MINIMAL SOLUTIONS

Manufacturers are working with researchers to develop ways to make products using less material and energy.

BY R.P. SIEGEL

Xerox's Webster manufacturing facility outside Rochester, N.Y., produces 24-foot long high-speed, high-resolution printers that sell for upward of half a million dollars. The process involves highly skilled union labor. These printers are the kind of products that most people can't imagine being made profitably in the United States anymore. But Xerox has a secret weapon that make the economics work: remanufacturing.

A vast majority of Xerox printers are leased, so the company retains ownership and responsibility for the machines throughout their life cycles. The company spent over $1 billion developing its iGen series of production printers based on a platform architecture and design intended to support remanufacturing.

Old iGen3 models coming off leases are returned to the factory to be converted into iGen4 and iGen5 machines. Remanufactured equipment is sold at the same price as brand-new, under the same terms and conditions and the same total satisfaction guarantee, even though it is less costly to produce a remanufactured printer than a new one.

According to Kevin Kelley, plant manager at the facility, "There's an exchange that occurs when the customer trades in the old model and gets the latest and greatest version and we then transform the old machine into a new one."

Xerox has been doing "reman" in one form or another since the 1960s. This has worked out well from every perspective including cost, quality, safety, and customer satisfaction.

Walking down the assembly line, Kelley pointed out how the returned "cores," as they are called, are stripped down to the frames, which are cleaned, inspected, and repainted. Internal modules are dispatched for various types of processing, which could include anything from cleaning, testing, various levels of refurbishing and updating, or recycling, with a significant portion being eventually fed back into the line and "model mixed" along with new-build products.

Manufacturers looking to make American factories more competitive with foreign-based facilities are finding opportunities through re-engineering long-held wasteful practices. To a large degree the U.S. economy is a linear one, where raw materials are dug or drilled from the ground, processed into feedstocks, and then turned into products. Those products generally have a brief life, are tossed out—usually into landfills where they are never seen again—and the cycle starts over again. Substantial energy is consumed at each step, particularly in the production of raw material.

The system was designed at a time when energy was cheap, alternatives few, and awareness of environmental considerations missing. None of that is true today, and the World Economic Forum estimates waste could cost $25 trillion between now and 2050.

REMANUFACTURING, WHICH CAN REDUCE that waste stream considerably, employs 180,000 people in the United States and is valued as a $43 billion industry, according to 2012 Department of Commerce data. Today it is in the $100 billion range once the military is factored in, said Nabil Nasr, chair of the Sustainable Manufacturing Innovation Alliance at the Rochester Institute of Technology.

"But the intensity is only 2 percent," Nasr said. "If you could double that to 4 percent, we're looking at quite a few new jobs.

"A lot of people think of recycling and remanufacturing as dirty and boring," Nasr continued. "It's a green field for innovation because so much has to be rethought. We've been doing things without thinking about the environmental impact. There is tremendous room for innovation."

The concepts underlying circular economics and the awareness of the energy embodied in products have been around for some time, but the size and complexity of the supply chains involved have made it a challenge to study in a rigorous and comprehensive way.

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> —MAGDI AZER, Illinois Applied Research Institute

To learn more about these concepts and how to apply them to real-world manufacturing, the U.S. Energy and Commerce departments, along with the National Institute of Standards and Technology, established the REMADE Institute in 2017. REMADE is a backronym for "reducing embodied-energy and decreasing emissions" and is chartered to "reduce life-cycle energy consumption and carbon emissions associated with industrial-scale materials production and processing." The institute coordinates activity among universities, private companies, industry trade associations, and seven national laboratories.

REMADE aims to develop technology enablers to accomplish such goals as reducing primary feedstock consumption in manufacturing by 30 percent, reducing energy demand of secondary material processing by 30 percent, and achieving a 25 percent improvement in embodied energy efficiency of materials such as metals, polymers, fibers, and electronic waste.

As part of a multi-pronged approach, Pradeep Rohatgi, professor of materials science and engineering at the University of Wisconsin-Milwaukee, is leading an effort at REMADE to examine manufacturing processes. Drawing on his experience in India developing low-energy manufacturing systems such as solar furnaces, Rohatgi is focusing on reducing energy.

Bringing in embedded energy as a criterion for material selection, he said, will have a major impact on the design process, energy consumption, and the environment. "It will likely also trigger some fundamental advances in materials science," he said.

Adding embedded energy to more traditional criteria such as strength, weight, stiffness, durability, and cost, expands the scope of any life-cycle analysis applied to products and could very well tip the balance in favor of a new material over another that had traditionally been used.

For instance, automakers have started making substantial portions of their vehicles, such as the Ford F-150 pickup and the Audi A8, from aluminum rather than steel. That switch to aluminum improves life-cycle energy use because the metal is lighter than steel, improving fuel economy. But from an embedded energy perspective, an even better choice would be recycled aluminum, as that requires 95 percent less electricity per ton to produce than raw aluminum.

Another approach for reducing embodied energy in aluminum production, Rohatgi said, is to replace a portion of the metal with filler materials, such as fly ash.

A worker at Xerox's Webster manufacturing facility refurbishes a high-end printer. These remanufactured machines sell for the same price and on the same terms as new ones.
Image: Xerox

The move to building automobile bodies from aluminum improves both life-cycle energy use and fuel economy.
Image: Audi

Casting is another area of opportunity. Today, castings yield only 40 to 50 percent of the material poured. Advanced models, combined with experimental results, can more accurately predict shrinkage and provide specific surface finishes, eliminating the need for secondary operations such as grinding, polishing, or machining as well as reducing flash and dross. This approach, known as near net shaping, can also be applied to ceramics, composites, and plastics in addition to metals.

With embedded energy as the measuring stick, it is also possible to find manufacturing processes that produce very low life-cycle energy costs using carbon fiber composites or high-strength steels. The use of plant-based materials should also be considered, Rohatgi said.

In order to economically recover reusable materials from the waste stream, advanced separation techniques are needed. According to Eric Peterson, an inorganic chemist at Idaho National Laboratory in Idaho Falls, recycling of polymers is hampered by the tendency of mixed plastics to deteriorate when melted together. The recycling efforts at REMADE are investigating how mechanical separation followed by a chemical process can extract valuable polymers cleanly from a mixed stream. One of the institute's industry partners—a company that shreds automobiles for scrap—has been looking for exactly such a solution to allow it to recover and utilize much of the plastic found in today's cars.

Another research group at the University of Utah has developed a new method for separating metals. Electrodynamic sorting, a hybrid approach utilizing magnetics and eddy currents, can separate stainless steel from aluminum alloys. Peterson hopes that efforts like that will help enable the sorting of nonmagnetic alloys for recycling.

Refurbishing worn products is another approach to retain the energy already embedded in it to reduce the cost of manufacturing. Michael Thurston of the Golisano Institute for Sustainability at the Rochester Institute of Technology, said his group was looking at materials that could withstand powerful, heavy surface cleaning, and whether that sort of process would make it more economical to clean nuts and bolts rather than replacing them.

Thurston's team has also developed the capability to restore parts through additive processes. A flame-sprayed polymer coating and high pressure cold sprays have enabled researchers to build up material thickness for dimensional restoration on mechanical parts that have experienced wear or corrosion or cracking, allowing them to be reused. The hope is that this sort of additive restoration could be done for a fraction of the economic and energy cost of fabricating new parts.

Researchers also recognize that in addition to these manufacturing technologies, supply chain management and industrial design are key disciplines for reducing the embedded energy in products and increasing the amount of manufactured parts that can be recycled. Magdi Azer, associate director for manufacturing science at the Illinois Applied Research Institute and REMADE's chief technology officer, asked, "Can we design [products] in a way that allows us to more easily recover materials?"

Companies that lease products rather than sell them outright have a decided advantage in understanding the life-cycle cost of their products.

XEROX TRACKS the performance of machines in the field through remote diagnostics, which enables the company to quickly identify any trends that occur. Robust information systems allow technicians to look up a serial number and see a machine's entire history, including its prior incarnations before remanufacture. Signature analysis stations, which test electromechanical components to determine whether they had sufficient life remaining to be safely sent back out into the field, are being replaced by a combination of remote monitoring and big data analysis.

Thanks to a shift toward circular economic thinking, Xerox has been able to drive down costs in its U.S. facilities, enabling the company to resist the temptation to move work to countries with lower labor costs.

During a tour of the Webster plant, Kelley (who has since left the company to begin a job with the Sustainable Manufacturing Innovation Alliance) pointed out one line where the product had been outsourced to a contract manufacturer in Mexico. The company gave the workers in the upstate New York plant the opportunity to see if they could produce the same product at a competitive price.

"We're kind of costly up here," Kelley said, "so we need to be a little smarter in how we do things. This is one area where we are really leveraging remanufacturing." After the cost of shipping the cores down to Mexico and the completed products back up north was figured in, the company decided to bring the work back in-house.

Another innovation that Xerox has been using in the remanufacturing process is CO_2 cleaning. Liquid carbon dioxide is pumped through a pelletizer machine, picking up rice-size grains and spraying them under pressure at machine parts to gently strip away dirt. Unlike solvents or water, which must be carefully disposed once used for cleaning, the liquid CO_2 sublimates into a gas under normal pressure and can be collected by a fume hood for recycling.

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In a sense, the idea of a product being a fixed and static thing—representing an endpoint once it has been produced—is no longer a given. Instead, Xerox and scattered research labs of the REMADE Institute have provided a vision of a product being an amalgamation of parts and materials that are in perpetual flux that we might use for various periods of time and then return like library books where they can be redistributed.

"If you're a company that's only manufacturing a product," Nasr said, "you're only doing half your job."

That might not sound as exciting or sexy as designing the next electric car or smartphone, but it is fundamental to the proposition that we can continue to build products for generations to come, because that can only happen if we learn to do it sustainably. **ME**

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