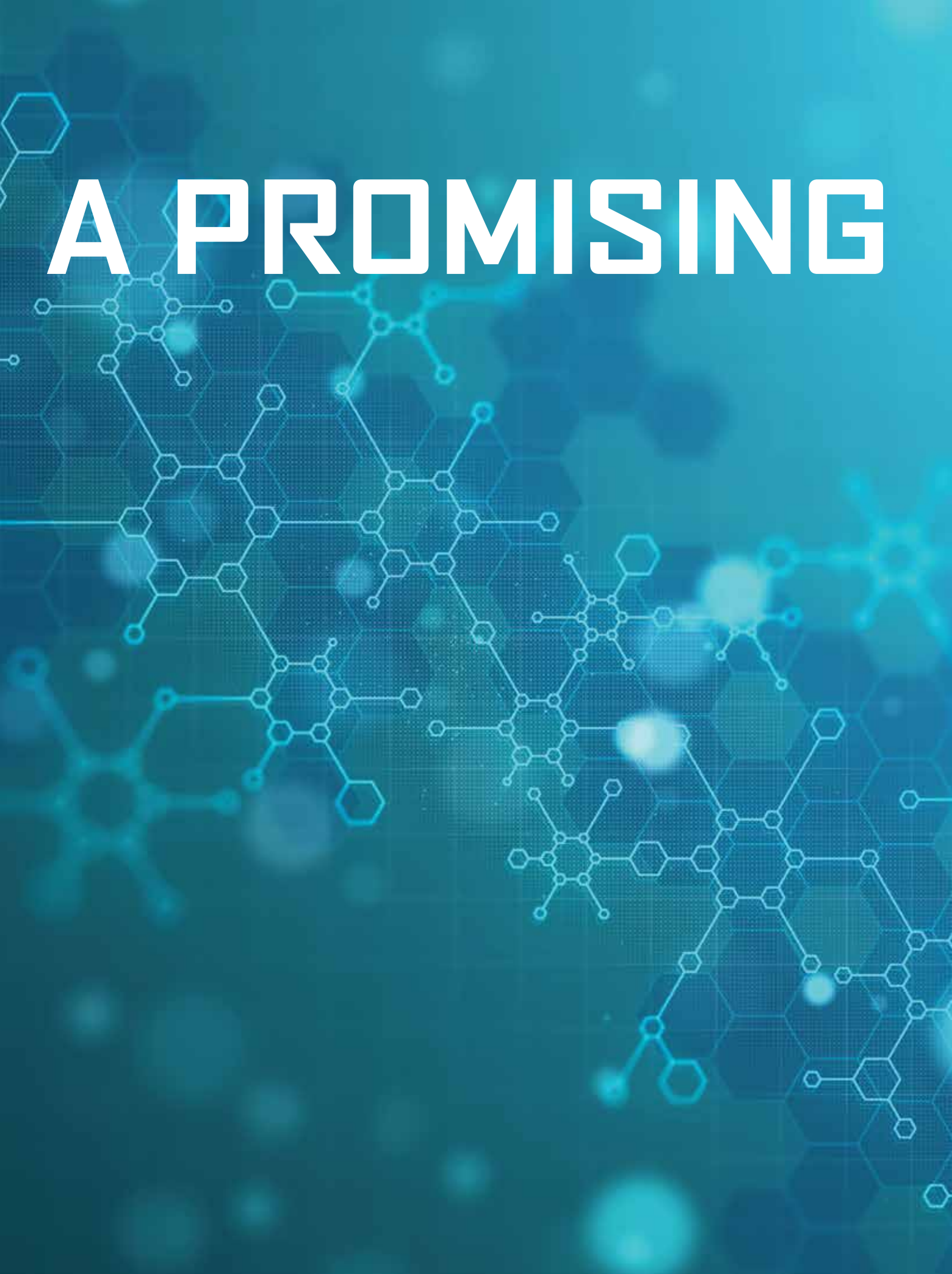
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CHEMICAL RECYCLING CAN TURN PLASTICS THAT MIGHT OTHERWISE GO INTO THE LANDFILL INTO SALABLE COMMODITIES. BUT IT WILL TAKE TIME—AND MONEY—FOR THESE TECHNOLOGIES TO SHOW THEIR FULL POTENTIAL. **BY MEGAN QUINN**

On a summer day in Troutdale, Ore., fans at an outdoor concert series sipped cold beers from plastic cups and waited for the headliner to take the stage. They were likely more focused on the performers than on what they would do with their cups once they threw them away.

Single-use plastics like beer cups rarely get recycled. Yet in the last 10 years or so, a steadily growing industry has taken an interest in collecting hard-to-recycle plastics and putting them through a process they call chemical recycling. The process breaks down plastics to their molecular-level building blocks such as monomers, polymers, and hydrocarbons. These can become feedstock for new products, such as new plastics, fuel, or additives for manufacturing processes. The polystyrene cups used during dozens of concerts at the Troutdale venue, McMenamins Edgefield, end up at Agilyx, a chemical recycler that creates new PS from chemically recycled styrene monomers. Last summer, about 2,000 pounds of PS from the concert series went to Agilyx's facility in Tigard, Ore.

Agilyx is one of more than 60 companies that are in some stage of building chemical recycling capacity. The timing couldn't be more critical, says Phil Torchio, owner of The Broomsmen (Bend, Ore.), the event recycling company in charge of collecting the polystyrene cups and delivering the plastic to Agilyx. Recyclers are grappling with changing or disappearing markets for some recycled materials due to Asian import restrictions, and news outlets are covering the problems of marine plastics more than ever, he says. At the same time, big brand owners such as Nestlé and Danone pledge to include more recycled plastic in their products.

Torchio and other proponents of chemical recycling say this new technology has the potential to change the way recyclers handle end-of-life plastics, especially single-use plastics and other plastics that don't traditionally make it into the recycling stream. "It's a way to give a home to materials that are otherwise being landfilled," he says. "The plastic is already out in our world, and we need to close the loop. Chemical recycling is a way to close that loop because these materials do have a value."

THE BROOMSMEN; GETTY IMAGES/PESHKOVA

A special sorting station at an outdoor concert venue in Oregon keeps polystyrene drink cups separate from other recyclables and trash. Chemical recycler Agilyx turns the plastic scrap into a recycled styrene monomer used to create new PS products.

Polystyrene joint venture Regenyx can process up to 10 tons of PS a day, but the company has plans to build a facility on the West Coast that aims to process up to 50 tons a day. The material comes from commercial, industrial, and municipal sources.

Chemical recycling has "enormous potential," but the process has a long way to go before it can really make a dent in the world's plastic problems, says Raj Bakaya, head of business development at Renewlogy (Salt Lake City), a chemical recycler that creates fuel from plastics. Chemical recycling "has graduated out of the demonstration stage, but it's still in early adoption," and many of these startups haven't yet had the time or the funding to show their technologies can work on a large scale, he said during an ISRI webinar about chemical recycling in June. Bakaya believes chemical recycling might be mainstream in as little as five years, but for now, the effort is growing in fits and starts. "Some of these companies are already producing high-quality products. Some are producing lower quality [products]. They all use different waste streams. But it's great that there are so many solutions available, and no two are alike."

MARKET POSSIBILITIES

Last year, Closed Loop Partners (New York), an organization that invests in advanced recycling methods and circular economy efforts, began to research the impact chemical recyclers might have on the recycling industry in the United States and Canada in the next few years. The group's market landscape report, "Accelerating Circular Supply Chains for Plastics," examined dozens of chemical recycling plants, ranging from those in the research stage to those in full commercial production. Only about a dozen chemical recycling companies have full commercial production capabilities, but Bridget Croke, vice president of external affairs for Closed Loop Partners, says she expects that number to grow if these companies can get the right kinds of investment.

Chemical recycling is neither a silver bullet that will solve every plastics recycling woe nor a replacement for mechanical recycling, Croke said during the webinar. Yet these new processes may be able to address the growing demand for plastic in North America by creating feedstock from material that normally goes straight to the landfill, she said. North American plastic demand in 2018 was 38 million mt, according to IHS Markit, and recycled plastic met just 6%, or 2.5 million mt, of that demand. More brands and manufacturers are committing to using recycled materials in their products, which will create new demand for recycled plastics that could reach between 5 million and 7.5 million mt by 2030, according to the report.

Chemical recyclers have the opportunity to access some of the estimated 34 million mt of plastic that the United States and Canada landfill or incinerate each year. If they do, they have potential revenue opportunities of $120 billion in just the United States and Canada, the report states. "It all comes down to meeting market demand," says Prapti Muhuri, manager of the American Chemistry Council's (Washington, D.C.) plastics recycling and recovery division and a representative of the Chemical Recycling Alliance, a group of chemical recycling technology owners and other stakeholders who want to increase awareness of and support for chemical recycling initiatives. "Demand is strong, but we need to strengthen post-use collection to provide a reliable stream of feedstocks."

WHAT IS CHEMICAL RECYCLING?

Chemical recycling is "definitely not a uniform technology. It's more of a category" of technologies, Croke says. Each company uses a different feedstock and a different method for breaking the plastic down, and each has different requirements for how clean or well-sorted the plastic needs to be—and what size or shape—before it enters the chemical recycling plant.

One of the three most common chemical recycling methods is *purification*, which dissolves plastic in a solvent, then separates and purifies the mixture to extract additives and dyes. What's left is a purified plastic manufacturers can use to make new products. The *decomposition* method,

AGILYX

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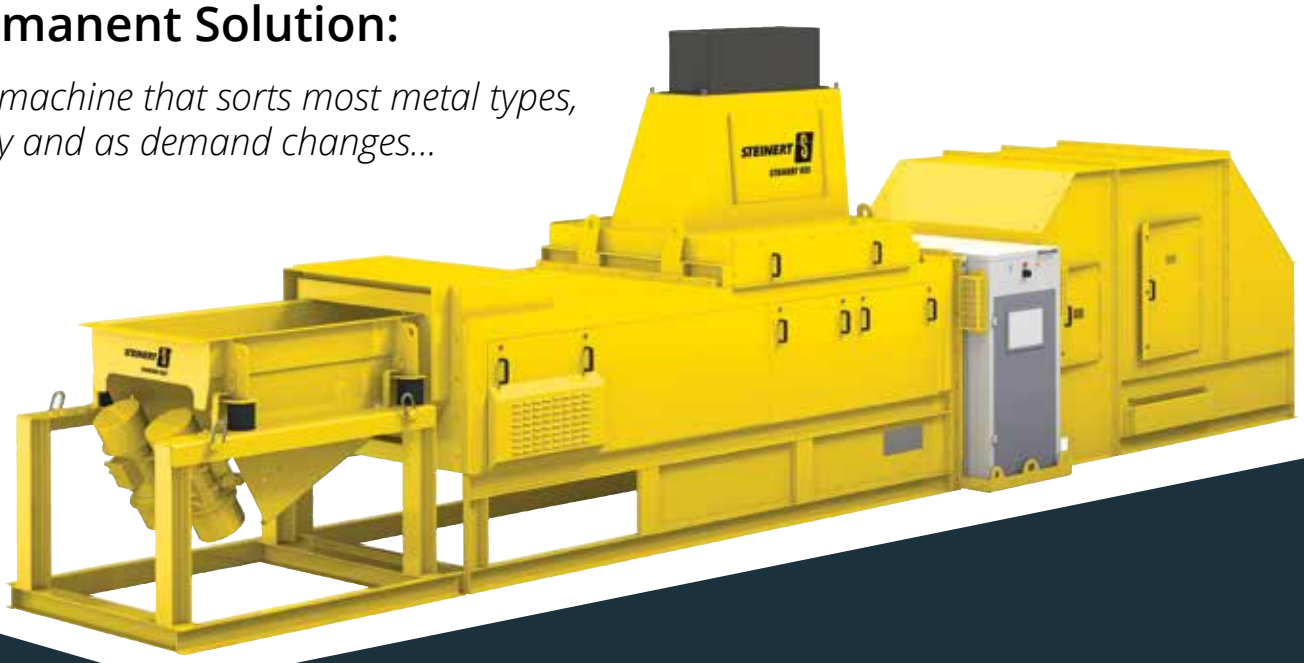

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Chemical recyclers use a variety of feedstocks and methods to break plastics down to their molecular building blocks. GreenMantra uses a depolymerization process (left) to create specialty polymer additives (above) for a range of applications.

also called *depolymerization*, breaks the molecular bonds of the plastic down to the monomers, which can be single molecules or short fragments of molecules, which are then reconstructed into plastics. Companies might use a biological, chemical, or thermal process to break the molecular bonds. The *conversion* method is similar to decomposition because it breaks the plastic's molecular bonds. The big difference is that the conversion method results in liquid or gaseous hydrocarbons that are similar to products derived from petroleum refining. Chemical recyclers can use these raw materials to make fuels or petrochemicals such as naptha, an ingredient used in plastics manufacturing.

Chemical recyclers use one or a combination of these techniques to create their niche products. For example, GreenMantra (Brantford, Ontario) uses a patented depolymerization process with a proprietary catalyst to convert postconsumer and postindustrial plastics such as polyethylene, polypropylene, and PS into specialty polymer additives used in products such as roofing and roads. Plastics processors that want to integrate more recycled material into their resins can use the additives to help lower formulation costs and make their operations more efficient, explains Jodie Morgan, the company's CEO.

GreenMantra puts the plastic in a reactor and exposes it to heat and its catalyst, which brings the plastic to a molten state where chemical reactions break specific links in the plastic's monomer chains. After a trip to the cooling tank, the material goes to a pastillator that turns the final product into small, solid pellets.

Ideally, GreenMantra sources recycled plastic feedstocks that are sorted by resin type, such as PE, PP, and PS, Morgan says. "We prefer the sorted stream because it helps drive higher production yields," she says. The system can accept up to 10% organic material such as dirt, food, or other residual plastics. "For every pound of product we feed the reactor, we get 92% to 95% out," she says. The other 5% to 8% is a mixture of monomers, oils, and fuels she says have secondary outlets.

Renewlogy also uses a depolymerization process, but the company creates fuel, naptha, and waxes instead of plastic additives. Its process uses bales of 3-7 plastics that include film and flexible packaging, says CEO Priyanka Bakaya. Renewlogy shreds the material and removes as much contamination as possible by putting the material through a mechanical sorting process. After depolymerization, 70% to 80% of the output is converted to liquid fuel, while about 20% is a noncondensable gas used to heat the system. The remaining 5% is an inert char made mostly from organic materials, she says.

Renewlogy can change its output based on what the markets demand, however. "We can make other end products, but diesel is our main target right now," Bakaya says. "Other end markets are somewhat limited, whereas diesel tends to be something that's used prevalently and is easy to sell into the market."

Agilyx has three different platforms for chemically recycling plastics. Its fuel production process uses thermal conversion to turn mixed plastics into a lower-carbon crude oil used for a variety of fuels, such as jet fuel, diesel, and bunker fuel. Since 2004, it has been able to turn more than 8 million pounds of mixed plastics into about 800,000 gallons of crude, which it

GREENMANTRA

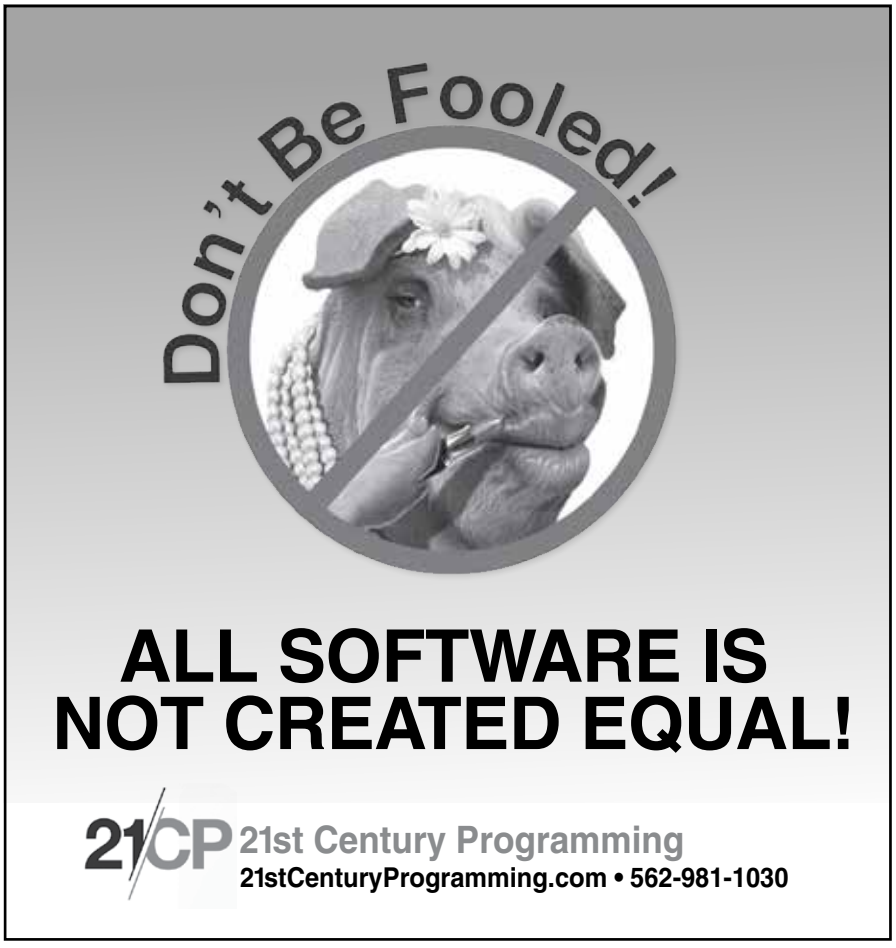
sells to U.S. Oil. It becomes jet fuel for the U.S. Department of Defense, says Joseph Vaillancourt, Agilyx's CEO. It also converts a variety of other plastics into a naphtha feedstock that companies can use to make new plastics.

Another platform is PS recycling company Regenyx, a joint venture between Agilyx and PS producer AmSty (The Woodlands, Texas) that's co-located at Agilyx's Tigard facility. Agilyx collects recycled PS and uses a decomposition process to turn the plastic scrap into a recycled styrene monomer. Then AmSty refines the monomer and uses it to make new PS products it says have a 50% to 70% lower carbon footprint than virgin PS. The Regenyx project can process up to 10 tons of PS per day, but the company plans to build a regional facility that would be able to process five times that amount, Vaillancourt says.

Much of Agilyx's chemical recycling system is proprietary, he says, but the general gist is that the processes break the chemical bonds of the various plastics and "create a chemical-rich gas, and then [they] reform the gas into a variety of hydrocarbon products." Agilyx uses the same system to process the plastics for all the products it makes, "except we do change the operating parameters of our system for each product, and we have different downstream product cleaning and refining technologies for each product," he says.

SOURCING STRATEGIES

To carry out each of these purification, decomposition, or conversion processes, chemical recyclers need the right type and amount of feedstock. They use diverse, nontraditional sources to gather enough plastic—but sourcing a sufficient amount and quality of material is one of the industry's biggest challenges, "given the extreme variability of the chemical composition of the very varied waste streams," Vaillancourt says.



Sourcing a sufficient amount of material is one of the industry's biggest challenges.

Agilyx's strategy is to source material "in a way that allows us to minimize the cost of production. If it costs a lot to secure feedstock, there's a tension with the feasibility," he says. It gets material from a mix of commercial, industrial, and municipal sources, as well as some "from big waste companies." Though Vaillancourt declined to name specific sources because of competition between chemical recyclers, the company has previously announced partnerships such as an agreement with Titus MRF Services (Los Angeles), which has a secondary MRF in Los Angeles that sources mixed plastics from several regional MRFs. Once Titus accumulates enough volume of PS foam and rigid PS, it sends it to Agilyx, according to an article in *Waste Dive*.

Agilyx sometimes gets material free, but the company will also pay for material if it needs "a really pure feedstock," Vaillancourt says. One free source is a community drop-off outside Agilyx's facility in Tigard, which is just outside of Portland, Ore., where residents can drop off PS foam and rigid PS in bins. Another place to source free polystyrene is Oregon's festival scene, adds The Broomsmen's Torchio. The event recycler brings its own bins to events and stations an employee next to each bin to help concertgoers source-separate their recycling, compost, and any materials they need to landfill. Before summer 2018, PS food service packaging went in the bin marked "landfill." But Torchio knew Agilyx was starting to collect PS and saw an opportunity for his company to separate it out of its waste stream. When Torchio told representatives from McMenamins about it, the event management company said it would order PS cups for the upcoming concert season so they could be recycled. "I really credit them for making that leap," he says.

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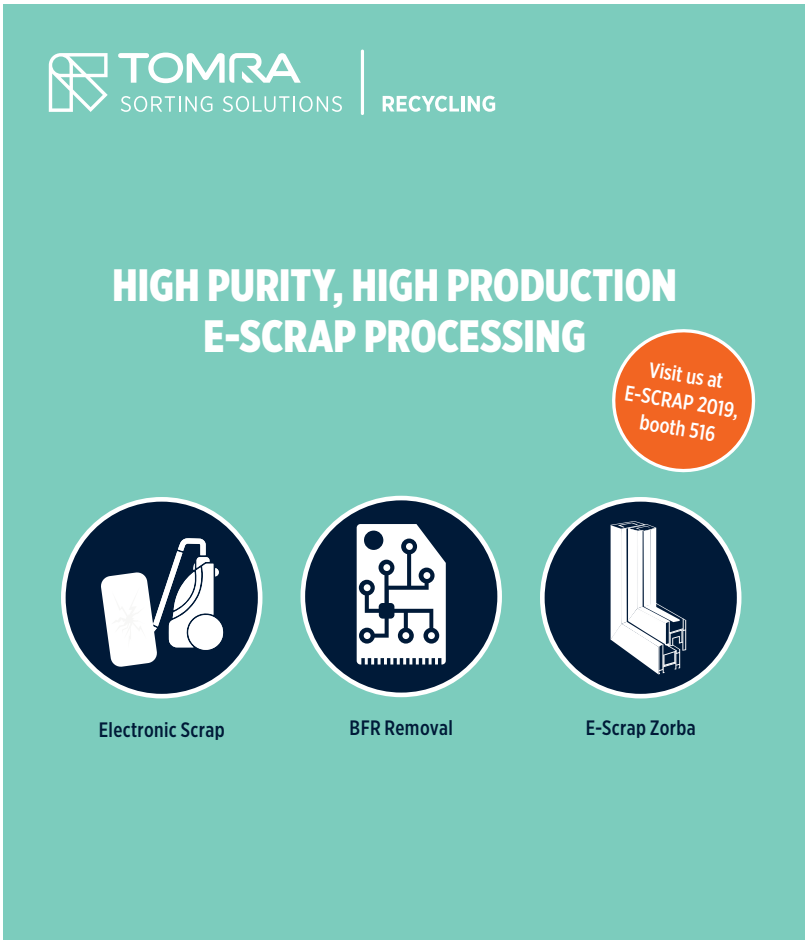
The Broomsmen does not get paid for the plastic it delivers to Agilyx, but that arrangement works fine for Torchio, whose company earns money for the collection services it provides, not the value of the materials it collects. McMenamins also must pay any landfill costs for materials that it can't recycle. "Right now, our partnership with Agilyx works great for us. There's no fee for us, and we're keeping it out of the landfill. The reality is that there would be a cost to put this in the landfill instead," Torchio says.

In Canada, GreenMantra's strategy is to collect plastic from wherever it can build good partnerships, even if those sources are far from the Brantford, Ontario, facility, Morgan says. "We are able to target streams of plastic that might otherwise go to the landfill. We also try to buy from nontraditional places that wouldn't otherwise have an outlet to recycle," she says. The state of California offers subsidies to those who can recycle carpet, so GreenMantra sources PP carpet backing from the state that comes from places like convention center trade shows there, where yards and yards of mostly clean carpet gets freshly installed for each new trade show and ripped up and discarded after only a few days of use.

GreenMantra also works with MRFs to try to create long-term outlets for plastic streams that might not be recycled today due to low collection volume, like plastic films or PS, because the plastics "lack a stable, viable outlet," Morgan says. The company is in talks with one particular MRF "that does not consciously collect polystyrene today, but it's being pressured [by the community] to collect it," she says. The MRF is torn. "There aren't a lot of outlets for it, and it's mostly air, so the logistics create a financial hurdle," she says. GreenMantra hopes to buy the PS if the MRF ends up collecting it. "If they're being asked to collect it, we can provide a home for it," she says.

MRFs can create partnerships with chemical recyclers that are mutually beneficial, says Joe Rossell, project manager for Reimagine Phoenix,



MRFs can create partnerships with chemical recyclers that are mutually beneficial.

the city of Phoenix's recycling and sustainability initiative. Phoenix's Department of Public Works put out an RFP last year seeking help managing the 3-7 plastic it could no longer sell because of market changes due to tightened import restrictions in Asia. In 2018, Phoenix's municipal MRFs landfilled 3-7 plastic. In the years prior, the MRFs baled that material and sold the mixed plastics to a variety of outlets, but after China implemented its import bans on postconsumer plastics and other countries followed, it became harder and harder to find markets, Rossell says.

Around that same time, the public works department launched Reimagine Phoenix with the goal to divert 40% of collected material from the landfill by 2020 and reach zero waste by 2050. "The City of Phoenix was interested in finding unique solutions around these problematic feedstocks," he says. "We were interested in going to the private sector to learn what was both viable and possible."

The result is Renew Phoenix, a chemical recycling joint venture among the city, Renewlogy, and industrial recycler Generated Materials Recovery (Phoenix). Once the facility is fully operational, the city expects it to process 10 tons of mixed plastics a day, which will generate about 60 barrels of liquid diesel fuel, he says.

Renew Phoenix will occupy a facility in Phoenix's 50-acre resource innovation campus, a "circular economy innovation hub" meant as an incubator for green projects. The location is ideal, Priyanka Bakaya says. The chemical recycler needs to be as close to area MRFs as possible to cut down on the cost of transporting materials. The MRFs do not need to change any sorting or baling processes because they already sorted and baled 3-7 plastics, Rossell says. "Now those plastics have a place to go that's not a landfill," he

says. Phoenix's MRFs don't generate enough 3-7 plastic to meet the needs of Renewlogy's process, so Generated Materials Recovery will provide about 70% of the plastic for the project, he says.

The project is still in the planning stages. The company and city are in contract negotiations to decide what will happen with the end product. "Public works is exploring the possibility of utilizing the diesel in the city fleet vehicles. Not only would we get to use up these low-value plastics, but the process is a possible savings for the city," he says.

Renewlogy already has a similar chemical recycling facility on the site of a MRF in Chester, Nova Scotia, operated by Sustane Technologies (Halifax, Nova Scotia). The facility's goal is to process up to 6 million pounds of plastic a year, she says.

Sourcing plastic directly from the MRF is an important part of Renewlogy's business model, she says. But the company also participates in the Hefty EnergyBag program, which asks residents in participating communities across the country to place hard-to-recycle plastics such as chip bags and foam to-go boxes in a special orange bag and place it in their recycling bin. The Boise, Idaho, area received a $50,000 grant from Dow Packaging and Keep America Beautiful to implement the Hefty EnergyBag program in 2018. Western Recycling (Boise), which operates the MRF that collects and separates the bags from the rest of the recyclables, sends the material to Renewlogy's Salt Lake City facility for it to convert it to fuel.

SOUND INVESTMENT STRATEGIES

Grants like the one from Dow and KAB are one way to kick-start chemical recycling initiatives, but chemical recycling's long-term stability hinges on companies securing long-term funding to scale up operations to prove both their profitability and their positive environmental impact, Croke says. Agilyx, GreenMantra, and Renewlogy were founded at least 10 years ago and are just now capable of producing the products they promised at a commercial scale. "On average, it takes 17

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years for [chemical recycling companies] to reach growth scale, and that is way too long," she says.

Major investments can speed up this timeline, "and we're beginning to see these developments happen," ACC's Muhuri adds. Brand owners and resin producers are beginning to commit to using more recycled resin in their products, but they need to know they have a reliable source for that material to reach their goals, she says. "Chemical recycling is a real opportunity for these brands, and we are working diligently to make that a reality," she says. Chemical recyclers in all stages of maturity have received funding from national and local government agencies such as the National Renewable Energy Laboratory and the REMADE Institute, and from companies in the petrochemical and plastics industries such as Dow Chemical Co., Indorama Corp., Lyondell Basell Industries, and SABIC.

Loop Industries (Montreal) is commercializing its PET depolymerization technology and plans to build its first commercial recycling facility in a joint venture with plastics producer Indorama Ventures (Bangkok). In May, Northern Private Capital agreed to invest CN$35 million in the company to help with research and development and recycling plant construction. The plant will have the capacity to produce tens of millions of pounds of recycled PET each year. In exchange, Loop will sell NPC more than 4 million shares of stock, giving it a 10.5% ownership stake in Loop, according to a news release announcing the deal. NPC's owner, billionaire private investor John Risley, said he sees enormous potential in Loop's chemical recycling plans. "Rarely in my long career have I come upon a company as well-positioned to disrupt a giant market as Loop is today," he stated in the news release. "On top of that, we are proud to be playing a part in reducing plastic pollution in the world today."

These types of major investments

show "there is now money to be made," Green Mantra's Morgan says. That's a change from her experience just 10 years ago, when many more companies were in the testing stage, and some folded before they were able to move up to the provable production phase, she says. "As more [chemical recycling] companies become successful, more investors are coming to the table because they see it as a good investment," Morgan says. Years ago, "companies that invested in this space did it because they thought it was good for the environment. But in our last round, we definitely got a lot more people who were interested in making a reasonable investment in a company that can show strong returns." One of those investors was the Closed Loop Fund, which gave GreenMantra $3 million in 2017 to help it expand its manufacturing operations and increase the plant's annual capacity from 5,000 mt to 7,500 mt.

As chemical recyclers seek funding, they should also seek strong partnerships, the Closed Loop report recommends. "Many of these technologies are founded by … scientists and chemists who are not necessarily experienced CEOs or marketers … so partnerships are critical for complementing their core expertise to build a successful business," the report says. Loop, for example, has signed supplier agreements with Gatorade Co., PepsiCo, and the Coca-Cola Co. and has investment term sheets with Danone, Nestlé Waters, and L'Oreal, Closed Loop says.

Croke is confident that more chemical recyclers will be able to successfully find a place in the plastics recycling marketplace, complementing the mechanical recyclers that have been recycling plastics for generations. Plastics recycling "is a complex challenge with complex solutions," she says. "These chemical recycling technologies are part of that solution." ■

Megan Quinn is senior reporter/writer for Scrap.

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