Green Engineering

Julie Zimmerman and Paul Anastas published a guidepost to engineering in a way that's both environmentally and economically beneficial. More than 14 years later, it still holds up.

"Innovation in design engineering has resulted in feats ranging from the microchip to space travel. Now, that same innovative tradition must be used to design sustainability into products, processes, and systems in a way that is scalable."

From the "12 Principles of Green Engineering"by Julie Zimmerman and Paul Anastas, March 1, 2003, *Environmental Science & Technology*

These days, it's common for businesses to tout the sustainability of its products, or its environmentally friendly manufacturing processes. Of course, this wasn't always the case.

In 2003, Julie Zimmerman and Paul Anastas published "The 12 Principles of Green Engineering" in the journal *Environmental Science & Technology.* It was intended as a guide to help engineers and corporations design and develop products, processes and services that are both benign to human health and the environment while being competitive in the marketplace.

"Green engineering," a term that they coined, focuses on how to advance sustainability through innovative science and technology. It builds on the successful traditions of environmental engineering by integrating the conventional skillsets with a broader systems view. The challenges that engineers are being asked to meet today are far more subtle, complex and diffuse and in many cases global as well as multi-generational. Addressing these new challenges will require new knowledge, new talents, new skills, and a new awareness. As a result, Zimmerman said, the field of engineering needs to shift from being primarily focused on functional performance to being actively involved in the design and development of technology that will not contribute to adverse environmental and social impacts.

"The idea of green engineering is that there's a lot of engineering knowledge that can be applied further upstream in the process to prevent issues from arising in the first place," said Zimmerman, professor of chemical & environmental engineering as well as forestry & environmental studies.

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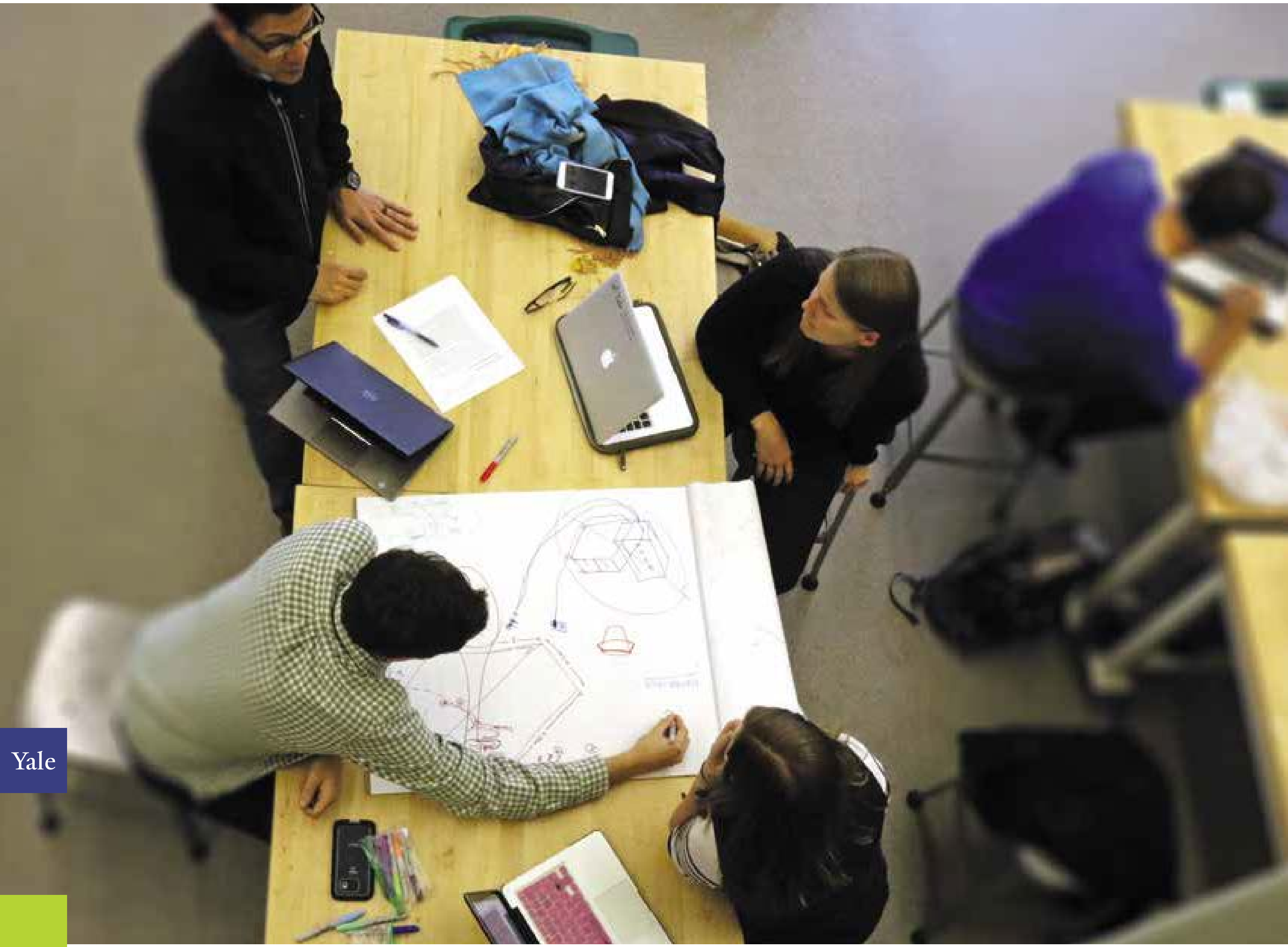

Yale

SUSTAINABILITY

More than 14 years later, the publication of the 12 principles has proven to have had a significant impact. They've been applied in construction and aerospace, and manufacturers of such consumer goods as cars and carpets have employed the principles in their work. Numerous pharmaceutical companies have also drawn from it.

"The Principles of Green Engineering have withstood the test of time, becoming more relevant as there is a growing interest in innovation of disruptive solutions by industry and an increasing awareness of the potential unintended consequences of technology on human health and the environment," Zimmerman said.

The idea for the 12 principles grew out of any earlier publication Anastas co-authored on the principles of green chemistry. That paper offered guidelines on how to make molecules and the synthetic pathways to make those molecules. Anastas and Zimmerman decided they should create something analogous for engineers and designers.

"It dealt with questions like 'Once you have all these great molecules and materials from green chemistry, how do you put them together into sustainable products, processes and systems?'" Zimmerman said. "'The idea grew from green chemistry and the need to think broadly about tangible goods and services that you want to design for sustainability."

The response was nearly immediate. Less than a year later, they edited a special issue of *Environmental Science & Technology* that contained a series of papers by research-

ers on how they employed the principles in their work. “It was nice to put out this framework and then really quickly be able to show their relevance and utility across all of the engineering disciplines and a wide variety of industrial sectors,” she said.

Zimmerman and Anastas, the Teresa and H. John Heinz III Professor in the Practice of Chemistry for the Environment at the Yale School of Forestry & Environmental Studies, also use the principles as a basis for their course on Green Engineering, which they co-teach.

This course provides a hands-on foundation to green engineering and the design and assessment of green products. “Approaching sustainability from a design perspective requires the need for a fundamental conceptual shift — from the current paradigms of production toward a more sustainable system, based on efficient and effective use of benign materials and energy across the life cycle,” she said. “The course is centered on identifying real-world sustainability challenges and then designing, developing, prototyping and ‘pitching’ solutions to them.

Above: *Students in the Green Engineering course have worked with major corporations such as U.S. Foods, Petco, Hyatt, and Hasbro to provide sustainability solutions to their products.*

The course was first offered 10 years ago. In its early stages, resources were a bit makeshift.

“Before the Center for Engineering Innovation & Design opened, we used

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A Summary of the
12 Principles of Green Engineering

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SUSTAINABILITY

1 **Inherent Rather Than Circumstantial**
Designers need to strive to ensure that all materials and energy inputs and outputs are as inherently nonhazardous as possible.

2 **Prevention Instead of Treatment**
It is better to prevent waste than to treat or clean up waste after it is formed.

3 **Design for Separation**
Separation and purification operations should be designed to minimize energy consumption and materials use.

4 **Maximize Efficiency**
Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency

5 **Output Pulled Versus Input-Pushed**
Products, processes, and systems should be "output pulled" rather than "input pushed" through the use of energy and materials. For instance, allowing consumer demand to determine quantity and time of production eliminates waste associated with overproduction, waiting time, processing, inventory, and resource inputs.

6 **Conserve Complexity**
Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.

7 **Durability Rather Than Immortality**
Targeted durability, not immortality, should be a design goal.

8 **Meet Need, Minimize Excess**
Design for unnecessary capacity or capability (e.g., "one size fits all") solutions should be considered a design flaw.

9 **Minimize Material Diversity**
Material diversity in multicomponent products should be minimized to promote disassembly and value retention.

10 **Integrate Material and Energy Flows**
Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.

11 **Design for a Commercial Afterlife**
Products, processes, and systems should be designed for performance in a commercial "afterlife."

12 **Renewable Rather Than Depleting**
Material and energy inputs should be renewable rather than depleting.

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to do prototyping with paper towel tubes, duct tape, and tissue boxes," she said. Today, they have major corporations turning to students for ideas. In recent years, the course has engaged companies such as U.S. Foods, Petco, Hyatt, REI, Nike, Curtis Packaging, and Hasbro. Representatives from these companies met with the students, each presenting a specific sustainability challenge relevant to their business. By the end of the semester, student have designed, prototyped and tested their ideas.

In one challenge, for instance, students were tasked by a major hotel chain to minimize the packaging burden of individual personal care amenities including shampoo, conditioner, and body lotion. After conducting surveys, the students determined that Americans prefer not to use shared wall dispensers. The students instead created a single-serving size capsule of each product contained within a water-soluble polymer. When the capsule gets wet, the polymer dissolves, and the guest now has just the right amount of product without contributing any waste to the landfill.

For the most recent class, student teams developed a device that pulls water from the air, a self-watering lawn system, and a machine that automatically sorts recyclables.

And green engineering has taken a place in the curriculum beyond Yale. The American Institute of Chemical Engineers has incorporated keywords from green engineering and sustainability into language on accreditation. For instance, it now requires accredited engineering programs to foster in students an ability to design "within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability."

Outside of academia, many of the ideas outlined in the 12 principles that might have seemed idealistic at the time are now common practice. It's no longer assumed that being mindful of the environment conflicts with a company's profits. HP Inc. allows customers to resell their ink cartridges back to the company, which then refills and resells them. "They actually make more money on the second one because they didn't have to remake the cartridge," Zimmerman said. With more than 4 billion pounds of carpet entering the United States' waste stream each year, carpet companies have pursued green engineering to strategically address this issue. Interface, the world's largest manufacturer of modular carpet, designed new products and a new business model by selling customers the service of a carpet instead the carpet itself. When the carpet reaches the end of its useful life, the company makes it the feedstock for the next generation of carpet and recycles it into a new floor covering to sell to the next customer.

"There are so many success stories now that the myths that 'green' products do not work as well, or going 'green' costs more to the company and the customer have been disproven," Zimmerman said.

The market has come to realize that green chemistry and engineering are actually better for business. That includes efficiency gains in terms of less waste from processing and packaging, and gains from having less inventory to manage and less liability from hazardous chemicals.

"Most importantly, because of the new innovation resulting from green chemistry and green engineering approaches, companies are realizing that this is not just about improving the bottom line, it is about top line growth," she said. "And as more and more of these case studies come out, it becomes self-sustaining while addressing sustainability challenges."