Growing world population and economic prosperity are straining the Earth's limited resources. The time is now to move from our "take, make, dispose" economic model to one that's circular, where materials flow through the economy. Materials innovations could be crucial for this transition.

The circuitous, but essential, path to a circular economy

By **Prachi Patel**
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Once upon a time, we expected things to last. Instead of throwing away shoes and tools at the first sign of fault, we took them to cobblers and repair shops.

Then, sometime after World War II, disposable products emerged as a way to promote business and create jobs. If products do not last, the thinking went, customers will buy replacements. We now live in a throwaway economy, where few products are built to last. One garbage truck full of textiles is burned or landfilled every second. A stupendous 5-plus billion tons of plastic is sitting in landfills or the natural environment, a number that could go up to 12 billion by 2050 if we continue apace producing disposable plastics, especially packaging and bottles that are tossed after one use.

It might be time to come full circle. A booming world population, growing economic prosperity, and an insatiable appetite for consumer goods are straining the Earth's limited resources. We are running out of metals and fossil fuels, and space to bury our trash. It might be time to move toward a circular economy model.

The idea is to go from today's linear "take, make, dispose" economic model—extract resources, make a product, discard at end of life—to one that is cyclical, where materials flow circularly through the economy. This captures the most value from materials while reducing waste and resource use.

It also requires a profoundly different way of thinking about goods. Prosperity and consumption are traditionally thought to go hand-in-hand: as nations get richer, they create more trash. A circular economy flips that idea on its head, said Gabrielle Gaustad, a professor of sustainability at the Rochester Institute of Technology. "The crux of a circular economy is to be able to decouple economic growth from resource consumption," she said.

That decoupling will be the only way to continue making people across the world healthy, wealthy, and happy, said Nick Voulvoulis, professor of environmental technology at Imperial College London. "There are more and more of us on the planet and more people moving from poverty to middle class," he said. "The world cannot sustain everyone in the middle class right now. We have to move towards a circular economy as a global need."

Getting there will require overcoming technical, social, and market barriers. Research, policies, and industry standards could speed things along. Transitioning would be expensive, but long-term benefits would outweigh risks and cost, according to a 2017 McKinsey & Company report. In addition to minimizing environmental impact, it could cut costs, create work, and improve quality of life, because things like waste management, repairing goods, and recycling all create jobs. The report finds that a circular economy could save €1.8 trillion annually in Europe by 2030. The disposable income of European households and Europe's GDP could be as much as 11 and 7 percent higher, respectively.

Circular economy concepts aren't new. Recycling often comes to mind. "But it's only one step, and it's not enough," Voulvoulis said. A circular economy model also includes designing products that are durable; designed from the start to find reuse; easy to repair and upgrade; and to disassemble and recycle.

Some products and materials might never be conducive to reuse or recycling. And not all circular economy concepts are equally green: reusing glass bottles, for instance, might take less energy than recycling them, while collecting heavy batteries and solar panels causes transport emissions. But there is a considerable and real opportunity for society to do a lot better.

Changes are slowly happening. A few companies have been exploring business models that include circular concepts. General Electric (GE), for instance, designs its gas turbines and locomotive engines to be used for as long as possible, said Angela Fisher, co-founder and director at consulting firm Aspire Sustainability. "You can put in a new smart component and just repair and replace components." Several carmakers and power companies are working to give used electric vehicle batteries a second life storing energy for homes and utilities.

Manufacturers are looking at 3D printing as a critical part of the circular economy, since it uses limited material types and eases the use of scraps and reuse of materials, Fisher added. By printing its Flyknit shoes using minimal material, Nike decreased manufacturing waste by 80%.

The fashion industry is becoming more aware of its environmental impact. The industry consumes an immense amount of water and chemicals, and produces 5% of global greenhouse gas emissions, as much as Russia, every year. Two dozen apparel brands belong to a coalition called Zero Discharge of Hazardous Chemicals to expand the use of nontoxic, sustainable chemistry in textiles and footwear. Companies such as H&M and Patagonia collect clothing and footwear for reuse and recycling.

The shared economy—Uber, Airbnb, bike shares—is a poster child for economic growth without using more resources. So is the leasing business model, which makes products cheaper for

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customers and keeps used ones out of the landfill. GE leases aircraft engines, and companies like Ricoh and Hewlett Packard lease copiers, allowing customers to purchase service and upgrades.

These are all promising successes. But it is still early, and there's a long, winding road ahead. Fear of the unknown and of breaking the mold, and a high real or perceived cost can slow down the transition to a circular economy.

So what will it take to realize a circular economy on a meaningful scale? Innovations in materials technologies, for one, will be crucial. The circular economy is "a challenge that's readymade for the material science and engineering community," said Steven Swartz, a partner at McKinsey. "We have to redefine the innovation agenda."

The ultimate bold research goal should be to disassemble material blends and recycle atoms. That would require keeping toxic materials out of products and retaining material value at the end of life. "Aluminum is a perfect example of a material that's highly recyclable and flows through the economy," he said. "After 30 years in an airplane frame, we reprocess and reuse it." A similar philosophy could be a game-changer for the plastics, electronics, and fashion industries.

A few years' worth of plastic litter brought in by the sea on a beach in northern Norway. Credit: Bo Eide.

Electronic waste contains a slew of materials, and while companies such as Umicore process electronic waste to extract some useful metals, today's processes are energy-intensive and waste much of the raw material's value. There is still no effective recycling technology for cotton and fiber blends, said Swartz. "We don't have a way to throw 1000 shirts in a tank and depolymerize them and make something new," he said. There is also a huge need for more sustainable synthetic clothing and more benign production processes.

Plastics present similar challenges. Producing plastic is water- and energy-intensive; about half of it is now made for single-use disposable items, and less than 10% of it is recycled. Many new polymers have been developed in the past decades, and hundreds of additives are used in these polymers. Plus, packaging uses a variety of polymers and other materials like papers, inks, and adhesives. This complexity makes it very difficult to identify and separate materials at the end. Chemical and mechanical recycling techniques that break down polymers are energy-intensive and degrade the materials. There is an urgent need for better sorting and recycling technologies and better chemistries, be it plant-based plastics or plastics that are durable yet degradable.

Chemists and materials scientists need to weigh the environmental impacts of their creations, said Ashley White, director of communications for the Advanced Light Source at Lawrence Berkeley National Laboratory and chair of the Materials Research Society (MRS) Focus on Sustainability Subcommittee. Designing products for reuse, using nontoxic materials, and making processes resource- and energy-efficient should be norm. "I think sustainability should play a role in everyone's research," said White. "If you're designing a new synthesis technique, you should think about the chemicals that go into it, where they're coming from, their toxicity, and where they will go at the end."

There are many tools at the materials science community's disposal: life-cycle analysis tools to quantify the material, energy, water, and carbon footprints of different products or systems; mass flow or energy flow analyses to show where opportunities exist for reducing footprint; and criticality assessments to understand what materials are the most vulnerable and what we can do about them.

Weaving circular economy concepts into academic training would help, added White. Early-career MRS members are especially driven by sustainability. Why not tap into their energy and give them solid technical know-how to bring a change from the ground up?

Popularizing circular economy models will require "bold displays of corporate leadership," said Swartz. In January, Coca-Cola announced a goal of helping to collect and recycle the equivalent of 100% of its packaging by 2030, and Evian declared a switch to 100% recycled polyethylene for their bottles. These are important steps but not nearly enough. "We need a thousand more such initiatives where large companies that consume materials send a signal into the supply chain that they would like to see sustainable materials," he said.

Companies would benefit from creating sustainability teams with well-defined roadmaps. Industrywide design standards could require businesses to make durable, upgradable products that can be easily disassembled.

The onus is not all on businesses. Funding and regulatory support are necessary for sustainability innovations to succeed, said Rochester's Gaustad. Policies in the form of incentives, taxation, or restrictions on pollution and waste will also provide a push, just as they helped make renewables competitive with fossil fuels.

Take for example the European Commission's plastics strategy, announced in January, which aims to make all plastic packaging reusable or easily recyclable by 2030, and recycle more than half of Europe's plastic waste by 2025. They plan to accomplish this by implementing standards for materials and packaging that would make recycling simpler and more economical; improving waste collection; funding recycling innovations; and creating markets for recycled and renewable plastics.

With its broad, ambitious Circular Economy Action Plan, the EU is providing a good lead for other countries to follow. If the impetus does not come from within, external forces could come into play soon: China's ban on imports of foreign waste just might push many nations to start thinking seriously about a circular economy. □

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