The Brief

ENGINEERING FOR GLOBAL IMPACT
AT **NORTHEASTERN UNIVERSITY**

Plastics, Health, and the Environment

From The Dean

Welcome to our first edition of *The Brief*–a publication series with each focused on a high-impact research area tackling a global challenge or an innovative educational initiative to develop the next generation of engineering leaders. In this issue, we feature interdisciplinary research our engineering scholars are conducting to address **Plastics, Health, and the Environment**.

Although humans produce 370 million tons of plastic each year, there is limited information on how it affects the environment and human health. What do low concentrations of plastics do to an ecosystem? Do we need to clean the ocean surface or is floating plastic okay because it will be broken down by sunlight? When plastics wash up on beaches, do they impede natural life forms? And where are plastics being found–from rivers to dust particles in human lungs, and even chemicals in the body affecting fetuses. Our researchers are seeking answers to these and other critical questions. They are also developing innovative alternatives to plastic materials and ways to upcycle them.

Read on to learn more and I invite you to reach out with ideas for collaboration or more information.

Kind regards,

Gregory D. Abowd

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WHAT'S INSIDE

Editorial credits and contributions: Cindy Fusco, Bill Ibelle, and News @ Northeastern

Plastics—A Geomaterial New in Earth's History

Plastics are everywhere. They're in our water, in our food, and even in the air we breathe. They show up in remote glaciers and deep in the ocean. And plastic is largely made up of carbon, which is released into the environment when that trash breaks down.

When Aron Stubbins, a professor of marine and environmental sciences, civil and environmental engineering, and chemistry and chemical biology, researched how much carbon plastics were adding to our planet's natural systems, the results were surprising. "It was clear that there were some environments in which plastics are now a significant amount of carbon. There's as much plastic carbon as there is natural carbon in some ecosystems," says Stubbins.

Building on this research, Stubbins and Samuel Munoz, an assistant professor of marine and environmental sciences, and civil and environmental engineering, put together the global plastic-carbon cycle and calculated the amount of carbon that plastics add to the environments they pollute. Their results were published in the July 2021 issue of ***Science*** and contend that plastics should be designated as an "emergent geomaterial" that has never been seen before in earth's history.

Although plastic is an entirely man-made substance, it now rivals natural geomaterials in terms of quantity and impact. As plastic particles of various sizes work their way into beaches, soils, and the ocean floor, they may change or smother the natural process. To understand their impact, scientists need to study plastics in the environment with the same scientific methods used to study natural geomaterials.

"We've added a new material plastic carbon cycle alongside the natural carbon cycle," Stubbins says. The implications of that are still unknown, he says, but so much carbon introduced by plastic pollution into the natural environment could have a ripple effect across life forms, ecosystems, and even the planet's climate.

Plastic-sourced carbon shows up in all kinds of ecosystems around the globe, but some of the most significant accumulation occurs in the surface waters of subtropical

"This paper [published in Science] is a call to arms for geoscientists to study plastics the same way they have studied natural materials. With focused work, we can learn much of what we need to know within a decade."

Aron Stubbins
Professor, Marine and Environmental Sciences, Civil and Environmental Engineering, and Chemistry and Chemical Biology
Northeastern University

Photo credit: Ruby Wallau, Northeastern University

Photo credit: Ruby Wallau, Northeastern University

ocean gyres, where ocean currents cycle in just such a way that floating materials accumulate in a sort of patch.

And those areas of the ocean are naturally low in carbon, Stubbins says. So, if the plastics that end up there are dissolving and releasing their carbon into that ecosystem, it could significantly alter the chemistry there.

Plastics everywhere

Although ocean gyres the size of cities are covered in thousands of tons of floating plastic, Stubbins believes that the plastic on our roadways could prove to be a bigger risk because it is chewed up by tires and transformed into dust particles that can be transported by the wind and enter our lungs as we breathe.

Samuel Munoz, assistant professor
Photo credit: Matthew Modoono, Northeastern University

Eighty percent of ocean plastic enters the sea from 1000 rivers worldwide; a large portion ends up as sediment in the floodplains in those rivers, causing environmental and health impacts.

These microplastics have been found in glaciers, near the peak of Mt. Everest, and in the bloodstreams of the majority of humans tested.

Like rock, plastics break down into ever-smaller pieces–stone, sand, dust–and move through the environment in a similar fashion. Since 80 percent of ocean plastic enters the sea from 1,000 rivers worldwide, Munoz contends that a large portion of the world's microplastics probably end up as sediment in the floodplains of those rivers. He notes that on the Brantas River in Indonesia, the amount of plastic-generated carbon already exceeds the levels of natural carbon.

In their paper, Stubbins and Munoz contend that it's time for scientists worldwide to turn their attention to the life cycle of plastic, using the skills they've developed during a century of studying natural systems.

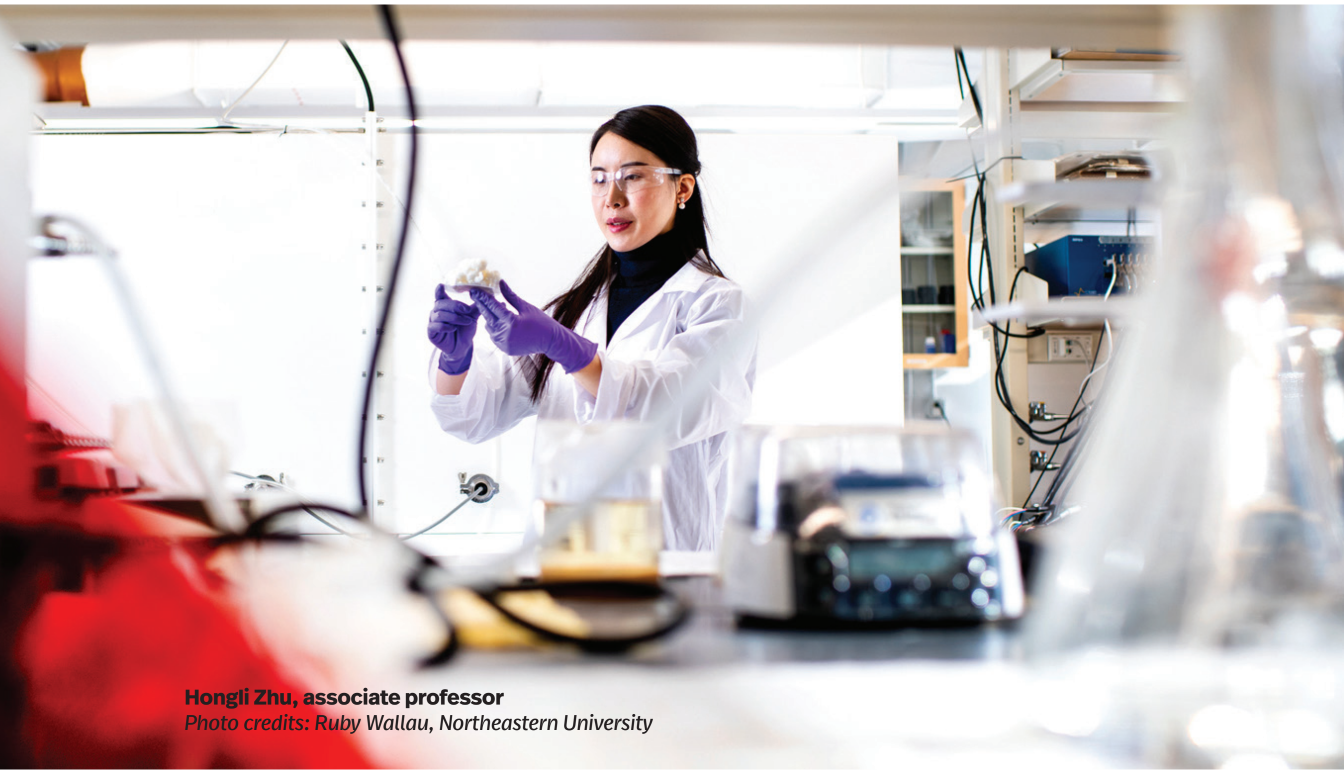
"This paper is a call to arms for geoscientists to study plastics the same way they have studied natural materials," says Stubbins. "With focused work, we can learn much of what we need to know within a decade." •

View the Journal Paper in *Science*

Aron Stubbins, Kara Lavender Law, **Samuel E Munoz**, Thomas S Bianchi, and Lixin Zhu. Plastics in the Earth system. Science, 2 Jul 2021. Vol 373, Issue 6550, pp. 51-55. doi: 10.1126/science.abb0354

A Biodegradable Substitute for One-Time Use Plastics

Instead of lasting for centuries, this plastic substitute disintegrates in 60 days



Hongli Zhu, associate professor
Photo credits: Ruby Wallau, Northeastern University

"Single-use plastic containers at supermarkets and restaurants are cheap and convenient, but most of these containers are not biodegradable," says Hongli Zhu, associate professor of mechanical and industrial engineering.

According to the Environmental Protection Agency, 27 million tons of plastic waste were diverted to landfills in 2018 in the United States. Plastic doesn't decompose over time. It gets broken down into smaller pieces known as microplastics that pollute rivers and oceans.

To address this, Zhu and her PhD students turned a sugarcane byproduct into a sustainable, compostable, and inexpensive material that's durable enough to serve as tableware, bags, and wrappers, and that biodegrades within 60 days.

"I have a 4-year-old son, and he eats a lot of candy," Zhu says. While reading the ingredients of her son's favorite snack, it struck her that sugarcane pulp, known in the industry as bagasse, is one of the most prevalent food waste products in the world. Maybe this ubiquitous waste product could serve as the basis for her new material.

View the Journal
Paper in *Matter*

Chao Liu, Pengcheng Luan, Qiang Li, Zheng Cheng, Xiao Sun, Daxian Cao, **Hongli Zhu**. Biodegradable hygienic, and compostable tableware from hybrid sugarcane and bamboo fibers as plastic alternative. Matter. Volume 3, Issue 6 (2020), pp. 2066-2079, ISSN 2590-2385, doi.org/10.1016/j.matt.2020.10.004

There was one problem. Although bagasse is plentiful and inexpensive, its fibers are short and not very strong. So, Zhu combined the sugarcane pulp with bamboo fibers.

Since bagasse and bamboo fibers are made up of similar underlying chemicals (cellulose, hemicellulose, and lignin), the material doesn't require any additional processing during the recycling and reusing processes to separate different components, unlike some currently available options. The result is an inexpensive, completely natural, and biodegradable material that is sufficiently durable to be molded into containers strong enough to hold food and liquids.

To test how the material degrades over time, Zhu and her students buried a sample outside and checked on it every ten days. The material began to break down after 30 days and disintegrated after 60 days.

Zhu and her research team published a paper describing their invention in the November 2020 issue of ***Matter***. She believes this solution provides a sustainable, low-cost approach to plastic pollution while utilizing the byproducts in the sugar industry to develop valuable, sustainable products everyone needs daily.

"The end goal is to tackle the plastic pollution problem," Zhu says. •

Exploring the Dangers of Microplastics

Microplastics are everywhere: in riverbanks, glaciers, deserts, fish populations, even in the air we breathe—yet we still have little understanding of how they affect the environment and human health.

These tiny bits of plastic have been found in human lungs, blood, and even the placenta. They are plentiful in our rivers and ocean and pose a threat to aquatic life worldwide, according to the National Oceanic and Atmospheric Administration.

And because plastics are extremely durable, they maintain a lasting presence on Earth.

“Plastic was designed to break down slowly, so it doesn’t disappear. It just becomes particles that get smaller and smaller,” explains Samuel Munoz, an assistant professor of marine and environmental sciences, and civil and environmental engineering. This is a growing concern since plastic production has soared from 1.5 million tons in 1950 to 300 million tons in 2017, according to the International Union Conservation of Nature.

Because plastic is made from the byproducts of fossil fuels—coal, crude oil, and natural gas—it is inexpensive to produce, says Aron Stubbins, a professor of marine and environmental sciences, civil and environmental engineering, and chemistry and chemical biology.

There are two ways that plastic particles can cause harm: by releasing the contaminants used to make plastic, such as flame retardants and antioxidants; and by latching onto other harmful chemicals in the environment, such as pesticides.

Stubbins notes that research has already established the harmful impact of some plastic additives, such as BPA, which is known to harm the brain, fetuses, infants, and children. He says that, in addition to reducing plastic production, we need stronger regulations to restrict the substances companies use to create plastics.

“In the U.S., there’s this ‘beg-for-forgiveness,’ rather than ‘ask-for-permission’ attitude toward companies putting certain chemicals in their products. You only get public pushback after a toxic impact is identified,” Stubbins says. “If public safety, rather than profits, were the dominant concern, then you’d have to take each of those chemicals through checks before you use it. This would create problems for industry but would likely benefit public health.

Microplastics have been found in human lungs, blood, and even the placenta. They are plentiful in rivers and the ocean, and pose a threat to aquatic life worldwide.

Samuel Munoz, assistant professor
Photo credit: Matthew Modoono, Northeastern University

Meanwhile, Munoz notes that while plastic waste in the ocean gets much of the attention, it only accounts for a fraction of the plastic waste we produce, which raises a big question: Where is all the waste going? To answer this, Munoz has focused his research on the river floodplains to track how microplastics move through Earth's natural sedimentary systems.

"We've spent more than a century trying to understand how sediment moves through the environment," he says. "And now there's this whole other material [of plastics] that's fairly important. But the mechanisms by which it moves is going to be different. Sometimes it'll float instead of sink. Sometimes it can become airborne more easily. Sometimes it won't settle out in a water column as easily as sediment does."

A Surprising Delivery System for Harmful Chemicals in Plastics: the Food You Eat

Scientists know that the tons of plastics waste dumped into landfills and the ocean leach harmful chemicals that disrupt the natural life cycles of the planet. But there may be an even more immediate threat to human health: plastic-based chemicals in our food.

“Two major classes of chemicals– Phthalates and PFAS (Per- and Polyfluoroalkyl Substances)–are used to make a variety of food contact materials, including plastic containers, wrappers and gloves used in the food industry,” says Julia Varshavsky, an assistant professor of environmental health sciences and civil and environmental engineering. “These chemicals are found in the majority of humans and have been found to contribute to infertility, preterm birth, neurological problems, obesity, diabetes, and cancer.”

The concern is that exposure–especially in fetal and early life development–leads to serious health and reproductive problems later in life. As Varshavsky puts it: “Babies are born pre-polluted.”

In a study published in ***Environmental International***, titled “Dietary Sources of Cumulative Phthalates Exposure Among the U.S. General Population in NHANES 2005-2014,” Varshavsky found that human phthalate levels are determined more by where you eat than by what you eat.

“There was virtually no difference between those who ate mostly vegetables and those who ate high-fat foods,” says Varshavsky. “But phthalate levels were much lower among those who ate food prepared at home. This is important given that two-thirds of the U.S. population dine out or get take-out daily.”

The study found a 35 percent increase in phthalate levels among those who frequently ate fast food, take out, or in cafeterias and traditional restaurants. Phthalate levels were 55 percent higher among teenagers, who get a high percentage of their calories from school lunches and takeout. The primary sources of these harmful chemicals appear to be the plastics used in food packaging, wrapping, and in the gloves used in food handling, although food conveyor belts, milk PVC tubing, and storage temperature may also be factors.

Solutions

The most immediate solution, according to Varshavsky, is to prepare a higher percentage of your meals at home.

"Phthalates and PFAS (Per- and Polyfluoroalkyl Substances) are used to make a variety of food contact materials, including plastic containers, wrappers, and gloves used in the food industry. These chemicals are found in the majority of humans and have been found to contribute to infertility, preterm birth, neurological problems, obesity, diabetes, and cancer."

Julia Varshavsky
Assistant Professor
Environmental Health and Civil and Environmental Engineering
Northeastern University

Photo credit: Bella Martinez, Northeastern University

"The good news is that phthalates leave the body very quickly when you're not ingesting them anymore," she says. "One study showed we can metabolize them in just three days."

The same is not true of PFAS—a class of over 9,000 chemicals used in a wide range of industrial and consumer products because of their stain and water-resistant properties. PFAS are far more durable and can affect bodily systems, including reproduction and fetal health, in very low doses. Northeastern University is the home of the PFAS-Tox Database, a collection of over 1000 different studies examining the effects of PFAS on health outcomes. Varshavsky leads the maintenance and growth of the database, which allows users to filter based on specific chemicals studied and whether the research focuses on humans, animals, or in-vitro.

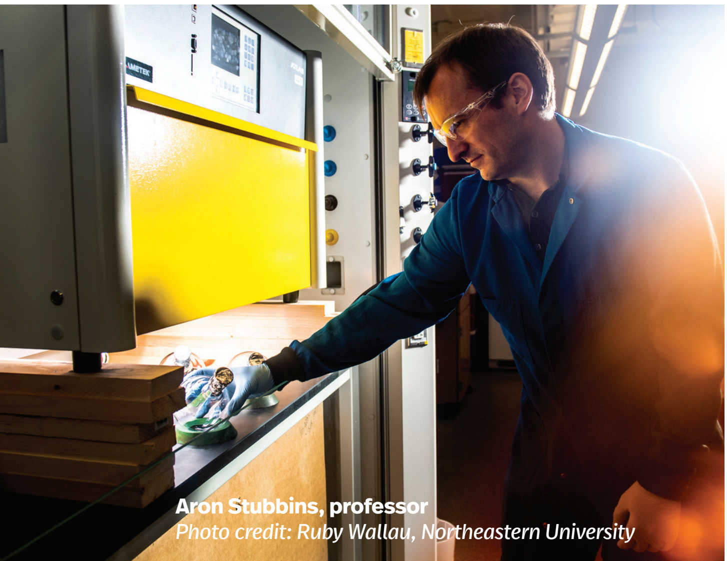
"We need to focus our efforts on improving the freshness of food (especially our school lunches), reducing unnecessary plastic packaging and food processing, and developing safer alternatives for use in food production and packaging," says Varshavsky. •

View the Study in *Environmental International*

Varshavsky JR, Morello-Frosch R, Woodruff TJ, Zota AR. Dietary sources of cumulative phthalates exposure among the U.S. general population in NHANES 2005-2014. Environ Int. 2018 Jun; 115:417-429. doi: 10.1016/j.envint.2018.02.029

Does Sunlight Degrade Floating Microplastics?

Has 98 percent of the 14 million tons of plastic that spill into the world's oceans each year vanished? Aron Stubbins, a professor of marine and environmental sciences, civil and environmental engineering, and chemistry and chemical biology, has a theory.



Aron Stubbins, professor
Photo credit: Ruby Wallau, Northeastern University

With funding from the National Science Foundation, Stubbins is exploring whether the sun's powerful ultraviolet rays can break down floating plastic into ever smaller pieces, and ultimately dissolve the material altogether, leaving only carbon.

Together with visiting doctoral fellow Lixin Zhu, Stubbins tested his theory in the laboratory by floating microplastics in seawater and subjecting them to artificial sunlight. Presto! No more plastic.

"This is good news, but it should be tempered," says Stubbins. "Sunlight's not going to solve all our problems."

One issue is that some types of plastics are not degraded by sunlight. For instance, while a five-millimeter piece of Styrofoam would disappear after just a few months of exposure, polyethylene–one of our most abundant plastics–would take "decades to centuries" to break down.

He also notes that only floating plastic will dissolve in this manner.

"Other plastics will just sink to the ocean floor," he says. "And if they get buried in river or soil sediments, or a landfill, they will degrade much slower in the dark. It might be thousands of years before they become microplastics. If plastic ends up in a stable environment, it essentially lasts forever."

The goal of this research is to understand how plastic degrades so we can identify the areas of greatest concern. For example, although ocean gyres have trapped city-size islands of floating plastic, these highly publicized environmental nightmares may not be the greatest concern. Much more damage may be done by microplastics on the ocean floor, in river floodplains, and even making their way into human lungs.

> *“The impact of the processes we can’t see is often greater than the impact of what we can see.”*
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> **Aron Stubbins**
> Professor, Marine and Environmental Sciences, Civil and Environmental Engineering, and Chemistry and Chemical Biology
> Northeastern University

Photo credit: Ruby Wallau, Northeastern University

Stubbins’ research has focused on invisible influences that shape our natural world, from single-celled plants that float in our oceans and legions of microbes that drift alongside them—to now microplastics.

Over the years, he has learned that out of sight should not be out of mind.

“The impact of the processes we can’t see,” he says, “is often greater than the impact of what we can see.” •

Transforming Plastic Waste into Clean Energy

When faced with the 27 million tons of plastic waste in the oceans, rivers, and floodplains of the world, College of Engineering Distinguished Professor Yiannis Levendis, mechanical and industrial engineering, came up with a solution: Burn it.

He knew the thick black smoke produced by burning plastic was highly toxic but wasn't deterred because he was also aware of its enormous potential as an energy source.

"One pound of plastic contains the same amount of petroleum as one pound of gasoline," Levendis explains. "The problem was how to use waste plastics as a source of clean energy. If we could master that challenge, we would be addressing two critical environmental challenges at the same time."

So Levendis and his research team designed a combustion system that adds a simple step to the burning process to turn plastic into a fuel that burns just as cleanly as natural gas. He accomplished this by heating the material to 800 degrees Celsius in an oxygen-free environment. This causes the plastic to become a gas, which is then mixed with air before it is burned as a clean fuel.

A byproduct of the patented process are carbon nanotubes, a microscopic substance that is extremely strong, flexible, and is an excellent conductor of heat and electricity. As a result, they are used for energy storage, auto parts, boat hulls, sporting goods, and electronic devices.

"Plastics don't decompose–they can break down into microplastic debris and release harmful chemicals into seawater if they're not removed," says Levendis. "My research focuses on upcycling this waste material to address other social and environmental needs."

A newly invented combustion system turns plastic into fuel that burns just as cleanly as natural gas. The patented process also produces carbon nanotubes—a microscopic substance that is extremely strong, flexible, and an excellent conductor of heat and electricity.

Levendis has spent much of his 33-year career at Northeastern focusing on clean energy and developing improved combustion methods that reduce particulate emissions. His recent focus on plastic pollution is the product of his deep love of nature.

"When I'm near the sea, and I notice trash or pollution, I see it as a problem," says Levendis. "But I also see it as an opportunity that is ultimately the key in addressing climate change. If we can work together to arrive at new, innovative solutions, we can restore the world to the way it should be—and turn back the clock on climate change." •

Northeastern College of Engineering At A Glance

Top 33

Graduate Engineering School

U.S. News and World Report, 2023

Over $80M

Annual External Research Awards

215

Tenured | Tenure Track Faculty

Over 115

Young Investigator Awards

(All current faculty)

8452

Student Body

54% Graduate | 46% Undergraduate

Fall 2021

Northeastern University
College of Engineering

With 215 tenured/tenure-track faculty and 18 multidisciplinary research centers and institutes with funding by eight federal agencies, the College of Engineering is a leader in experiential education and interdisciplinary research focused on discovering solutions to global challenges to benefit society.

Northeastern University

Founded in 1898, Northeastern is a global research university and the recognized leader in experiential lifelong learning. Our approach of integrating real-world experience with education, research, and innovation empowers our students, faculty, alumni, and partners to create worldwide impact.

Northeastern's comprehensive undergraduate and graduate programs lead to degrees through the doctorate in nine colleges and schools across our global system of campuses. Learning is personalized and experiential, with a curriculum that emphasizes the intersection of data, technology, and human literacies—uniquely preparing graduates for lives of fulfillment and accomplishment.

Our research enterprise, with an R1 Carnegie classification, is solutions-oriented and spans the world. Our faculty scholars work in teams that cross not just disciplines, but also sectors—aligned around today's highly interconnected global challenges and focused on transformative impact for humankind.

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About the Cover

Assistant Professor Samuel Munoz, marine and environmental sciences, jointly appointed in civil and environmental engineering, is conducting research on the environmental and health impacts of plastics waste in the ocean and river floodplains at Northeastern University's Marine Science Center in Nahant, Massachusetts. Located on a peninsula five miles northeast of Boston, it houses year-round research laboratories and teaching facilities.

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