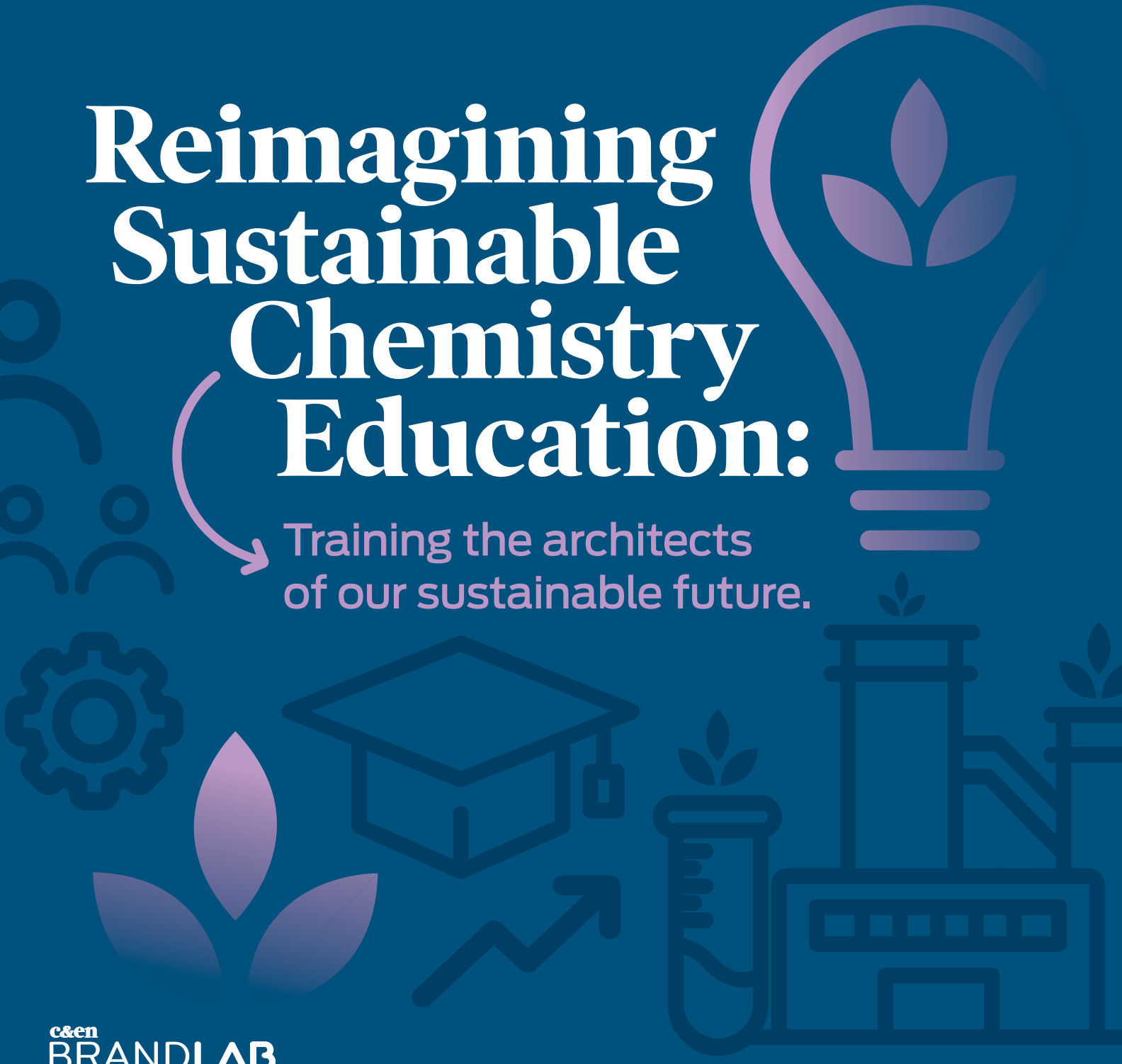
DISCOVERY REPORT

An ACS member exclusive

ACS Chemistry for Life®

Reimagining Sustainable Chemistry Education:

Training the architects of our sustainable future.



c&en BRANDLAB

Preface to Discovery Report

United Nations Sustainable Development Goal 4 highlights the need to ensure that all children complete free, equitable, and quality primary and secondary education that leads to relevant and effective learning outcomes by 2030. Given the high level of expertise required for training chemists, this goal extends to access to higher education and professional development.

Since the late 1990s, there has been a growing recognition that green chemistry and sustainability should be part of chemistry education. This recognition is congruent with increased awareness of chemistry's impact on human health and the environment.

Over the course of those years, the creation and implementation of green chemistry curricular materials has slowly but steadily increased. While the proliferation of such resources throughout undergraduate courses in higher education is gaining momentum, there remain critical knowledge gaps.

First, we have yet to include systems thinking skills in foundational undergraduate chemistry courses—skills that are known to be vital in designing greener chemistries. Second, we lack coursework in more advanced green chemistry tools and techniques at the upper undergraduate, graduate, and professional levels. The last is critical for upgrading the skill sets of chemists already in the workplace, for whom training in green chemistry is not yet readily accessible. Finally, we have yet to connect the chemistry curriculum in a meaningful way to either chemistry's potential to benefit society or, conversely, to the human and environmental cost of designing chemistries without considering their impacts outside the lab.

To this end, the ACS Office of Sustainability, which encompasses the ACS Green Chemistry Institute, in collaboration with the ACS Division of Education and the nongovernmental organization Beyond Benign, held the 2nd Annual ACS Sustainability Summit, Reimagining Chemistry Education, in December 2023. This summit brought together educators and thought leaders from the spectrum of stakeholders working to advance green chemistry and sustainability in undergraduate, graduate and professional education, as well as in industry and government sectors worldwide.

The discussions that took place among panelists and participants sought to facilitate critical connections between academia and industry to catalyze the propagation of green chemistry and sustainability concepts throughout curricula, while expanding educational opportunities for both students and professionals. Participants further highlighted urgent requirements for accessible training that can provide every chemist and engineer with opportunities to cultivate valuable skill sets that empower them to make significant contributions toward achieving the UN Sustainable Development Goals.

This report highlights the salient parts of those discussions. We envision these engagements as catalytic in helping accelerate progress needed to attain quality and equitable educational opportunities for every aspiring and practicing chemist, and we look forward to continuing to work with our community to achieve this goal.

Adelina Voutchkova, PhD
Director, Sustainable Development
American Chemical Society

INSIDE

MEETING THE EXPERTS
ACS Campaign for a Sustainable Future Chemistry Education Summit
P.5

CONNECTING THE DOTS
As demand for sustainable products grows, so does demand for students proficient in green chemistry
P.7

Meet the bond builders
P.12

MAKING A DIFFERENCE
Linking chemistry to environmental justice to inspire young chemists
P.16

BUILDING A SYSTEM
ACS adds green chemistry and systems thinking to bachelor's degree guidelines
P.20

Green chemistry teaching modules for the modern era
P.22

THINKING GLOBALLY
Training the global chemistry workforce to meet sustainability challenges
P.24

Published by
c&en BRANDLAB

Editor
Shane M. Hanlon

Contributing writer
Alexandra A. Taylor

Creative
Juana Merlo

Copyeditor
Michele Arboit

Production
Heather Lockhart-Neff

Comments or questions?
Email CENBrandLab @acs.org

ACS Chemistry for Life®

ACS Campaign for a Sustainable Future Chemistry Education Summit

Chemists from around the world convened Dec. 7–8, 2023, at the American Chemical Society headquarters in Washington, DC, and virtually for the second annual ACS Sustainability Summit: Reimagining Chemistry Education. The summit was part of the ACS Campaign for a Sustainable Future, in partnership with the ACS Education Division and Beyond Benign.

Kate Aubrecht
» **Stony Brook University**

Loyd Bastin
» **Widener University**

Molly Blessing
» **Household & Commercial Products Association**

Nesta Bortey-Sam
» **University of Pittsburgh**

Wilfried Braje
» **AbbVie**

Christiana Briddell
» **American Chemical Society**

Michelle Brooks
» **American Chemical Society**

Amy Cannon
» **Beyond Benign**

Terri Chambers
» **American Chemical Society**

Amy Chu
» **Saint Mary's College of California**

Juan Colberg
» **Pfizer**

Jaime Curtis-Fisk
» **Dow**

Sandra Gaona
» **US Environmental Protection Agency**

> "Green and sustainable chemistry can be misunderstood as not being fundamental, when actually it is fundamental —it's just fundamental in a different way."
>
> —Peter Licence, professor of chemistry, University of Nottingham, and editor in chief, *ACS Sustainable Chemistry & Engineering*

Javier Garcia Martinez
» **International Union of Pure and Applied Chemistry**

LaTrease Garrison
» **American Chemical Society**

Lisa Gilbert
» **Cabrillo College**

Lin He
» **National Science Foundation**

Thomas Holme
» **Iowa State University**

Philip Jessop
» **Queen's University**

Sarah Kennedy
» **Radford University**

"Who *isn't* implementing green chemistry? What industries out there are not implementing it? What facilities? Let's find out why not, and let's try to help them."

—Steven DeVito, branch chief, US Environmental Protection Agency

Edmond Lam
» **American Chemical Society**

Grace Lasker
» **University of Washington Bothell**

David A. Laviska
» **American Chemical Society**

Ann Lee-Jeffs
» **Modern Meadow**

Peter Licence
» **University of Nottingham**

Jennifer MacKellar
» **Change Chemistry**

Peter Mahaffy
» **King's University**

Isamir Martínez
» **American Chemical Society**

Avtar Matharu
» **University of York**

Stephen Matlin
» **Imperial College London**

Laura McConnell
» **Bayer Crop Science**

Audrey Moores
» **McGill University**

Hubert Muchalski
» **California State University Fresno**

Areej Nitowski
» **MilliporeSigma**

Nimrat Obhi
» **Beyond Benign**

Sarah Prescott
» **University of New Hampshire at Manchester**

John Randazzo
» **North Park University**

Lars Ratjen
» **Yale University**

Sederra Ross
» **American Chemical Society**

Jitesh Soares
» **American Chemical Society**

Bryan Tweedy
» **American Chemical Society**

Saskia van Bergen
» **Washington State Department of Ecology**

Adelina Voutchkova
» **American Chemical Society**

Hans-Georg Weinig
» **German Chemical Society**

Jane Wissinger
» **University of Minnesota**

Titles and affiliations as of the Reimagining Chemistry Education summit in December 2023.

A future with sustainable infrastructure will require a sustainable workforce.
CREDIT: WHYFRAMESTUDIO/GETTY IMAGES

As demand for sustainable products grows, so does demand for students proficient in green chemistry

The chemical industry is changing. From 2015 to 2019, demand for products based on green chemistry—defined by the US Environmental Protection Agency as chemical products and processes that reduce or eliminate the use or generation of hazardous substances—grew almost 13 times as fast as their conventional counterparts, according to a 2021 report by Change Chemistry, formerly the Green Chemistry & Commerce Council.[1]

The need for chemists and engineers who can develop tomorrow's sustainable products will increase along with consumers' appetite for those products. That translates to high demand for graduates with green and sustainable chemistry skills. Some of the critical skills they will need: the ability to perform life-cycle and carbon footprint analyses; design for circularity; conduct hazard assessments; scale reactions from lab to plant, and communicate their science to funders, policymakers, and collaborators in different disciplines.

"There isn't a single corporation out there" that isn't talking about some form of sustainability, says Areej Nitowski, green chemistry education manager for MilliporeSigma. "You can sit there and say that people are

Industry has increasingly recognized the need to start early with workforce training. CREDIT: SDI PRODUCTIONS/GETTY IMAGES

acting reactively or getting paranoid, but the reality is, it's the right thing to do."

Ann Lee-Jeffs, senior director of corporate sustainability at Modern Meadow, says today's graduates of chemistry programs must be further educated when they enter the workforce. She would like some of that training—such as how to use waste and renewable plants as feedstocks for products—incorporated into the curriculum so that new hires can start strong.

A sustainable curriculum

Another important area in which chemists need training is the chemistry of formulations. "When chemists join the workforce, they may know how to make a certain ingredient. But they don't know how to combine that ingredient with other things or what happens to it when they do; that's a challenge for our industry," says Molly Blessing, vice president, sustainability and product stewardship at the Household and Commercial Products Association. "Furthermore, chemistry education should instill life-cycle thinking, particularly as it pertains to formulations.

> "There isn't a single corporation out there" that isn't talking about some form of sustainability.
>
> —Areej Nitowski, green chemistry education manager for MilliporeSigma

When formulations degrade, they can affect the product's packaging or leave behind contaminants," Blessing says.

She would like to see students trained to use existing industrial equipment. "A lot of what's done at the academic level may not take into account the industrial-scale processes or the type of infrastructure that's used within our companies," Blessing says.

Finally, she wants students trained in public communication and the regulatory process. They should be aware of how the public perceives the materials that go into products so that "when they come into the workforce, they're not blindsided," Blessing says. These considerations are particularly important for household product companies, which are close to the consumer.

Jaime Curtis-Fisk, a senior R&D leader in analytic science at Dow, says the company is seeing demand for more sustainable consumer products. "Academia wants to prepare students who are ready for industry," she says. "Industry needs to make things that our consumers will actually buy." She says continuing to make the sustainability case to consumers will be critical for keeping that demand alive.

While many companies are advocating for chemistry education that includes green chemistry, some are engaged directly in educating future chemists. For example, MilliporeSigma reaches K–12 students via its Curiosity Labs: employees either volunteer in schools or bring students to one of the company's sites for hands-on involvement in green chemistry experiments such as making a more sustainable glue.

Educators at all levels can draw on existing resources to incorporate more green and sustainable chemistry into the curriculum. The American Chemical Society's new Guidelines for Bachelor's Degree Programs, which will go into effect in 2025, provide further incentives for academics to incorporate more green chemistry (see page 20). To do so, however, requires readily available resources. The Green Chemistry Learning Modules, developed by the ACS Green Chemistry Institute (GCI), are designed for easy integration into existing lesson plans (see page 22). The Green Chemistry Teaching and Learning Community, a partnership between GCI and Beyond Benign, offers not only a library of curricular resources developed by Beyond Benign and the community of instructors but also

networking opportunities for instructors. Instructors can also take advantage of workshops on green chemistry offered at ACS national meetings, the society's Green Chemistry and Engineering Conference, and through the ACS Institute, a learning platform. The GCI plans to provide more online courses in green and sustainable chemistry through the ACS Institute in the coming year.

Transitioning to sustainable chemistry will require education in greener processes and products. Eric Beckman, professor emeritus in the University of Pittsburgh's chemical engineering department, introduced a course on product design for chemical engineers in the early 2000s, when the curriculum was entirely process based.

Beckman believes that product design is an essential component of chemical engineering and that it must be grounded in sustainability. Many products that were stumbled upon, rather than designed, have later been shown to have significant unintended environmental and health impacts. These include per- and polyfluoroalkyl substances (PFAS), bisphenol A, chlorofluorocarbons, and certain plastics. "In the future, the chemical industry is going to be pushed to actually *design* these things—not just sort of tweak them—so that they're sustainable from the get-go," Beckman says. "Therefore, it has to be part of every science student's education." He would like life-cycle analysis and hazard assessment—which are often housed in distinct departments—become a central part of the chemistry and chemical engineering curriculum.

While it is clear that there are opportunities to incorporate skill sets identified by industry into the current curriculum, industry will need to continue to openly communicate with academia to inform these changes. Mark B. Shiflett, a Foundation Distinguished Professor in the University of Kansas School of Engineering, spent nearly 3 decades at DuPont before moving to academia. Shiflett says educators need companies to tell them which cours-

The field of green chemistry offers various career paths, so education should adapt to these different opportunities. CREDIT: CAÍQUE DE ABREU/GETTY IMAGES

> "Academia wants to prepare students who are ready for industry."
>
> —Jaime Curtis-Fisk, senior R&D leader in analytic science at Dow

es and electives they want students to take so that they can prepare students to meet industry's needs.

Partnerships in action

Research is getting more difficult to do in companies, Shiflett says. Universities, on the other hand, are well set up to do research—and that can lead to fruitful collaborations. He has been successful in attracting research funding from industry for his lab.

"If you're a Fortune 500 company, you really have to pay close attention to your stock price," he says. "Sometimes they just don't have the luxury that they used to have to do basic research or have some of the cutting-edge instrumentation and be able to really delve deep into the fundamentals."

By partnering with companies, Shiflett's graduate students and postdocs get invaluable experience, and firms gets to know the researchers. Some of those companies have hired members of his lab after they graduted. "As soon as [companies] start getting not only research but also people, they want to come back for more and more," Shiflett says. Similarly, he adds, "those connections that you create through the students that you graduate also build future connections."

Then there is the potential to commercialize green chemistry discoveries made in an investigator's lab. Shiflett's group has already spun out one company, Icorium Engineering, which is focused on commercial-scale separation of azeotropic mixtures such as refrigerants. His former student Kalin Baca is a cofounder of the firm and its chief operating officer. Shiflett is working on technologies—including for recycling lithium-ion batteries from electric vehicles and removing PFAS from the environment—that he thinks could one day spin off as start-ups that his students could run when they graduate.

Addressing challenges

Collaboration between industry and academia isn't always easy, though. Shiflett concedes that intellectual property rights can be a stumbling block for academia-industry partnerships. He says companies and universities will "need to figure out how to work it out, because both need each other." Additionally, students may be interested in entrepreneurship but worried about taking a path that's less financially stable than a job at an established company or organization. While grants such as those available through the Small Business Innovation Research program can help reduce this risk, given start-ups' failure rate, entrepreneurship remains the road less traveled for chemistry graduates. But Dow's Jaime Curtis-Fisk says that even if a start-up fails, students will be highly employable as long as they can show what they have gained from the experience and demonstrate their resilience.

To maintain the necessary momentum, green and sustainable chemistry education must be recognized as an important component of outreach associated with federal funding. Nitowski at MilliporeSigma says policymakers' support will be critical for these changes to be made on the necessary time scale and that education policymakers will have to recognize sustainability as a core concept. "Policymakers could make green and sustainable chemistry an essential part of receiving funding," says Amy Cannon, executive director and cofounder of Beyond Benign, "That would be a huge mover."

David A. Laviska, portfolio manager for green chemistry and sustainability in education at the Green Chemistry Institute, says that to advance green and sustainable chemistry, chemists will need to learn how to communicate and advocate. "Many chemists do not want to be in the spotlight and perhaps are more comfortable in the lab," he says. "We need to be more visible as a community in many respects." Chemists will also be required to collaborate with social scientists, mathematicians, and others. "Chemists cannot work alone," says Lin He, deputy director of the US National Science Foundation's chemistry division. Educators should prepare students to speak a common scientific language so they can work with people from various disciplines.

The entire ecosystem may need to make a cultural shift toward viewing chemistry holistically, as opposed to equating sustainability with environmental impact alone. Rather than think of green chemistry only as a fix for existing problems, "we can transition to a perception of being part of a solution—catalyzing a solution," Ann Lee-Jeffs says.

As Nitowski puts it: "We all have a moral obligation to our students to train them in the newest and best ways to keep chemistry moving forward and saving the planet."

---

1. Golden et al., "Green Chemistry A Strong Driver of Innovation, Growth, and Business Opportunity.

ACS
Chemistry for Life®

American Chemical Society

TAKE THE NEXT STEP IN YOUR CAREER

Prepare for your next move with resume reviews, interview strategies, and more with help from the ACS Career Consultants. Visit ***www.acs.org/nextstep*** to get started.

Meet the bond builders

These three chemists share what they've learned from forging bonds between academia and industry to advance green and sustainable chemistry.

Eric Beckman

COURTESY OF ERIC BECKMAN

Technologies that are developed in an academic lab occasionally make it to market, but it is not every day that that a principal investigator leaves the lab to bring a product to market on their own.

Eric Beckman, now professor emeritus in the University of Pittsburgh's chemical engineering department, specializes in the sustainable design of chemical products. He developed a surgical adhesive technology there and took an entrepreneurial leave of absence from 2007 to 2009 to commercialize it.

He was the first person at the University of Pittsburgh to take an entrepreneurial leave of absence. "It was seen as this wild and crazy thing because no one had ever done it before," he says.

Beckman recalls that the person he recruited as CEO of the firm he cofounded, Cohera Medical, challenged him, saying, "Look, if you think this is really going to fly, then get yourself in here and help us turn the technology into a product."

> "Time is the great enemy of bringing something to market," Beckman says. "The faster you can do it and still be good, the better off you are."

Beckman and his team eventually commercialized the technology as TissuGlu under Cohera Medical. The product became the first internal tissue adhesive to be approved by the US Food and Drug Administration.

He says translating science into a product is much harder than it seems. "Most people in academia think, you have this great science . . . and you just hand it to some company, and then they just magically turn it into a product and sell it," he says. "It can be very hard to get academics to shift off the science pathway and toward the product pathway."

For an academic wanting to partner with the private sector, Beckman suggests understanding as much as you can about a company, its product line, and its potential sustainability issues before approaching it. Some large chemical firms have been making their products the same way for decades and may be reluctant to change, whereas start-ups won't have the same history.

When designing a product, the most precious resource isn't money but time. "Once you start bringing investors in, then the time crunch starts because they want things done faster and faster and faster," Beckman says. He advises keeping your science or technology in stealth mode for as long as possible, pushing it as close as you can to the product phase before spinning it out of the university or incubator.

Areej Nitowski

Areej Nitowski left her job as a seventh-grade science teacher to help industry promote green and sustainable chemistry in academia.

Nitowski, a green chemistry education manager for MilliporeSigma, now promotes Beyond Benign's Green Chemistry Commitment, a program through which institutions of higher education commit to incorporating green chemistry learning objectives into their chemistry

COURTESY OF AREEJ NITOWSKI

> "I think the biggest way to make an impact is to make young people aware that these skills are needed and that they can get them," she says.

programs. "My biggest goal is to get as many green chemistry commitment signers for Beyond Benign as possible," she says.

In a way, Nitowski's career pivot was a return to her roots: she had held roles as an application specialist, trainer, and sales development manager for companies such as Sigma-Aldrich and PerkinElmer; then, a love of teaching and a desire to empower young women in the sciences led her into the classroom for over a decade. But Nitowski eventually grew concerned about the sustainability of her own career in K–12 education and decided to return to industry.

She now creates awareness campaigns and trains MilliporeSigma salespeople on green and sustainable chemistry. When salespeople encounter labs or faculty members who may be interested in changing the curriculum, they alert Nitowski, who can then reach out and speak with them about green and sustainable chemistry and the Beyond Benign program.

Her background in education has prepared her well to interface with academics. "I can appreciate from a teacher's perspective how difficult it is to incorporate new materials into your lessons. The curriculum is just jam-packed full of stuff," Nitowski says. "But times have changed, and this need is just so significant."

Nitowski's advice for industry chemists interested in promoting green chemistry: Start with yourself in the laboratory. Take advantage of all the resources available on green chemistry, such as online classes. Then go back to your alma mater and talk with student groups about industry's need for graduates who have skills in/who are knowledgeable about sustainable chemistry. Or, if you have an industry partner, ask how you can participate in its outreach.

Mark B. Shiflett

COURTESY OF MARK B. SHIFLETT

It's not uncommon for a chemist to leave academia for industry; leaving behind a decades-long career at DuPont for a professorship at a university, as Mark B. Shiflett did, is much less common.

Shiflett, who is now a Foundation Distinguished Professor at the University of Kansas (KU) School of Engineering, has worked in academia for the past 8 years. He directs the National Science Foundation (NSF) funded EFRI DChem: Next-generation Low Global Warming Refrigerants project, which is focused on developing sustainable technologies for separating and recycling complex refrigerant mixtures. He also founded the university's Wonderful Institute for Sustainable Engineering.

During Shiflett's 29 years in DuPont's Central Research and Development unit, many of his projects focused on sustainability. They included inventing new refrigerants that are used in the supermarket industry, ice machines,

Shiflett says that however hard he worked in industry, he has worked even harder in academia. But the effort has been worthwhile. “When I worked at DuPont, we made products,” he says. Now, he adds, “I make people.”

and air conditioners, and trying to make the pigment titanium dioxide more environmentally friendly.

While at DuPont, Shiflett received his PhD in chemical engineering at the University of Delaware. He discovered a love of teaching and became an adjunct instructor in his last 6 years with the company.

When Shiflett left DuPont for the University of Kansas, his former employer donated all the equipment for his lab and has since sponsored projects in his group. Former contacts at DuPont have now moved on to other companies, and Shiflett has also worked on sustainability-related projects for those firms.

DuPont was “always challenging us to really think out into the future,” he says. “That works really well when you come into academia because you’ve got to have ideas, and you’ve got to get funded.” His relationships have helped Shiflett get letters of industry support for his proposals; that in turn has helped him obtain funding from the NSF, Department of Energy, and other sources.

Most academics do not enter their jobs with a Rolodex of industry connections, however. Shiflett encourages them to attend conferences, such as those organized by the American Chemical Society, the American Institute of Chemical Engineers, and the Materials Research Society, to network as well as to present their research. He says he has even had success with cold-calling companies after reading something interesting about their work in C&EN. He counsels researchers to remain open-minded about their core areas of expertise, as working in a new area could offer opportunities and funding.

CREDIT: HISPANOLISTIC/GETTY IMAGES

Calling All Sustainability Stars!

We're looking for scientists that are making "chemistry" synonymous with "sustainability."

How to enter: Tell us your story!

Nominate yourself today!

WINNERS WILL RECEIVE:

- Recognition from ACS
- One free year of premium ACS membership
- A free registration to GC&E conference

ACS Campaign for a Sustainable Future

ACS Chemistry for Life®

Science is no longer confined to the bench.
CREDIT: ANDERSON COELHO/GETTY IMAGES

Linking chemistry to environmental justice to inspire young chemists

Lloyd Bastin, now a professor of chemistry and sustainability at Widener College, had only just started teaching when a student asked him, "Why are chemists killing our environment?"

Before this question, Bastin had not considered chemistry's impact on the environment. The query sent him on a journey to understand more, which included attending a green chemistry workshop at the University of Oregon in 2014. He has been thinking about how to incorporate green chemistry and sustainability into the curriculum ever since. A good place to start? In his own backyard.

Widener is located in Chester, Pennsylvania—a small city with the environment on its mind: the Covanta incinerator, the largest trash-burning plant in the US, is located there. According to a 2019 report by The New School's Tishman Environment and Design Center, the facility was third on the list of top emitters of fine particulate matter—particles less than 2.5 μm in diameter, or $PM_{2.5}$—in 2014. Such plants can expose local residents to toxic air pollution

> "The people who are going to be the most excited about the work we're doing are the people who are most impacted."
>
> —Sederra Ross, program specialist with the ACS Green Chemistry Institute

from substances such as dioxins that are released as a result of plastic combustion. In the US, Black people in particular are exposed to significantly more $PM_{2.5}$ than White people, according to the US Environmental Protection Agency's National Center for Environmental Assessment.

Inspired by his local community, Bastin started teaching green chemistry and sustainability through the lens of environmental justice. According to the EPA, environmental justice is "the just treatment and meaningful involvement of all people, regardless of income, race, color, national origin, Tribal affiliation, or disability, in agency decision-making and other Federal activities that affect human health and the environment..." Sederra Ross, program specialist with the ACS Green Chemistry Institute (GCI), says more educators should emphasize chemistry's real-world implications to increase student engagement. Knowing that they can impact their community can motivate students to get involved in chemistry. "The people who are going to be the most excited about the work we're doing are the people who are most impacted," she says.

Although green chemistry and the environmental justice movement have a mirrored history—for example, both are based on a set of principles, the 12 Principles of Green Chemistry and the 17 Principles of Environmental Justice, respectively, that were codified in the early 1990s—Ross notes that the two movements seem to be happening in silos.[1,2]

To strengthen their connection, Grace Lasker, a teaching professor and director of health studies at the University of Washington Bothell, says it's important to be clear about the motivation behind the work. "I believe that 'saving the planet' is coded language for not having to think about people, and not having to think about our most vulnerable people who are most affected by the decisions that we make," she says. "And so, when we don't have to think about people, and we don't frame the work that we do in green chemistry and engineering . . . as a people-oriented purpose, then we miss out on that opportunity to bring in those folks that have that perspective to be able to change the world in very meaningful ways.

"Collectively, we need to decide whether saving people is our 'why,' and if it is, we need to embed that in our day-to-day existence in industry, policy, academia, government, [nongovernmental organization], and beyond," Lasker says. "And that's the systems thinking aspect—if we're all working toward that same, common goal, we will make progress."

From pollinators to people, environtmental pollution is a pervasive threat. CREDIT: FASIL TIRU/GETTY IMAGES

An education in justice

An individual's impact on people is more significant than their individual research. Yet it's not always clear to members of the broader chemistry community how their individual contributions could fit into green and sustainable chemistry. "Lots of people don't like to be seen as part of the fashionable movement, and they like to be evaluated for their science," says Peter Licence, a chemistry professor at the University of Nottingham. Drawing connections from fundamental chemistry to environmental justice requires an even greater shift in mindset.

For instructors, challenges include where to find material and how to make time for environmental justice in a packed curriculum. The topics will apply more naturally to some lessons than others. The recently launched Green Chemistry Teaching and Learning Community includes case studies and networking opportunities that instructors can use to find people to speak with their classes about these matters. The EPA maintains EJScreen, an en-

vironmental justice screening and mapping tool, and the Toxics Release Inventory, which tracks toxic chemical releases and efforts to prevent pollution. EJAtlas monitors ongoing environmental issues around the world.

Another instructional tool is storytelling, which helps students learn difficult concepts, remember material, and make sense of the world. Environmental justice is full of stories that can empower students to make a difference. According to the GCI's Ross, instructors can use case studies "to really galvanize and excite the students about why [environmental justice] is important to chemistry and how we can use it." Presenting green and sustainable chemistry as a solution to environmental injustices can help students with firsthand experience feel empowered to make positive change in their communities.

The need for more environmental justice education is pressing. Globally, 2.2 billion people lack access to clean water, and 7 million people die prematurely each year as a result of air pollution. In fact, 13% of deaths globally can be attributed to environmental causes, and vulnerable groups are the most heavily impacted. Environmental pollution also decreases global gross domestic product by 4.7% annually, Ross says.

The Joe Biden administration has signaled that environmental justice is a priority. The Environmental and Climate Justice Program provides funding and technical assistance for environmental and climate justice activities that benefit environmental justice communities.[3] As part of the Environmental and Climate Justice Community Change Grant program, $2 billion in grants will fund community-driven projects that address climate change and reduce pollution. In addition, the administration's Justice40 Initiative[4] seeks to allocate 40% of the benefits from certain federal investments to underserved communities that are overburdened by pollution.

Clean water access remains a pressing global concern, disproportionately impacting vulnerable communities worldwide. CREDIT: KOSMOS111/ GETTY IMAGES

Communities neighboring pollution sources are often constrained in their pursuit of a healthy lifestyle. CREDIT: SCHROPTSCHOP/ GETTY IMAGES

Ross says academics should seize the moment by approaching their research with an eye toward having an immediate, positive impact. Such details can be discussed as part of the "broader impacts" statement when preparing a funding proposal for the National Science Foundation.

"Go out to the community. Connect with your community members. Find out what's actually happening in your neighborhood," Ross says. To achieve positive impact, the research community can work toward solutions to environmental problems alongside people who are impacted; integrate environmental justice considerations into research and grant proposals; and collect and share evidence of how chemistry research can address real-life environmental justice issues.

A spotlight on industry

On the industry side, Jennifer MacKellar, program director for Change Chemistry, an organization focusing on shifting the chemical industry towards safer and more sustainable chemicals, says her organization is starting a project with the EPA's Smart Sectors Program to help industry think about environmental justice.

> "Go out to the community. Connect with your community members. Find out what's actually happening in your neighborhood."
>
> —Sederra Ross

Environmental justice "is a really tricky topic for industry, especially large chemical manufacturers, textile companies, brands, electronics folks," MacKellar says. These firms "have historical reputations that they need to consider, and so trying to make reparations, which is a really important part of the environmental justice mechanisms, is incredibly challenging," she adds.

Companies will need to learn how to work closely with communities and advocacy groups to understand how to truly engage the community, MacKellar says. "Right now, we are just trying to help them understand what environmental justice is, how to ask questions about environmental justice from an industrial perspective, how to use tools to understand the impacts of their chemicals on environments and people, and how to make better choices."

Engaging with communities in a nonperformative manner will be critical for building and maintaining trust. "This isn't a transaction," says Nimrat Obhi, a program manager for Beyond Benign, an organization that creates resources for green chemistry education. "We're not approaching these communities because we want something from them to make ourselves look better." They cite Texas Women's University conducting outreach in local malls and the University of Oxford's plans to incorporate indigenous ways of knowing into its chemistry curriculum as two examples of institutions interfacing with communities through storytelling. As the chemistry community becomes more diverse, Obhi says, chemists will better understand how to approach environmental justice communities. "They *want* green solutions. That's not the problem," Ross says. "And I think, when we bridge that gap, we have the ability to work together to really see the impact sooner than we thought we could."

---

1. "Principles of Environmental Justice."
2. US EPA, "Basics of Green Chemistry."
3. US EPA, "Inflation Reduction Act Environmental and Climate Justice Program."
4. "Justice40 Initiative | Environmental Justice."

ACS adds green chemistry and systems thinking to bachelor's degree guidelines

Green chemistry and sustainability, along with systems thinking, were new additions to the 2023 ACS Guidelines for Bachelor's Degree Programs. The study of green chemistry and sustainability will prepare students to design products and processes that meet societal challenges, such as the United Nations Sustainable Development Goals, and systems thinking will help them develop the skills needed to confront the complexity of chemical problems. Both will help ready students for careers in industry. This change impacts the hundreds of chemistry degree programs across the US that rely on the ACS guidelines for accreditation.

The inclusion of these topics comes after years of advocacy on the part of the American Chemical Society community of educators, member committees, thought leaders in green chemistry, the ACS Green Chemistry Institute (GCI), and Beyond Benign. The ACS Committee on Professional Training (CPT) revises the guidelines about once every 5 years.

The update marks a timely transformation. "This is an emergency," says David Laviska, portfolio manager for green chemistry and sustainability in education with the GCI, "We are teaching a curriculum that is 50, 60, 70 years old, that hasn't changed—but our planet has changed."

Jane Wissinger, professor emerita in the chemistry department at the University of Minnesota Twin Cities and a prominent leader in green chemistry education, became involved with the effort to add the discipline to the guidelines in 2017, when a committee she was on wrote a green chemistry supplement. She says the goal was always to include green chemistry as a full part of the guidelines. Wissinger says that it was "wonderful" to see this happen and that she immediately shared the new guidelines with her department.

Michelle Brooks, assistant director of the ACS Office of Higher Education and staff liaison to the CPT, says the new guidelines try to provide space for programs to be creative while still maintaining approval. Programs can weave green chemistry into existing study materials rather than having to create separate courses.

Commitment to green chemistry

Organizations such as the GCI and Beyond Benign are helping with academia's adoption of these standards. The latter's Green Chemistry Commitment program provides an opportunity for institutions of higher education to incorporate green chemistry learning objectives into their chemistry programs. Amy Cannon, cofounder and executive director of Beyond Benign, says adoption of green chemistry has accelerated. Of institutions signing the commitment, the number of those that serve historically marginalized racial and ethnic groups and those outside the US more than doubled last year, she adds.

Some of Beyond Benign's student learning objectives overlap with the new ACS guidelines. When the guidelines came out, Cannon says, it was "a really exciting thing that literally took my breath away, and then I think I had tears in my eyes."

The guidelines will go into effect in 2025. Resources specifically tailored to the guidelines will be available later this year. In the meantime, teaching resources for green chemistry and sustainability and systems thinking are available through the GCI and the Green Chemistry Teaching and Learning Community.

Cannon hopes to see a tipping point among higher education institutions soon. "I think we're getting to a point where we're seeing that green chemistry should be expected, and it's a critical requirement and a marker of excellence," she says.

Green chemistry curriculum components

The new ACS guidelines incorporate green chemistry and sustainability into coursework and add a systems thinking dimension to professional skills and competencies.

Coursework

Critical requirements

The curriculum must provide students with a working knowledge of the 12 Principles of Green Chemistry.

Normal expectations

Case studies are used to demonstrate to students the interplay of chemical, environmental health, regulatory, and business considerations that dictate chemical processes and product design.

Markers of excellence

Offer a variety of in-depth courses, an example of which could be green and sustainable chemistry. Students are given the opportunity to assess chemical products and processes and design greener alternatives when appropriate. Students understand and can evaluate the environmental, social, and health impacts of a chemical product over the life cycle of the product, from synthesis to disposal.

Professional Skills and Competencies

Critical requirements

Instruction and coursework should demonstrate that the interconnection of chemistry with other disciplines is necessary to develop a comprehensive view of how physical, chemical, and biological systems behave, interact, and affect one another.

Normal expectations

Students should be made aware that solutions to problems in the world around us require decision-making that takes into consideration chemical knowledge as well as social, economic, political, moral, or environmental factors.

Markers of excellence

Students work through problems that bring in chemical knowledge, as well as social, economic, political, moral, or environmental factors.

Source: 2023 ACS Guidelines for Bachelor's Degree Programs.

Green chemistry teaching modules for the modern era

A new version of the ACS Guidelines for Bachelor's Degree Programs that includes green and sustainable chemistry and systems thinking concepts will go into effect in 2025. To help instructors incorporate these concepts into their curricula—or for anyone interested in learning more about them—the ACS Green Chemistry Institute (GCI) is developing a set of Green Chemistry Teaching Modules.

The modules are intended for instructors—and adjunct instructors in particular—who have limited time to devote to curricula development. The topics are pulled from standard general and organic chemistry curricula. The six modules currently available are Systems Thinking in Chemistry, Stereochemistry: Introduction to Chirality, Ideal Gases and the Nitrogen Cycle, Hydrocarbons and Functional Groups, Amines, and SN1 and SN2 Reactions. Developed by many authors, the modules vary in structure, scope, and depth of content. Each module includes curricular materials adaptable to four to six 50-minute class periods. A total of 30–40 modules will become available during the first phase of this initiative.

The module project was launched in 2020 and features work by instructors from 40 different universities. One of the original 47 authors was David A. Laviska, who at the time was an assistant professor at Seton Hall University. He joined the GCI as portfolio manager for green chemistry and sustainability in education in 2022 and now leads the module program. Laviska says the project aims to advance the conversation about how chemistry is taught and to enable instructors to teach more effectively, replace outdated teaching materials, or both. The goal is to include green chemistry, systems thinking, and references to the UN Sustainable Development Goals in the standard curriculum, without expanding an already-full curriculum.

For chemistry instructors who would like to incorporate more toxicology, Beyond Benign, an organization that promotes sustainable chemistry education and that collaborates with the GCI, has 11 modules available for download as part of its Toxicology for Chemists curriculum. It also offers ChemToxTidbits, slides that feature organic chemistry reactions or compounds and relate them to examples in toxicology from environmental or human biology.

Grace Lasker, a teaching professor and director of health studies at the University of Washington Bothell, helped with the integration of social justice, the UN Sustainable Development Goals, and systems thinking into many of the modules. She sees them as a way to begin framing chemistry as a people-oriented endeavor. Ghada Rabah, a chemistry professor at North Carolina State University, says that "the narrative is going to be important to push this forward." Focusing on modules' ability to increase student engagement and retention, rather than presenting them as a way to add green and sustainable chemistry and systems thinking to the curriculum, will be key to making them attractive to instructors, she adds.

Peter Licence, a chemistry professor at the University of Nottingham, says he views the modules as breaking down the silos between disciplines such as toxicology and mainstream chemistry. "I think that drawing connections between modules is something which is critical for all educationalists," he says. "As people that make bonds and break bonds [and] make new molecules, we've really got to understand not just the reactivity on a molecular level but the interactions the biological level and communities and ecosystems."

"Most degree courses are taught in compartmentalized packages, and lots of learners that I interact with have challenges or difficulties in connecting material from different packages," Licence says. "Using this approach is a really outstanding way of showing that chemistry is one subject."

Discover New Skills

Branch into new areas with an in-person or online professional education course.

Visit ***institute.acs.org*** to get started.

ACS Institute
Learn. Develop. Excel.

Global challenges will require global solutions.
CREDIT: CHARLIE CHESVICK/ GETTY IMAGES

Training the global chemistry workforce to meet sustainability challenges

Making meaningful progress toward the United Nations Sustainable Development goals will require a global workforce trained in green and sustainable chemistry. But an uneven distribution of such skills presents a challenge for training the next generation of chemists.

This uneven distribution is visible in the publication of green chemistry–related research. According to CAS, a division of the American Chemical Society, less than 1% of papers dealing with green chemistry published in 2022 in the journals CAS indexes came from low-income countries as classified by the World Bank.[1] These 34 papers were by researchers in six countries: Ethiopia, Uganda, Yemen, Sudan, Burkina Faso, and the Democratic Republic of Congo. Lower-middle- income countries contributed 3,759 green chemistry–related papers, more than either high-income countries or upper-middle-income countries; 60% of those papers were written by researchers from India.

The disparity is also visible in funding. In a recent analysis of green and sustainable chemistry funding, the ACS Green Chemistry Institute (GCI) found that US-based institutions received 15% of all grants awarded globally between 2013 and 2022 for basic research in the chemical sciences, industrial biotechnology, and chemical engineering that aligns with at least one UN Sustainable Development Goal.[2]

Adelina Voutchkova, director of sustainable development at ACS, attributes this gap not to the quality of the work being done in low-income countries but to factors such as the availability and quality of resources, including money and equipment and other facilities. She says the chemistry community will need to use new strategies to promote and support the work of researchers worldwide.

Expanding global reach

One way to address the skill imbalance is for researchers in higher-income countries to connect with those in other parts of the world through long-term collaborations. Some partnerships of this type are already bearing fruit.

Nesta Bortey-Sam is a professor of environmental and occupational health at the University of Pittsburgh whose research focuses on toxicology and chemistry. He completed his undergraduate and master's work at Kwame Nkru-mah University of Science and Technology in Ghana and has since collaborated with researchers there. He has also given talks about chemical toxicology at his alma mater and at the University of Ghana and is in discussions with the former to develop a curriculum on chemical toxicology. His partnership has yielded papers on human exposure to neonicotinoid insecticides, heavy metals, and polycyclic aromatic hydrocarbons in Kumasi, Ghana. His study on neonicotinoids is the first to examine neonicotinoid exposure in Africa.

Peter Licence, a chemistry professor at the University of Nottingham in England, has taught green and sustainable chemistry to undergraduates and graduate students as a visiting professor at Addis Ababa University since 2007. The relationship was born out of a chance encounter between Martyn Poliakoff, also a professor at the University of Nottingham, and Nigist Asfaw, now an emeritus associate professor of chemistry at Addis Ababa University in Ethiopia, while Poliakoff was vacationing in Ethiopia. It has led to workshops, research collaborations, and the exchange of funding and resources such as journal access.

The combination of Addis Ababa University's strong chemistry program and international support has allowed Ethiopia to establish an international presence in green and sustainable chemistry. According to CAS, among the low-income countries to publish green chemistry research in 2022, papers from researchers in Ethiopia accounted for 62%.

> "Data is not very good at convincing people...what we need is a new narrative."
>
> —Javier Garcia Martinez, past president of the IUPAC

Collaborations also happen at the institutional level. The Global Greenchem Innovation and Network Programme is a collaboration between Yale University's Center for Green Chemistry and Green Engineering, the UN Industrial Development Organization, and six countries—Indonesia, Serbia, Peru, Uganda, Ukraine, and Jordan—the last three of which the World Bank classifies as low income or lower-middle income.[3] The program aims to create a green chemistry network, support innovation and entrepreneurship through a green chemistry accelerator program, and upscale and implement green chemistry alternatives for persistent organic pollutants and mercury in industry.

But for international collaborations to be truly successful, the exchange of information and training must be a two-way street, according to Philip Jessop, Canada Research Chair in Green Chemistry at Queen's University in Canada and an adjunct professor at Hashemite University in Jordan. Hearing collaborators' ideas and needs and keeping an open dialogue is critical. "We need to be working with them before, during, and after information transfer in both directions," he says.

A new narrative

It all starts with listening, according to Javier Garcia Martinez, immediate past president of the International Union of Pure and Applied Chemistry (IUPAC). "Data is not very good at convincing people," he says. "What we need is a new narrative," which can be obtained through careful listening, he says.

Hans-Georg Weinig, director of education, career, and science for the German Chemical Society, also points to language differences as a factor to consider when disseminating training materials. He is hopeful that artificial intelligence will make it easier to translate green chemistry courses and make them more widely available.

Openly sharing data will also be critical to advance green and sustainable chemistry globally, according to Weinig. "Everyone needs access to the data we produce in science," he says.

Garcia Martinez is concerned that, as technology advances, the expectation to use cutting-edge instrumentation will increase barriers for scientists from low-income

A global workforce has the capacity to craft innovative solutions with a broad impact while remaining rooted in local contexts.
CREDIT: THEGIFT777/GETTY IMAGES

countries to participate on the world stage. He believes it is unfair to ask researchers in such countries to compete with fewer resources. "I'm really concerned that science can be a divider," he says.

But emphasizing a well-equipped lab might distract from systemic problems, such as unconscious bias toward research conducted in higher-income countries, according to Avtar Matharu, a professor of green chemistry and deputy director of the Green Chemistry Centre of Excellence at the University of York. "Just because you have access to cutting-edge equipment doesn't guarantee cutting-edge research," he says.

Matharu encourages his students to look further than traditional norms would dictate as a way to counter unconscious bias by increasing the citation of the science being done in low-income countries. As a result, he says, his students have made him aware of high-quality papers, despite not being published in top journals.

Most of the world's population lives in the Global South—which usually refers to Africa, Latin America and the Caribbean, and much of Asia and Oceania—and yet education is largely limited to the Global North, Matharu says. This imbalance is a challenge but also represents an opportunity to expand the green and sustainable chemistry community worldwide.

The University of York has undertaken an effort to decolonize and diversify its undergraduate chemistry curriculum to avoid framing chemistry as a series of discoveries by people of White, European descent.[4] The program has incorporated global examples of chemistry such as those from ancient China, India, and the Middle East, as well as the work of a wider range chemists, such as Nobel Prize winner Tu Youyou.

> "Just because you have access to cutting-edge equipment doesn't guarantee cutting-edge research."
>
> —Avtar Matharu, professor of green chemistry and deputy director of the Green Chemistry Centre of Excellence at the University of York

To document citation diversity, Matharu presented what he calls a Matharu plot—a one-page graphic that shows the distribution of global literature cited. His goal is to eventually have researchers include a Matharu plot with their paper when submitting it for publication.

The final reference list does not always reflect the effort put into identifying diverse sources, however, says Audrey Moores, a professor of chemistry at McGill University. She has looked for papers from low-income countries on certain issues and found that they didn't exist.

Moores says that often, instructors in low-income countries don't have time to write papers because they have so many administrative and other duties. "It's an entire system that's going against them," she says, and in order to be able to cite globally, there is a need to connect researchers with resources.

Being the change

Beyond the issue of authorship, region-specific challenges of low-income countries are often overlooked by scientists elsewhere. But encouraging the pursuit and publication of sustainable science could make a material difference to people living in these regions. What's more, the solutions discovered could unlock insights into global challenges.

People closest to the problem are also often closest to the solution, says Jennifer MacKellar, program director for Change Chemistry, an organization focusing on shifting the chemical industry towards safer and more sustainable chemicals. Whether in the US or abroad, it's important to involve those affected by problems.

"We want to make sure we're incorporating all the powerful voices that might be coming up with solutions we've never even thought of, because they've seen different things and have different experiences that they can bring to the table," says Sederra Ross, a program specialist with the GCI.

Achieving this will require full engagement from the entire green and sustainable chemistry community, Licence says. Stakeholders must be prepared to appreciate local variation and avoid a one-size-fits-all approach. What works well for one region or one discipline may not work as well for another.

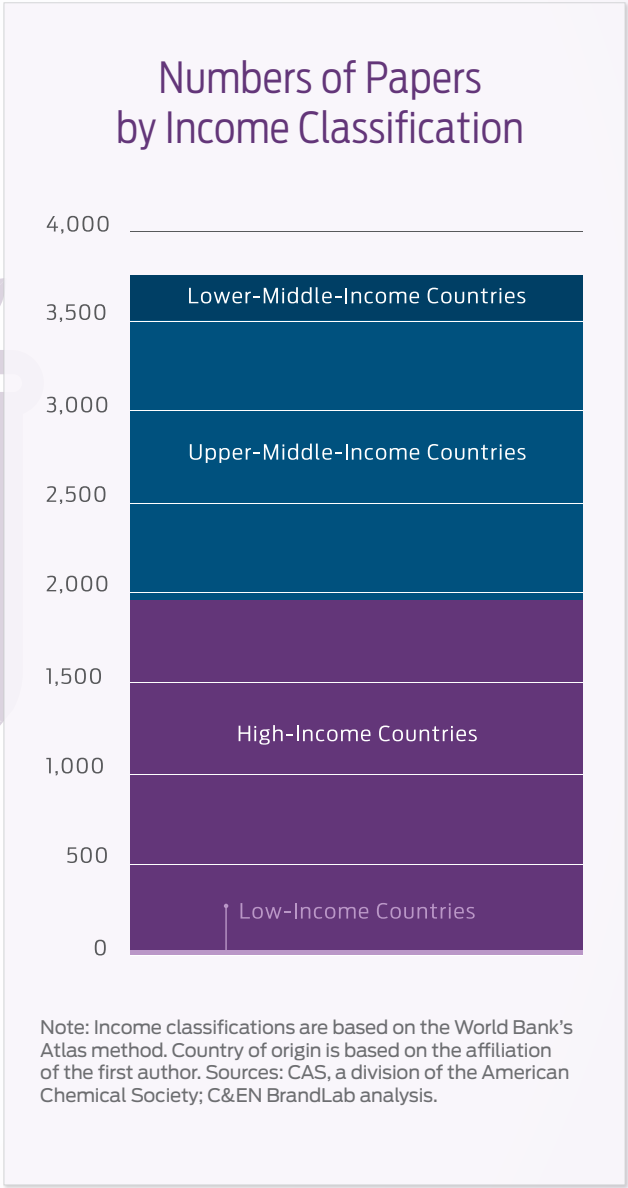
"We don't need to be same. We need to be different," Licence says. "We need to celebrate the differences."

ACS, Yale's Center for Green Chemistry, and Beyond Benign, an organization that creates resources for green chemistry education, have developed a platform dedicated to connecting researchers and resources around the globe with a long-term goal of accelerating innovations in green and sustainable chemistry. It will also aim to forge relationships between researchers in academia and industry—a key goal of the ACS Office of Sustainability and the GCI. The platform, Chemistry for Sustainability, will be formally launched at the ACS Green Chemistry and Engineering Conference in June.

1. World Bank DataHelp Desk, "World Bank Country and Lending Groups."
2. ACS Green Chemistry Institute, "The Funding Landscape of Green and Sustainable Chemistry."
3. Global Environmental Facility, "The Global Greenchem Innovation and Network Programme."
4. Dessent et al., "Decolonizing the Undergraduate Chemistry Curriculum."

Green chemistry research by country

Lower-middle-income countries published the most green chemistry–related papers in the journals that CAS indexes in 2022. Low-income ones published less than 1% of all green chemistry research.



Note: Income classifications are based on the World Bank's Atlas method. Country of origin is based on the affiliation of the first author. Sources: CAS, a division of the American Chemical Society; C&EN BrandLab analysis.

Download a copy of this
and all Discovery Reports at
www.acs.org/discoveryreports