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Marcus Banks, Molly Metz & Davida S. Smyth

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The Sustainability Challenges Facing Research and Teaching Laboratories WHEN GOING GREEN

by Marcus Banks, Molly Metz, and Davida S. Smyth

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In an HIV testing laboratory, single-use plastic syringes, pipettes, and filters are disposed of in a red hazardous materials waste bag.

The Plastic Problem

While 8.2 billion tons of plastic has been produced worldwide to date, only 9% of it has been recycled.[1] Approximately 400 million tons of plastics are manufactured every year, of which about 146 million tons is destined for use in packaging.[2] Most of this plastic ends up in dumps, landfills, or our rivers and oceans. If we continue to produce plastic and mismanage the waste, it is estimated that by 2050, we will be faced with approximately 12 billion tons of plastic waste.[3] The production and improper disposal of petroleum-based plastics continue to cause a plethora of problems in our environment and are major contributors to climate change. Plastic bags block our rivers and waterways, clogging sewers and providing breeding grounds for disease vectors such as mosquitoes, which carry malaria, among other diseases. The breakdown products of plastics, microplastics, have been found in the pristine waters of the Arctic, and single-use plastics have been found blocking the airways and stomachs of hundreds of species, often ingested by sea creatures mistaking them for food.[4] Packing materials including styrofoam products, often used to transport materials for research, contain carcinogenic chemicals like styrene and benzene that are highly toxic if ingested, damaging the nervous system, lungs, and reproductive organs.[5] In underresourced countries, plastic waste is often burned for heating or cooking in open-air pits, exposing people to toxic emissions and harmful gases like furan and dioxin.[6]

A recent Intergovernmental Panel on Climate Change (IPCC) report noted that plastic production has quadrupled in the last 40 years, and the manufacture of the oil-based material has an enormous carbon burden.[7] In light of the staggering impact of plastic on human health and the environment, major efforts are being made to reduce plastic use, with some companies and even countries banning their use. To date, 60 countries have introduced bans and fees to help reduce plastic use. In the United States, however, the landscape of plastic bans is complicated, with several states and locales clashing over whether or not it is in fact legal to ban plastic.[8] The European Parliament has approved a ban on single-use plastics,[9,10] and more recently the University of Leeds pledged to go single-use-plastic-free by 2023 and the largest university in the United Kingdom, University College London, has made a commitment to ban single-use plastic in its labs by 2024.[11,12] This poses a challenge for certain types of activities and procedures in the laboratory. UCL researcher Tim Arnett investigates the development of bone cells using dishes made of transparent polystyrene. The bone cells adhere to the surface of the dish and can be visualized and photographed through it.[13] He recently told *The Scientist*:

> *By washing these plates very carefully after use and then reusing them … you'd never get rid of all of the cell debris that was attached, and if you used conditions that were sufficiently aggressive to do so, you would almost certainly damage the plates themselves and damage that optical clarity.*

The Five Rs in the Lab

There are limited data available on the contribution of research and academic/teaching labs to the problem of plastic waste, where many different types of plastics are used and, for safety and sensitivity reasons, many are disposed of after a single use. Data from the University of Exeter in the United Kingdom revealed that 280 of its bench scientists generated about 267 tons of plastic waste in 2014.[14] It is estimated that about 20,500 institutions worldwide are involved in biological, medical, or agricultural research, resulting in around 5.5 million tons of lab plastic waste in 2014. This is roughly the combined tonnage of 67 cruise liners, and equal to 83% of the plastic recycled worldwide in 2012.[15]

At The New School, sustainability is part of the day-to-day operations of the University Center. The New School's sustainability dashboard provides data in real time to students, staff, and faculty and shows the efforts of the college to reduce waste.[16,17] All office paper on campus is Forest Stewardship Council (FSC) certified and contains 100% post-consumer recycled content; our toilet paper is made of 100% recycled material; paper towels are made of 70% recycled material; and the cafeteria uses biodegradable (compostable) dishware, including take-out packaging, coffee cups, and utensils. While the university diverts approximately 48% of waste from landfills, a recent audit of The New School's waste stream revealed that more than two-thirds of waste could be diverted simply with better sorting at the waste bin. This speaks to the need to educate more about, and to promote awareness of, sustainability initiatives at the college.[18,19]

In accordance with our sustainability mission, considerable efforts have been made to refuse, reduce, reuse/reclaim, repurpose, and recycle as much as we can in the teaching labs, which are designated as biosafety level 1 (BSL1). This includes reusing pipette tips for workshops/classroom activities that do not involve pathogens, and using glassware in lieu of plastic when possible. Our commitment to sustainability extends beyond plastic, where we also try to reduce our environmental impact by using millipore drainage water for soaking and cleaning glassware and, importantly, turning off equipment like ice machines and incubators when not in use.[20,21]

When Pathogens Enter the Lab

In fall 2018, we established our new biosafety level 2 (BSL2) laboratory in The New School's University Center, a LEED-certified building. On the sixth floor, close to our building's green roof and adjacent to the teaching lab, the new BSL2 lab houses a biosafety cabinet (Figure 1), incubators for growing the pathogenic bacteria, and a DNA sequencer allowing us to study bacterial

Figure 1. Our biosafety cabinet in the Biosafety Level 2 Laboratory. The cabinet is used when working with pathogenic bacteria.

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Figure 2. Commonly used, single-use plastics or "consumables" from the laboratory. A selection of conical tubes, PCR tubes, filter tips, multi-well plates and microcentrifuge tubes are shown.

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microbiomes. The additional engineering controls and protective equipment used in BSL2 spaces enable students and faculty members to work safely with pathogenic or disease-causing bacteria while protecting the public from the potential hazards within. As excited as we are to house this new lab on campus, it comes with many unique challenges for sustainability. BSL2 laboratories, like any other laboratory, use plastic, much of which is single-use in the form of pipette tips, pipettes, petri dishes, and conicals (Figure 2). Single-use plastics are used preferentially in these types of labs that deal with pathogenic bacteria, as they can be used, contaminated with bacteria during use, and disposed of immediately after use. Biohazardous plastic waste is decontaminated and sent to a landfill or for incineration. Any plastic that has been used inside a biosafety cabinet is considered contaminated and biohazardous and therefore cannot be recycled. Therein lies the problem. We describe our understanding of the plastic loop in Figure 3, which shows how the plastic loop of the laboratory intersects with the plastic loop of everyday life.

We must use the biosafety cabinet to work safely, and during the course of our research we generate plastic waste that cannot be recycled. There are possible solutions but none without challenges. Some labs use glass pipettes that are decontaminated and washed/resterilized by a dedicated team of technical staff. Glass can pose a problem should it break in a lab where work is being conducted with pathogenic bacteria, and specific protocols and procedures must be taken when dealing with broken contaminated glass. After use, glass must also be decontaminated and washed, a laborious and tedious task. This can be a burden where technical support is lacking and lab cleanup and turnover (e.g., in teaching labs) is pressing. Bunsen burners cannot be used inside a biosafety cabinet, so plastic loops or alternatives are used. Many of the strategies being used to go green in the lab can in fact be used in BSL2 labs (closing the sash on chemical hoods, reducing the temperature on freezers, turning off incubators when not in use), but many others cannot. While gloves can be recycled when not contaminated with biological contaminants, they currently cannot be recycled from BSL2 labs. The recycling loop cannot be closed here, and this represents a wicked, capacious problem. We make several suggestions in Table 1 for those working in BSL1 and BSL2 labs.

Plastic and Policy

Inspiration and ideas can be gleaned from our colleagues in health care and in human and veterinary medicine who are striving for sustainability. Medical waste (which includes biohazardous laboratory waste) is complex for a number of reasons. About 15–20% of medical waste is regulated by several agencies, including the Environmental Protection Agency (EPA), Occupational Safety and Health Administration (OSHA), Department of Transportation (DOT), Drug Enforcement Agency (DEA), and others. Such regulated medical waste, which includes pharmaceutical and hazardous chemical waste and radiological waste, is 10 to 100 times more costly to manage than solid waste or recyclables.[22] Improper handling of this waste is a devastating environmental hazard across our planet.[23] Discarded needles and other sharps can also pose a deadly risk to the public and waste workers, exposing them to potential needle-stick injuries and infections when containers break open or needles are mistakenly sent to recycling facilities. Janitorial and housekeeping staff can also be harmed when loose sharps poke through plastic garbage bags, emphasizing the need for sturdy puncture-proof sharps containers; such needles can transmit serious bloodborne disease such as human immunodeficiency virus (HIV) and hepatitis.[24] Worse than that, plastic supplies for medical institutions are often discarded when they reach their "best-before" date. Plastics are used preferentially as a cost- and time-saving measure.

Efforts to recycle and to ensure proper separation and handling of waste are being recognized not only to protect human and environmental health, but surprisingly also as a cost-saving measure in clinical settings, with Federal agencies playing a leadership role.[25] The National Institutes of Health (NIH) developed the Green Labs Program (GLP), to promote the awareness and participation of their laboratory personnel in sustainable laboratory practices. The NIH GLP is a collaborative initiative, led by the Sustainability Management Team, to recognize laboratories that choose to reduce their environmental footprint by participating in NIH environmental initiatives.[26] The Centers for Disease Control (CDC) is also committed to waste reduction and sustainability, producing an annual sustainability report that details its progress toward nine distinct sustainability goals.[27] The CDC and the NIH have jointly developed the upcoming sixth edition of the "Biosafety in Microbiological and Biomedical Laboratories Guide" (BMBL), the seminal resource for designing and operating laboratories used in research and teaching labs alike. The updated BMBL guide's new sustainability appendix helps designers plan laboratories that limit environmental waste through safer design and green chemistry.

Disposal of biomedical waste is regulated at the state level. According to the New York Department of Environmental Conservation (NYSDEC), there is nothing in the NYSDEC 6 NYCRR Part 360 regulations that would preclude the separation, recycling, and repurposing of unsoiled, unused, and clean plastic material from a BSL2 laboratory. Thus,

Figure 3. The plastic loop, inside and outside of the lab. Pink lines indicate the current usage. Blue lines indicate where efforts can be made to reduce, reuse, repurpose, and recycle.

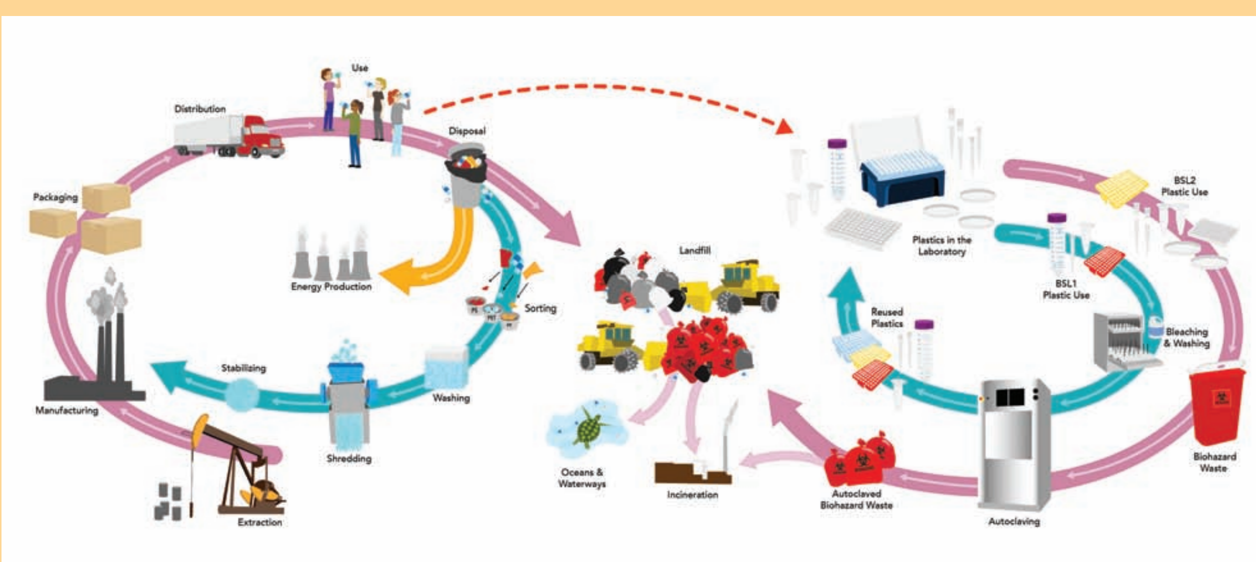

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Table 1. Suggestions and Ideas for Labs Operating at BSL1 and BSL2		
	Biosafety Level 1	**Biosafety Level 2**
Refuse	Do not buy single-use plastic consumables. Choose autoclavable/biodegradable plastic or glass instead. Choose vendors that have reduced their use of plastic. Avoid overreliance on kits.	Do not buy single-use plastic consumables. Choose autoclavable/biodegradable plastic or glass instead. Choose vendors that have reduced their use of plastic. Avoid overreliance on kits.
Reduce	Modify protocols and procedures to use fewer plastic materials where possible. Substitute glassware when possible for plastic material (test tubes, petri dishes, pipettes). Source alternative and biodegradable materials. Provide education on how to reduce plastic use and how to reuse and sterilize glassware.	Modify protocols and procedures to use fewer plastic materials where possible. Substitute glassware when possible for plastic material (test tubes, petri dishes, pipettes) when working with RG1 organisms.* Source alternative and biodegradable materials. Provide education on how to reduce plastic use and how to reuse and sterilize glassware.
Reuse/Reclaim	Decontaminate (bleach or autoclave) and wash for reuse. Grind, melt, extrude, and mold.	Decontaminate (bleach or autoclave) and wash materials that have not been in contact with pathogenic microbes prior to reusing/reclaiming. Grind, melt, extrude, and mold.
Repurpose	Decontaminate (bleach or autoclave) and wash for repurposing. Be creative in how plastics can be reused in the lab.	Decontaminate (bleach or autoclave) and wash for repurposing. Be creative in how plastics can be safely reused in the lab.
Recycle	Send for recycling whatever cannot be reused, reclaimed, or repurposed. Ensure that material is recycled. If not, find out what prevented it from being recycled (plastic type, plastic form, contamination).	Send for recycling whatever cannot be reused, reclaimed, or repurposed. Decontaminate (bleach or autoclave) and wash materials that have not been in contact with pathogenic microbes prior to recycling. Obtain permit to recycle materials that have been in contact with pathogenic microbes. Ensure that material is recycled. If not, find out what prevented it from being recycled (plastic type, plastic form, contamination).

**It can be difficult and potentially hazardous to substitute glass for plastic when working with organisms of Risk Group 2 (RG2) and above. In addition some protocols/techniques in their current form require the use of plastic. Risk Group 2 organisms can cause disease in humans, but the disease is treatable or preventable. Risk Group 2 organisms need to be worked with in a biosafety cabinet and include the organisms Streptococcus, Herpes virus, and most mammalian cell lines.*

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if teaching and research facilities were generating plastic waste that had not been used for transferring, manipulating, or conducting research with infectious agents or potentially infectious agents, biological toxins, biologicals, or attenuated or genetically modified agents, they could be recycled. If a facility wanted to autoclave materials that may have been in contact with any of the above, a 6 NYCRR Part 360/365 permit would be needed to operate the autoclave. Many faculty members, researchers, and staff members are completely unaware of this.

At The New School, like many other academic institutions, we use a company to decontaminate and process our biological waste. Companies such as Stericycle have permits allowing them to process our lab-generated waste. Stericycle has several commercial transfer and treatment (autoclave) facilities throughout New York State, as well as in Rhode Island, Ohio (medical waste incinerator), and other parts of the country. Waste is transported from academic sites to the company processing site, and once decontaminated it is typically incinerated or sent to a landfill. It is unclear which is worse for the environment, incineration of our waste or disposal of our waste in landfills. Most faculty members and researchers are completely unaware of the ultimate destination of the waste they generate. Fewer still consider how long this waste could linger in a landfill.

While academic facilities could obtain the necessary permits to process their own waste in house, it is also important to recognize that autoclaving plastic poses its own hazards.[28] In addition, autoclaving cannot destroy RNases, enzymes that degrade RNA.[29] This means that for sensitive procedures and samples, autoclaving and reusing tips is not ideal, and manufacturers must continue to supply us with RNase and DNase free tips. Manufacturers often tout the advantages and benefits of their plastic "consumables" as being uniform so as to reduce variability and to maximize sensitivity.[30] Plastic consumables are designed and manufactured with precision and fit in mind and to be free of human genomic DNA. Common molecular biology techniques such as polymerase chain reaction (PCR), quantitative PCR (qPCR), and next generation sequencing all require plastics to be free of such contaminants, as they would ruin the integrity of experiments and produce "false positive and negative" results.

What Are Others Doing to Promote Sustainability in Labs?

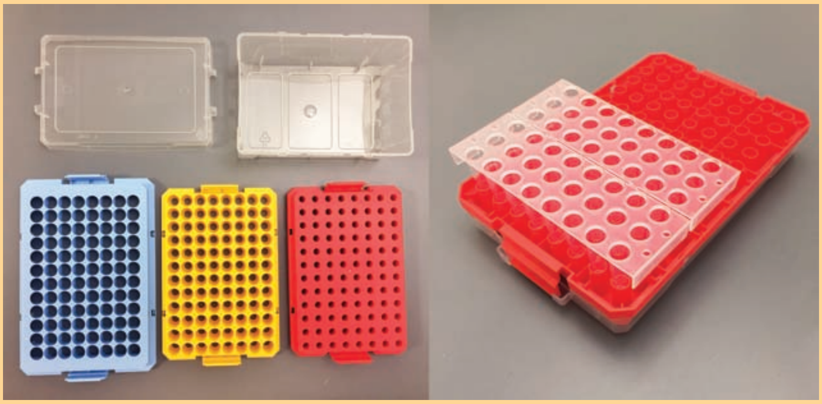
Thankfully, several organizations, colleges, not-for-profits, and societies have taken up the baton against waste in laboratories. My Green Lab is a not-for-profit organization that has helped many labs create a culture of sustainability.[31] It provides tips and tricks to reduce, reuse, and recycle plastic waste, and describes several take-back programs. Labconscious is an open resource for life scientists and describes several ways to reduce waste, use green chemistry, conserve water, and save energy. It maintains a fantastic database of green-lab supplies and equipment and offers tips and tricks on how to green your lab.[32] Commonly used vendors such Sigma, Qiagen, and New England Biolabs are increasingly offering take-back programs, and in addition companies specializing in the recycling of lab waste have emerged. USA Scientific has several options for pipette tips, including reload wafers (Figure 4). TerraCycle offers free recycling programs to help with recycling, as well as zero-waste boxes to collect almost everything, including gloves.[33] Technological advances are also providing options to wash and reuse materials such as tips.[34]

Well-Intentioned but Wrong

Often touted as a possible solution to the plastic problem, scientists are anxiously watching the biodegradable plastic field as it evolves. Jacqueline McGlade, chief scientist at the UN Environment Programme, has called biodegradable plastics "well-intentioned but wrong."[35] Biodegradable plastics, unlike matter of biological origin, need very specific conditions to biodegrade, which often include exposure to high temperatures and sunlight. Most of these types of plastic will not decay at temperatures below 50°C, reducing the likelihood that they would degrade if they made their way into the ocean. These types of plastics need special facilities to degrade. Their buoyancy is also an issue: They are dense and sink to the ocean floor, making them inaccessible to the sunlight needed for their decay (this would also be an issue in landfills). For these and other reasons, such "well-intentioned" solutions will not solve the plastic problem in our labs. But if we could identify ways in which these types of plastics could be designed to decay under natural conditions such as the ocean or in a landfill, this could be a breakthrough. An alternative to biodegradable plastics is bioplastics such as chitosan bioplastic, derived from crustacean shells, or those generated by the genetic engineering of plants to express bacterial genes. Such bioplastic is produced from renewable resources and is carbon neutral, reducing atmospheric CO_2. And while bioplastics are not biodegradable, they are recyclable.[36]

A solution to our problem may in fact come from science, technology, and design. Bacteria have been identified and characterized with the ability to break down plastic due to the presence of a special enzyme called PETase that can degrade polyethylene terephthalate (PET), the polyester polymer resin most commonly used in fabrics and storage materials.[37] The use of this enzyme to tackle this problem is being intensely investigated. The biodesign and synthetic biology movements are also generating new ideas and directions in terms of packaging and alternatives to plastic.[38] Large companies such as IKEA have made the switch from polystyrene packaging to fiber-based materials such as corrugated and molded paper in a honeycomb structure, taking inspiration from bees, and more recently IKEA has begun to use mushroom based packaging. It took 4 years for IKEA to

Figure 4. The image on the left shows reusable plastic reload wafers and plastic packaging that comes with pipette tips that we purchased. The image on the right is a PCR rack that we constructed by repurposing a reload wafer from the pipette tips, a lid, and some hot glue.



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phase out polystyrene foam in almost all its flat packs and replace it with the new recyclable packaging, and this reduced the use of polystyrene by 7,300 tons per year. This equals more than half the volume of the Empire State Building.[39] Other groups have established hubs such as Materiom that allow individuals to share open-source recipes and formulas for natural materials.[40] Several of these materials could provide sustainable alternatives to polystyrene packing. If vendors such as VWR, Carolina, and Fisher were to adopt these materials for packing, this would potentially have a major impact on the plastic problem in labs, and while ship-back programs help reduce the use of new plastic, biodegradable and compostable alternatives are a much better solution.

Another possible direction is the reuse and repurposing of existing plastic. The Precious Plastics movement is a community of practitioners interested in reusing and repurposing existing plastics as a material for design and construction.[41] We have established a connection with our colleague Dave Marin at The New School's School of Constructed Environments and are investigating the possibility of grinding down our plastics, melting and extruding them and molding them into lab equipment such as tube racks and containers. In the future such reclaimed plastic could conceivably be converted into filament for use with three-dimensional (3D) printers. This effort could be a possible way to reduce our need to purchase new plastics materials for the lab and to integrate these activities into our curriculum. Many educational institutions now have maker spaces and 3D printers and could reuse their plastic waste to create tube racks and containers, as we're attempting to do. Other faculty members and researchers are finding ways to reuse, repurpose, and recycle plastic, often by partnering with companies.[42]

Getting the Message Out

> *This survey has made me aware of how much I don't know about purchasing decisions made for teaching labs in my department.*
>
> —The New School Survey Participant

With funding from the Tishman Environment and Design Center at The New School, we've started a survey of our peers and colleagues in the United States with respect to their recycling practices and knowledge about lab sustainability.[43] Our friends and colleagues are, like us, challenged by the sustainability issue, and through our survey we've identified several key knowledge gaps and areas that we can all mutually address. We've targeted our survey to several academic and professional scientific communities including SENCER (Science Educa-

Plastic waste contaminates a beach on a tropical island.

tion for New Civic Engagements and Responsibilities), SABER (Society for the Advancement of Biology Education Research), POGIL (Process Oriented Guided Inquiry Learning), PULSE (Partnership for Undergraduate Life Sciences Education), and ESATYCB (Empire State Association of Two-Year College Biologists) and we leveraged our social media accounts, sending our survey out by Twitter, Instagram, LinkedIn, and Facebook and to individual colleges and colleagues. Our results to date are coming from institutions accounting (approximately) for more than 500 biology, 150 chemistry, and 50 physics lab sections annually. About 58% of respondents reported being unaware of packaging material ship-back programs, with only 28% reporting that they participated in these ship-back programs. In addition, 94% of the respondents did not recycle their gloves and 84% were either unsure about or did not have decontamination protocols for nontoxic, uncontaminated, recyclable glass and plastic. Only ~40% of respondents reported recycling or sometimes recycling aluminium or metal materials. Some 60% of the respondents were unaware about the restrictions around recycling in BSL2 spaces. The response to our survey has been positive, with the respondents detailing challenges and issues while making suggestions regarding the importance of educating students to be sustainable in their future jobs/careers. Our respondents had several useful suggestions and ideas. One suggested that we should:

> *Request administrative support for green practices, e.g., hire work-study students to wash and autoclave glass pipettes, or to truly practice recycling on campus (bins are set up but it's obvious that everything ends up in the trash).*

It is noteworthy that several of the faculty members stated that technical support would be needed to implement much of what has been suggested. A return to using glassware and sterilizing and reusing materials would place an additional burden on the technical staff. In other cases our survey highlighted that even within the disciplines there can be different approaches and perspectives toward recycling. As one respondent noted:

> *the cell/molecular folks who make up the majority of the department don't seem to care about making their labs green even when we have done a waste audit and shown them the potential for recycling on a yearly basis. In the ecology labs, we reuse everything but the cell/molecular folks will even throw out containers that have just had sterile water in them. At other universities I have washed weigh boats, larger conical tubes, etc. to prevent unnecessary plastics waste. I would love to know if you have a suggestion that I could share with members of my department for getting started with recycling some of these items!*

As an educator, I, like many others, engage in what has been called "classroom-based undergraduate research." This type of classroom experience involves students in an authentic research experience while inside the classroom.[44] Engaging students in research is considered a high-impact practice, and placing research into the curriculum has several notable benefits for students and faculty alike.[45,46] Students in my microbial ecology class participate in a crowdsourcing experience called "Tiny Earth," which is a consortium of about 10,000 students enrolled in courses in 45 U.S. states and across 15 countries, all engaged in the search for new antibiotics generated by soil-derived microbes.[47] In my other course, "The Microbiome of Urban Spaces," my students study the antibiotic-resistant microbes of the built environment using next generation sequencing.[48] Both of these courses use research-grade plastic consumables, filter tips, and precise instruments and equipment. We cannot use recycled materials for this work. Instead, I am working to replace plastic with glass where we can, and to modify my protocols and procedures to reduce the amount of plastic we use in the classroom research sessions. The line between research lab and classroom is blurring and students are no longer seen as students; rather, they are being seen as research partners and equals. This represents a great opportunity to train students new to research in how to begin their careers in research being as sustainable as possible. One of our survey respondents made this suggestion:

> *Teaching or at least mentioning to students what the lab's sustainability efforts are. Hope that it sticks so that they can apply it to future jobs/research they do.*

We believe that once you are aware of the incredible impact our waste is having on the environment, it is impossible to ignore it and to continue to work as we have always done.

Concluding Remarks

We believe that once you are aware of the incredible impact our waste is having on the environment, it is impossible to ignore it and to continue to work as we have always done. Our plastic "consumables" are not consumed by our work if they simply end up languishing in landfills, contaminating our environment. Across our planet, researchers, scientists, and educators are diligently working but struggling to identify simple and straightforward solutions. Several are coming from those working in the field and at the bench. At The New School, we're adapting our protocols and methods to refuse, reduce, reuse, repurpose, and recycle. Using the TerraCycles program we've made an effort to recycle gloves from our teaching space (Figure 5). We also adapted reload wa-

Figure 5. Gloves collected in our teaching lab over a period of 4 months. All these gloves were sent to be recycled via TerraCycle. Only 2 of our survey respondents had a plan for single-use glove recycling.

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fers (and some hot glue) for use as PCR plates (Figure 4). And we're getting the word out about lab sustainability via conferences and guest lectures (Figure 6). Organizations such as SENCER (Science Education for New Civic Engagements and Responsibilities) are holding symposia for educators and generating courses and modules that place the plastic problem at center stage. All the presented talks, seminars, and lectures from the Smyth lab now feature how we've committed to lab sustainability while we're conducting our research, and our ongoing survey of academic and research labs continues to identify gaps and barriers to sustainable science (Figure 6). To try to encourage others to achieve similar gains, we've established an open-source repository on the QUBEShub that is allowing us to share ideas, protocols, and challenges among the scientific community.[49] This repository not only will help faculty members refuse, reduce, and recycle, but also will help them consider ways to reuse and repurpose plastic from their labs while we take the steps toward a plastic-free science landscape.

The issue of sustainability affects the whole system of science: not just the educators, students, and researchers, but the suppliers and vendors that make the kits, consumables, and equipment we use, the transporters who bring the materials to our labs, the institutions that house the labs and provide the people with support, and the policymakers and those responsible for regulatory processes at the state and Federal levels. We must encourage our vendors and manufacturers to use more sustainable and ethically sourced materials; ensure that what we send for recycling is actually being recycled; and reconsider how we do our science, reimagining our protocols and techniques in the lab to be more sustainable (Table 1). We can change our ways one lab at a time, one institution at a time, and when we all work together to promote change at a systemic level we will be successful.[50]

Our findings so far emphasize the need to increase awareness about the various organizations that can and do help us to achieve our sustainability goals. They also highlight the pressing need to continue to educate the faculty members, staff, and students about

Figure 6. Marcus Banks and Prof. John Dennehy of Queens College at MACUB. In October, our lab attended the 51st Annual Conference of the Metropolitan Association of College and University Biologists (MACUB). Attended by approximately 350 undergraduate and graduate students, as well as faculty and college staff and featuring two keynotes, 17 short talks and 137 posters, this conference is one of the largest in our region and presented an opportunity for us to connect our ongoing work to promote lab sustainability with the greater academic community.

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what they can do to be sustainable. At The New School we're committed to continuing our work with colleagues to construct modules and learning activities that can be used in classrooms to educate future generations and budding scientists about the need for science to be sustainable. We hope that sustainable science becomes the norm rather than the exception, and that scientists begin to recognize plastic "consumables" for what they are: a lasting legacy that will continue to blight our land, rivers and oceans should we not change our ways.

ORCID

Davida S. Smyth https://orcid.org/0000-0002-4049-0337

Marcus Banks has a BS in biology from Duquesne University in Pittsburgh, PA, and is pursuing an MFA in design and technology at Parsons School of Design. He has been working in science labs for more than 10 years and currently manages microbiology, molecular biology, and chemistry labs for The New School in New York City. His work focuses mostly on the intersection between sustainability, science education, and DIY tech, where he leads outreach activities for nonscience students. **Molly Metz** is an undergraduate student in the Interdisciplinary Science Program at Eugene Lang College of Liberal Arts at The New School in New York. Molly has been working in the science labs of The New School for more than a year and has taken an interest in exploring the microbiome of the built environment, sustainability in scientific research, and bridging social and scientific research to the public through science communication. **Davida S. Smyth** is an associate professor of natural sciences at Eugene Lang College of Liberal Arts at The New School in New York. She previously served as an associate professor and Chair of Natural Sciences at Mercy College. Her research focuses on the genomics of *Staphylococcus aureus* and the prevalence of antibiotic resistance in clinical and environmental strains of staphylococci. She is a SENCER Leadership Fellow.

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NOTES

1. United Nations Environment Programme, "Single-Use Plastics: A Roadmap for Sustainability" (UNEP—UN Environment Programme, 2018), http://www.unenvironment.org/resources/report/single-use-plastics-roadmap-sustainability.
2. H. Ritchie and M. Roser, "Plastic Pollution," in *Our World in Data* (1 September 2018), https://ourworldindata.org/plastic-pollution.
3. United Nations Environment Programme, Note 1.
4. M. Bergmann, S. Mützel, S. Primpke, M. B. Tekman, J. Trachsel, and G. Gerdts, "White and Wonderful? Microplastics Prevail in Snow from the Alps to the Arctic," *Science Advances* 5, no. 8 (2019): eaax1157.
5. M. Christensen, J. Vestergaard, F. d'Amore, J. Gørløv, G. Toft, C. Ramlau-Hansen, Z. Stokholm, I. Iversen, M. Nissen, and H. Kolstad, "Styrene Exposure and Risk of Lymphohematopoietic Malignancies in 73,036 Reinforced Plastics Workers," *Epidemiology* 29, no. 3 (2018): 342–51.
6. R. Verma, K. S. Vinoda, M. Papireddy, and A. N. S. Gowda, "Toxic Pollutants from Plastic Waste—A Review," *Procedia Environmental Sciences* 35, Waste Management for Resource Utilisation (2016): 701–8.
7. Anonymous, "Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C Approved by Governments" (IPCC, 2019), https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments (accessed 25 November 2019).
8. Anonymous, "See the Complicated Landscape of Plastic Bans in the U.S.," https://www.nationalgeographic.com/environment/2019/08/map-shows-the-complicated-landscape-of-plastic-bans (accessed 23 November 2019).
9. United Nations Environment Programme, Note 1.
10. Anonymous, "European Parliament Approves Ban on Single-Use Plastics," *The New York Times*, 25 October 2019, https://www.nytimes.com/2018/10/25/world/europe/european-parliament-plastic-ban.html (accessed 23 November 2019).
11. Anonymous, "UCL to Phase Out Single-Use Plastics, Including Pipette Tips," *The Scientist Magazine,* 25 October 2019, https://www.the-scientist.com/news-opinion/ucl-to-phase-out-single-use-plastics--including-pipette-tips-66637 (accessed 23 November 2019).
12. A. Bell, "Can Laboratories Curb Their Addiction to Plastic?," *The Observer*, sec. Environment, 10 November 2019, https://www.theguardian.com/environment/2019/nov/10/research-labs-plastic-waste.
13. Anonymous, Note 11.
14. M. A. Urbina, A. J. R. Watts, and E. E. Reardon, "Labs Should Cut Plastic Waste Too," *Nature* 528, no. 7583 (2015): 479–79.
15. Ibid.
16. Anonymous, "Sustainability Initiatives | Buildings," https://www.newschool.edu/buildings/sustainability-initiatives (accessed 23 November 2019).
17. Anonymous, "Sustainability Dashboard | Buildings," https://www.newschool.edu/buildings/sustainability-dashboard (accessed 25 November 2019).
18. Anonymous, Note 16.
19. Anonymous, Note 17.
20. Anonymous, Note 16.
21. Anonymous, Note 17.
22. Anonymous, "Hospitals Save Millions with Sustainability Programs, Cut Back on Waste," *Healthcare Finance News*, 2019, https://www.healthcarefinancenews.com/news/hospitals-save-millions-sustainability-programs-cut-back-waste (accessed 23 November 2019).
23. Anonymous, "The Environmental Hazards of Medical Waste," http://www.senseandsustainability.net/2017/09/29/dumped-medical-waste-hazardous-to-the-environment (accessed 23 November 2019).
24. Anonymous, "Medical Waste. Policies and Guidance" (U.S. EPA, 2019). https://www.epa.gov/rcra/medical-waste.
25. Anonymous, Note 22.
26. Anonymous, "Sustainable Labs," https://nems.nih.gov/greening-tools/Pages/Sustainable-Labs.aspx (accessed 23 November 2019).
27. Centers for Disease Control and Prevention (U.S.), Quality and Sustainability Office, "2018 Annual Sustainability Report: A Decade of Sustainability," CDC:76357 (19 July 2018), https://stacks.cdc.gov/view/cdc/76357.
28. Julia Hadar, Tsvi Tirosh, Ora Grafstein, and Evgeny Korabelnikov, "Autoclave Emissions—Hazardous or Not," *Journal of the American Biological Safety Association* 2, no. 3 (1997): 44–51.
29. J. T. Corthell, *Basic Molecular Protocols in Neuroscience: Tips, Tricks, and Pitfalls* (Cambridge, MA: Academic Press, 2014).
30. Anonymous, "PCR Plastic Consumables | Life Science Research | Bio-Rad," https://www.bio-rad.com/en-us/category/pcr-plastic-consumables?ID=027f88f2-615e-424a-803a-9baa28b55cab (accessed 29 November 2019).
31. Anonymous, "My Green Lab," https://www.mygreenlab.org (accessed 23 November 2019).
32. Anonymous, "Green Lab Supplies and Laboratory Equipment Guide Labconscious®," *Labconscious,* https://www.labconscious.com/green-lab-supplies-and-lab-equipment-guide (accessed 23 November 2019).
33. Anonymous, "TerraCycle," *TerraCycle*, https://www.terracycle.com/en-US (accessed 23 November 2019).
34. Anonymous, "Grenova TipNovus," *GC Biotech*, https://gcbiotech.com/product/grenova (accessed 24 November 2019).
35. Anonymous, "What Are the Problems with Biodegradable Plastic? | Eradicate Plastic," https://eradicateplastic.com/what-are-the-problems-with-biodegradable-plastic (accessed 23 November 2019).
36. Anonymous, "Pipet Tips, Flasks and Plates: Eco-Friendly Plastic in Your Green Lab Labconscious®," *Labconscious,* https://www.labconscious.com/blog/2016/11/9/pipet-tips-flasks-and-plates-sustainable-plastic-in-your-green-lab (accessed 23 November 2019).
37. Anonymous, "A Bacterium That Degrades and Assimilates Poly(Ethylene Terephthalate) | Science," https://science.sciencemag.org/content/351/6278/1196 (accessed 1 December 2019).
38. Anonymous, "Packaging," *Ecovative Design*, https://ecovativedesign.com/packaging (accessed 23 November 2019).
39. W. D. H. Time, "IKEA Starts Using Biodegradable Mushroom-Based Packaging for Its Products," *Medium*, https://medium.com/wedonthavetime/ikea-starts-using-biodegradable-mushroom-based-packaging-for-its-products-42d079f98bb1.
40. Anonymous, "Materiom: Home," https://materiom.org (accessed 24 November 2019).
41. Anonymous, "Precious Plastic Mission," https://preciousplastic.com/en/mission.html (accessed 23 November 2019).
42. Anonymous, "Life Scientists Cut Down on Plastic Waste," *The Scientist Magazine,* https://www.the-scientist.com/careers/life-scientists-cut-down-on-plastic-waste-64547 (accessed 24 November 2019).
43. Anonymous, "Lab Sustainability—Google Forms," https://forms.gle/pvGSJsev7XDxK7xr6 (accessed 1 December 2019).
44. Anonymous, "CUREnet," https://serc.carleton.edu/curenet/index.html (accessed 1 December 2019).
45. Anonymous, "High-Impact Educational Practices | Association of American Colleges & Universities," https://www.aacu.org/leap/hips (accessed 1 December 2019).
46. Anonymous, "About Us—Tiny Earth," https://tinyearth.wisc.edu/about-us/ (accessed 1 December 2019).
47. Ibid.
48. Anonymous, "Microbiome of Urban Spaces | LSCI3055 | Course Catalog | The New School," https://courses.newschool.edu/courses/LSCI3055/ (accessed 1 December 2019).
49. Anonymous, "QUBES—Group: Sustainability in the Lab," https://qubeshub.org/community/groups/labsustainability (accessed 27 November 2019).
50. M. Koerth, "Science Has A Sustainability Problem," *FiveThirtyEight* (2019), https://fivethirtyeight.com/features/when-trying-to-save-the-world-also-trashes-it.