INDUSTRY AS AN ECOSYSTEM

When we fixate solely on cutting out waste, the outlook for the environment can be discouraging. It seems we'll need a million campaigns to save our planet from discarded items as simple as plastic straws to those as complex as lithium-ion batteries. If we look closer though, we find that ecosystems themselves hold the key to their own preservation. When we learn from the way nutrients are constantly broken down and repurposed in natural systems, we find opportunity everywhere.

Bubbling in natural geysers all over the world—such as the hot mud of Old Faithful—there's a creature that's made a home for itself. It's a bacteria called *Methylocystis parvus*, and it feeds on the methane released from plants decaying in slow motion. For over 200 million years, these organisms have evolved in a microscopic ecosystem where the main energy source is a gas.

Dr. Allison Pieja spent years in the labs at Stanford studying how these bacteria work. She published extensively on how they use methane to build long chains of complex polymers. It was during her PhD studies that she met Dr. Molly Morris, who was working on sustainable materials for the construction industry. "It turns out that Molly's work needed Allison's work, and Allison's work needed Molly's work," said Dr. Anne Schauer-Gimenez, who would later join their team.

When you picture startups in the San Francisco Bay Area, you might think of a hip coworking space with cold-brew coffee on tap and walls plastered with inspirational quotes by Steve Jobs. The office of Mango Materials is a little different. I let Greg know that I'd be happy to check it out for both of us.

The road reached a dead-end at the Redwood City wastewater treatment plant and the smell was as you might expect. Anne welcomed me through the gates. We put on hard hats and walked down a set of stairs, following a network of metal pipes to an outdoor expanse of giant concrete drums. They were biodigesters that used bacteria to break down waste into a form that doesn't make us sick. Another set of pipes connected one of the digesters to a much smaller ten-foot-tall cylindrical chamber. This, I was told, is where the magic happens.

Methane from the digester enters the chamber where it feeds a colony of hungry bacteria. At first, they start dividing like crazy. Their numbers surge as they colonize this new habitat. Then, with a few twists of the knobs, they're cut off from their food source. They go into survival mode, building up an energy reserve for later. This energy reserve is made from the exact compound of an extremely versatile biopolymer, an ideal building block for a wide range of plastics. The Mango team then harvests the crop of microbes, leaving a seed group behind for the next batch. From the microbes, they extract a fine white powder, which they pelletize and then inject into plastic molds.

All the waste from the process is fed back into the biodigester. It's broken down with everything else, releasing the methane within, which is then looped back into the beginning of the cycle.

The plastic that comes out is different from plastic as we know it. Because it's a naturally occurring substance, it's easily broken down. Where most compostable plastic on the market has to be processed in industrial-scale composting facilities, these polymers can biodegrade in the yard. "We've done some very unscientific studies in our CEO's home

compost," said Anne. More importantly, this polymer can decompose in the ocean. If an animal happens to eat it, they're able to digest it.

There are also many more applications for these polymers than for most of the existing biodegradable plastic on the market. The bacteria can produce over 100 different monomers—the building blocks of plastic polymers—allowing for plastics of many forms. "It's inherently a more rigid plastic. It's great for electronic casings or things that need to be durable," said Anne. "But you can also make it into thin, flexible films. It has a huge design space. You just have to know how to do it." That's what Mango has spent the last eight years figuring out.

The current plastics industry has a huge advantage as all the infrastructure is already set up, which allows existing companies to produce at a very low price. However, Anne pointed out that there are 1,200 facilities in the US that generate natural methane and already have some system to capture it. To avoid releasing it into the atmosphere, most places just burn it. At best, they can get a few cents per kilowatt hour for the power produced, if they happen to have a generator on site. Using methane to make plastic would create significantly more value.

According to Anne, "We're three times more economical than electricity and two times more valuable than converting that methane into liquid fuel."

Mango provides a dual solution. They prevent heat-trapping methane from escaping into the atmosphere as a greenhouse gas, while significantly reducing the harm done by plastic in our environment. At the same time, they present a powerful incentive for methane emitters to transform a harmful waste stream into a source of revenue.

This technology creates a new way to look at recycling altogether. Even if your bio-plastic bottle were to end up in the landfill—if that landfill were connected to one of Mango's systems—it would decompose back into methane. There, it could be captured and transformed back into another plastic bottle. It's essentially a biological recycling system

that could help us reconceive landfills as not the end of the line for our products, but the beginning. Sites not for waste, but for value creation.

Mango envisions a new approach to infrastructure that is significantly less capital-intensive. Rather than establish massive plastic factories, Mango wants to license mobile modules that can plug into any source of methane and start producing immediately. Imagine if every city had its own source of extremely versatile materials made from the sweet nectar of benevolent bacteria. It's a rose-colored dream compared to relying on the concentrated byproducts of petrochemicals that are shipped across plastic-choked seas.

Mango uses biology to re-envision the way we make things. It's what's called a "biocycle." But not all industrial systems that copy the way nature regenerates materials have to use biology. There's another cycle that uses artificial means to do what natural nutrient cycles do so well. It's been dubbed the "technocycle" by architect William McDonough and chemist Michael Braungart, the authors of *Cradle-to-Cradle*, who helped popularize a vision for circular industry. The "technocycle" includes basically all manufactured products that can't be broken down by nature. These materials are persistent and often toxic, like heavy metals. When they do end up in nature, they're what we call pollution.

It's possible, though, to find ways of safely breaking them down. Rather than letting them destroy our environment, we can keep them in circulation, where they create value rather than destruction. For a glimpse of what that might look like, we now turn to the fastest-growing waste stream on the planet.

While shiny and sleek on the front end, our tech industry has created a monster on the back end. Each new gadget kicks millions of older models into obsolescence. Discarded electronics get shipped by the crateload to the developing world, where their toxic components can poison entire neighborhoods. In Bangladesh, children dip circuit boards into open vats of acid to get at the copper and gold nested inside. In

the Congo, warlords use slave labor to mine the cobalt that supplies the world's battery manufacturing.

Before Peter Holgate learned of the dark side of Moore's Law, he'd founded several companies in the tech space. However, it wasn't until he received a letter from his mother that he'd come to chart a different path. "The last thing in the letter was that she'd met Michael Musk, Elon Musk's uncle, and Michael told her that Elon had built a rocket ship which flew into space and landed square on a platform in the Pacific Ocean. And then she goes, 'How's your career coming along?'"

But before Peter had a chance to respond, she passed away. In the months of grief that followed, he couldn't stop thinking about what his mother would've wanted his impact on the world to be.

During this time, he happened to watch the documentary *Ghana: Digital Dumping Ground*. In it, he saw how his career in tech might be contributing to a looming problem. He became inspired, not to create the newest gadget, but to figure out what to do with those gadgets when they're disrupted by the next big thing. "You've got phenomenally good-looking devices, and these things do well, they're powerful. You've got stores that are amazing. They're like a temple, right? And yet, you haven't been giving the back end enough attention."

So Peter went searching for solutions. Rather than try to invent a new technology from scratch, he suspected that the tools to address the problem might already be out there. He stumbled across a strange piece of equipment built for an entirely different purpose. At the time, it was languishing in the tent of an environmental remediation company. It was a machine made up of a 13-foot-long steel bar surrounded by electromagnets. It's "basically a massive tuning fork," originally built to "literally shake the gold out of mine tailings using sound energy."

This sonic machine is extraordinarily efficient at separating materials, especially when compared to smelting—the main method for recovering metals from our discarded electronics. Traditional recycling uses an

arc plasma furnace to melt everything down, which requires a tremendous amount of power, often generated by burning coal. By contrast, the tuning fork technology separates the mélange of materials in a circuit board by using what's known as "harmonic resonance."

"When you go 'ping,' the tuning fork is humming and you just add a touch of energy, just to keep it at that rhythm and state, a harmonic state." From this technology, Peter and his partners founded Ronin8, a company focused on creating a circular life for electronic devices.

At their facility, old laptops, monitors, and cell phones enter the process whole. They're shredded under water to prevent toxic dust from escaping into the air. These minced bits of e-waste are then fed into the machine, which fine-tunes its pitch to separate each material based on its specific density. First the non-metals are released. Finally, one by one, each metal resonates with its perfect harmony.

"We've found up to 21 different metals in most electronics. It's like the entire periodic table. Even the guys who are recovering the primary metals—you know, gold, copper, silver, platinum, palladium—are ignoring most of the rarest elements, like promethium and tungsten," said Peter. "We started down the path of being able to recover all of them." Currently, mining these rare-earth metals requires an intensive chemical process to liberate them from the dirt. Often they're bound up with radioactive byproducts like thorium, all of which end up seeping into the groundwater.

The current smelting process to recycle metals isn't able to recover these rare earth elements. In addition, it requires high levels of energy and emits toxic particles. "You create dioxins, which are the same thing you find in DDT and Agent Orange." The two main ingredients in Ronin8's process are sound and water. After the discarded electronic components have been separated, the remaining particles are filtered through a fine sieve and the water is reused indefinitely.

Peter hinted that the process might be well suited for recycling solar panels. "The entire solar panel industry is staring down at a legacy issue

without the means to solve it," he said. "The solar panels that were built 15 to 20 years ago are all aged out and need to be taken down. These work incredibly well in our sonic system."

Currently, Ronin8's main focus is perfecting their technology to safely and affordably recycle lithium batteries. This could help address the looming specter of the millions of used electric car batteries that the world will come to generate every year.

Ronin8's goal is to develop partnerships with the big manufacturers. "We want to be their facilitator of the circular economy," said Peter. He sees the need for larger companies to fundamentally rethink their business models. "I see the brands as custodians of the circular economy, not as the sellers of gadgets." They're going to look at all the metal they have in their products, and say, "Look, we've deployed a hundred million tons of gold—or whatever the number is—and we are the steward to make sure it's going 'round and 'round."

Ronin8 also wants to provide an opportunity for people in the developing world who live where this waste falls through the cracks. They envision their technology being able to fit into a shipping container. "Instead of having some kid melt away the plastic to get at the copper, you have a simple, easy way to separate the two." It could give people living anywhere in the world the means to safely transform complex waste into a cornucopia of useful materials.

In nature, leaves and branches fall into streams and end up far away from their places of origin. But they don't pollute their new environments. Natural systems are adept at converting leaf litter into food, fertility, and new life. In our modern economy, we're not talking about branches and leaves, but circuit boards and copper wires. The material may be different, but our approach and intention when dealing with them should model nature's. Our goal should be to allow anyone, wherever they are, the opportunity to create value from the problem formerly known as pollution.

In the US, regenerating the value from discarded products could help bring back manufacturing jobs. James Killkelly, the founder of Apto Solutions, a company that dismantles electronics and repurposes their internal parts, sees a major opportunity on the horizon. "The good news is that a lot of the 'Rust-Belt' locations that have been left behind could really benefit from a more circular economy. This kind of work we're doing has the potential to revive American manufacturing."

Interestingly enough, this work can't be outsourced to China because the government there has banned the import of used goods. The backside of our economy may be a sleeping giant of job creation.

We've spent the last 100 years perfecting the assembly line. It's now time to perfect the *disassembly* line. Nature is able to take extremely complex structures and break them down into the pieces needed for the next generation. For everything we create, we need an efficient solution to break it down and cycle it back into the pieces from which it came. In doing so, we can create value out of nothing, protect the environment from toxic chemicals, and avoid depleting our precious natural resources.

KEEP EXPLORING

- *What are the broken circles of stuff that I notice in everyday life?*
- *What treasure do I see ending up in the trash?*
- *How could my local economy endlessly regenerate all the materials it uses?*