# Chemical Recycling:

*A False Promise for the Ohio River Valley*

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# Glossary

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| **Chemicals of concern (CoC)** | Chemicals that have the potential to harm the environment and cause adverse impacts on human health due to their inherent hazardous properties (Strategic Approach to International Chemicals Management (SAICM)) |
| **Conversion** | Thermochemical processes (sometimes called thermolysis) that convert carbonaceous polymers into simpler molecules (not monomers). For this reason, the process is sometimes called "feedstock" recycling, as some of the resulting products can be used to manufacture chemicals, including those involved in plastics production. These can then be processed in much the same way as oil, using conventional refining technologies. These processes require hydrocarbon polymers and operate without oxygen so they can process polyethylene (HDPE/LDPE), polypropylene (PP), polystyrene (PS), and ABS (which are those not well suited for depolymerization). The main conversion technologies are pyrolysis and gasification. |
| **Depolymerization** | Processes that involve breaking down the long polymer chains that make up plastic into single monomers (full depolymerization) or shorter polymer fragments (partial depolymerization), known as oligomers, through chemical treatments. Depolymerization methods are often further categorized based on the solvent used (e.g. methanolysis, glycolysis, and enzymatic hydrolysis). Monomers are precursors to polymers and can be repolymerized to produce virgin-quality plastics. The process is currently applicable only to certain types of plastic. Depolymerization is also referred to as chemolysis, solvolysis, or decomposition. |
| **Fenceline community** | A community that lives immediately adjacent to highly polluting facilities like fossil fuel infrastructure, industrial parks, or large manufacturing facilities, and is directly affected by the traffic, noise, operations, and most concerningly, chemical and fossil fuel emissions of the operation. |

**Forever Chemicals** See Persistent Organic Pollutants or (POPs)

**Flaring** A process of gas incineration, which can emit contaminants like dioxins, particulates, and other products of incomplete combustion

**Fugitive emissions** The unintentional and undesirable emission, leakage, or discharge of gases or vapors from pressure-containing equipment or facilities, and from components inside an industrial plant such as valves, piping flanges, pumps, storage tanks, compressors, etc. Fugitive emission is also known as leak or leakage. The term "fugitive" is used because these emissions are not taken into account and calculated during the design of the equipment and components. In addition, these emissions are unanticipated; as such, they are not detected by typical monitoring and control devices.[1]

**Gasification** As a type of Conversion technology, gasification uses high temperatures with air or steam to degrade plastic. (Pyrolysis processes also occur in many cases prior to gasification but the common description of the overall technology is gasification.) The primary product is syngas (a mix of hydrogen, carbon monoxide, and some carbon dioxide). The syngas can then be used to produce a variety of chemicals (e.g., methanol, ammonia, hydrocarbons, acetic acid) for plastics production as well as fuel and fertilizer.

**Greenhouse gases** Gases such as carbon dioxide (CO2), methane (CH4), nitrous oxide ($N_2O$), and others in the earth's atmosphere that trap heat. Greenhouse gases are transparent to incoming (short-wave) radiation from the sun but block infrared (long-wave) radiation from leaving the earth's atmosphere. This greenhouse effect traps radiation from the sun and warms the planet's surface. As concentrations of these gases increase, more warming occurs than would happen naturally.

**Microplastics** Solid plastic particles with a diameter smaller than 5 millimeters that come from the degradation of plastics. Microplastics have become ubiquitous in nature due to plastic waste pollution and therefore affect both wildlife and humans. Due to their characteristics, namely, small synthetic materials with high polymer content, insoluble in water, and non-degradable, microplastics are easily introduced into the environment and persist there for a long time. Microplastics have been detected in many marine species, but also in drinking water and in numerous foods, such as drinking water, shellfish, sea salt, sugar, honey, and beer. Exposure to microplastics can also occur through inhaled air.[2]

**Monomer** A small molecule or atom that can bond with other monomers to form more complex structures, such as polymers.

**Nanoplastics** Nanoplastics are solid plastic particles 1 to 100 or 1,000 nanometers in diameter that come from the degradation of plastics. Like microplastics, they have become ubiquitous in nature due to plastic waste pollution, and therefore affect both wildlife and humans. Due to their characteristics, namely, small synthetic materials with high polymer content, insoluble in water, and non-degradable, nanoplastics are easily introduced into the environment and persist there for a long time. Nanoplastics have been detected in many marine species, but also in drinking water and in numerous foods, such as drinking water, shellfish, sea salt, sugar, honey, and beer. Exposure to microplastics can also occur through inhaled air.[3]

**Persistent Organic Pollutants (POPs)** Toxic chemicals that adversely affect human health and the environment around the world. Because they can be transported by wind and water, most POPs generated in one country can and do affect people and wildlife far from where they are used and released. They persist for a long time in the environment and can accumulate and pass from one species to the next through the food chain. For that reason POPs were nicknamed "forever chemicals." (US EPA)

**Petrochemicals** Chemical substances made primarily from coal, oil, and natural gas. Petrochemicals are used to make consumer products such as aspirin, detergents, shampoo, pesticides, milk jugs, gasoline, carpeting, and more. Petrochemicals are considered feedstock, which is a raw material used for processing or manufacturing another product.

**Polymer** Large molecules assembled from many smaller molecules called monomers. Polymers consist of many repeating monomer units in long chains, sometimes with branching or cross-linking between the chains.

**Polymerization** A process by which monomers are combined to form a polymer.

**Polyolefins** A family of thermoplastics that include polyethylene and polypropylene. They are produced by polymerizing respectively ethylene and propylene, mainly obtained from oil and natural gas but can also be derived from renewable resources (e.g., sugar cane). Their versatility has made them the most largely used type of plastic. Examples include polyethylene (HDPE, LDPE) and polypropylene (PP), or polyvinyl chloride (PVC).

**Pyrolysis** A type of Conversion technology that heats the plastic waste without oxygen, breaking the polymer chains. A number of side reactions deliver a diverse set of hydrocarbon products, typically including a liquid output (pyrolysis oil, or “pyoil”) and a gas that is usually combusted along with solids, waxes, and char, which are wastes or low-value products.

**Purification** Sometimes called solvent- or dissolution-based purification, this process uses a solvent and a series of physical purification steps to separate different types of plastics and to separate plastics from additives, colorants, or other contaminants. The result is a colorless, purified form of the same input plastic that was originally fed into the process (e.g. the same polymer chain). Purification does not change the polymer itself but does use additional chemicals.

**Recyclate** Material that comes from the recycling process and is used in the production of new products. It can consist entirely or partly of recycled substances.

**Syngas (Synthesis Gas)** A mix of molecules containing hydrogen, methane, carbon monoxide, carbon dioxide, and water vapors, as well as other hydrocarbons and condensable compounds. It is the main product of gasification and the majority product of high-temperature pyrolysis carried on any biomass, residues, and waste. When produced in pyrolysis, it is created by the vaporization of volatile compounds from the raw material when the heat induces a set of

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| | complex reactions. |
| **Thermoplastics** | Plastic polymer materials that are soft and flexible when heated, which makes them easy to mold and shape. They are also lightweight and have a low resistance to heat and chemicals. Examples of thermoplastic polymers are Polyethylene (PE), Polypropylene (PP), Polyvinyl chloride (PVC), and Polyethylene terephthalate (PET). |
| **Thermosetting plastics, or thermosets** | Plastic polymer materials that are rigid and hard when heated, which makes them difficult to mold and shape. They are highly resistant to heat and chemicals, very strong and durable, and have a low level of recyclability. Examples of thermosetting polymers are Polyurethane resin (PUR), Unsaturated polyester resin, Epoxy resins, and Melamine resins. |
| **Virgin plastic** | A new, unused plastic material created from resin produced from natural gas or crude oil. |
| **Volatile Organic Compounds (VOCs)** | VOCs are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which have short- and long-term adverse health effects and are common groundwater contaminants. VOCs have a high vapor pressure and low water solubility. Many VOCs are human-made chemicals that are used and produced in the manufacture of plastics, paints, pharmaceuticals, and refrigerants. |

# Key Findings

1. **Chemical recycling is an energy-intensive process that produces very little virgin-like plastic.** Unlike mechanical recycling, which reprocesses plastic polymers largely by physical processes, chemical recycling describes highly engineered technologies that use chemicals, pressure, and/or heat to break down plastics to the polymer, monomer, or chemical feedstock level. These feedstocks can be potentially further reprocessed into virgin-like quality plastic. But chemical recycling (also called advanced, or molecular recycling), converts only 15-20% of plastic waste into recycled plastic products. Most end up as emissions, process fuel, or hazardous waste.

2. **The most common forms of chemical recycling are not recycling.** Many so-called recycling facilities simply convert plastic waste into fuel, which is not circular. It does not meet the definitions of recycling.

3. **Only ten chemical recycling facilities operate in the US.** Nearly all are in pilot- or demonstration-stage. None have become commercially successful. Two of these ten are in the Ohio River Valley: Alterra and PureCycle. Several more have been proposed.

4. **Chemical recycling is financially and technically risky.** It is based upon immature technologies and relies on yet-to-emerge supply chains and infrastructure. It faces challenging market dynamics. Recycled plastic must compete with a global oversupply of virgin plastic. The glut of virgin plastic may last for another decade.

5. **Plastic recycling processes are toxic and dangerous for workers and communities.** Out of more than 16,000 chemicals associated with plastic production, at least 4,200 are considered “highly hazardous” to human health and the environment. However, only 980 of these chemicals of concern are regulated globally at this time. Mounting evidence by the scientific community suggests that hazardous chemicals emitted through the chemical recycling processes are extremely toxic for fenceline communities. Deregulating these processes would increase risks for local communities.

6. **The petrochemical industry has lobbied for chemical recycling to be reclassified and deregulated at the federal and state levels.** The EPA currently designates pyrolysis and gasification — the most common forms of chemical recycling — as solid waste incineration, which is strictly controlled under the Clean Air Act. But, due to industry pressure, 25 states now classify these processes as manufacturing facilities, which are less heavily regulated. States, however, must

adhere to federal EPA rules. This means pyrolysis and gasification facilities remain subject to the strictest air pollution controls.

7. **Co-location of chemical recycling facilities will further burden communities already impacted by the petrochemical industry.** Existing petrochemical and chemical recycling plants are already located in low-income communities, imposing environmental burdens and injustice. Communities, such as the Ohio River Valley, will become more polluted if chemical recycling facilities are co-located with existing petrochemical facilities.

8. **The fossil fuel industry expects the growing virgin plastics market to offset declining demand for transport fuel.** As the energy transition progresses, virgin plastics have become the industry's Plan B. The petrochemical/fossil fuel industry has touted chemical recycling as a solution for plastic waste, though it has known for decades that recycling plastic will not solve the plastic pollution problem. This perception has enabled the unbridled growth of virgin plastics.

9. **Chemical recycling is not a silver bullet to solve the plastic waste pollution problem — far from it.** Measures to reduce the production of virgin plastic are required.

10. **The Ohio River Valley has better options than chemical recycling.**

# Executive Summary

**Plastics are a problem.** The world is awash in plastic. It is a major contributor of greenhouse gases (GHGs) and poses risks to workers and communities, especially environmental justice communities. Micro- and nanoplastics are everywhere, and we are learning more and more each day about the risks associated with the thousands of chemicals involved in the plastic lifecycle.

Plastic recycling would seem to provide a solution. But plastic recycling has struggled for 30 years, with recycling levels never reaching more than 10% of the plastic produced annually. Current estimates are even lower, with US recycling rates only 5-6% of plastics generated in the US, according to the World Economic Forum.

“Chemical recycling” is the latest proposed solution to the growing plastic production and waste problem. Unlike mechanical recycling, which reprocesses plastic polymers largely by physical processes, chemical recycling is a broad category of technologies that use chemicals and/or heat to break down plastics to the polymer, monomer, or chemical feedstock level. It comprises three main technologies: purification, depolymerization, and conversion (primarily pyrolysis and gasification). These technologies purport to provide a solution to the limitations of current mechanical recycling by providing a pathway to near-virgin quality plastic.

But, as this report will illustrate, chemical recycling is a false solution, one that ignores the health impacts inherent in the various chemical recycling processes. It also sidesteps the technical and economic headwinds that have, to date, stymied the industry. The pursuit of chemical recycling diverts attention and resources from solutions that would address the growing problems associated with production, use, and end-of-life treatment of plastics.

After decades of research and significant private and public investment, only ten chemical recycling facilities operate in the US, and none produce at scale. The technology used in various types of chemical recycling in each of these facilities remains in the pilot or demonstration stages. Two of the ten operating chemical recycling facilities are in the Ohio River Valley: Alterra and PureCycle. Both are in Ohio. Dozens more are planned throughout the country, including several in the Ohio River Valley (see Sidebar: Plastic Recycling Projects in the Ohio River Valley). Many proposed projects have been canceled or delayed, likely due to the poor economics of the industry coupled with local opposition as citizens broadcast the dangers posed by chemical recycling.

## Fig. 1: Plastic Recycling Projects in the Ohio River Valley

### Plastic Recycling Projects in the Ohio River Valley

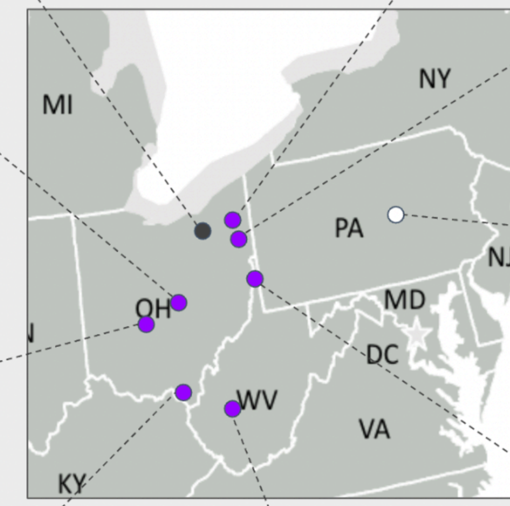
**Alterra**
Akron, OH
- **PHASE**: operational
- **PLAN**: thermochemical liquefaction, converting hard-to-recycle plastic waste into pyrolysis oil ("PyOil"), feedstock for production of new plastic products

**Freepoint Eco-Systems**
Hebron, OH
- **PHASE**: initial construction of the plant, including two pyrolysis units and one fractionation unit, NPDES permit granted on 9/28/2023. On track for completion in 2024.
- **PLAN**: pyrolysis of plastic waste to feedstock for production of new plastic products

**PTTGC America LLC**
Fayette County, OH
- **PHASE**: Study & preparation
- **PLAN**: the company's website claims **mechanical recycling** of PET bottles into pellets for production of new bottles

**PureCycle**
Ironton. OH
- **PHASE**: initial construction, permit issued, in testing phase; in operational pause as of April 1, 2024
- **PLAN**: polypropylene waste using solvent-based purification, creating a polypropylene resin that, according to the company, is nearly identical to virgin polypropylene plastic

**SOBE Thermal Energy Systems**
Youngstown, OH
- **STAGE**: claims to be initial construction; 12-month moratorium passed and signed by Youngstown City Council on Dec 26, 2023. Ohio EPA issued a permit-to-install-and-operate on Feb 14, 2024; appeals were filed in March 2024 against SOBE and Ohio EPA's director.
- **PLAN**: Thermolyzer unit to generate syngas from Tire Derived Chips (TDC) by pyrolysis




**Clean Seas/Clean Vision**
Quincy, WV
- **PHASE**: announced, securing funding
- **PLAN**: pyrolysis to transform waste plastic into fuels to be used as precursors for new plastic products,

**SOBE Thermal Energy Systems**
Lowellville, OH
- STAGE: announced
- PLAN: Thermal conversion of plastic, carpet, tires, and electronic waste to syngas

**Encina Point Township Circular Manufacturing Facility**
Point Township, PA
- **PHASE**: **CANCELLED following the community pushback**
- **PLAN**: Phase 1 is a plastics sorting facility. Phase 2 included a petrochemical processing plant that was planned to use catalytic pyrolysis to turn plastic waste into benzene, toluene, xylene, and other chemicals.

**Empire Green Generation**
Follansbee, WV
- **PHASE**: announced, securing funding, gas bladder building permit passed city council Dec 2023
- **PLAN**: plastic waste pyrolysis to syngas

● **Proposed/non-operational**
● **Operating**
○ **Cancelled**

Source: EPA, US Census Bureau[4]

All chemical recycling processes are toxic. When waste plastics are processed through chemical recycling, the additives and other contaminants present in these plastics can be transferred to emissions, wastewater,  solid waste, or output products. Many of the processes also involve flammable compounds or solvents that can pose fire risks. These processes can contaminate residual hazardous waste streams with  Persistent Organic Pollutants (POPs) and cause contamination of the chemical recycling output. If the output is used as fuel, then the POPs may be emitted into the atmosphere as the fuel is burned. To produce recycled plastic material, outputs of chemical recycling processes must be further integrated into an already toxic plastic production process that generates toxic Volatile Organic Compounds (VOCs), such as benzene, toluene, and other chemicals of concern.

Risks from chemical recycling particularly impact workers and the surrounding communities. Chemical recycling facilities tend to be built near petrochemical supply chains.  Since existing petrochemical facilities are often located near communities of color and/or low-income communities, the source of emissions is concentrated, as is the environmental injustice burden.[5]

Despite the hype around chemical recycling, most chemical recycling facilities do not, in fact, *recycle* plastic. Many produce only fuel, which does not meet many definitions of recycling which explicitly excludes technologies that do not reprocess plastics back into materials, but into fuels or energy.

**These facilities use confounding terms like "advanced" and "recycling," when in reality they are just producing fuels from plastic, and are, therefore, not circular or recycling at all.**

According to Veena Singla, a senior scientist at the Natural Resources Defense Council (NRDC), "The benefit of recycling comes when you return materials into the production cycle, which reduces the demand for virgin resources. Now if you're taking plastic and burning it as fuel, it's not feeding back into plastic production. And so to keep making [new] plastic, you have to keep extracting fossil fuel."[6]

Furthermore, depending on the type of plastic that enters a pyrolysis vessel, the output (or end product) may shift from what was originally planned and announced publicly. These changes make it challenging for local communities to fully analyze the impact of a proposed chemical recycling facility.

The potential benefits of chemical recycling have been touted, in particular, by the petrochemical industry, which is part of the fossil fuel industry. The petrochemical industry implies that difficult-to-recycle plastic can be recycled safely, all while creating economic benefits for local communities. Why is the fossil fuel industry so bullish on chemical recycling? Because petrochemical and oil and gas companies see plastic production as Plan B, which will fuel their growth even as the energy transition evolves and demand for transport fuel declines. Annual virgin plastic production has grown rapidly over the past decade and its rapid growth is forecast to continue. Petrochemicals, which include plastic, currently account for roughly 12% of oil use, but the sector is expected to surpass oil demand from trucks, aviation, and shipping by 2050, according to the International Energy Agency (IEA). In short, petrochemicals are vital to the oil and gas industry's future.

Recent documentation has revealed that the petrochemical and fossil fuel industries have, for decades, promoted plastic recycling with full knowledge that it is a false solution to the plastic problem. These industries have deceitfully suggested recycling would address the plastic waste problem, allowing them to continue to produce ever more virgin (or new) plastic.

Beyond implying that chemical recycling is a magic solution for plastic waste, the petrochemical industry lobbies for reduced federal and state-level regulation of the two most common types of chemical recycling, pyrolysis and gasification. The industry claims that these technologies should be considered manufacturing, rather than solid waste incineration, which requires stricter pollution controls and oversight. Such deregulation would further risk workers and local communities.

Economic benefits of plastic recycling, particularly chemical recycling, have not borne fruit, and are unlikely to. The economics of chemical recycling appear insurmountable without billions of dollars of investment. Thus far, the private sector has been slow to move forward with the scale of investment needed. No wonder, as the economic viability of the industry depends on several factors, many of which lie outside the industry. Beyond capital expenditures (CapEx), creating positive operating cash flow depends on low waste feedstock costs, collection and sortation of plastic waste, and high and stable prices for recycled plastic.

Recycled plastic must compete with abundant, low-cost virgin plastic. The US is now the world's largest producer of both natural gas and oil, both of which are feedstocks for plastic production. This glut of natural gas and oil has fueled a production boom for petrochemicals and plastics, primarily along the US Gulf Coast. At the same time, China has ramped up its petrochemical industry. The result is an oversupply of virgin plastic production. Experts believe the glut could last for a decade.

While low-cost virgin plastic is a challenge facing mechanical recycling, it is more challenging for chemical recycling. The technology for chemical recycling processes is unproven, yields are lower, its infrastructure is immature, and the market for its product, while promising, is still undeveloped.

Chemical recycling is toxic and dangerous, particularly for those who work in or live near a recycling facility. Other economic development projects in the region would reap greater rewards than pursuing unproven, unsafe technologies with no realistic hope of job creation or other markers of financial viability. The Ohio River Valley Institute's Roadmap for Industrial Decarbonization in Pennsylvania, for example, provides many alternative paths that focus on industrial development to create shared prosperity while addressing urgent decarbonization goals.

**Chemical recycling is not the solution — either for plastic pollution or for local communities.**

# Introduction

## THE WORLD IS AWASH IN PLASTICS

Plastic production, use, and waste are increasing. According to a recent Organization for Economic Co-operation and Development (OECD) report, both use and waste will nearly triple by 2060 even with some increase in plastic recycling.[7] Beyond the issue of visible plastic waste, the plastic industry is a major contributor of greenhouse gases (GHG) and poses toxic risks throughout its lifecycle through chemicals emitted to the air and water and the growing problem of micro- and nanoplastics.

Plastics are formed from the same oil and gas sources used as fossil fuels. In that sense, their formation begins at the oil or gas wellhead, which is often subject to gas leaks. The pipelines that transport oil and gas to a chemical plant also leak. The lengthy chemical process to convert oil or gas into raw plastic resin makes plastic one of the most energy-intensive materials to produce.[8] GHG emissions linked to the life cycle of plastics represented 3.4 percent of the global total in 2019. If plastic were a country, it would be the fifth largest emitter of greenhouse gases in the world.[9] In a 'business as usual' scenario, plastic could emit 19 percent of global greenhouse gas emissions by 2040,[10] though other estimates suggest 15 percent by 2050.[11]

Plastic production releases toxic chemicals with documented health risks for workers and communities. Out of 16,000 known chemicals that are potentially used or unintentionally present in plastics, more than 4,200 (~26%) are chemicals of concern due to their hazardous properties, meeting one or more criteria of being persistent, bioaccumulative, mobile, and/or toxic[12] (see Sidebar: Chemicals in Plastics).

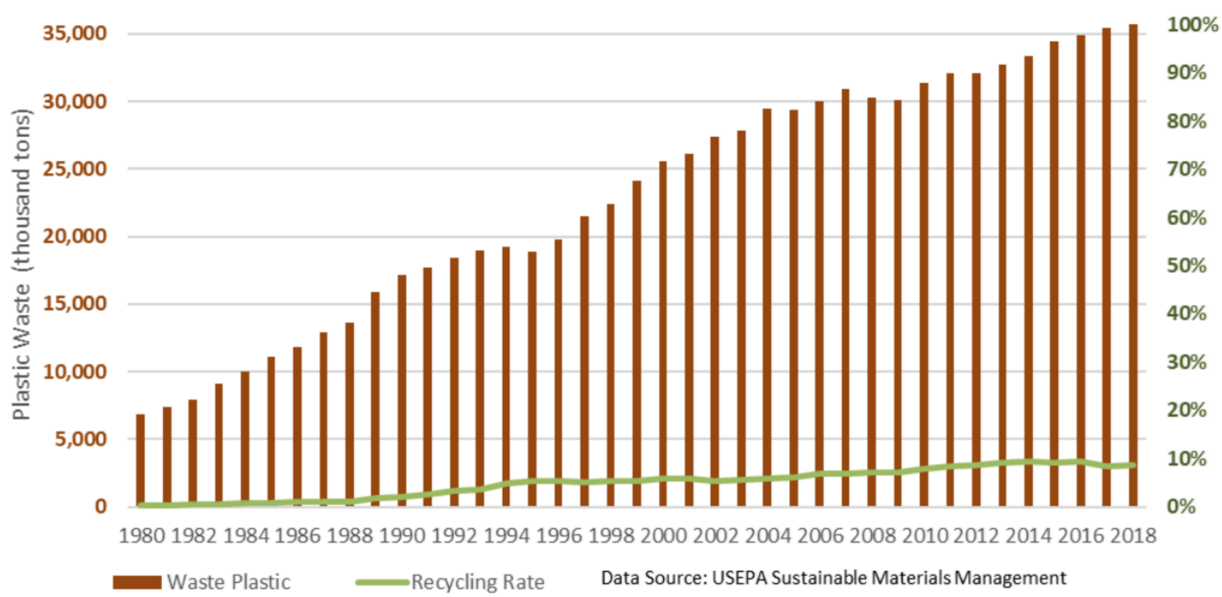
Micro- and nano-plastics also represent problems for human and animal health.[13] Found throughout the world, microplastics and nanoplastics are even more prevalent than previously thought.[14] Microplastics have been found in every corner of the earth from Antarctica to the bottom of glacial lakes, and the risks to humans and wildlife are just being uncovered, with most of the chemical compounds in plastics largely untested.

## RECYCLING HAS BEEN PRESENTED AS THE SOLUTION

The solution to exploding plastic production and resulting plastic waste would seem to be plastic recycling. In fact, increasing the rate of plastic recycling is currently being negotiated as part of a global treaty to deal with plastic waste, along with limiting single-use plastics (SUP) and capping the production of virgin plastic. Increased consumer awareness, corporate pledges, regulations, and legislation have boosted the idea of plastic recycling. "More than 80 global consumer-packaged goods (CPG), packaging and retail companies have made public commitments to reach recycled content in their packaging between 15 to 50 percent by 2025,"[15] according to a McKinsey report.

However, after more than 30 years of plastic recycling, the rate of plastic production and waste continues to grow. Over 8.3 billion tons of plastic have been produced since 1950 with most only used briefly and then discarded in landfills, incinerated, or leaked into the environment.[16] The US plastic recycling rate has never been higher than 10% and has steadily declined since 2018 when the US exported millions of tons of plastic waste to China, much of which ended up burned or dumped.[17] A new study estimates that less than 5-6%[18] of the 46 million tons of plastic waste generated in the US in 2021 made it to a plastic recycling facility. A recent study by Greenpeace contrasts the failure of plastic recycling with the success of paper recycling over the same timeframe, which increased from 21% in 1980 to 68% in 2018.[19] **In short, unlike glass, paper, or metal recycling, plastic recycling has largely failed due to technical, social, and economic challenges.**

**Fig. 2: Post-Consumer Plastic Waste vs. Recycling Rate, 1980-2018**




Source: Beyond Plastics and The Last Beach Cleanup[20]

## FRAUDULENT CLAIMS BY THE PETROCHEMICAL INDUSTRY

But the plastic industry, along with the larger fossil fuel industry, has known all along that recycling was a false promise to the plastic pollution problem, according to a widely circulated report[21] by the Center for Climate Integrity (CCI). The report provides documentation that the petrochemical industry has knowingly deceived the public on the recyclability of plastics resulting in an exponential increase in virgin plastic production over the past sixty years.[22]

Citing evidence going back decades, the CCI report makes the case for legal action. Overhyping recycling as a solution was a fraud, claim the report's authors, designed to protect and expand virgin plastic production and to quash or forestall legislative or regulatory action, perpetuating the global plastic waste crisis and imposing significant costs on local communities. The report cites internal industry documents by trade groups and petrochemical companies, including Exxon, that suggest the industry and participants were aware that plastic recycling was unlikely to solve plastic pollution.

The fraudulent claims that plastic can be recycled have become even more important as the petrochemical industry faces mounting pressure from climate change and expected declines in demand for transport fuel. Plastics are seen as a vital "Plan B" for the oil industry.[23] The petrochemicals used to produce virgin plastic polymers and other products currently account for roughly 12% of the total primary demand for gas and oil, according to the International Energy Agency (IEA). As annual virgin plastic production increases, it is expected to surpass oil demand from trucks, aviation, and shipping, accounting for nearly half of the growth in oil demand by 2050, according to the IEA.[24]

ExxonMobil was the largest producer of virgin polymers bound for single-use plastic in 2021. It and two other oil giants, Sinopec and Saudi Aramco, were among the five largest producers of virgin polymers bound for single-use plastic (SUPs).[25]

## CHALLENGES FACING "MECHANICAL RECYCLING" PROCESSES

The dominant technology for recycling plastic is mechanical recycling. In this process, reclaimed plastic is essentially reground and extruded to form pellets with no significant change to the chemical structure of the plastic. While this process can provide economic and environmental benefits, it is limited due to several factors.

Primarily, the mechanical recycling process works best on pure materials, single polymers with low levels of contamination. Unfortunately, today's plastic waste stream is composed of many different polymers, often mixed and combined with other materials and additives all contributing to challenges in plastic recycling.

Under the best conditions, single-material plastics with low levels of contamination can be sorted by polymer, color, and type and mechanically recycled. In the US, established markets for polyethylene terephthalate (#1, PET), high-density polyethylene (#2, HDPE), and polypropylene (#5, PP), can deliver the highest-grade recycled material. However, even this “recyclate” faces issues.

The high temperatures and sheer force of the extrusion process can break down the polymer chains, reducing the thermochemical properties with each recycling cycle. Although this may be mitigated to some extent with process control and additives, the additives often introduce additional challenges to the recycling process. Therefore, while mechanical recycling may extend the useful life of polymers, it is not a solution that will enable the infinite cycling of resources. As an example, the ductility (a measure of pliability) of PET drops from ~310 to ~218% after one cycle and is 2.9% by the third cycle[26]. As a result, only a small portion of PET is recycled for its original application, with most (50–77%) being converted into fibers used for the production of mixed materials such as carpeting.[27]

In addition, many plastics are multi-layered, multi-material, or composite plastic. Although some composites can be recycled, the result is a low-value, low-grade product. Therefore, much of today's recycled plastic is used in lower technology “open-loop” processes where the plastic is made into a product with lower requirements or “semi-closed-loop” recycling systems where the recycled material is mixed with substantial amounts of virgin polymer to achieve the desired characteristics.

Similarly, thousands of additives can be used in the production process of plastics (e.g. plasticizers, flame retardants, antioxidants, stabilizers, etc.). While these additives may have provided useful functionality to the original product, they pose challenges to the quality of the recycled material, often precluding mechanical recyclate from food/medical grade applications.

Finally, it is worth noting that thermoset polymers  (such as polyester and silicone) that represent about 15-20% of global plastic production cannot be remelted and are therefore not recyclable via mechanical recycling.

Chemical recycling is being billed as a way to address many of these limitations. Positioned as a way to handle “hard to recycle” materials and produce near-virgin quality plastic, chemical recycling is just the latest distraction perpetuating the problems of plastic production and imposing risks on the regions that host it.

# Chemical Recycling Is Not the Solution

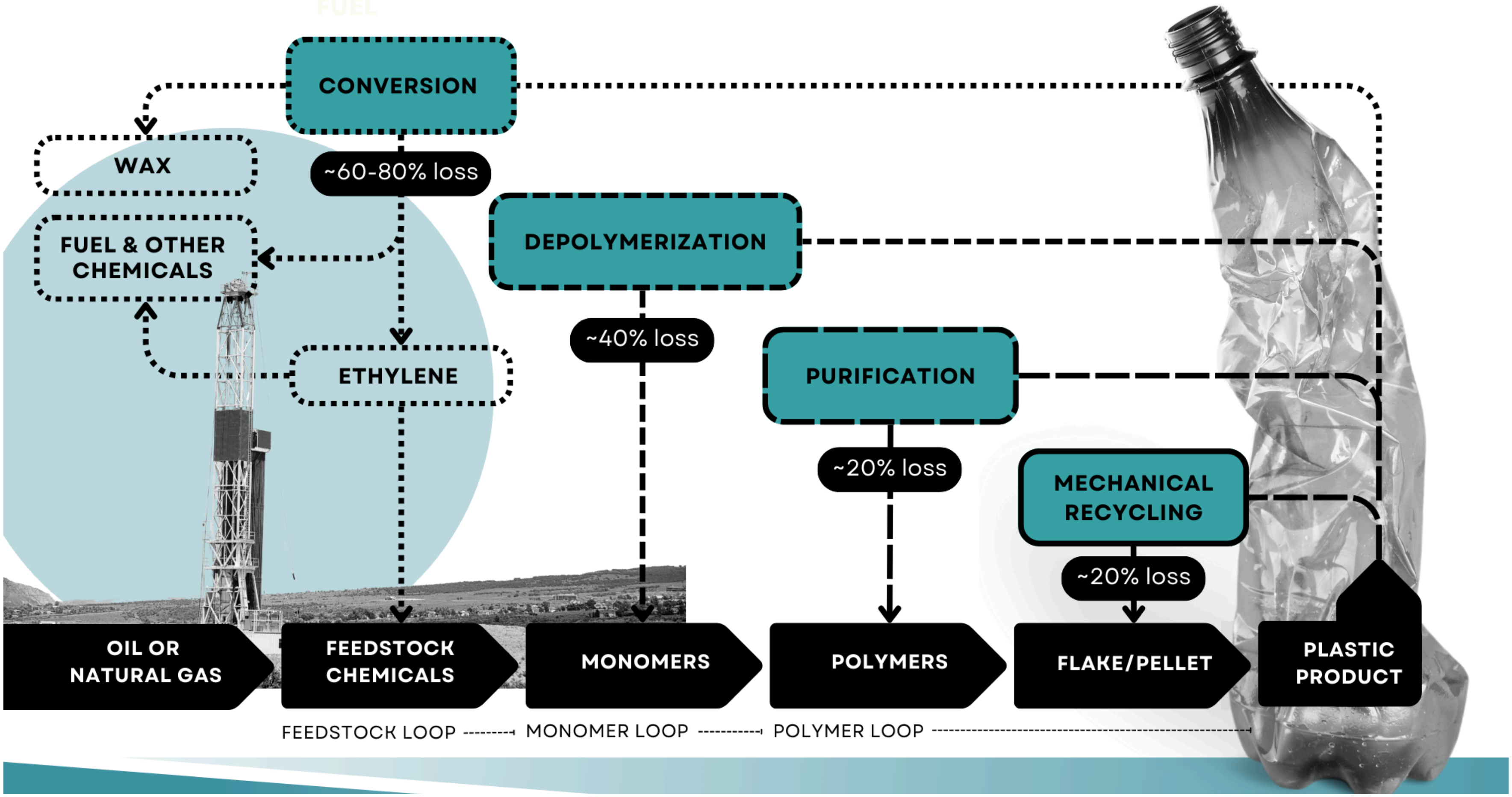
## *WHAT IS CHEMICAL RECYCLING?*

**Chemical recycling, advanced recycling, and molecular recycling** are all terms being used to describe a broad set of highly engineered processes that use heat, pressure, and/or chemicals to convert post-use plastics into products that can potentially be further reprocessed into virgin-like quality plastic.

For the purposes of this paper, we will generally use **"chemical recycling"** as an umbrella term. Recycling technologies are distinguished by the predominant way of transforming the material (physical/mechanical or chemical process) and the level to which materials are broken down for recovery (e.g. polymer, monomer, or molecular loops). Three common groupings of chemical recycling technologies are: purification, depolymerization, and conversion.

## Fig. 3: The Plastic Production Chain

"Chemical," or "advanced," recycling describes a broad set of highly engineered processes that use heat, pressure, and/or chemicals to convert post-use plastics into products that could be re-processed into virgin-like plastic. **The longer the recycling production chain, the less value is retained, the more energy and materials are required, and the more waste and environmental impact is generated.**




Source: Ohio River Valley Institute

## *TYPES OF CHEMICAL RECYCLING*

Below is a brief discussion of the types of chemical recycling. Key parameters in evaluating the likely success of the technologies are the type and purity of materials it can process (and therefore the degree of sorting required), the yield of the process, technology maturity, and environmental and economic performance relative to virgin plastic.

### Purification

**Purification** (sometimes called solvent or dissolution-based purification) uses a solvent and a series of physical purification steps to separate different types of plastics and to separate plastics from additives, colorants, or other contaminants. The result is a colorless, purified form of the same input plastic that was originally fed into the process (e.g. the same polymer chain). Since solvent-based purification does not change the polymer itself but does use additional chemicals, discussions are ongoing as to whether this technology should be included as chemical recycling or as a separate class altogether.

Different purification technologies use single-polymer feedstock (e.g. PP[28]) or multi-resins (e.g. Polyethylene (PE)/Polypropylene (PP), or Polyamide (nylon)(PA)/Polypropylene (PP) films.))[29]. The result is a purified polymer enabling a plastic-to-plastic outcome. While this process can produce a food-grade polymer quality, there is still some thermal degradation induced, although less than mechanical recycling, suggesting its circularity remains limited.[30]

Since the end product of solvent-based purification is a polymer, as opposed to a monomer or building block feedstock, these technologies typically have lower carbon footprints than other chemical recycling technologies. A study by a 12-member Department of Energy team, with lead author Taylor Uekert of National Renewable Energy Labs (NREL study), examined the benefits and trade-offs among current and emerging technologies. The NREL study showed a slight increase in lifecycle greenhouse gas emissions relative to virgin production and emissions an order of magnitude higher than mechanical recycling.[31] [32] However, even though the solvents can be reused and managed, many of the solvents most commonly used (e.g. xylenes and hexanes) are flammable, toxic, or become contaminated through the process, posing risks to workers and communities.

Yields are high compared to other chemical recycling technologies, similar to mechanical recycling. However, these technologies are not yet financially viable, often requiring high levels of sortation to improve yield. This is a new set of technologies and efforts are underway to scale up to a commercially viable level.

## Depolymerization

Depolymerization is also referred to as chemolysis, solvolysis, or decomposition. These processes involve breaking down the long polymer chains that make up plastic into single monomers (full depolymerization) or shorter polymer fragments (partial depolymerization), known as oligomers, through chemical treatments. Depolymerization methods are often further categorized based on the solvent used (e.g. methanolysis, glycolysis, and enzymatic hydrolysis). Monomers are precursors to polymers and can be repolymerized to produce virgin-quality plastics.

Depolymerization requires pure resins and is primarily applied to a subset of polymers – condensation polymers – that include atoms besides carbon in their backbone, e.g. polyesters (PET), polyamides (PA), polyurethanes (PUs), and polycarbonates (PCs).[33] (These polymers are formed by sequential addition of monomers and depolymerization essentially aims to do the reverse). Depolymerization is much more challenging for polymers that have a strong carbon-carbon bond, like polyolefins [e.g. polyethylene (HDPE, LDPE) and polypropylene(PP)] or polyvinyl chloride (PVC) polyolefins, which make up a majority of the waste stream.[34]

The monomers can be reformed into plastics, creating virgin-like quality and removing additives, which allows for food-grade applications. However, this process generates greater loss (over 30%)[35] and still requires additional steps (i.e., energy and chemicals), which results in higher environmental and human health impacts. The NREL study found depolymerization technologies to have energy and water use impacts an order of magnitude higher than mechanical recycling. GHG impacts were on a similar order to virgin plastic production, with all but glycolysis showing higher impacts.[36] The state of the various technologies varies from experimental to prototype demonstration level.[37]

## Conversion: Pyrolysis and Gasification

**Conversion** technologies are thermochemical processes (sometimes called Thermolysis) that convert carbonaceous polymers into simpler molecules (not monomers). For this reason, it is sometimes called "Feedstock" recycling, as some of the resulting products can be used to manufacture chemicals, including those involved in plastics production. These can then be processed in much the same way as oil, using conventional refining technologies. These processes require hydrocarbon polymers and operate without oxygen so they can process Polyethylene (HDPE/LDPE), PP, PS, and ABS (which are those not well suited for depolymerization). The main conversion technologies are pyrolysis and gasification.

- ➔ ***Pyrolysis*** heats the plastic waste without oxygen, breaking the polymer chains. A number of side reactions deliver a diverse set of hydrocarbon products, typically including a liquid output (pyrolysis oil, or "pyoil") and a gas that is usually combusted along with solids, waxes, and char, which are wastes or low-value products. Pyrolysis, on average, yields around 50-75% pyrolysis oil, which is similar to petroleum naphtha and can theoretically be transformed into plastic through similar processes.[38] Other constituents that are either fuel, waste, or low-value products, include about 10-30% " synthesis gas" (or syngas) and 5-15% solid "char."[39] However, the yield and quality of pyrolysis products depend on various factors, such as the type of plastic, pyrolysis temperature, and residence time, which are difficult to control when processing mixed plastic waste streams. According to Eric Hartz, cofounder and president of the pyrolysis firm Nexus Circular, "There's a kind of art going on here when dealing with heterogeneous inputs as opposed to homogeneous. There's not a perfect science to it about why some compounds behave the way they do in these environments."[40] Certain plastics, including PET, and PVC, can lead to contaminated output, greater char, and inorganic additives, such as carbon black, carbonate, and clay. It is important to note that the output of the pyrolysis process (pyoil) must further be refined to create plastics with additional losses incurred along the pathway resulting in only around a 40% conversion rate to plastic pellets[41].

- ➔ ***Gasification*** uses high temperatures with air or steam to degrade plastic. (Pyrolysis processes also occur in many cases prior to gasification but the common description of the overall technology is gasification.) The primary product is syngas (a mix of hydrogen, carbon monoxide, and some carbon dioxide). The syngas can then be used to produce a variety of chemicals (e.g., methanol, ammonia, hydrocarbons, acetic acid) for plastics production as well as fuel and fertilizer. Gasification typically requires pre-treatment to remove moisture and increase the energy value. A very efficient gas cleaning system at the elevated process temperature is needed to meet the requirements for applying the syngas to chemical production.

While these processes are also commonly referred to as "advanced recycling," they have been around for decades, primarily as a way to treat waste. Their status as recycling has also been contentious since they yield very small amounts of chemicals that still then require processing to transform them into plastic. Researchers at NREL objected to considering these technologies "closed loop" recycling. These researchers noted that pyrolysis and gasification require "large amounts of energy, emit significant pollutants and greenhouse gases to turn discarded plastics into oil or fuel, or chemicals such as benzene, toluene and xylene, synthesis gases, and a carbon char waste product."[42] According to the NREL study, conversion processes are 1.5-100x more expensive and environmentally impactful than fossil fuels and chemicals and 10-100x more expensive and environmentally impactful than virgin plastic.

## A note on Plastic to Fuel (P2F), compared to Plastic to Plastic (P2P)

Conversion technologies create a mix of petrochemicals. The composition of the products and their relative quantities are highly dependent on the operating parameters and the waste plastic feedstock[43].

When the pyrolysis oil is used to create fuel it is referred to as a Plastic to Fuel (P2F) process (sometimes also called Waste to Energy (WtE)). This does NOT reduce the need for virgin plastic and is therefore NOT recycling. (While it can be considered a waste treatment it is essentially a fossil fuel process (creating $CO_2$) and releasing toxins.) Many of the so-called "advanced" facilities, including the majority of those operating or proposed in the Ohio River Valley (see graphic), will not convert plastic waste into plastic products or even feedstock for plastic products, according to their own websites or announcements. Rather, their end-products will be fuel used for a variety of sources. It is not "recycling," as there is no circular path back to plastics production.

By contrast, in a P2P (Plastic to Plastic) process, the pyrolysis oil can be transformed similarly to traditional hydrocarbons (e.g. naphtha) through a series of chemical reactions into chemicals such as ethylene which can then be polymerized to polyethylene. So the pyrolysis processes can go either way (e.g. Plastic to Energy or Plastic to Plastic). However, as stated earlier, the quantity and quality of the pyrolysis oil is highly dependent on the feedstock and process parameters. Therefore, low-quality input feedstocks may create pyrolysis outputs that cannot be competitively marketed to petrochemical companies. Market economics such as competition from low-cost virgin material may also encourage pyrolysis plants to shift their output mix towards more lucrative fuel markets (Plastic to Fuel) even if their initial intention was P2P.

The main product of gasification, syngas, is composed of much simpler compounds (e.g. $CO_2$, $CO$, $CH_4$, and $H_2$). While these chemicals could potentially enter the chemical pipeline, and eventually be polymerized into plastics, they are generally used for the production of fuels, methanol and hydrogen. Thus, gasification would often be a P2F pathway.

## *CHEMICAL "RECYCLING" POSES RISKS FOR WORKERS AND LOCAL COMMUNITIES*

While researchers debate whether chemical recycling processes should be considered recycling, other researchers have been studying the chemicals involved in plastic production and recycling. The emerging research suggests chemical recycling is dangerous and toxic for workers and local communities.

### Evolving and Troubling Chemicals of Concern

From a chemical perspective, plastic products are complex mixtures of one or more polymers, fillers, several additives, and many (often unidentified) non-intentionally added substances.[44]

While the negative physical impacts of plastics in the environment are often visible (e.g. waterways clogged with plastic waste, turtles and other animals eating plastic debris and feeding plastic to their young, birds building nests with discarded plastic), less apparent are the health risks associated with the chemicals used in production and released into the environment during the lifecycle of plastics (see Sidebar: Chemicals in Plastics).

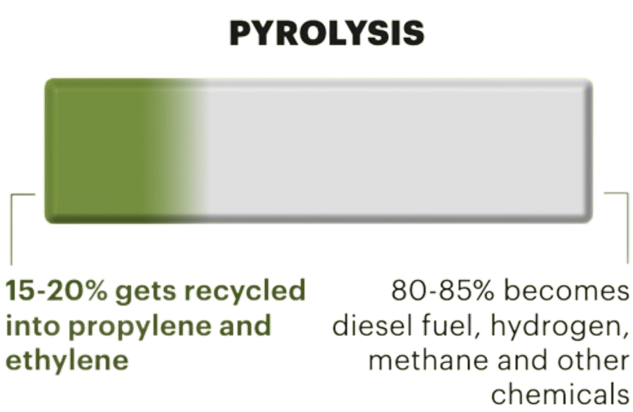
The realization that we do not even know the hazards presented by all the chemicals associated with plastic production is daunting. A 2024 study by PlastChem, a project funded by the Norwegian Research Council, is just the latest addition to our growing scientific knowledge of the dangers associated with the plastic industry. It identified 16,000 chemicals associated with plastic production, at least 4,200 of which are considered to be "highly hazardous" to human health and the environment, and only 980 of which are regulated globally at this time.[45] "There are many more unregulated chemicals that we're just unaware of how they may be hazardous to our own health or the environment," said Martin Wagner, an associate professor of biology at the Norwegian University of Science and Technology in Trondheim and one of the study's authors. This research builds upon a 2023 study by a global consortium of scientists and healthcare workers that determined that "plastics cause disease, disability, and premature death at every single stage of the plastic lifecycle."[46]

### Toxic VOCs, Waste, and Fires are a Risk to Workers and Communities

Specific knowledge on the environmental impacts of chemical recycling processes is evolving, but there is a reason for significant concern. The low yields of many chemical recycling processes mean that large amounts of often toxic waste are generated. A report by NGOs International Pollutants Elimination Network (IPEN) and Beyond Plastics provides some context citing a disclosure from Brightmark to the EPA that 70% of the output from a plant it is building in Ashley, Indiana, will be gases that it plans to use for energy or to flare. This would mean that a plant that processes 100,000 tons of plastic waste per year may generate from 70,000 to tons of emissions or waste products.[47] [48] Brightmark now says those figures were submitted in error and that such gases represent only about 18% of the output, and it is submitting the updated figure to the EPA.[49]

Reliable data on yield is not available as commercial scale plants do not exist and the strong dependance of  the input feedstock and contaminants (e.g. PET) on process outputs makes it difficult to estimate.  Even assuming average pyrolysis output yields of 50-75% of plastic waste input means that 25-50% of plastic material input is lost in the pyrolysis process as emissions, process fuel, or hazardous waste. A recent ProPublica article describes how after naphtha, the part of pyrolysis oil essential for making plastic, is fed into a steam cracker, less than half of what is produced becomes propylene and ethylene, gases that can be turned into solid plastics. The article explains that as a result of all this processing, if "a pyrolysis operator started with 100 pounds of plastic waste, it can expect to end up with 15-20 pounds of reusable plastic."[50]

**Fig. 4: Most of the old plastic that goes into pyrolysis doesn't become new plastic**




Source: ProPublica

Chemical recycling of plastics results in the generation of toxic Volatile Organic Compounds (VOC) emissions, such as styrene or vinyl chloride monomers, benzene, toluene, carcinogenic polycyclic aromatic hydrocarbons (PAHs), formaldehyde, high-temperature tars, and other toxic chemicals.[51, 52, 53] Many highly toxic chemicals have been used as additives in plastics as plasticizers, flame-retardants, or light stabilizers (including short-chain chlorinated paraffins (SCCPs), polybrominated diphenyl ethers (PBDEs), hexabromocyclododecane (HBCD), and phenolic benzotriazole (UV 328)). These Persistent Organic Pollutants (POPs), or so-called "forever chemicals", can contaminate the residual waste stream and cause contamination of the chemically recycled output, eventually ending up in “new” plastic products made from this output.

While many of the technologies are still at laboratory- or pilot-scale, pyrolysis has been around for decades. It constitutes the majority of the proposals for new chemical recycling facilities in the US. When waste plastics are processed through gasification and pyrolysis plants, the additives and unintentional contaminants present in the plastics (see Sidebar: Chemicals in Plastics) can be transferred to emissions, solid waste, output products, or wastewater.

If pyrolysis oil is used as fuel, the POPs may be emitted into the atmosphere as the fuel is burned.[54] For example, pyrolysis of plastic from Waste Electrical and Electronic Equipment (WEEE) or end-of-life vehicles containing halogenated flame retardants and polyvinyl chloride (PVC) can result in pyrolysis oils highly contaminated with polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs), some of the most hazardous POPs ever studied. Another example is pyrolysis of fluoropolymers and side-chain fluorinated polymers, substances characterized by their chemical resistance, thermal stability, and electrical insulation and therefore used in many applications, such as electronics, films for electrical insulation, medical equipment, and even children’s car seats. During pyrolysis these can form and release fluorinated POPs, ozone-depleting substances, and greenhouse gases.[55]

Additionally, pyrolysis units use flares to burn syngas during startup and shutdown, as well as to relieve pressure during emergencies.[56] Flaring is a process of gas incineration, which can contribute contaminants like dioxins, particulates, and other products of incomplete combustion to the emissions of a facility.[57]

Purification and depolymerization technologies generate their own varieties of hazardous waste as they specifically seek to separate useful monomers/polymers from plastic waste with various solvents. The solvents themselves may be hazardous and/or flammable, and even if recyclable, a certain fraction will become waste, requiring treatment.[58] Moreover, these technologies have the potential for fugitive emissions due to the volatility of some solvents used, and may also use flares.

Table 1 presents NRDC’s analysis of state-level permit data for the existing chemical recycling facilities in the US: Agilyx, Alterra Energy, Braven Environmental, Brightmark, Nexus Fuels, and PureCycle Technologies (Alterra Energy and PureCycle Technologies are located in Ohio River Valley.) It shows that these facilities release, or are permitted to release, chemicals known or suspected to cause cancer or other serious health effects like birth defects (Table 1).

## Table 1: Health Hazards of Chemicals Generated by Chemical Recycling Facilities

(1) Health hazards of chemicals sent off site as hazardous waste by Agilyx and (2) hazardous air pollutants (HAPs) listed in Agilyx's Air Toxics Emissions Inventory and in air permits for Agilyx, Alterra Energy, Braven Environmental, Brightmark, Nexus Fuels, and PureCycle Technologies.[32] Data on hazard traits from California Safer Consumer Products Candidate Chemicals list.[33]

| Chemical | Carcinogen | Reproductive toxicant | Developmental toxicant | Neurotoxicant | Persistent | Bioaccumulative | Liver toxicant | Cardiovascular toxicant | Respiratory toxicant | Kidney toxicant | Skin toxicant | Eye toxicant |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (1) Hazardous waste sent offsite by Agilyx | | | | | | | | | | | | |
| Lead | X | X | X | X | X | X | X | X | | X | | |
| Cadmium | X | X | X | X | X | X | | | X | X | | |
| Selenium | | | X | X | X | X | X | X | X | | X | |
| Benzene | X | X | X | X | | | X | X | X | | | |
| 1,2-dichloroethane | X | | | X | | | X | X | | X | X | |
| Chromium | X | | | | | | | | | | | |
| Vinyl chloride | X | | | X | | | | | X | | | |
| Barium | | | | X | | | X | X | | | | |
| (2) Hazardous air pollutants (HAPs) associated with multiple facilities | | | | | | | | | | | | |
| Styrene | X | X | X | X | | | X | | | | | X |
| Benzene | X | X | X | X | | | X | X | X | | | |
| Toluene | | | X | X | | | X | X | X | X | | X |
| Mercury | X | | | X | X | X | X | X | X | | X | |
| Arsenic | X | | X | X | | | X | X | X | | X | |
| Dioxins | X | X | | | X | X | X | | | | X | |
| Ethyl benzene | X | | X | X | | | X | | X | X | | X |
| Xylenes | | | X | X | | | X | | X | X | | X |
| Naphthalene | X | | | X | X | X | X | | X | | | X |
| Acetaldehyde | X | | | | | | | | X | | X | X |
| Formaldehyde | X | | | | | | X | | X | | | X |
| Hydrochloric acid | | | | | | | | | X | | X | X |
| Methanol | | | X | X | | | | | | | | |
| Hexane | | X | | X | | | | | | | | |

Source: NRDC[59]

Furthermore, dangerous vapors, flammable solvents, and by-products involved in chemical recycling can lead to accidents at facilities, putting workers and surrounding communities at risk. For example, as InsideClimate News reported in June 2023,[60] there had been at least six or seven fires (at least one producing a plume of smoke that could be seen 35 miles away) since Brightmark's "'advanced' plastic recycling plant" started testing its chemical recycling pyrolysis plant near Ashley, Indiana, in 2020. In addition to the fires, there were recurring problems with oil spills and plastic dust issues. Oil spills can potentially threaten local groundwater, and plastic dust issues caused by shredding and washing of plastic in recycling facilities may turn as much as six to 13 percent of incoming waste into microplastics—tiny, toxic particles that are an emerging and ubiquitous environmental health concern for the planet and people.[61] [62]

A particularly dangerous pyrolysis plant was described in ProPublica's cautionary tale, an exposé about a Chevron plastic-to-pyrolysis-derived jet fuel plant in Mississippi. A citizens group has recently sued the EPA for approving the plant, despite the EPA's own calculations that 1 in 4 people exposed to the pollution from the plant would be expected to develop cancer in their lifetime, a level 250,000 times greater than the level that would normally be permitted.[63]

## Costly to Communities

In an effort to connect petrochemical supply chains with chemically recycled plastic, companies like ExxonMobil intend to build chemical recycling plants at many of its manufacturing sites around the world.[64] Thus, chemical recycling workers and nearby residents, already burdened by toxic emissions from petrochemical refineries and plastic production facilities, will be exposed to additional health risks.

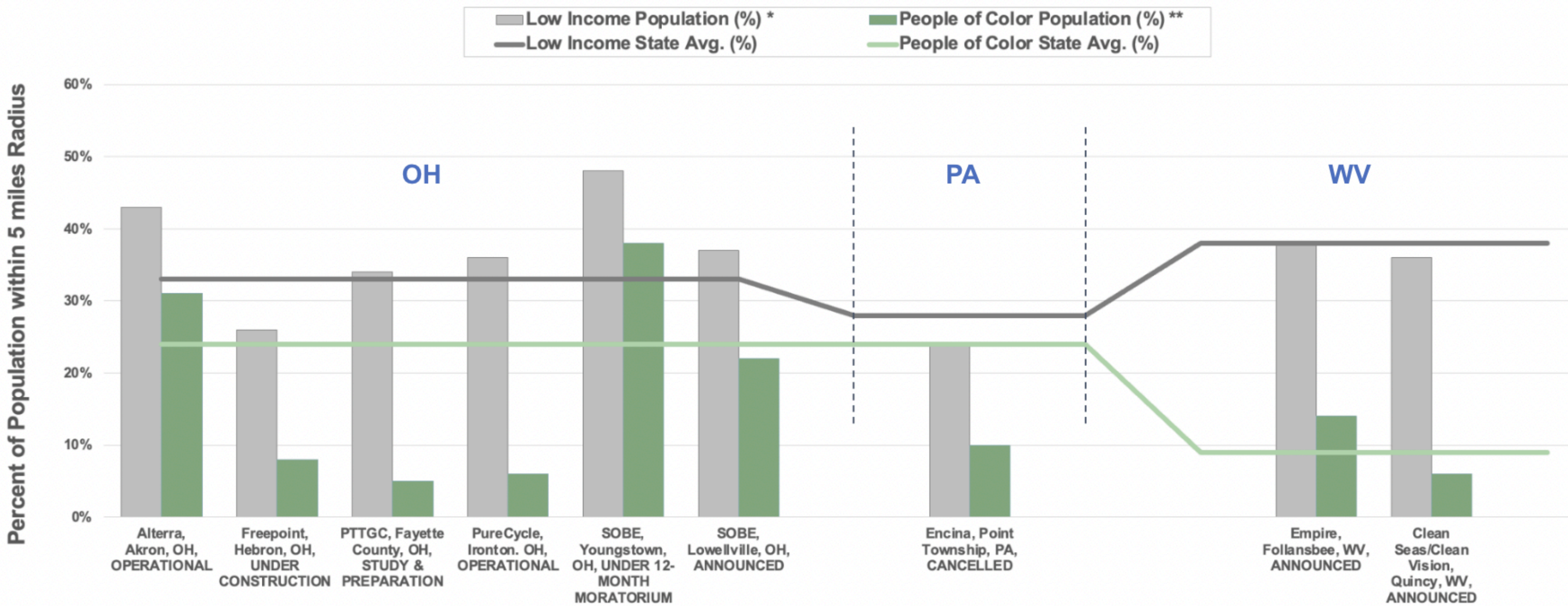
Once petrochemical plants become ingrained in a community, upstream and downstream supply chains develop. A petrochemical cluster, or hub, forms, which may benefit the petrochemical industry, but it concentrates the impacts on the surrounding communities. A case in point is Louisiana's "Cancer Alley," an 85-mile stretch along the Mississippi River. It is home to more than 200 petrochemical and oil refining facilities, primarily sited in Black communities. Its cancer rate is many times greater than the national average and was the subject of many investigations, including one by the EPA, which has since been dropped. Some years ago, local residents began to fight new petrochemical projects. They formed Rise St. James, after the name of a parish (Louisiana's equivalent to a county), and have tried to stop the expansion of chemical plants in the region.

Proposals to co-locate chemical recycling facilities near existing petrochemical facilities in Cancer Alley have local residents concerned. Jo Banner, a resident and advocate in Cancer Alley who co-founded the Descendents Project in St. James Parish, said when asked about the prospect of adding chemical recycling facilities: "First they kill us with the problem and now they want to kill us with what they are calling the solution."

Like Cancer Alley, "fenceline communities" are often communities of color and low-income communities that bear the burden of this environmental injustice.[65] A report by IPEN and Beyond Plastics analyzed the locations of constructed chemical recycling facilities in the US. The analysis revealed that more than 70% of these plants are located in low-income areas and more than 60% in neighborhoods of color.[66]

Our analysis of chemical recycling plants in the Ohio River Valley showed similar results. We used the US Environmental Protection Agency's Environmental Justice Screening and Mapping Tool to assess the socioeconomic indicators for the locations of currently operating, under construction, announced, and canceled plants. Of the nine facilities we analyzed, six were located in neighborhoods with a higher percentage of low-income households than the state average. In addition, three are located in neighborhoods predominantly of color.

**Fig. 5: Prevalence of Low-Income Households and People of Color Around Operating, Under Construction, Announced and Canceled Chemical Recycling Plants in Ohio River Valley**




** **Percent people of color** is the percent of individuals in a block group who list their racial status as a race other than white alone and/or list their ethnicity as Hispanic or Latino. The word "alone" in this case indicates that the person is of a single race, not multiracial.*

*** **Percent low-income** is percent of individuals whose ratio of household income to poverty level in the past 12 months was less than 2.*

Source: Ohio River Valley Institute

While the industry may promise job creation and other markers of economic development to support new plastic recycling facilities (see Sidebar: Plastic Recycling: Just the Latest Industry-Hyped False Promise), the social costs on communities that host petrochemical companies often go overlooked.

Economist Maureen Cropper of the University of Maryland estimates a global cost of $592 billion in 2015 associated with plastic production, including the social costs of accidents, injuries, and environmental exposure to chemicals[67]. Consistent with this, according to a report issued in January 2024, a group of hormone-disruptive plastic chemicals including polybrominated diphenyl ethers (PBDE), phthalates, bisphenols, and polyfluoroalkyl and perfluoroalkyl substances (PFAS) cost the US healthcare system an estimated $249 billion in 2018 alone due to the development of chronic disease and death.[68]

The Minderoo-Monaco Commission on Plastics and Human Health, an interdisciplinary commission composed of scientists, clinicians, and policy analysts from around the world coordinated by the Global Observatory on Planetary Health at Boston College, documented the following risks to human health in a recent report. Plastic production workers are at increased risk of leukemia, lymphoma, hepatic angiosarcoma, brain cancer, breast cancer, mesothelioma, neurotoxic injury, and decreased fertility. Workers producing plastic textiles die of bladder cancer, lung cancer, mesothelioma, and interstitial lung disease at increased rates. Plastic recycling workers have increased rates of cardiovascular disease, toxic metal poisoning, neuropathy, and lung cancer. Residents of fenceline communities adjacent to plastic production and waste disposal sites experience increased risks of premature birth, low birth weight, asthma, childhood leukemia, cardiovascular disease, chronic obstructive pulmonary disease, and lung cancer.[69]

## Regulating Chemical Recycling

The EPA has classified pyrolysis and gasification as an incineration process since 1995. All facilities that burn waste, no matter their size or what they manufacture, are currently regulated as solid waste incinerators. They must meet the strictest air pollution and control standards covering incineration, combustion, or waste-to-energy facilities, under the Clean Air Act.

Incineration regulations address "emission limitations, good combustion practices, operator training and certification, facility-siting criteria, permit compliance and inspections, and record keeping and reporting requirements," according to the National Research Council (US) Committee on Health Effects of Waste Incineration.[70]

Incinerators are one of the most dangerous sources of pollution, according to James Pew, Director of Federal Clean Air Practice at EarthJustice. He has worked on clean air standards for more than 20 years and has observed many efforts to reclassify facilities that burn waste as something besides incinerators. The petrochemical industry is following this path.

The American Chemistry Council (ACC), a trade association for chemical companies, has lobbied for years against federal EPA rules that classify pyrolysis and gasification units as solid waste incineration units. The ACC seeks to classify pyrolysis and gasification as manufacturing. Even though pyrolysis and gasification do use combustion and generally convert plastic waste to produce fuel, rather than new plastic, the ACC suggests that "advanced recycling facilities receive plastics feedstock as a raw material and manufacture it into a higher value commodity in processes that do not involve incineration."[71]

In May 2023, the EPA rejected the reclassification of pyrolysis and gasification, which had been proposed under the Trump administration. The EPA noted in its decision to retain the classification that more time is needed to study the complex pyrolysis/combustion processes, and that "the EPA does not believe it would be appropriate for those sources to become unregulated emissions sources during the time required for our analysis of pyrolysis/combustion units to be completed, particularly if the Agency ultimately concludes that regulation is needed."[72]

A crucial part of ACC's lobbying centers is now focused on reclassifying chemical or advanced recycling facilities as manufacturing, rather than waste management facilities, at the state level.

These efforts have been successful. Currently, 25 states, including Pennsylvania, Ohio, and West Virginia, classify chemical recycling as a manufacturing process, rather than waste disposal or waste management.[73] Manufacturing facilities are subject to less stringent environmental regulations.

However, state laws do not override federal laws. Pyrolysis and gasification units must meet federal standards. And "under federal law, it doesn't matter what they make, if they're burning something, they're incinerators," according to Pew. "Even if pyrolysis facilities called themselves manufacturing facilities, they still have to go through the permitting process. In fact, they're incinerators and must be permitted as incinerators, complying with all those requirements."

The decision by the EPA to retain the classification for pyrolysis and gasification is important, as typically, the EPA regulations set the floor for what states have to achieve.[74]

## Deregulation Increases Risk to Neighborhoods

The reclassification of advanced recycling units to manufacturing from solid waste incineration at the state level is an attempt by the petrochemical companies to reduce regulations and oversight of their industry.

Any deregulation of chemical recycling would particularly impact fenceline communities, according to a letter co-written by 35 lawmakers who wrote to the EPA about the dangers of deregulating chemical recycling: "Changes in how these facilities are regulated could have significant impacts on local air emissions in the communities where these facilities are located, disproportionately impacting minority and low-income communities. The plastic and petrochemical industry has lobbied at the state level to eliminate emission control requirements for incinerators using these technologies, exposing vulnerable fenceline communities to toxic emissions from these processes." [75] Air pollution continues to be an ongoing area of research by the EPA.[76]

# *RISKY FINANCIAL INVESTMENT*

Only ten chemical recycling facilities operate in the US, two of which are in the Ohio River Valley (see Sidebar: Plastic Recycling Projects in the Ohio River Valley). These ten chemical recycling facilities are described as demonstration or pilot projects and/or producing far less than initial plans.

Industry groups and researchers have touted the potential of chemical recycling for decades, yet, private markets' investment in chemical recycling remains tepid. The economics of chemical recycling have proven challenging, as illustrated by plant closures and cancellations.

A joint venture, Regenyx, claiming to be the the first US company to turn post-consumer polystyrene back into virgin-quality plastic (via pyrolysis) in Oregon shut down in early 2024, after just five years. Its low production fell far short of its 2019 vision to develop a 50-ton-per-day facility, and did not move beyond the "demonstration project." According to the company's management, "the scale of the facility didn't make sense to keep operating as anything beyond a demonstration of the concept."[77] Since 2021, the facility has lost an estimated $4.5 million, according to public financial filings.[78]

Within the Ohio River Valley, Encina canceled a $1.1 billion facility that would have used pyrolysis. The company claimed it had better opportunities elsewhere than in Point Township, PA, where it faced stiff local opposition and legal challenges.[79] [80] The plant, announced in 2022, was intended to convert waste plastics into feedstock chemicals, such as benzene.[81]

This weak interest in chemical recycling from the private market suggests investors are waiting for public subsidies before they move forward. But chemical recycling remains a risky public investment, with immature technologies that may never become economically viable. Even the most ardent supporters of chemical recycling acknowledge the challenges to scale, noting the need for "substantial investments in collection and sortation infrastructure," among other measures.[82]

## *TECHNOLOGY IS IMMATURE AND UNPROVEN, CURRENTLY NOT ECONOMICALLY VIABLE*

Even the most optimistic industry reports on chemical recycling suggest it will be years, if not decades, before these technologies will become viable at scale.[83] Chemical recycling, according to McKinsey, would require a $40 to 90 billion investment to produce just 6-10% of the "plastic supply" by 2040, with the important caveat: if constraints were resolved. Constraints include having an ample supply of plastic waste, improved economics, technological improvements, scaling, investments, and continued green premiums.[84] Each type of chemical recycling — whether conversion, depolymerization, or purification — faces distinct technical challenges.

### Collection and Sorting Imposes Additional Costs and Volatility

Obtaining a quality supply of used plastic feedstock is critical to increasing yield and enabling the economic viability of chemical recycling.

As the current market for mechanical recycling feedstock has demonstrated, this can be challenging. All plastic recycling efforts include the collection of used plastic. This often involves a logistical challenge, with pick-ups done by third-party companies that use diesel-fueled trucks. Often this contributes to environmental injustice as the access to collection in rural areas can be limited. Furthermore, this can be subject to unpredictable operational costs, as diesel prices and labor costs have spiked in recent years.
Once the plastic waste is collected, it must be sorted. For much of the current plastic waste stream, this is done at a Material Recovery Facility (MRF), sometimes with automation or robotics and sometimes manually. Plastic waste often then needs to be cleaned to remove contaminants, requiring additional costs and energy and generating wastewater that must be treated. If we look at the current established markets, despite

potential growth in demand for recycled plastic, over the past few years there has been "no step-change increase in PET collection or sorting."[85]

Chemical recycling processes still require feedstock collection infrastructure and market development.

Moreover, despite claims to handle a broad range of materials and contaminants, these technologies still generally require sorting or pretreatment. Purification and Depolymerization technologies often require specific polymer streams. Sorted feedstock is particularly important given the current maturity levels of these technologies, where higher yields are required for financial viability. Expanding the ability to collect, sort, and market plastics beyond the established markets for PET and HDPE will require additional infrastructure at additional cost. This may entail significant investment in technology at MRFs, secondary sorting, or development of other plastic waste sourcing models, such as dropoff programs, commercial and post-industrial collections, and specialty partnerships.[86]

While pyrolysis can accept mixed waste, polyolefins are preferred. PET- and PVC-type plastics are detrimental to the product or process and are preferred to comprise less than 5% of input feedstock. PVC causes corrosion in the reactor and renders the oil halogenated, PET degrades the oil quality and can clog the process.[87] Furthermore, as mentioned above, carcinogenic compounds such as dioxins or additives in plastics, even in low concentrations, can accumulate across the petrochemical chain and present a risk to human health. Countermeasures should be taken, which may add cost.[88] The impact of various feedstock mixes on the quality of the pyrolysis oil is difficult to predict. It is unclear whether the downstream petrochemical industry is willing to adapt to unstable and potentially low-quality process output. Recent studies have shown that pyrolysis oil from plastic (PP) differs in terms of hydrocarbon composition (e.g. more cyclic olefins with a bromine number of 85 to 304) relative to petroleum-based naphtha (e.g. low olefinic content and bromine around 1). This may indicate that plastic pyoil is NOT compatible with existing industrial steam crackers processing naphtha which in turn may indicate that costly adjustments to downstream infrastructure are required.[89]

## Recycled Plastic Faces Competition from Low-Cost Virgin Plastic

Blame simple economics for some of the failures of plastic recycling. Chemical recycling does nothing to change that. Simply put, the price of recycled plastic must compete with virgin plastic. And, as virgin plastic production has exploded over the past decades, its production cost has declined. Except for a short-lived spike in prices during COVID-19, plastic prices have steadily declined over the past decade. Commodity grade HDPE, for example, has declined from an average of roughly $1.10/pound in 2014 to .55-.70/pound in 2023 and 2024.[90]

Virgin plastic prices are likely to remain depressed due to global oversupply, with petrochemical analysts expecting the oversupply to last for another decade, at least, according to petrochemical analyst, ICIS' John Richardson.

The global glut of virgin plastics resulted from several assumptions, each of which has proved to be faulty. The following list includes these assumptions and their flaws:

- **ASSUMPTION:** Demand for virgin plastics would outpace global GDP growth, which is generally estimated to be 3% per year. Demand in Asia, particularly India and China would be particularly strong.
    - **FLAW:** As the world reckons with plastic pollution and a slowdown in China's economy, petrochemical analysts are questioning that high-growth assumption.
- **ASSUMPTION:** Abundant, low-cost feedstock in the US would provide the domestic petrochemical industry with a permanent, competitive advantage. Advances in oil and gas production, namely horizontal wells and hydraulic fracturing (so-called fracking), propelled the US to become the largest producer of both oil and natural gas. Byproducts of both oil and natural gas are feedstocks for the petrochemical industry. Domestic petrochemical plants are expected to capitalize on abundant, low-cost feedstock, particularly ethane. The domestic industry rapidly expanded capacity in 2018 and 2019, particularly along the US Gulf Coast.
    - **FLAW:** Low-cost domestic feedstock, including ethane and naphtha, has not been sufficient to provide a competitive advantage for US petrochemical producers.
- **ASSUMPTION:** China would remain a net importer of petrochemicals.
    - **FLAW:** Even as the domestic petrochemical industry added capacity in the US, China was also building capacity. At the World Polyolefins Conference in Vienna, John Richardson, a petrochemical analyst at ICIS, described the huge capacity growth in petrochemical building blocks. As Richardson noted: "China has pretty much bankrolled the global petrochemicals industry since 1992. . . . Such was the subsequent strength of China's consumption growth versus insufficient investment in local capacity that the petrochemicals industry became over-reliant in lucky events in just one country. Now our luck has run out."[91]

Low oil and gas prices will continue to keep the production costs of virgin plastic low, weakening the market value of recycled plastic. As plastic production increases, so does off-spec, or wide-spec resin, which is virgin plastic that is not produced to specification for prime plastic but is still marketable for applications similar to recycled content. Wide-spec plastic is often sold at a break-even by producers primarily concerned with maintaining higher prices for prime production. Some industry observers worry that manufacturers may switch from recycled to wide-spec plastic, increasing volatility and reducing demand for recycled plastic.[92]

While both mechanical and chemical recycling face pressure from low-cost virgin plastic, chemical recycling faces additional challenges because its technology is unproven, and significant costs will be required to create chemical-recycling-specific infrastructure and to develop a new market.

## Chemical Recycling Is Often Not Really Recycling

Very little chemical recycling converts plastic waste into plastics. Recycling processes that produce fuel or energy-like outputs are not considered recycling, based on accepted definitions based upon international standards,[93] the US EPA [94] and the EU Waste Framework Directive (WFD) of 2018.[95] Many of the companies seeking to operate in the region are using terms like "advanced" and "recycling" in their press releases and websites, but are actually Plastic to Fuel (P2F) processes.

"In the United States, recycling is the process of collecting and processing materials (that would otherwise be thrown away as trash) and remanufacturing them into new products," according to the EPA.

As much as 80% of plastic waste input may be lost in the pyrolysis process as emissions, process fuel, or hazardous waste, according to a report by NGOs International Pollutants Elimination Network (IPEN) and Beyond Plastics.[96] [97] In a study from NREL, government researchers estimated that only 1% to 4% of plastics sent to conversion chemical recycling pathways will result in new plastic.[98] This sobering statistic is unlikely to change, according to an analysis by the Minderoo Foundation (an Australian NGO), which examined advanced recycling capacity expected to come online within five years. It found that less than 25% will be recycled back into plastic products.[99]

Although industry groups, such as the ACC, suggest that fuel or energy produced from plastic waste is a form of recycling, by the definition according to internationally recognized standards, plastic recycling must "displace primary or raw materials." [100] It is not recycling when plastic is burned as energy or made into a fuel. Even when companies intend to produce chemical feedstock for plastic production, poor quality inputs and competition with low-cost virgin plastic may cause them to shift to producing energy or fuels. As the Ellen MacArthur Foundation elaborates, if these same processes are used for Plastic to Energy (PTE) or Plastic to Fuel (PTF) applications, these activities cannot be considered as recycling (according to ISO definition[101]), nor as part of a circular economy. Furthermore, chemical recycling processes, as well as virgin plastic production, should not use hazardous chemicals or pose a significant risk to human health or the environment. Chemical recycling processes involve many toxic chemicals and pose significant risks to communities and the environment. As the data have demonstrated, chemically recycled material is not displacing virgin plastic with only a fraction of plastic waste used in chemical recycling getting converted into plastic products. The production of virgin plastic continues to explode.

## Chemical Recycling Doesn't Really Solve the Plastic Waste Problem

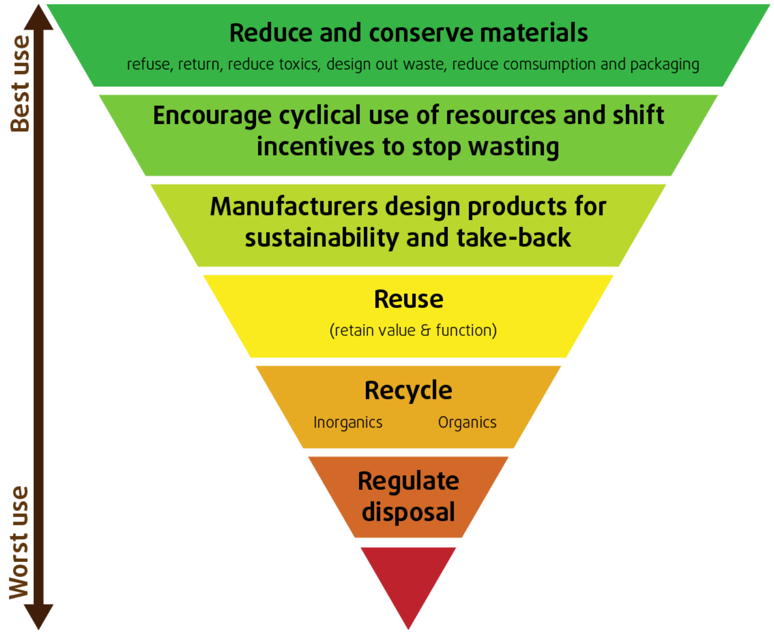
Each stage of the plastic life cycle brings with it impacts. This includes climate impacts, damage to human health, and ecosystem impacts. Lifecycle GHG emissions occur from oil and gas extraction and transport to the processing of petrochemicals, life-cycle energy use, and incineration at the end of life. Exposure of workers and fenceline communities to hazardous chemicals, particularly during production but also along the full plastics life cycle, poses risks to human health. Chemicals released into the air and water also pose risks to ecosystems. Finally, solid waste that ends up unmanaged on land and in waterways causes problems like clogging up stormwater systems and entangling marine life.

It is widely agreed, therefore, that a reduction in plastic production is critical to addressing the plastics problem. Chemical recycling, however, will not meaningfully solve the problem. McKinsey's optimistic reports suggest that even with a $40 billion investment over the next decade, chemical recycling will only reduce 4-8% of plastic waste — and only if current constraints can be resolved.[102] Constraints include immature technology that is not scalable, inadequate supplies of plastic waste, and substantial investments, none of which are likely or imminent. An assessment using material flow analysis modeling in Europe was more optimistic, finding that, by 2030, the "highest achievable" end-of-life recycling rate for chemical recycling would be 15% for plastic to plastic and 19% for plastic to chemicals..[103]

Chemical recycling, even if combined with mechanical recycling, cannot solve the plastic waste problem. It is, at best, a "marginal activity for the plastics sector," according to the Minderoo Foundation. It found that from 2019-2021, the growth of single-use plastic was supplied with 15 times more virgin, than recycled, plastic.[104]

As shown in the waste hierarchy (Figure 4), prevention, reduction, and reuse represent the highest and best use for wasted plastics with waste management techniques such as recycling, disposal for energy recovery, and landfill least preferred.

**Fig. 6: The Zero Waste Hierarchy**




Source: Zero Waste International Alliance[105]

Plastic recycling can be beneficial when the material captured reduces the production and impact of virgin plastic. Furthermore, the systems should incentivize circular products that can be managed at the end of life (reducing the amount of hard-to-recycle materials that cannot be managed at the end of life). Finally, there should be incentives to reduce the use of additives, colorants, and stabilizers without a deep understanding of their impacts on humans and the environment. Chemical recycling may have a place in this model, but synergistic with these goals it is a small role for special cases (at the bottom of the hierarchy.)

## Chemical Recycling Diverts Funds from Real Solutions

An analysis by the Minderoo Foundation calculated that of the roughly two million tons of advanced recycling capacity scheduled to come online over the next five years, less than half a million tons of these facilities' output will actually be recycled back into plastic goods. The rest of the output is destined to power airplanes, trucks, and other heavy transportation.

Estimates to ramp up chemical recycling run in the tens of billions of dollars. These billions of investment will not solve the plastic waste problem. Even its supporters acknowledge chemical recycling will address, at most, 4-19% of plastic waste produced over the next decade. And for communities in which chemical recycling facilities are located, residents and workers are likely to face toxics that will negatively impact their lives.

Investing in chemical recycling diverts funds for real solutions — both for economic development and the large problem of plastic waste. Burning plastic and refining it into fuel is an intensive and expensive process, one that would require government subsidies were it ever to become widely used. There are so many better projects that could use that funding to create real waste solutions, but “chemical recycling” diverts that money away.

The plastic that is deemed unsuitable for mechanical recycling is particularly complex to treat, and industrial processes have not yet found either technically or economically viable solutions.  Rather than providing incentives to restrict the complexity in the design of plastics and to limit plastics to those for which safety is better understood, these technologies provide false hope and mixed signals to brands, further perpetuating the problems of poor plastic design.

Chemical recycling processes that produce monomers or feedstock chemicals still require additional production steps to transform those inputs into plastic or other products and, in fact, are often integrated into existing virgin production processes, thus perpetuating the plastic lifecycle’s health risks. Moreover, steps must be taken to reduce the amount of plastic produced, limit the chemicals used in plastic production, and better understand the impacts of those chemicals. Chemical recycling will do exactly the opposite by enabling the perpetuation of more and “harder to recycle plastics.”

As Senator Jeff Merkley wrote in 2023 in the letter to the EPA Administrator Michael S. Regan, “So-called ‘chemical recycling’ has been touted by companies like Chevron as a way to reduce plastic waste through repurposing it but turning plastic waste into fuel increases greenhouse gas emissions, subsidizes the petrochemical industry, and harms frontline communities located near these facilities. While it is urgent that our country takes actions to address climate chaos  we need to ensure that the steps we take actually reduce greenhouse gas emissions and do not do so by sacrificing historically marginalized communities and those who are already overburdened by toxic pollution.”[106]

# Conclusion

## *CHEMICAL RECYCLING: NEGATIVE CONSEQUENCES FOR THE REGION AND A DISTRACTION THAT DIVERTS ATTENTION FROM MORE SUSTAINABLE SOLUTIONS*

Chemical recycling is not a solution for either plastic waste or economic development in the Ohio River Valley. There are better options for both.

Unlike mechanical recycling, which reprocesses plastic polymers largely by physical processes, chemical recycling describes highly engineered technologies that use chemicals, pressure, and/or heat to break down plastics to the chemical feedstock level. But chemical recycling (also called advanced, or molecular recycling), converts only a small percentage of plastic waste into recycled plastic products. Most end up as emissions, process fuel, or hazardous waste.

Out of the more than 16,000 chemicals associated with plastic production, at least 4,200 are considered to be "highly hazardous" to human health and the environment. Mounting evidence by the scientific community suggests that hazardous chemicals emitted through the chemical recycling processes are extremely toxic for fenceline communities.

Deregulating chemical recycling processes would increase risks for local communities. The EPA currently designates pyrolysis and gasification — the most common forms of chemical recycling — as solid waste incinerators, which are strictly controlled under the Clean Air Act. But, due to industry pressure, 25 states now classify these processes as manufacturing, which is less heavily regulated. States, however, must adhere to federal EPA rules. This means pyrolysis and gasification facilities remain subject to the most stringent air pollution regulations.

Existing petrochemical and chemical recycling plants are already located in low-income communities, imposing environmental burdens and injustice. Communities, such as the Ohio River Valley, will become more polluted if chemical recycling facilities are co-located with existing petrochemical facilities.

Many so-called chemical recycling facilities simply convert plastic waste into fuel, which is not circular. It does not meet the definitions of recycling.

The fossil fuel industry touts chemical recycling as a solution for plastic waste, though it has known for decades that recycling plastic will not solve the plastic pollution problem. This perception has enabled the unbridled growth of virgin plastics. The petrochemical/fossil fuel industry is likely to continue to support chemical recycling as the energy transition progresses, since virgin plastics have become its Plan B.

Despite the fossil fuel industry's claims, chemical recycling is based upon immature technologies and relies on yet-to-emerge supply chains and infrastructure. It faces challenging market dynamics. Recycled plastic must compete with a global oversupply of virgin plastic. The glut of virgin plastic may last for another decade. No wonder there are only 10 chemical recycling facilities operating in the US, two of which are in Ohio.

Many more chemical recycling facilities are planned, however, despite the economic and technological hurdles facing the nascent industry. The industry hopes to benefit from public investment at the federal and local level, supporting industry-funded research touting the benefits of advanced recycling.

Decisions about how to allocate public funds must be made thoughtfully, to make sure investments benefit the region in the long run.

An example of an economic pathway, focused on industrial decarbonization to advance the local economy and boost employment, was put forth in "A Roadmap for Industrial Decarbonization in Pennsylvania," a report by Strategen for ORVI in 2024.[107] It offers an alternative approach to economic development, focusing on energy efficiency, increased electrification, and developing and leveraging the region's abundant renewable energy resources.

Finally, chemical recycling is not a silver bullet to solve the plastic waste pollution problem – far from it. Measures to reduce the production of virgin plastic are required.

# SIDEBAR: Plastic Recycling: Just the Latest Industry-Hyped False Promise for the Region

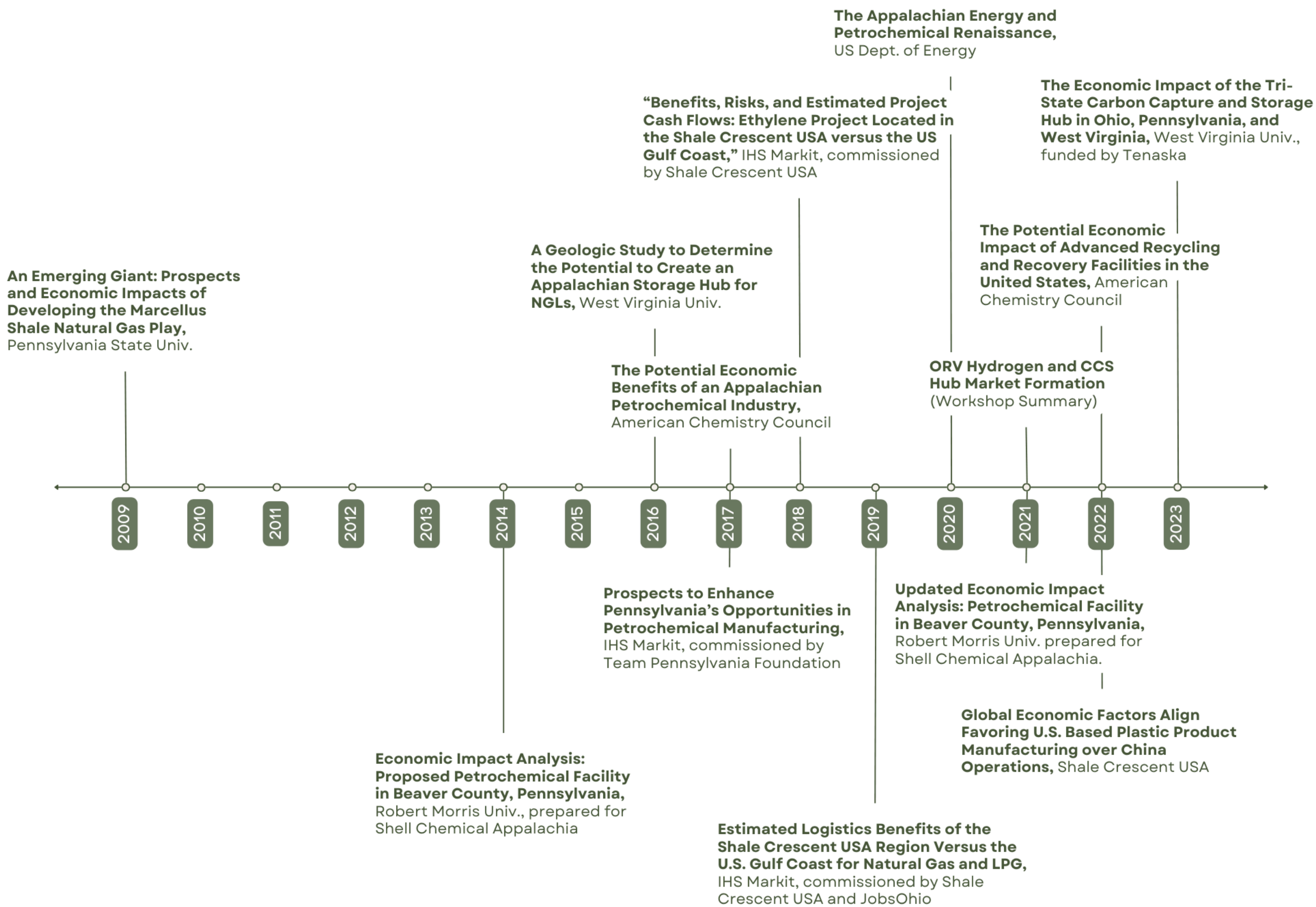
Over the past 15 years, the fossil fuel industry has touted various projects in the Ohio River Valley, heralding outsized economic benefits for the region. These projects, by and large, have quietly been shelved. Even projects that have moved forward have not led to economic benefits at the local level.

In general, these endeavors provide poor foundations for economic development for the following reasons:

- They are highly capital-intensive and not at all labor-intensive.
- Beyond brief construction periods, they do little to local commerce or engage with local economies.
- They are polluting, damage quality of life, and harm property values.

Studies funded by industry groups to support new endeavors have often been quietly removed from websites, likely because their findings of job growth and economic benefits have manifestly failed.[108]

## Fig. 7: Examples of Industry-Funded Studies Supporting Fossil-Fuel Projects: 2009-2023




Source: Ohio River Valley Institute

# SIDEBAR: Plastic Recycling Projects in the Ohio River Valley

While chemical recycling has been touted as a solution to global plastic pollution, only 11 chemical recycling facilities were currently operational in the U.S. at the end of 2023, according to a report published by Beyond Plastics, "Chemical Recycling: A Dangerous Deception."[109] In March, one of the 11 facilities, located near Portland, Oregon, closed down after five years, after losing an estimated $250 million.[110]

Two of the ten remaining facilities are located in the Ohio River Valley: Alterra Akron Plastic Recycling Facility ("Alterra") and PureCycle. Both are in Ohio.

Many chemical recycling projects are announced to great fanfare, but fail to reach a Final Investment Decision (FID). Even the few existing chemical recycling facilities have faced technical issues and operate far below capacity. This is the case with both Alterra and PureCycle. Their financial and technical failures exemplify the headwinds facing chemical recycling facilities.

## *ALTERRA*

While Alterra broke ground for its Akron, Ohio plant in 2014 and was commissioned in 2020, it has only run as a "demonstration plant."[111] As a private company, Alterra is not required to disclose financial data, limiting in-depth analysis of its financial history and future prospects.

The Alterra facility uses pyrolysis, in which mixed plastic waste is used as a feedstock to produce petrochemical feedstocks, called pyrolysis oil or "pyoil." According to the company website, the Alterra plant system can process up to 60 metric tons of waste plastic per day.[112] Since it does not convert plastic to plastic, it is not, according to EPA guidelines, a recycling facility.

Two foreign companies, Neste and Ravago, have acquired the rights to use Alterra's technology in Europe.[113] In February, Freepoint Eco-Systems agreed to license Alterra's technology for a proposed facility on the Gulf Coast.[114]

According to the IPEN and Beyond Plastics report, the Alterra plant generated nearly two tons of hazardous waste in the last six months of 2018 alone, despite having operated for only one week that year, and more than 86 tons of hazardous waste from 2019 to 2022. These included ignitable wastes, benzene compounds, halogenated and non-halogenated solvents, methyl ethyl ketone, and the heavy metals barium, cadmium, and lead.[115]

According to permit records, each year Alterra may be releasing up to 16,343 tons of greenhouse gases, 3.9 tons of particulate matter, 18.6 tons of nitrogen oxides, 7.8 tons of volatile organic compounds, 0.4 tons of sulfur dioxide, 5.6 tons of carbon monoxide, and 0.3 tons of other hazardous air pollutants.[116]

The emission testing conducted in December 2023 showed that Alterra's "nitrogen oxides (NOX) and volatile organic compound (VOC) emissions were higher than the estimated emissions that were submitted in any of the permit applications." [117]

## *PURECYCLE*

Located in Ironton, Ohio, PureCycle's flagship operation uses Solvolysis, a solvent-based technology licensed from Proctor & Gamble, to convert post-consumer and post-industrial polypropylene into virgin-like plastic.

Categorized by the US EPA ECHO system as a "small quantity generator," the PureCycle Ironton Plant has the potential to generate ignitable, corrosive, and reactive types of waste, arsenic, mercury and waste from spent solvents and solvent mixtures that include both halogenated and non-halogenated solvents, including but not limited to tetrachloroethylene, trichloroethylene, and chlorobenzene.[118] It is considered a minor source of air pollution with the potential to emit 12 tons of criteria air pollutants each year.[119]

Based in Orlando, Florida, the company has repeatedly fallen short of its timeline and production goals. In its 2017 statement, PureCycle projected its Ironton facility would be operational by 2020, though it did not reach "mechanical completion" until 2023.[120]

The company went public in 2021, through a Special Purpose Acquisition Company (SPAC), with an estimated market cap of $1.2 billion.[121] Its current market cap, roughly $930 million in June 2024, is about $860 million, a 28% decline since going public.

Short sellers have repeatedly challenged the company's financial forecasts and technology, including Hindenburg in 2021, [122] which published "PureCycle: The Latest Zero Revenue ESG SPAC Charade Sponsored by The Worst of Wall Street." Bleeker Street Research updated its earlier negative report on the company, "PureCycle: It Looks as Bad as it Smells,"[123] in late 2023. Based on public earnings, PureCycle's yield of pellets from plastic feedstock was only 25%, far less than it had forecast. More recently, PureCycle was the subject of a New York Times article,[124] which repeated many of the short sellers' claims, including the company's practice of using virgin plastic, rather than waste plastic, as feedstock.

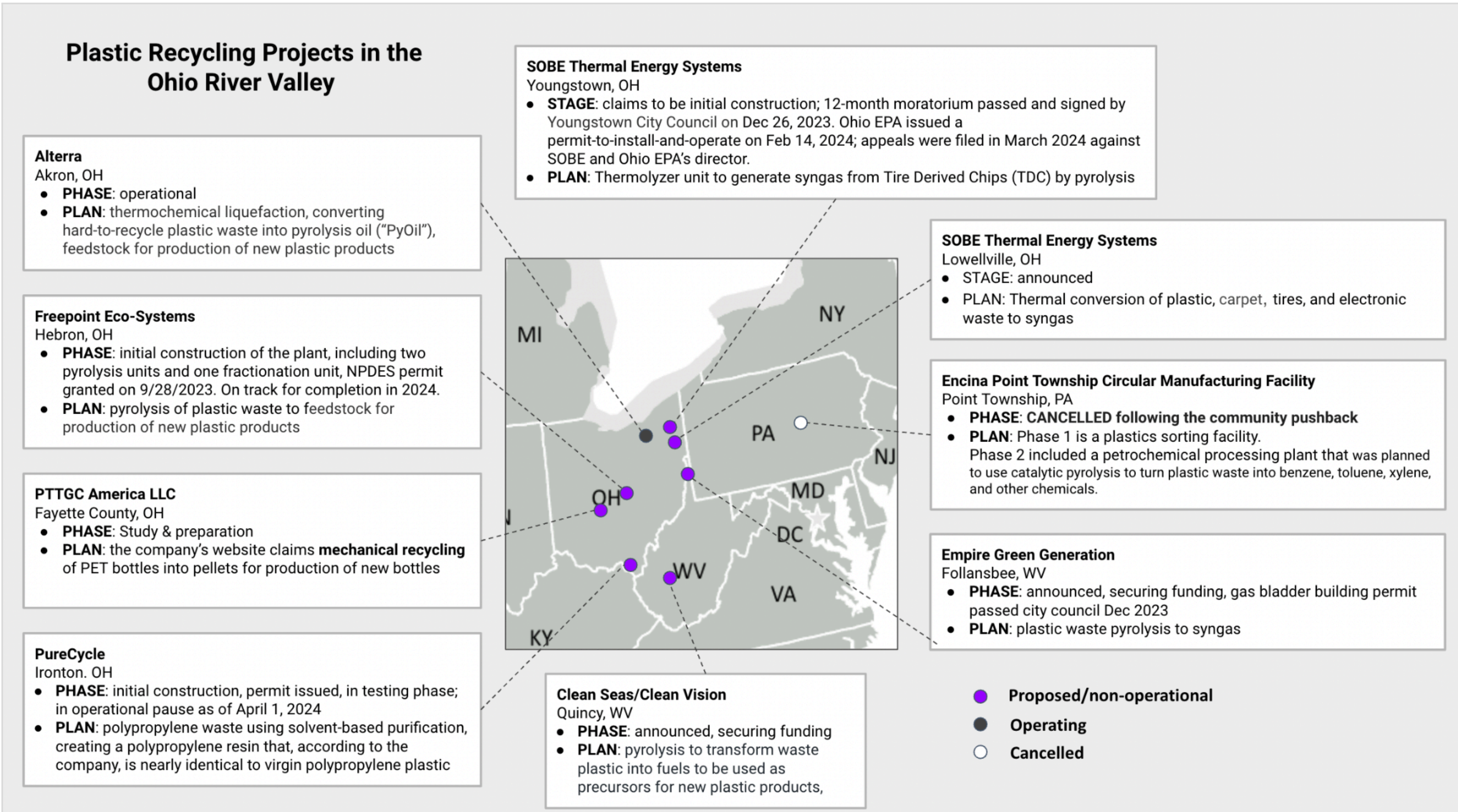
The initial investment in the Ironton plant was $361 million[125], which was at the "higher end of the project investment," according to the company. Industry publications, including Plastic News, have reported extensively on the company's failure to meet production goals, including the CEO's statements, such as his June 2023 statement: "This has been a struggle. I'm not going to lie. I have underestimated the timing for this plant."[126]

Since its mechanical completion in Q2 2023, the plant has struggled with seal failures, leaking beads, and other technical failures that have caused numerous outages, according to its March 2024 investor presentation.[127] Some of its financing depends on meeting production goals, which it has consistently failed to meet. A thunderstorm in August halted production, and the company declared a force majeure in September, acknowledging the company would miss production goals, which were a condition of its financing.[128] PureCycle's licensing agreement with P&G requires it to meet production goals as well.[129]

The company has been sued by shareholders for misleading statements. In May 2024, it settled these claims for $12 million.[130]

Despite the production and financial shortfalls, PureCycle plans to build new recycling production facilities, in Augusta Georgia,  Georgia, and may expand to South Korea and Belgium, according to its 2023 Annual Report.[131]

## Fig. 8: Plastic Recycling Projects in the Ohio River Valley




Source: EPA, US Census Bureau[132]

# SIDEBAR: Chemicals in Plastics

Depending on their specific applications, plastic products are designed by selecting one or more synthetic **polymers** and several **additives** used to enhance a material's properties such as pliability, resistance to thermal or UV degradation, and color (e.g., plasticizers, flame retardants, UV light stabilizers, pigments, and fillers) (Figure 7).

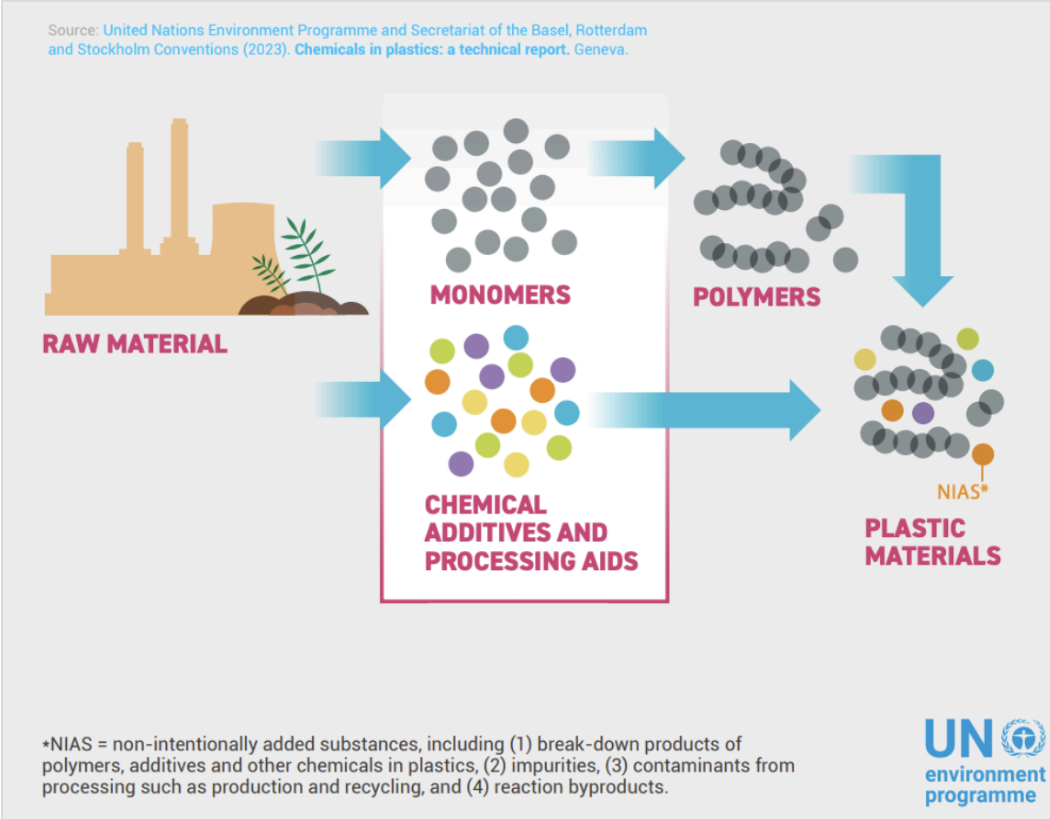
**Polymers** are constructed from molecular fragments known as monomers that are joined together into long chains. There are two main types of synthetic polymers: **thermoplastics** and **thermosets**.

**Thermoplastics** are soft and flexible when heated, which makes them easy to mold and shape. They are also lightweight and have a low resistance to heat and chemicals. Examples of thermoplastic polymers are Polyethylene (PE), Polypropylene (PP), Polyvinyl chloride (PVC), and Polyethylene terephthalate (PET).

**Thermosetting plastics,** or **thermosets,** are rigid and hard when heated, which makes them difficult to mold and shape. However, they are highly resistant to heat and chemicals, very strong and durable, and have a low level of recyclability. Thermosets account for around 20% of all plastic production and, since they are not suitable for mechanical recycling, chemical recycling is a common method for recycling thermosets [133] even though in some cases (e.g. epoxy resins) their robustness "poses a significant challenge in terms of closed-loop recycling and re-processability." [134] Examples of thermosetting polymers are Polyurethane resin (PUR), Unsaturated polyester resin, Epoxy resins, and Melamine resins.

The **additives** deliver a material's functionality such as pliability, resistance to thermal or UV degradation, and color. On average, 4% of the weight of plastics consists of additives, but different polymers use different amounts. For example, plasticizers can make up over 50% of the total weight of polyvinyl chloride (PVC)-based plastic.[135]

**Fig. 9: Chemicals in Plastics Overview**

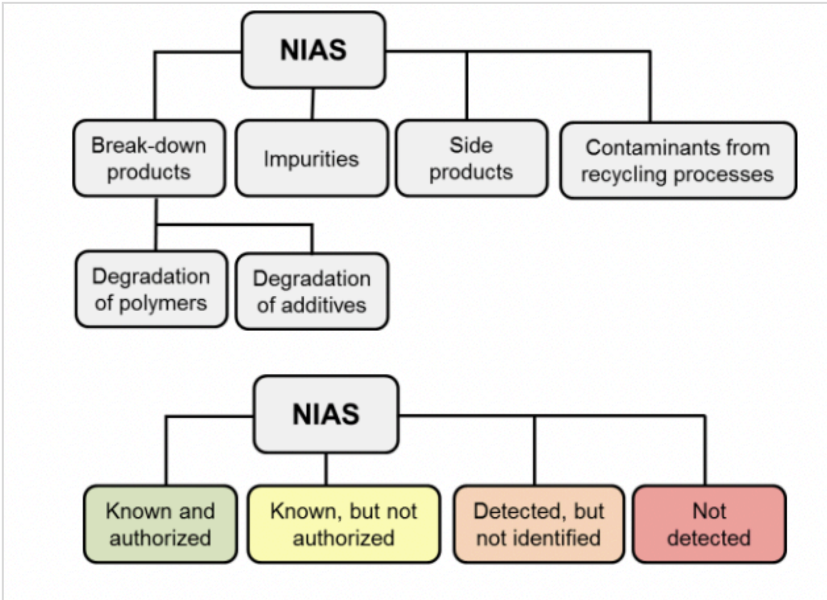



Source: UN Environment Programme

Additionally, **other chemicals** might be present in plastic, including **intentionally added substances (IAS)** such as solvents, unreacted [during the polymerization] monomers, starting substances, and processing aids, as well as **non-intentionally added substances (NIAS)**, which include polymer impurities, reaction by-products[136], breakdown products[137] [138], and contaminants from recycling processes (Figure 8). Some chemicals may also be adsorbed from the environment during plastics' storage, use, and disposal phases.

Many of these added chemicals are highly toxic. They include carcinogens, neurotoxicants, and endocrine disruptors such as phthalates, bisphenols, per- and poly-fluoroalkyl substances (PFAS), brominated flame retardants, and organophosphate flame retardants.

**Fig. 10: Sources and categories of NIAS.**




Source: Birgit Geueke[139]

According to PlastChem's report, there are at least 16,000 known chemicals that are potentially used or unintentionally present in plastics. More than 4,200 of these chemicals (~26%) are chemicals of concern due to their hazardous properties, meeting one or more criteria of being persistent, bioaccumulative, mobile, and/or toxic (PBMT) (Figure 9). Each major polymer type can contain at least 400 chemicals of concern. Rubber, polyurethanes, polycarbonates, and PVC are the most likely to contain such compounds.[140]

**Fig. 10: PMBT Hazard Criteria**

**The 4 PBMT hazard criteria**

| | |
|---|---|
| **Persistence:** long-term presence of a chemical in air, water, soil, or organism | **Bioaccumulation:** the potential of a chemical to stay and accumulate in wildlife and humans |
| **Mobility:** the potential of a chemical to spread in fresh- and drinking water systems | **Toxicity:** the potential of a chemical to cause harm to living organisms |

Source: PlastChem

Many of these chemicals of concern are used, emitted, and released throughout the plastic's life cycle – from the extraction of oil and gas and the production of polymers and chemicals to manufacturing, use, and end-of-life management. These chemicals have been found to be associated with a wide range of acute, chronic, or multi-generational toxic effects, including specific target organ toxicity, various types of cancer, genetic mutations, reproductive toxicity, developmental toxicity, endocrine disruption, and ecotoxicity.[141, 142, 143, 144, 145] They are classified as having these hazardous properties in the United Nations (UN)'s Globally Harmonized System of Classification and Labelling of

Chemicals (GHS)[146] and the European Union's Classification, Labelling and Packaging Regulation (CLP).[147]

Additives are added to plastic for flexibility (softeners and plasticizers), durability against heat or sunlight (stabilizers and antioxidants), color, flame retardancy, and as fillers. But they are an underestimated environmental problem. For example, brominated flame retardants, phthalates, and lead compounds are among the most hazardous additive types. Some brominated flame retardants like polybrominated diphenyl ethers (PBDEs) structurally resemble polychlorinated biphenyls (PCBs), which are environmental contaminants belonging to Persistent Organic Pollutants (POPs), or "forever chemicals."

Additives are known to accumulate in the fat tissues of aquatic animals, causing neurotoxic effects and altering the function of thyroid hormones.[148] Once they have been released, including through incineration of plastic, they persist in the environment, building up in the food chain.[149]

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