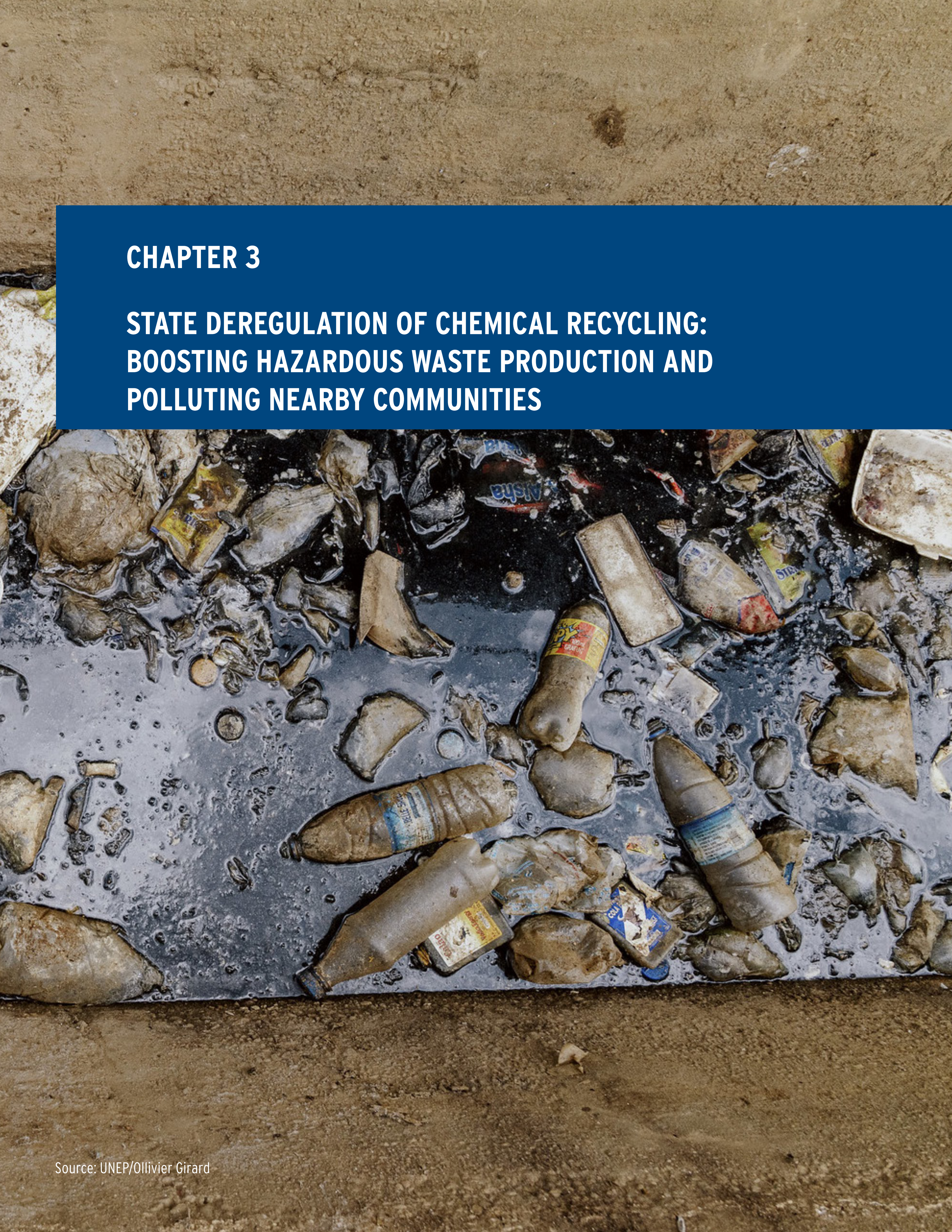

CHAPTER 3

STATE DEREGULATION OF CHEMICAL RECYCLING: BOOSTING HAZARDOUS WASTE PRODUCTION AND POLLUTING NEARBY COMMUNITIES

Source: UNEP/Ollivier Girard

The U.S. petrochemical and plastics industry, spearheaded by the American Chemistry Council, has been highly active in seeking to deregulate or minimize regulations in the chemical recycling sector. They use the term “advanced recycling” to suggest that some new form of novel technology is about to resolve the plastic waste crisis.

In addition, industry lobbies for laws to reduce environmental regulation at the facility level and for public funding of its buildout via subsidies, tax breaks, and other financial incentives. This enormously profitable industry, which can well afford to fund any kind of recycling activity itself, is counting on chemical recycling to distract policymakers into thinking chemical recycling will solve plastic pollution and keep them from restricting plastic production and associated growth in profits.

The attempts to deregulate chemical recycling at the state level are preemptive regulatory strategies to enable chemical recycling plants to avoid strict pollution control laws that would apply to waste incinerators — mostly before regulators are even aware of the environmental impacts of these plants. Instead, the ACC advocates for chemical recycling operations to be treated as “manufacturing facilities” with much lower levels of environmental regulation (see Section 3.1).

As technology assessors are finding out at the highest level of international waste management regulation, data is scant on the hazards, emissions, and waste profiles of chemical recycling, but what is available suggests that grave risks are involved. Currently, 24 states[1] have enacted laws that will regulate chemical recycling as manufacturing processes and not waste management facilities. While this may make it easier for chemical recycling proposals in these states to access funding and support for construction of facilities, federal regulation by the U.S. EPA may still override critical issues related to emissions and other environmental impacts.

Positioning an end-of-pipe solution as a silver bullet was an effective strategy in the 1980s, when plastic pollution generated high levels of public concern. At that time, the plastics industry message[2] to lawmakers was that mechanical recycling of plastic would solve the plastic waste problem. Polymer numbers appeared in recycling triangle symbols on plastic products, consumer education advertising was rolled out, and Americans were encouraged to recycle. Policymakers and regulators were encouraged to let recycling grow and solve the problem.

Forty years later, the recycling “solution” has been an abject failure, with only 9% of all plastic produced having been recycled by mechanical means, while the rest has been dumped, landfilled, or incinerated (Geyer et al. 2017). A great deal of that plastic now circulates the planet as tiny, toxic particles of microplastics in the atmosphere, our food, our water, and our bodies (Sharma and Chatterjee 2017, Jung et al. 2022).

Most observers expect Big Plastic to have a carefully prepared playbook to hold off any kind of regulation that would limit production and profits. But few would expect such an effort to extend to measures like promoting significant deregulation of chemical recycling emissions control, putting neighboring communities at risk — all while pushing for the public to subsidize operations.

Those who will bear the highest of these risks are the nearby residents and workers, many of whom are already impacted by toxic emissions of petrochemical refineries and plastic production facilities. Environmental injustice, or the distribution of high-risk, unwanted land uses in communities of color and low-income communities, will be a key factor in the siting of chemical recycling plants.

Those who will bear the highest risks from chemical recycling facilities are the nearby residents and workers, many of whom are already impacted by toxic emissions of petrochemical refineries and plastic production facilities.

People already bearing an unequal share of the environmental risk imposed by hazardous facilities for the benefit of the wider community should not be forced to endure even greater risks for the failure of the plastics industry to deal with the pollution caused by their products. There is a growing trend for companies to seek to co-locate chemical recycling plants near or alongside existing petrochemical refineries, many of which are located in areas that undermine environmental justice. ExxonMobil has stated it intends to build chemical recycling plants at "many of its other manufacturing sites around the world" and is assessing sites in Louisiana, Illinois, Belgium, and Singapore. Such co-location will further exacerbate local emissions and fire hazard risks.

Those risks could be great. When considering the siting of high-risk polluting facilities, state regulators calculate a standard measure of one additional risk of cancer in a lifetime per 1 million people as an acceptable level of risk for emissions. Sometimes a project will be allowed to proceed under certain circumstances with a higher emission risk level than 1 in a million, but allowing a risk level of 1 to 100,000 is considered very high.

Yet, a proposal by Chevron in Pascagoula, Mississippi, to refine plastic-derived pyrolysis oil into jet fuel was recently assessed by the U.S. EPA as having a public risk[3] factor of 1 out of 4 — a level 250,000 times greater than would normally be permitted. This means that 25% of the local population would likely develop cancer in their lifetime as a result of exposure to the facility's emissions. Dr. Linda Birnbaum, a toxicologist and the former head of the National Institute of Environmental Health Sciences, said of the proposal's emissions, "That kind of risk is obscene; you can't let that get out."[4]

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In the case of the Chevron pyrolysis oil-to-fuel proposal in Pascagoula, Mississippi, an assessment of public health impacts by the "EPA identified skin and eye irritation; acute toxicity; systemic toxicity (neurotoxicity, body weight effects, and liver, kidney, blood, spleen, and other organ effects); reproductive and developmental toxicity; oral and inhalation portal of entry effects; genetic toxicity; and carcinogenicity as hazards of these new chemical substances." (US EPA 2022)

The EPA also noted that the fuel made using plastic-derived pyrolysis oil would lead to food-chain contamination and that "overall, these new chemical substances have the potential to bioaccumulate and be persistent in the environment, such that repeated exposures may cause food-chain effects via accumulation in exposed organisms." (US EPA 2022) The actual specifications of these new substances are redacted in the U.S. EPA consent order as commercial business information (CBI) and are not available to the public.

Investigative journalists have recently uncovered another astounding issue at Chevron's refinery in Pascagoula, Mississippi. In this instance, the EPA approved Chevron's use of a component for boat fuel that was to be made from plastic waste and which had a calculated risk of 1.3 to 1^5, meaning that all people exposed to the chemicals in the fuel over a lifetime would be expected to develop cancer.[6] Instead of the acceptable regulatory limit of 1 in 1 million cancer risk, the risk from the boat fuel equates to a level 1 million times higher — that is, of nearly 1 million people exposed over a lifetime, there would be nearly 1 million excess cancer cases.

However, the emissions from making and burning this fuel are not the only reason for the extremely high risk to the public - indirect risks are also a factor. Indirect impacts include exposure from environmental contamination. Investigative journalists who researched the EPA consent order found that "for every 100 people who ate fish raised in water contaminated with that same product over a lifetime, seven would be expected to develop cancer — a risk that's 70,000 times what the agency usually considers acceptable."[7]

In response to criticism over this and other plastic to fuel proposals at the same facility, the EPA has proposed a rule[8] — which has not been approved — that would allow them to test the oil from the chemical recycling process for contaminants such as dioxin, PFAS and flame retardants before it could be used to make the 18 fuels and associated chemicals listed in the Chevron consent order. It is not clear if the EPA would then be able to prohibit the manufacture of the fuels if the contamination was considered too high. Testing of oils and other outputs from chemical recycling should be mandatory before they are used as fuel or feedstock to prevent widespread contamination of products and human exposure to unacceptable toxic risks.

These risk factors are due to emissions of persistent, cancer-causing compounds from the chemical recycling facilities or their fuel products. Typical emissions from pyrolysis include carcinogenic polycyclic aromatic hydrocarbons (PAHs) (Zhou 2015, Blankenship 1994), volatile organic compounds (VOCs), chlorinated and brominated dioxins, furans (PCDD/DF, PBDD/DF) (Weber and Sakurai 2001; Blankenship 1994; Chen 2014, Rosemann et al 1998; Ortuño et al 2014), and acid gases, such as HCl, heavy metals, ammonia, and sulphur dioxide (Chen 2014). PFAS may also be a contaminant of concern in chemical recycling output, but little information is available on the subject.

While examples such as the Chevron proposals seem extreme, they support the case that all chemical recycling facilities must be subject to full environmental impact assessments, whether new facilities or modifications to existing facilities. The community must be given the opportunity to meaningfully participate in these assessments at the earliest opportunity. Proposals must not be permitted to proceed unless they include measures to monitor emissions and mitigate waste streams to ensure they are within acceptable limits. If proposals are assessed that represent a high risk to the community, they should not be approved. Removing impact assessments and monitoring of all relevant air emissions should not be the primary objective of the chemical recycling industry in seeking to convince lawmakers to regulate the operation of their facilities as manufacturing plants.

Given the detail of the scale of the hazards that are now emerging, environmental justice and siting considerations suggest that it may never be appropriate to locate such facilities in areas of low income, communities of color, and/or other vulnerable communities.

3.1 THE STATE DEREGULATION STRATEGY: INCREASING SUBSIDIES WHILE DECREASING EMISSION CONTROLS

The strategy of the ACC is to convince U.S. state lawmakers to pass bills that significantly deregulate chemical recycling using several key provisions. The most significant provision is to have chemical recycling facilities regulated as manufacturing plants[9] and not as waste management facilities (ACC 2018). This would also require pyrolysis and gasification units to be removed from the classification covering incineration, combustion, or waste-to-energy facilities and be reclassified as manufacturing plants by the state EPA — another rule change being pursued by the ACC[10] on the U.S. EPA level.

This has several flow-on effects, including removal of requirements to monitor many hazardous air emissions, which would be required for waste management facilities, such as waste incinerators. Typically, the U.S. EPA regulates pyrolysis and gasification units as incineration processes with hazardous emissions, requiring monitoring, emission limits, stack bypass limits, and filtration controls. The European Union also classifies these technologies as incineration processes under EU directive 2000/76/EC (WI Directive)[11] and the U.S. EPA continues to regulate pyrolysis and gasification as solid waste incineration processes as it has since, 2005[12] despite recent attempts to change[13] the regulations.

The state-by-state deregulation process may allow much weaker regulation of emissions under the Clean Air Act, including air toxics (e.g., benzene, particulate, VOCs, and PAHs), GHGs, and even POPs emissions (e.g., dioxins and furans) with little or no monitoring, limits, mitigation, or enforcement. These pollutants have frequently been identified in emissions of pyrolysis and gasification technologies, which make up the bulk of chemical recycling proposals. Deregulation may also allow high levels of hazardous waste to be generated, stored on-site, and shifted to other locations with reduced oversight.

The ACC produced a set of guidelines on how U.S. state policymakers and regulators should, in its view, regulate chemical recycling facilities, first in 2014 (ACC 2014) and then with a version dated 2018 released in 2021 (ACC 2018). At the core of the ACC regulatory proposal is its claim that the mixed plastic waste received at a chemical recycling facility is not, in fact, mixed plastic waste. In yet another variation on the term chemical recycling, the ACC renames such facilities “plastics-to-fuel and petrochemistry” (PTFP) plants and claims they do not burn or combust plastic or waste (ACC 2018), hence they should not be regulated as solid waste disposal facilities.

The Basel Convention (see Section 4.2.1) classifies these facilities as waste disposal operations if they produce fuel from plastic waste. Such plants are coded as “Annex IV Disposal Operations Part B, R1 — Use as a fuel or other means to generate energy.” If the plastic waste is combusted without energy recovery, the facility is considered Annex IV Disposal Operations Part A, D10 — Incineration on Land. At the 2023 Conference of the Parties of the Basel Convention, an unsuccessful attempt was made to insert chemical recycling as an “Annex IV Part B Operation R3 — Recycling/Reclamation” of organic substances that are not used as solvents (see Section 4.1.1), in hope of codifying these technologies as recycling. In any of these operational interpretations, chemical recycling would be defined internationally as a waste disposal operation, not a manufacturing operation.

The ACC’s claims that it does not handle mixed plastic waste are not credible. It suggests companies will be paid to receive “mixed plastics” and has coined a new category for these materials: non-recycled plastics (NRP) instead of solid waste or plastic waste (ACC 2018). It is not clear if the ACC means post-industrial, post-consumer mixed plastics, or some form of residual plastic waste left after recyclable material has been removed.

The ACC notes that chemical recyclers may be paid a fee to take these “clean pre-processed” materials, which they describe as “sorted and graded feedstock.” But they fail to explain why the generators of these non-recycled plastics would clean, sort, and grade them for the chemical recycling facility and then pay the facility to take them.

Despite the ACC’s claims that plastic arriving at chemical recycling plants will be clean and sorted, their guidance discusses the need to dump ”off-spec feedstocks” that are contaminated, as well as “process wastes.”

The ACC guidelines have several internal contradictions. They claim chemical recyclers will not combust plastic or waste, but acknowledge they will have flares to combust contaminated waste gases from heating plastic. “Alternately, these gases may be fully combusted without energy recapture to destroy certain compounds,” said the ACC in 2018.[14]

The ACC also admits chemical recyclers will resort to burning gases produced by heating plastic waste, including “combustion of any vaporized portion of the plastics that cannot be condensed into liquid petroleum products” and “combustion to supply electricity.” These gases can be of very large volumes, with ACC claiming they constitute “10% to 15% of the mass of the vaporized plastics and can be combusted like natural gas in commercial-scale PTFP systems to provide process energy” (ACC 2018). By any account, it is not possible to conclude that chemical recyclers will be doing anything other than burning a large part of the waste they receive.

The ACC asserts that pyrolysis is not “combustion” or “incineration” because the process is an “oxygen-free environment” (ACC 2018 p 3, 11). However, it neglects to mention in its guidelines that many polymers, such as polyester and polycarbonates, contain a significant amount of oxygen in their chemistry. However, the ACC does acknowledge this on its website under “Facts and Highlights”: “The term ‘plastics’ includes materials composed of various elements, such as carbon, hydrogen, oxygen, nitrogen, chlorine, and sulfur” (ACC 2023).

This is an important omission, as U.S. regulators are aware that heating wastes containing carbon and chlorine in the presence of oxygen has similar potential to generate emissions expected from incinerators, such as chlorinated dioxins, PAHs, chlorinated VOCs, and other highly hazardous chemicals. By claiming an “oxygen-free” process for pyrolysis, promoters of chemical recycling are hoping to avoid categorization as incinerators and regulation as persistent organic pollutant (POP) emitters, particularly of highly toxic dioxins.

Also, in trying to claim an oxygen-free process, the ACC only describes the initial pyrolysis reactor component. But the flaring of plastic waste vapor and its combustion as process fuel are all indisputably incineration operations involving combustion with oxygen. If outputs of the chemical recycling process are used as fuels beyond the facility, then there is also potential for the contaminants to be released into the atmosphere, increasing human exposure.

By trying to obscure the formation of highly toxic chemicals, such as dioxins, caused by oxygen in pyrolysis, promoters of chemical recycling hope to conceal the fact that the gases, char, and hydrocarbon output of their process may also be contaminated — a situation the incineration industry has never been able to overcome, as it is highly regulated for these substances, especially in the EU.

Indeed, it is difficult to reconcile the “low-emission” PTFP facilities described by the ACC in its 2018 guidelines for regulators with the 2023 Chevron PTFP proposal in Pascagoula, Mississippi, which was assessed by the U.S. EPA as having an astronomical public cancer emission risk factor of 1 to 4.

The classification as a manufacturing facility can also have financial benefits for the operators opening the door to access state tax benefits and potentially to government bonds for construction support.

The classification as a manufacturing facility can also have financial benefits for the operators opening the door to access state tax benefits and potentially to government bonds for construction support. A proposal by Brightmark for a plastics-to-fuel operation in Bibb County near Middle Georgia Regional Airport came close to securing $500 million in exempt facility revenue bonds[15] from the Macon-Bibb County Industrial Authority. If the agreement had been signed, the county would effectively have been endorsing the proposal, signaling reduced risk, which would attract investors who would also avoid state and federal tax on any interest on the bonds.

While there was no direct financial risk to the county, its reputation[16] in the bond market would have been at risk[17] if the proposed Brightmark facility turned out to be unprofitable and investors lost money. In turn, this could have had implications for the ability of the county to raise funds in the future. Although this project was rejected after failing to meet administrative deadlines while facing community opposition, an earlier Brightmark plastic-to-fuel plant in Indiana claims to have been operating at pilot scale, but has not been reported to be producing any output. (Other examples of chemical recycling facilities in the U.S. receiving different forms of public subsidies are detailed in Appendix 1: U.S. Case Studies.)

The attempts to pass state laws minimizing regulation of chemical recycling are a political ploy to hide the true environmental and health risks associated with this process.

The attempts to pass state laws minimizing regulation of chemical recycling are a political ploy to hide the true environmental and health risks associated with this process. Attempts to politicize such risks have also been seen at the federal level. Toward the end of the Trump administration, the U.S. EPA proposed a new rulemaking stating that pyrolysis is not combustion and thus should not be regulated as incineration, aligning itself with the ACC's advocacy for state bills that deregulate chemical recycling.

However, in September 2021, the Biden administration re-examined the EPA proposal and opened it to public comment. In July 2022, 35 members of Congress wrote to the EPA urging them to retain the definition of pyrolysis and gasification as incineration with all the emission controls that are warranted for such technology.

The lawmakers pointed out that,"[C]hemical recycling facilities emit highly toxic chemicals — including benzene, toluene, ethyl benzene, xylenes, and dioxins — many of which are linked to cancer, nervous system damage, and negative effects on reproduction and development. 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."

More recently, similar concerns were raised by federal lawmakers in a House Appropriations Committee report[18] related to the federal budget that called for the U.S. EPA to continue to regulate chemical recycling as incineration and ensure that strict clean air requirements were met. At the time of writing this report, no decision had been finalized by the U.S. EPA on this matter. The attempts by the plastics industry to pre-empt federal U.S. EPA regulations on emissions control from chemical recycling through a state-by-state deregulation campaign may yet prove to be ineffective.

However, if the industry push to remove emission controls at both the state and federal level is successful, local communities can expect more carbon emissions, microplastics pollution, air toxics emissions, ramped-up hazardous waste generation, and even threats to waterways.

3.1.1 COMMUNITIES' RIGHT TO KNOW

Citizens cannot fully participate in the democratic decision-making process for waste management facilities in their community unless they have been informed of the typical and worst-case scenarios associated with their operation.

In many countries, an environmental impact assessment (EIA) or similar public consultation processes are conducted where the proponent of a new or expanded facility is required to detail the anticipated emissions, releases, and other environmental impacts of the facility, including increased traffic, lighting and noise impacts, visual pollution, and specific impacts on local protected species or natural features.

The proponent is typically required to release a report detailing all relevant impacts, including emission types, concentrations, and volumes; ground-level concentrations; stack heights; air pollution control equipment; mitigation measures (process controls); seasonal emission fluctuations (inversion layers, wind directions); hazardous waste management; stockpile management; fire control and emergency response; and much more.

Key issues, such as worst-case emission scenarios during OTNOC (other than normal operating conditions) for the facility when filters and flares break down, must also be detailed. Opportunities to make these impacts transparent through an environmental impact assessment (EIA) process will mostly be lost if the facility enjoys weaker regulatory oversight as a manufacturing facility.

The EIA report should be open to public and expert comment, and if the risk of operation is deemed by the public to be too high, it should not proceed. If the local community already faces numerous risk facilities and significant emissions (i.e., environmental justice considerations), the impact of any additional plant must be considered as part of a cumulative assessment and not as a single facility divorced from the context of the reality on the ground.

In addition, chemical recycling facilities should have a social license to operate (Bice and Moffat 2014) and this can only be obtained via transparency about the impacts of the facility. A social license to operate refers to the level of acceptance or approval by local communities and stakeholders of industrial operations in their community. It is not a regulatory or legal permit, but it is in the interests of the facility operator to ensure the community is not opposed to the project. Some projects present such significant risks to the community that they may never be accepted.

In the next section, more detail about the impacts associated with chemical recycling are outlined with a specific focus on the intrinsic toxicity of plastic and how this contributes to high levels of pollutants from the chemical recycling process.

3.2 PLASTICS IN, TOXICS OUT (PLUS CLIMATE CHANGE IMPACTS)

Nearby communities around chemical recycling plants are right to be concerned about the impacts of the facilities, which will be handling and stockpiling plastic waste, as well as processing it in ways that generate hazardous emissions and toxic waste streams — all while increasing the risk of significant plastic waste storage fires and microplastic releases.

Several factors influence the risks faced by communities around a chemical recycling facility. These include the toxicity of the plastics and the additives they contain, the creation of additional toxic compounds in the processes used, the use of hazardous agents in the process, and the generation of hazardous wastes from the processes (UNEP 2023). In addition, stockpiling and processing of plastic waste at such facilities releases microplastics (Brown et al. 2023) and increases the risk of fires with hazardous emissions and long-term soil contamination. Carbon emissions from chemical recycling are also high and will contribute to climate change at local and global levels, especially if the industry scales up.

A recent study[19] found that greenhouse gas emissions from plastic waste pyrolysis were likely to be between 10 and 100 times higher than those emitted from the production of virgin plastic. If carbon pricing mechanisms were applied, it could render chemical recycling unviable.

Chemical recycling claims to be able to recover either monomers, polymers, or hydrocarbon mixes that can be used as plastic feedstock from mixed plastic wastes. This report makes it clear that in most cases, mixed plastics are not suitable for chemical recycling (see Technical Addendum 2.4). However, if it is to be assumed that chemical recycling can "extract" useful materials from mixed plastic waste, it logically follows that the process separates "contaminants" from the target chemicals/polymers, creating a hazardous waste stream.

3.2.1 TOXIC ADDITIVES IN, POLLUTANTS OUT

The majority of these contaminants will be chemical additives, intentionally or otherwise present in the waste feedstock. As many are hazardous, they will form a significant hazardous waste stream at each facility, due to the large volume of plastic needed to make the plant economically viable (see, for example, the Alterra case study on page 85 of Appendix 1). This may take the form of contaminated char, sludges, filter residues, effluents, and emissions.

The lower the yield from a chemical recycling process, the greater the hazardous waste stream. In many cases, contaminated gas from the process will be flared — a process of gas incineration, which has the capacity to contribute further contaminants like dioxins, particulates, and other products of incomplete combustion to the emissions of a facility.

At least 3,200 plastic additives have been identified as substances of potential concern, based on their hazardous properties (Aurisano et al. 2021, Wiesinger et al. 2021), including carcinogenicity, mutagenicity, reproductive toxicity, endocrine disruption, and ecotoxicity to aquatic organisms, according to the UN Globally Harmonized System of Classification and Labelling of Chemicals (GHS) and the European Union's Classification, Labelling and Packaging Regulation (CLP) (European Commission 2008).

Many of these toxic additives have the potential to contaminate plastic waste streams, emissions, and outputs of chemical recycling. There is little transparency about or regulation of the additives used in plastic formulations, which contributes both to human exposure and problems with plastic recycling.

The toxicity of plastics varies between polymers and is heavily influenced by the type of additives that are used to impart different properties to plastic products, including colorants, flame retardants, UV stabilizers, plasticizers, and so on. Virtually all plastics contain combinations of additives, and some are more toxic than others.

The chemical additives business is a major global activity, and various market analysts place the plastic additives sector's current market value at between $30 billion to $50 billion, with a compound annual growth rate (CAGR) around 4% to 5%[20] by 2032. Many market analysts vary in their predictions, but the CAGR and total value tend to be of the same order of magnitude. Much of this growth is predicated on future demand and production increases for plastics, which require increasing volumes of additives to form products. Some polymers have intrinsic toxicity even before additives are used in the formulation.

Table 2 The Types of Toxic Additives Commonly Used in Plastics in a Multitude of Combinations

Flame retardants	Bisphenols	Biocides
Per- and polyfluoroalkyl substances (PFASs)	Certain alkylphenols and alkylphenol ethoxylates	UV stabilizers
Phthalates	Polycyclic aromatic hydrocarbons	Metals and metalloids

Many of the thousands of chemicals used as additives in polymers are hazardous and can be released from the plastic products via a range of pathways that cause human exposure (Hahladakis et al. 2018). While additives are major contributors to the toxicity of plastics, some monomers — the building blocks of polymers — are also toxic to humans. Common monomers and their toxicities include:

- Acrylonitrile: human carcinogen (liver, brain);
- Vinyl chloride: human carcinogen (liver);
- Formaldehyde: animal carcinogen (nasal) and human carcinogen (can cause leukemia and cancers of the nose, throat, and sinuses);[21]
- Methylenedianiline: suspect human carcinogen (Gad 2005); and
- Bisphenol A (BPA, IUPAC ID: 4,4ğ-(propane-2,2-diyl)diphenol). (Human Developmental Toxicity, Female Reproductive Toxicity)[22]

3.2.2 NON-INTENTIONALLY ADDED SUBSTANCES (NIAS)

NIAS are not added to improve the polymer product, but include breakdown products of polymers during virgin production and use, impurities in starting materials, unwanted byproducts, and various contaminants from recycling processes (Geueke 2018). They may also include organic contaminants from the mixed waste collection process. When plastic waste is removed from the ocean, NIAS may also include chemicals, some that are POPs such as PCBs and dioxins, that adsorb (bind) to the plastic from ocean pollution. Breakdown products can evolve from polymers, additives, and processing aids (which can include PFAS compounds to help with plastic extrusion, etc.) — for instance, hazardous volatile organic compounds (VOCs) such as toluene, xylene, or ethylbenzene (Kato and Conte-Junior 2021).

Contaminants can occur in both additives and raw materials for polymer production (Roosen et al. 2020). One example is the presence of brominated furans in commercial brominated flame-retardant additives (Wahl et al. 2008). Output products from pyrolysis can become contaminated within the process, and these contaminants can be transferred back to polymer products if outputs are used for plastic feedstock, thereby perpetuating a chain of contamination into new plastic products (DiGangi et al. 2017).

In virgin polymer production, side reactions occur as the starting substances, materials, and additives are mixed in subsequent steps and can generate NIAS (Kato et al. 2021). While the main reactions are important to determine the properties of the polymer, side reactions also occur that can result in NIAS formation, but this is rarely measured. Contaminants can also enter plastics previously recycled and continue through the chemical recycling chain. These include legacy additives, such as prohibited POPs (e.g., PBDEs, PCBs, and SCCPs) and the transfer of pesticides from recycling of plastic pesticide containers (Eras et al. 2017).

3.2.3 PERSISTENT ORGANIC POLLUTANTS

Many chemicals have been used as additives in plastics that have subsequently been assessed as persistent organic pollutants (POPs). These are among the most dangerous and toxic chemicals ever developed and are prohibited or otherwise regulated by the Stockholm Convention on Persistent Organic Pollutants (see Section 4.6). They include polybrominated diphenyl ethers (PBDEs) and hexabromocyclododecane (HBCD) used as flame retardants, short-chain chlorinated paraffins (SCCPs) used as plasticizers, polychlorinated biphenyls (PCBs) used as plasticizers and flame retardants, and others. Plastics in electronic waste casing and automotive upholstery can contain very high levels by weight of brominated flame retardants. Large stockpiles of plastic waste still exist that are contaminated with POPs and are not easily separated as they are often mixed with other plastics.

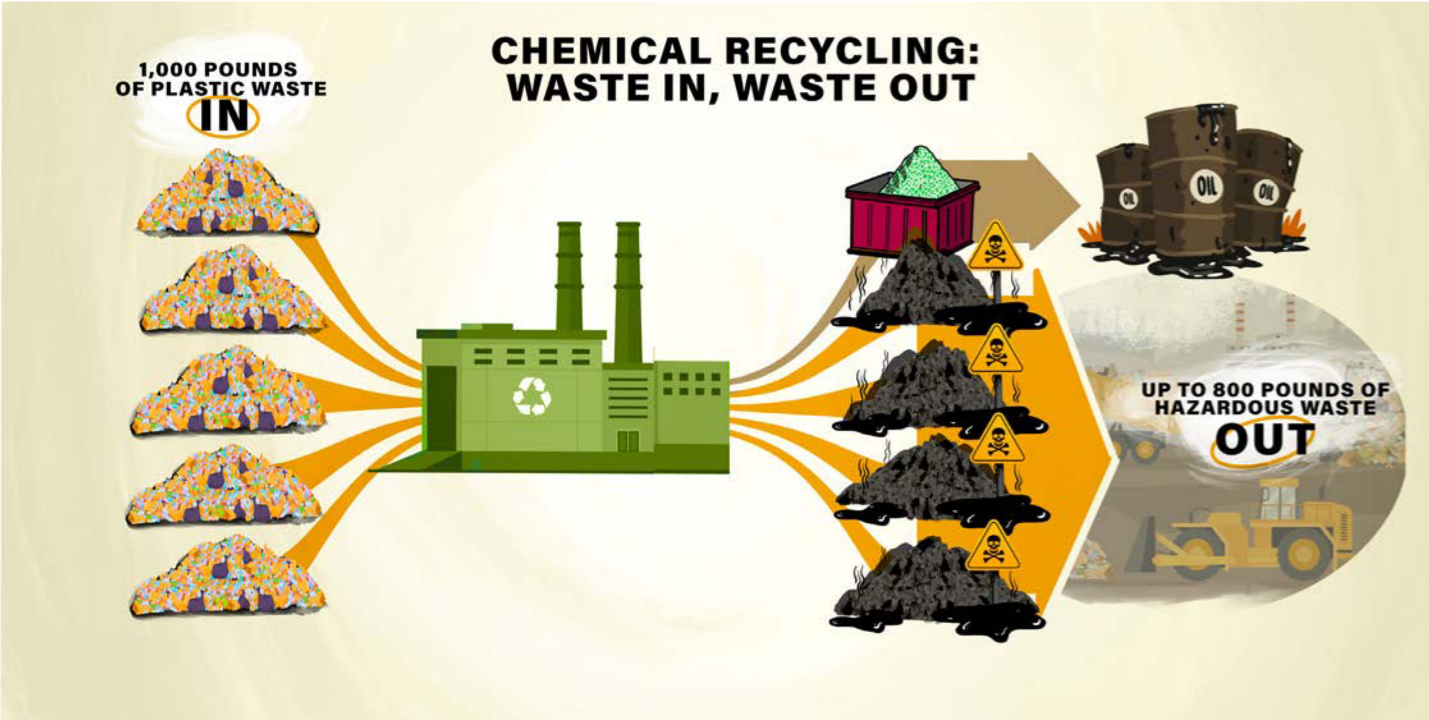
Plastic waste may also contain unintentional POPs (UPOPs) as a result of its production, usually carried into the plastics as contaminants in plasticizer additives (Takasuga et al. 2012), color pigments (Anezaki et al. 2015; Government of Japan 2006;), or as degradation products of polymerization catalysts (Herkert et al. 2018). PBDD/DFs (brominated dioxins and furans) have been identified as NIAS in plastics containing PBDEs or other BFRs (Weber and Kuch 2003; Sindiku et al. 2015). These brominated dioxins have been identified as being transferred via mechanical recycling into new products, including toys (Petrlik et al. 2018; Budin et al. 2020).

At the 2023 Conferences of the Parties to the Basel, Rotterdam, and Stockholm Conventions, two widely used plastic chemicals, the phenolic benzotriazole UV stabilizer UV-328 and Dechlorane Plus, a flame retardant for polymers, were added to the Convention's list of globally banned POPs chemicals. Other chemicals used in plastics are under consideration for listing.

3.3 HAZARDOUS WASTE GENERATION AND EMISSIONS

As mentioned above, when the target monomers/polymers or hydrocarbon outputs are obtained from the chemical recycling process, they are termed the "yield" — which, for pyrolysis, is typically relatively low, at 20% to 30% of plastic waste input, meaning up to 80% of the plastic waste going in for "recycling" is actually lost as process fuel, emissions, or becomes hazardous waste consisting of additives, NIAS, POPs, non-target hydrocarbons, and a range of chemicals that are produced in the process as side reactions. These include PAHs, dioxins/UPOPs, VOCs, heavy metals, and other contaminants. These non-target materials become solid wastes, oily wastes, gaseous wastes, char, and liquid effluents (depending on the emissions scrubbing system), and all are hazardous.

The Regenyx so-called "plastic-to-plastic" facility in Tigard, Oregon, United States — owned by parent company Agilyx — claims to convert polystyrene back to usable styrene feedstock using pyrolysis. However, in 2015, Agilyx reported to the U.S. EPA that much of the styrene output from its facility (totaling 165 tons) supposedly intended for polystyrene feedstock was actually sent for incineration.[23] Data submitted to the U.S. EPA in 2019 indicated the plant sent 283 tons[24] of hazardous waste off-site for incineration and co-processing in cement kilns, consisting of corrosive waste, cadmium, chromium, lead, selenium, benzene, 1,2-dichloroethane, vinyl chloride, and other ignitable wastes.



Plastic waste must be stockpiled to allow sufficient uninterrupted supply of inputs for the chemical recycling process. Such stockpiles are well-known fire risks and, if stored on-site with large volumes of hazardous waste from the chemical recycling process, could represent a serious danger to the surrounding community. Hazardous waste streams from chemical recycling will be significant. If a facility claims 100,000 tons per year throughput of plastic waste and has a very high yield (output product) of 50%, then it could be assumed that the other 50% of input material (50,000 tons per year) will have become waste in the form of gas, char, or unwanted hydrocarbon fractions. The lower the yield, the more waste is created.

Pyrolysis units produce oils and gas and generally have a flare to burn dirty gaseous emissions during startup and shutdown, as well as gas released to keep pressure within safety specifications for the unit during emergencies (Elsdon and Pal 2011). Flaring of contaminated gases from these units will release some entrained pollutants, such as VOCs and PAHs, into the local atmosphere (Kindzierski, 1999) and may create new combinations of pollutants, such as dioxins, which are carried on fine particulates from the flares.

Many unknown products of incomplete combustion may also be released from flares, including benzene and naphthalene, carbon black particles (Fawole et al. 2016) CO, and partially burned and altered hydrocarbons and BTEX (Mirrezaei and Orkomi 2020). Also emitted are nitrogen oxides (NOx) and — if sulfur-containing material, such as hydrogen sulfide or mercaptans, is flared — sulfur dioxide (SO2) (US EPA Emission Factors – Industrial Flares).

However, the exact composition of emissions from any chemical recycling facility will depend on the input plastic waste types and operational controls. For example, if high levels of PVC and brominated WEEE plastics are used, brominated and chlorinated dioxin levels can be expected to be much higher, due to the precursor levels of chlorine and bromine in the system. Contaminants identified in flue gas from plastic pyrolysis plants include dioxins, PCBs, and large quantities of VOCs, including mono-aromatics, oxygenated VOCs (O-VOCs), chlorinated VOCs (Cl-VOCs), and acrylonitrile (He et al. 2015, An et al. 2014; Paladino and Moranda, 2021).

As an example of the volume of gas burned, the photo on this page shows an under-construction pyrolysis facility that will make fuel from plastic waste using a flare to burn off excess syngas from the process. The Brightmark plant in Ashley, Indiana, intends to process 100,000 tons of plastic waste per year. Most of the gas produced from pyrolysis of plastic waste will be mixed with natural gas to power the plant, leading to contaminated emissions that may exceed safe regulatory limits.

Brightmark Energy facility in Ashley, Indiana. Source: The Last Beach Cleanup

Produced waxes are proposed to be sent for commercial use in candle manufacture, and no information is available about potential contamination of the wax. The solid char is proposed to be dumped at a non-hazardous waste landfill, but no information is provided on heavy metal, dioxin, PCB, or other POPs levels in the char, all of which are key determinants of hazardous waste.

In December 2021, Brightmark provided documents to the EPA noting that just 20% of the output of the facility is fuel, the business's primary product. Around 70% is output syngas that will be mixed with natural gas to produce process heat. (Twenty percent of that syngas will be incinerated in an open flare.) The balance is solid char, which has not been tested for POPs content.

Flares and other emissions stacks are the key day-to-day sources of hazardous air emissions with any chemical recycling facility, although fugitive emissions (those which escape from other points in the process and are unfiltered) may also represent a hazard. Solvent-based chemical recycling has the potential for fugitive emissions, due to the volatility of some solvents used, and may also use flares (see Technical Addendum Sections 2.3 to 2.3.3). Solvent-based chemical recycling will also generate hazardous waste, as it specifically seeks to separate useful monomers/polymers from the mixed plastic waste with a range of solvents. In many cases, the solvents themselves are hazardous and/or flammable, and even if recyclable, a certain fraction will be as waste fraction or as a byproduct of the process.

3.4 MICROPLASTICS AND CONTAMINATED WASTEWATER

Stockpiling, shredding, cleaning, and other pretreatment of plastic waste at recycling plants has recently been found to be a major source of microplastic pollution, especially in wastewater released from such facilities. In one study, up to 13% of all incoming waste ended as microplastics waste at the facility (Brown et al. 2023).

At the Brightmark, Indiana, chemical recycling facility, which shreds and pelletizes plastic waste on-site before feeding it into six pyrolysis units, an employee has claimed their lung injuries followed from exposure to microplastic dust. The facility has also recently experienced several fires and significant oil spills. These problems have occurred even before the plant is commercially operating, with an inspector[25] from the Indiana Department of Environmental Management noting that it "has yet to create product on-site."

Other forms of water pollution from chemical recycling facilities can also impact fenceline communities when wastewater is discharged to local waterways. As water use is very high at some plants for washing plastic waste and process cooling, wastewater volumes can be significant. Microplastic pollution from wastewater has been identified as a potential problem at plastic recycling plants (Brown et al. 2023), and PFAS and phenol contamination of waterways may also occur (see Technical Addendum Section 2.5).

Fire at New Hope Energy's Trinity Oaks plastics recycling plant in Tyler, Texas. Source: City of Tyler Fire Department

3.5 FIRES AND EXPLOSIONS

Since China's National Sword Policy, which banned the importation of certain types of solid waste, including plastic, plastic waste stockpiles in the U.S. and other OECD countries have multiplied and grown rapidly, and in many cases pose fire risks. Since plastic wastes are petrochemicals, they are flammable, and stockpile fires are difficult to extinguish. In the U.S., plastic waste stockpile fires have been increasing in both size and severity, though not all such fires are reported in the media. The U.S. nonprofit group The Last Beach Cleanup has been mapping plastic-waste fires[26] that are reported in the U.S. (see Figure 7).

Plastic waste stockpile fires release a complex cocktail of poisonous chemicals, including air toxics such as volatile organic compounds, benzene, chlorine, and hydrogen cyanide, and particulates that are sometimes monitored[27] by the U.S. EPA and other emergency response officials. Open burning of plastic waste has also been demonstrated to contaminate soil and the food chain with brominated and chlorinated dioxins (PBDD/DF and PCDD/DF), polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers, per- and polyfluoroalkyl substances (PFAS), hexabromocyclododecane (HBCD) compounds, and a range of other highly toxic persistent organic pollutants (Petrlik, et al. 2021a, Petrlik et al. 2021b).

Very high levels of dioxin and other POPs were found in chicken eggs at many locations around the world where plastic waste had been open-burned on the ground or burned as a fuel. While chicken eggs are effective indicators of local soil contamination as chickens forage from the soil, humans can be impacted by exposure to the contaminated soil and dust blown around following a fire. The persistence of some of these highly toxic chemicals means they can recirculate in soil and dust through the community for many years without breaking down.

Process fires from the operation of solvent-based and pyrolysis facilities can also be expected. Even though not yet fully operational, the Brightmark, Indiana, facility has already had several fires,[28] including reactor fires that resulted in releases of contaminated process vapors that ignited and developed a fire jet from the reactor that was difficult to bring under control. The New Hope pyrolysis plant in Tyler, Texas, also suffered a fire in 2020.[29]

In other countries, there have been several major fires and explosions at pyrolysis plants. In 2020, a plastic waste pyrolysis plant near a school in the town of Egebjerg, Denmark, experienced a major explosion, causing damage to the equipment. It exploded again in 2021, resulting in plastic waste stockpile fires and the complete destruction of the plant. The cause was attributed to flammable pyrolysis vapors self-igniting (Hedlund 2023). This was also the cause of a fire at the Brightmark, Indiana, facility. In Finland in 2014, the Fortum Power and Heat Oy in Joensuu suffered a significant explosion[30] due to nitrogen levels (used to suppress oxygen ingress to the reactor) dropping below acceptable levels due to a system blockage. Three workers were injured.

These incidents sometimes occur because pyrolysis is an inherently dangerous process using flammable gases under heat and pressure. Unless high levels of risk assessment and hazard mitigation as well as strict operating procedures are observed, the possibility of fire, explosion, and toxic gas release remain a concern.

Figure 7 Fires at U.S. Plastic Recycling Facilities

Source: The Last Beach Cleanups

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