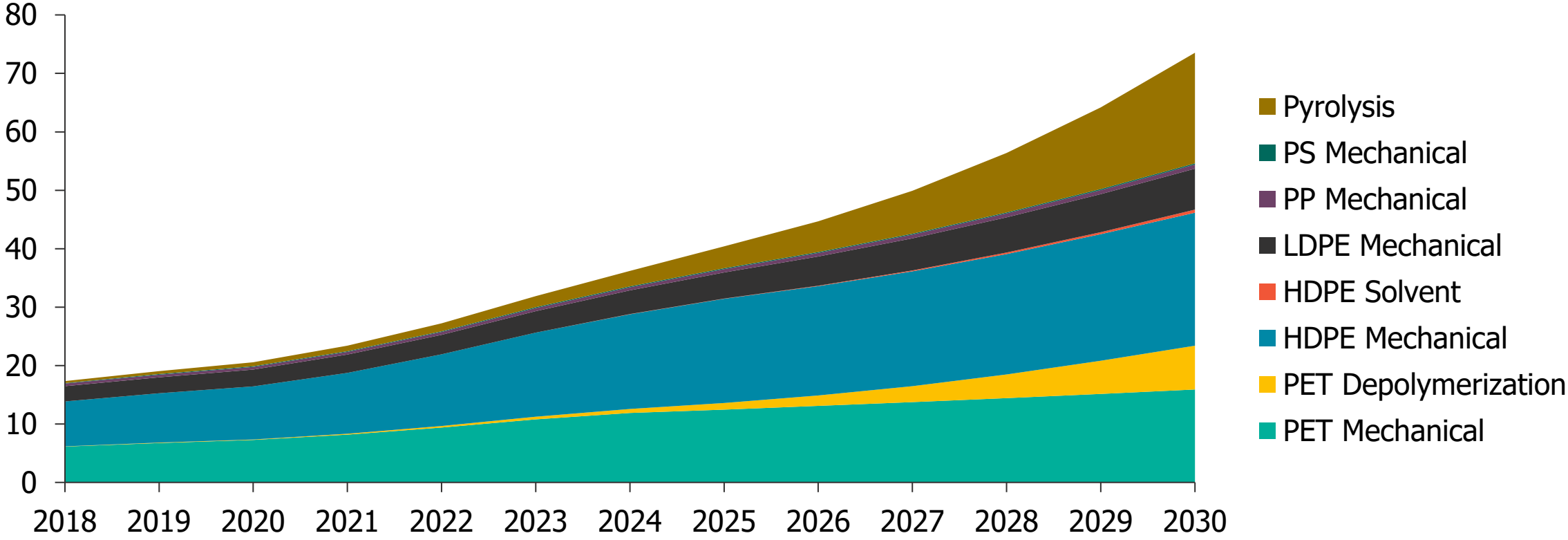
- 50% ban on LDPE/HDPE grocery bags, 2023
- 90% ban on all PS packaging, 2025
- 10% ban on PET bottles, 2027
- Low adoption of paper bottles; aluminum cans take around 7% of current PET bottle market

LIKELY CASE SCENARIO

Recycling capacity grows to 73 million tons

Recycling capacity

Million tons of plastic treated



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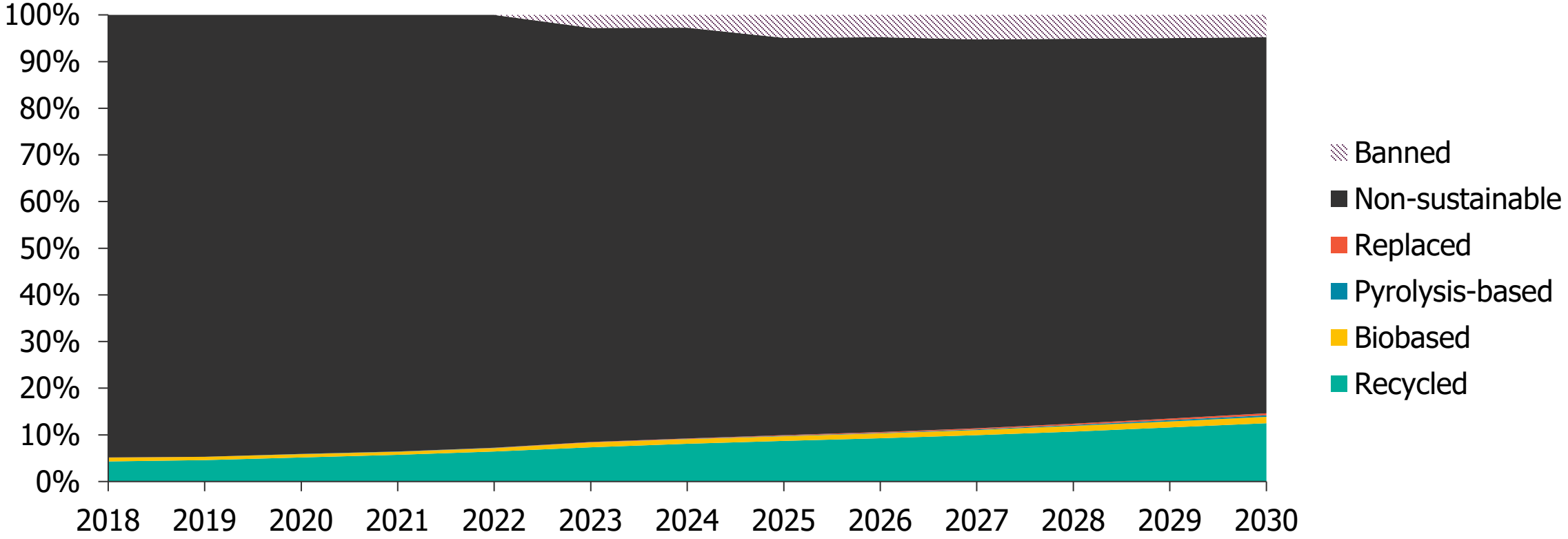
LIKELY CASE SCENARIO

Sustainable plastics make up 15.4% of plastic production after bans

Sustainable plastics

Share of plastics #1 to #6 production



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LIKELY CASE SCENARIO

Oil-derived plastics will struggle to grow as recycling, bans, and alternatives chip away at market share

MODEL HIGHLIGHTS

The global PET recycling rate approaches 60%, about where the EU is today

Adoption of C2C in the EU and pyrolysis oil cracking in Japan and China would increase polymer output by 4 million tons and sustainable share to 17%

Oil-derived plastics demand grows at just 0.2% per year overall; PET and PS demand shrink

2030 RESULTS SUMMARY

Recycling capacity	73 million tons
Recycled plastics output	42 million tons
Oil-derived plastics demand	396 million tons
Recycling infrastructure availability	23%
Material conversion capacity spending	$24 billion
Sustainable plastics share	15.4%

LUX TAKE

Our likely case presents a mixed outlook for the future of plastics. Certainly, major strides are made in both plastic waste reduction and the substitution of fossil-based resources with more sustainable alternatives, both approaches tripling in volume in the next decade. Still, the plastics industry has a long way to go: Around 285 million tons of plastic waste will not be recycled in 2030, and there will still be major pain points like PP lacking a sustainable solution. At the same time, plastics producers will face a double threat of shrinking demand for oil-derived plastics and growing competition from oil and gas companies moving downstream into plastics, potentially oversupplying plastics markets. Chemicals companies will need to either invest in both the cheapest sources of conventional resources and the circular economy (ideally in mechanical recycling as well as pyrolysis and depolymerization) or else cede their position in plastics and move into higher-value materials.

TECHNOLOGY OUTLOOK

A regulatory reckoning is coming for pyrolysis

Is pyrolysis sustainable? The short answer is that there is no short answer. Certainly, pyrolysis can have a lower CO_2 footprint than incineration in some scenarios but compared to incineration with high levels of energy recovery, it's more of a wash. Worse, pyrolysis has a larger CO_2 footprint than landfilling and using a relatively cheap source of oil to produce primary plastic. This concern is probably not an issue in China, where there's a huge opportunity to replace incineration; or in Japan, where waste accumulation and a desire to increase recycling rates are likely to be bigger drivers for adoption. But in Europe, the question of how to sustainably use pyrolysis is likely to be a major sticking point.

A complicating factor is that no one knows the quality of pyrolysis oil produced from post-consumer plastic waste. Biomass pyrolysis produces oil that retains a lot of oxygen, requiring substantial and expensive upgrading before cracking to make plastics. A plastic waste stream of mostly polyolefins should have very little oxygen, but at scale, the degree of purity and of biological contamination – from food and paper – could dramatically impact the quality of the oil. This key unanswered question will determine how cost-effective plastic recycling with pyrolysis really is.

Pyrolysis's problematic CO_2 footprint and the difficultly of converting it back into plastic are likely to limit its favorable treatment by regulators and thus its full potential. Overall, there's a good case that displacing oil production with pyrolysis is generally sustainable because of its value in handling waste, but even there, the degree of benefit depends on the oil source: displacing energy-intensive fracking is much better than cheap crude from the Middle East. While using pyrolysis oil to make plastics might satisfy the desire of chemicals companies and CPGs to tout their products and packaging as "circular," that may not be the most environmentally beneficial use of the pyrolysis oil. As regulators better understand the issue, they may be less likely to accede to desires to count pyrolysis oil-based plastics toward recycled content requirements – and brands may not be as eager to embrace them for their own sustainability targets.

Outlook summary

1 **The issue of plastic waste will not be fixed this decade.** Even in our most aggressive case, there was still unrecycled plastic waste. Moreover, plastic plays a crucial role in our economy, and eliminating it isn't a net positive even from a sustainability standpoint.

2 **The outlooks for disparate industries are linked.** While the packaging space gets the most attention, the future of sustainable plastics hinges on a huge and complex web of groups encompassing energy, paper, apparel, consumer goods, and the public sector.

3 **Major gaps in plastic sustainability remain.** Sustainability is not coming evenly to the plastics space, as the outlook for the most sustainable plastics is likely to improve while laggards stagnate – and major investments in infrastructure are still needed.

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