

# A Case for **Green Chemistry Education** at the University of Colorado Boulder



*By the CU Green Labs Program*

*A program of the Environmental Center and Facilities Management*

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University of Colorado  
Boulder

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## Overview

The need for green chemistry education is becoming increasingly clear. Green chemistry, defined by the EPA as “the design of chemical products and processes that reduce or eliminate the generation of hazardous substances,” is only made possible when members of society are properly educated with the knowledge and tools necessary to to conduct scientific processes in a more responsible manner. Green chemistry education provides the academic framework and foundation that students need to conduct chemistry-based processes in more sustainable ways, taking into consideration the health of the planet and its people. Many students not only want this education as part of their chemistry coursework but there is also a growing demand among the citizens of the world for responsible care of the planet. There has also been an increasing emphasis on the need for green chemistry knowledge from various industries, making green chemistry topics and skills useful and applicable for students who are preparing to enter the workforce. In many ways, the University of Colorado Boulder (CU Boulder) is already a leader in green chemistry by implementing numerous actions in line with the principles of green chemistry that many universities across the nation have yet to begin. However, there is much more that CU Boulder could be doing to provide students with the opportunity for green chemistry education, especially in a manner that can be recognized on their resumes as they leave the university to find employment and further their careers.

The purpose of this report is to:

- Document current green chemistry efforts at CU Boulder
- Share the results of interviews and surveys soliciting input on interest in green chemistry education at CU Boulder
- Give an overview of what other universities and organizations are doing for green chemistry education
- Provide reasoning why green chemistry education would be beneficial for students and for CU Boulder
- Provide recommendations and resources to help with incorporating green chemistry principles and practices into its curriculum

CU Boulder prides itself on its commitment to being a leading campus in the areas of sustainability and social impact. Other US universities have already formally incorporated green chemistry education into their curriculum and are providing students with skills they will need in this changing world. As CU Boulder strives to “shape tomorrow’s leaders, be the top university for innovation, and positively impact humanity” while also enhancing interdisciplinary education and maintaining its leadership in sustainability, the campus should consider joining other universities in providing robust green chemistry education opportunities. This move would help CU Boulder students gain the experience necessary to meet the needs of various industries and best address some of the most complex issues facing their time. We hope that this report will provide the impetus and tools to help make that happen.



## Green Chemistry at CU Boulder

Throughout the CU Boulder campus, there are many initiatives in place that are increasing sustainable practices within laboratories and science education. Leadership and support for green chemistry in the Chemistry Department has been demonstrated through [actions taken to incorporate sustainable practices](#) into teaching and research labs, EH&S waste diversion programs, and various CU Green Labs initiatives, including a collaborative effort with members of the Chemistry Department to create a Green Chemistry Scholarship program. Some research labs are also leading scientific investigation on green chemistry solutions to world problems (examples provided in the appendix) and demonstrating sharing of equipment resources between labs.

However, more could be done by CU Boulder and the Chemistry Department to highlight and share the positive actions that have already been taken to foster greener chemistry and sustainable practices. Practice improvements primarily have been initiated and led by staff and graduate students with the support of faculty. While these initiatives have had a noteworthy positive impact, there is an opportunity for impact of greater magnitude by increasing community awareness of the efforts, university support and standardizing practices across campus labs where possible. When discussing the university's green chemistry efforts with current chemistry student, Batool Altaher, she noted a lack of emphasis on the subject despite its growing momentum on campus.

“They have applied green chemistry but they are not saying that it is green chemistry or advocating or advertising it for the students. They are more just like, ‘Oh we went to a safer chemical.’ But it’s important to label that process.”

-Batool Altaher, Senior - Chemistry Major

Emphasizing the university's commitment to sustainable and safe chemistry practices will position CU Boulder as a leading university in the areas of sustainability, interdisciplinary education, and career development, showing both current and prospective students and faculty the value of being a part of the CU Boulder community. As a result, CU Boulder will attract talent to campus and bring positive attention to the leadership role that the university is taking to provide students with the tools necessary to “positively impact humanity,” a goal of CU Boulder's strategic imperatives.

### *Chemistry Teaching Lab Modifications*

The Chemistry Department at CU Boulder has already begun to demonstrate green chemistry practices by restructuring many teaching lab experiments and procedures in order to reduce waste and minimize the use of toxic chemicals. These changes exemplify the intersection between sustainability and chemistry and demonstrate to students the ways in which chemistry practices can be adjusted to address environmental and health concerns. Because thousands of students enroll in the chemistry teaching labs each year and experiments are repeated over and over again by students, the positive impacts realized from each change to a teaching lab experiment is large. Some of the lab

improvements include implementing more water and energy efficient lab equipment and practices, substituting experiments with those that use less toxic chemicals, micro-scaling to reduce the amount of chemicals used, distilling solvents for reuse using a commercial unit, recycling of brown glass chemical bottles and metal solvent drums, and piloting a glove recycling program (See *Appendix* for more details on actions taken). Previously, there was little to no inclusion of green chemistry practices in organic chemistry teaching labs. However, at least one-third of undergraduate experiments have been redesigned to highlight topics related to green chemistry (See *Appendix* for more detail). Some possible future directions include efforts to select greener solvents where possible, replacing additional teaching lab experiments with greener versions, micro-scaling additional experiments where possible, and the creation of communication materials to raise awareness and educate students about green chemistry initiatives.

“I believe the department and university's vision is to conduct business in an environmentally responsible manner. Green chemistry clearly aligns with this vision.”

-Matthew Wise, PhD, *Director of General Chemistry Labs - Chemistry*

#### *Water Reductions in Chemistry Labs*

Very large water reductions have been achieved in laboratories within the Chemistry Department through the use of small vacuum pumps to replace water aspirators, and recirculating chillers and processed chilled water for cooling in place of single-pass tap water use. These efforts were originally accomplished in collaboration with Facilities Management who provided the upfront funding to purchase vacuum pumps, recirculating chillers and needed infrastructure to connect equipment with large cooling needs to the processed chilled water system. In a [2003 CU Boulder Today article](#), it is estimated that ~10 million gallons of water is being saved annually from just substituting the use of water aspirators with vacuum pumps in chemistry labs.

#### *EH&S Waste Minimization Efforts*

The EH&S Department at the University of Colorado Boulder is committed to sustainability on campus through their waste minimization efforts, responsible handling and disposal of hazardous waste, safety and environmental protection efforts for lab members and the campus community and their role in recycling programs. Specific efforts include:

- The treatment of hazardous waste to make it non-hazardous where feasible
- Support of solvent re-use and solvent recycling including actions such as distilling solvents for re-use and ensuring the efforts follow regulations for safe and compliant storage and transport of chemicals
- Redistribution of surplus chemicals to other campus labs (e.g., when a lab retires or moves)
- Re-use of carboys for hazardous waste collection, shields for radioactive work, and recycling of batteries

- Implementation of protocols to greatly reduce research-related radioactive waste leaving campus
- Collaboration with CU Boulder Green Labs on implementing and growing lab specific waste diversion efforts

“EH&S is fully supportive of a green chemistry curriculum at CU Boulder. As a generator of hazardous waste, CU is obligated by regulation to reduce the volume and toxicity of the wastes we generate. Many of our students studying scientific disciplines will eventually work for organizations that are bound by the same obligations, and having the knowledge to implement green chemistry practices and credentials of this knowledge could provide them with an advantage in the job market.”

-Mark Lapham, Associate Director of EH&S

### *CU Green Labs Program*

The CU Green Labs Program, jointly funded by the Environmental Center and Facilities Management, spearheads and manages various programs on campus that aim to minimize the use of energy, water, material goods, and hazardous chemicals and promote efficient, effective use of research equipment and laboratory space in CU Boulder laboratories. With approximately 400 laboratories on campus, major laboratory research buildings at CU Boulder occupy 22% of the campus landscape and are responsible for 43% of campus energy use (data from 2017). Efforts to increase efficiency and encourage green chemistry education in these spaces include:

- Green chemistry webinars, speaker, and trivia events
- A previous green chemistry fund used to pay for supplies for labs to try innovative new ideas
- Support of graduate student leadership in the Chemistry Department and travel to green chemistry conferences to share CU Boulder green chemistry efforts
- Survey of undergraduate interest in green chemistry education
- Presentations on sustainability and green chemistry efforts at CU Boulder, including during new graduate student orientations
- Stimulation of green chemistry ideas and efforts in the Chemistry Department
- Foundational work leading to metal and brown glass chemical container recycling, pipet tip box recycling, plastic film recycling, and foam recycling in the Chemistry Department. This is an expansion to other campus recycling programs that the Chemistry department was already strong participants of including recycling of paper, containers, cardboard and printer cartridges.
- Fume hood sash signage and contest in collaboration with EH&S and the Chemistry Department raising awareness of the large energy consumption of fume hoods and importance of closing sashes for safety and energy savings when hoods have variable-air-volume technology

### *Green Chemistry Scholarship Program*

A collaboration between the CU Green Labs Program and CHEMunity in the Chemistry Department has further encouraged green chemistry education by offering CU Boulder students the opportunity to take an online [Green Chemistry and Chemical Stewardship Certificate Program with the University of Washington](#), supported by scholarships from Sustainable CU, the Chemistry Department, the EH&S Department, and the Graduate School. The generous contributions from these campus units is enabling students to take the course at no cost to them. To date, two undergraduate students have completed the course in 2019, one undergraduate in 2020, and three students (two graduate students and one undergraduate) have been selected from a pool of applicants to receive scholarships for the 2020-2021 program.

This program has added great value to the students' science education, supplementing their core and elective course load with applied learning courses focused on green chemistry education. The courses explore different topics such as stakeholder engagement, supply chain management, and toxicology, tying these subjects back to the core principles of green chemistry. When asked about the course, the students have emphasized the applicability of the course material to their intended career paths and how complementary the experience was to their undergraduate education.

"The second you can start getting [students] involved in green chemistry and have them realize how applicable it is, and how it will evolve in the next few years, is something that CU, chemistry professors, and the department should be focusing on."

-Spencer Bajcar, Senior - Chemistry & Sociology Majors

It is clear that the topic of green chemistry is timely, relevant, and engaging. One of the scholarship recipients, senior Spencer Bajcar (Senior - Chemistry & Sociology major), emphasized that "the critical thinking skills that you gain in looking downstream and upstream and also looking at a collective systems approach and the smaller pieces within it, that alone is something that can be taken away and used in a lot of social science or other science aspects." The positive reception of this course and the students' emphasis on the relevance of its content to many different areas of academia and society demonstrate the value that offering similar courses could have at CU Boulder.



## Surveying Undergraduate Interest in Green Chemistry

In collaboration with different stakeholders within the chemistry department, and with the help of graduate students, a survey was written to gauge undergraduate student interest in green chemistry education as part of their chemistry coursework at CU Boulder. CU Green Labs asked instructors and faculty teaching chemistry courses to share the survey with their students. Some of the key findings are highlighted in this section.

After the first set of survey responses from the Fall of 2018 were analyzed, the results were shared with CU Boulder's Chemistry Department Chair David Jonas, PhD who provided suggestions for a future survey. The following semester, an updated survey was created using the Chair's feedback. After the second survey was distributed and the results analyzed, the findings were again shared with the Chemistry Department Chair, and then with Chemistry faculty and staff at a Chemistry faculty meeting where interest was expressed in having CU Green Labs continue to collect and monitor this data. As a result, the CU Green Labs team intends to continue to evaluate the interest of students in green chemistry education on campus by continuing to conduct the survey periodically and asking for stakeholder input.

"Especially given CU's huge focus on sustainability, and a lot of the efforts that CU has, the university definitely generates a culture of sustainability that's very distinct from other university's cultures and I think [green chemistry] would be widely received here."

-Spencer Bajcar, Senior - Chemistry & Sociology Majors

The survey results below clearly demonstrate the large student interest in green chemistry education as part of their undergraduate chemistry coursework at CU Boulder. This trend also aligns with findings by Academic Futures recommending more interdisciplinary education opportunities at CU Boulder. Currently, attempts at meeting this demand for green chemistry education are being addressed by offering students the opportunity to apply for a CU Boulder scholarship to the online certificate program at the University of Washington described in the last section above. While this has proven to be a positive experience for students, that opportunity will only benefit a few students at most each year and requires a 9-month, 3-course commitment that does not receive course credit at CU Boulder. Student interest in receiving some degree of green chemistry education could be met through direct offerings at CU Boulder. By offering a variety of intriguing classes on campus, students will remain motivated to fulfill their chemistry coursework at CU Boulder rather than taking those credits elsewhere and transferring them. In the Spring of 2020 during the COVID-19 pandemic, campus reported that every 1% reduction in student enrollment is connected to \$7.5 million in revenue loss for the university (Source is Energy Master Plan Working Group Meeting). This points to not only the importance of attracting students through appealing educational opportunities at CU Boulder but also the importance of retaining students at CU Boulder for the financial health of the institution.



## Survey of Student Interest in Green Chemistry

Fall 2018

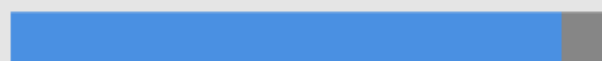
Spring 2019

% of students are **very interested, interested, or a little interested** in learning more about green chemistry.

**85%** of 302 students



**92%** of 225 students



## Survey of Student Interest in Green Chemistry in the Curriculum

**"If a course was offered through the Chemistry Department focused on green chemistry, would you be interested in taking it?"**



Yes (42%) No (58%)



Yes (50%) No (50%)

**"Rather than a separate course on green chemistry, if the present course you are taking was offered with a green chemistry emphasis, would you have chosen that course over your current course?"**



Yes (52%) No (48%)



Yes (59%) No (41%)

## Select Survey Feedback

"Would love to see CU take a lead in green chemistry."

"Green chemistry for non majors would be a valuable class for many in engineering, public policy, etc."

"Needs to be more student events relating to green chemistry."

"Green chemistry sounds extremely interesting."



# Universities Embracing Green Chemistry Education

## Formalized Green Chemistry Education

Across the country, universities are formally introducing green chemistry concepts into their curriculum to prepare students with knowledge and skills that are both useful and beneficial as students enter the workforce and contribute to the world. Many top tiered colleges have demonstrated their commitment to a more sustainable future by offering green chemistry courses and events, reflecting the subject's value and importance. As the University of Colorado Boulder and the Department of Chemistry strive to remain competitive amongst today's leading universities, embracing changes that provide opportunities for student enrichment and preparedness will be important considerations. In the opinion of the authors of this paper, increasing the number of courses and opportunities that directly address and encourage green chemistry practices is a great way to cultivate a rich academic environment, maintain a strong reputation for sustainability, and shape leaders that will positively impact humanity.



## UNIVERSITY OF CALIFORNIA - BERKELEY

- Course offerings include: Green Chemistry: An Interdisciplinary Approach to Sustainability, Graduate Ethics Course, Green Chemistry Laboratory, Engineering and Health Impact Methods in Green Design, Ethics and Decision-Making in Green Product Design, The Basics of Toxicology for Green Molecular Design
- Berkeley Center for Green Chemistry funds and guides research in designing novel chemical processes and teaches a core program of courses that integrate the chemical and environmental health sciences



## COLORADO SCHOOL OF MINES

- Sustainability and the principles of green chemistry are valued throughout the curriculum and are the focus of many of the research areas
- Graduate students and postdoctoral scholars explore scientific solutions to global sustainability challenges, including sustainable energy, at the ACS Summer School on Green Chemistry & Sustainable Energy



## GEORGE WASHINGTON UNIVERSITY

- Masters Program in Environmental & Green Chemistry
- Undergraduate students can complete the masters degree on an accelerated track.
- Exclusive internships and mentoring opportunities at institutions like the World Health Organization, the Environmental Defense Fund, the American Chemical Society and the Environmental Protection Agency.



## UMASS BOSTON

- Home to the first PhD program in green chemistry in the country
- Undergraduates can Minor in Environmental Chemistry
- Students completing a degree in chemistry will develop an understanding of green chemistry and environmental responsibility



## CARNEGIE MELON UNIVERSITY

- Course offerings include: Chemistry & Sustainability, Introduction to Green Chemistry
- The Green Chemistry Roundtable is a forum within the Institute for Green Sciences at Carnegie Mellon University to gather multidisciplinary experts to address specific topics of institutional, legal, regulatory and governance infrastructure necessary to enhance the use of green chemistry practices as mainstream options.

## Committed to Green Chemistry

There are many other universities that are following suit; 66 universities have pledged to incorporate green chemistry education on their campuses in the near future by signing onto the Green Chemistry Commitment put forth by the organization Beyond Benign. These universities have agreed to work towards preparing “world class chemists whose skills are aligned with the needs of the planet and its inhabitants in the 21st century.” The commitment also calls for the design and development of “innovative, efficient, and environmentally sound chemical solutions to the health, safety and effectiveness of chemical products and processes.” This commitment allows for universities to implement incremental changes at their own pace and style, encouraging improvement in a flexible way; universities are able to incorporate green chemistry education in ways that align with their campus cultures and curriculums. Collectively, this commitment is shifting science education in a more sustainable direction. Some of these universities are highlighted below.





## Benefits of Moving in This Direction

As we continue to see the need for innovative environmental and socially just solutions for our future generations, it's imperative that the university increase the opportunities for CU students to engage in sustainable thinking by offering green chemistry education. When students practice green chemistry, they learn to think critically about the global and environmental impact of their field and possibility of an environmentally just future for all people regardless of socio-economic stature. The benefits of moving in this direction are tremendous - not only for the students but also for the university as a whole and its role in preparing students to be responsible citizens of the world.

Younger generations are demanding more from corporations, companies, and educational institutions when it comes to taking action that supports protection of the environment and people. Talented faculty members and students are drawn to universities that are committed to a cleaner future and want to engage in education that will enable them to make a positive social impact. In fact, in a 2017 survey, 92% of students said it's important that CU Boulder has a strong commitment to environmental sustainability and 40% said they chose CU Boulder in part because of its sustainability reputation. The importance of a reputation in sustainability for recruitment was recognized by the Chancellor of CU Boulder in a recent [CU Boulder Today article](#).

Students who engage with an inspiring and empowering curriculum may be more inclined to stay connected with their university after graduation in the form of alumni relations or even donations. Current PhD candidate in the Chemistry Department at CU Boulder, John Malecha, explained how he takes pride in his undergraduate institution, the University of Minnesota, "because of how heavily sustainability was emphasized on campus and in courses." The majority of his chemistry classes frequently explored green chemistry principles; every set of reactions in Organic Chemistry were explained through a green chemistry lens, and often the reactions done in labs were alternatives to ones that used more toxic reagents and less sustainable reaction conditions. John plans to continue to support and donate to the university "to help continue that type of education."

"From inside the classroom to out in the field, the environment is a focus at CU Boulder. The courses and degrees offered here promote the discovery and exchange of knowledge that enables students to contribute to a more sustainable society."

-Sustainability in Academics, [colorado.edu](http://colorado.edu)

Additionally, there has been a growing, expressed need for professionals with a solid understanding of sustainability as it relates to [many different industries](#). In fact, a large number of significant companies have signed the [Green Chemistry & Commerce Council's Policy Statement on Green Chemistry in Higher Education](#) signaling the importance of green chemistry knowledge in the workforce. Some of these companies include Dell, Johnson & Johnson, Nike, and Dow Chemical Company. These

corporations have expressed a preference for candidates with “a demonstrated knowledge of and ability to utilize the principles of green chemistry and sustainability.”<sup>1</sup> The American Chemical Society (ACS) [host roundtables](#) for such companies to come together to catalyze green chemistry solutions within their respective industries. Recently, the [ACS program approval](#) for bachelor’s degree program has also published a [Supplement on Green Chemistry in the Curriculum](#) giving reasons and discussing ways for incorporating green chemistry into general chemistry, organic chemistry, inorganic chemistry, analytical chemistry, physical chemistry and biochemistry courses. The document recognizes that “Many undergraduate chemistry programs already implement green and sustainable chemistry concepts that have resulted in increased laboratory safety and decreased volume and toxicity of waste.” The creation of this supplement could be an indication that it is only a matter of time before green chemistry education becomes a requirement of the ACS accreditation for undergraduate degree programs.

Training students with knowledge of toxicity and environmental hazards will yield significant results “including less pollution, increased energy efficiency, increased mass efficiency, fewer hazards, less generation and use of toxic substances, creation of products from renewable resources, and creation of products that can be readily recycled or that fully biodegrade at the end of their useful lives.”<sup>2</sup> ACS has created [tools](#) that can be used in this training process like the solvent selection guide and life-cycle analysis tool. Training in green chemistry and sustainable design empowers students to look at the entire life-cycle of a product and to be a part of creating solutions, including the development of economically viable and improved alternatives to hazardous processes and products.

However, preparing students to work for such companies is just the first step in helping develop their careers in sustainability. Connecting students with companies and opportunities that require these skills will further support them in their job search. Facilitating workforce development through the implementation of Green Chemistry will not only better prepare CU Boulder’s students for the professional world, it will also positively reflect on CU Boulder as graduates secure impactful, prestigious positions based on their holistic understanding of and approach to complex issues. For example, Christina Boville, a [CU Boulder alumna, has been recognized as a MIT Innovator under 35](#) and is CEO of a [start-up company, Aralez Bio](#), she founded focused on producing compounds such as pharmaceuticals in a more efficient, sustainable manner using engineered enzymes compared to more traditional chemical synthesis methods, therefore reducing time, energy, costs, and the use of hazardous chemicals.

Additionally, a concerted effort to increase sustainability efforts on campus is in line with the University’s overall goal and position as a global leader in sustainability. The University of Colorado Boulder has a strong reputation for using education as a tool to encourage positive social impact. The university currently has 474 sustainability-related courses offered in 52 departments, totaling 19% of

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<sup>1</sup> Green Chemistry and Commerce Council Policy Statement on Green Chemistry in Higher Education; <https://greenchemistryandcommerce.org/assets/media/images/Projects/GC3%20HigherEdPolicy.pdf>

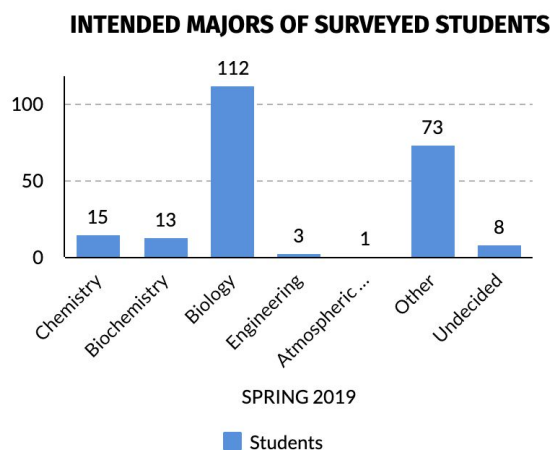
<sup>2</sup> Green Chemistry and Commerce Council Policy Statement on Green Chemistry in Higher Education; <https://greenchemistryandcommerce.org/assets/media/images/Projects/GC3%20HigherEdPolicy.pdf>

the available coursework. However, there is not one class that directly addresses the topic of green chemistry within the course title or description.

“Our goal is nothing less than being the global leader in sustainability – and that aspiration carries with it great responsibility to advance on all fronts ...”

- Phil DiStefano, CU Boulder Chancellor

Recently, there has been a push for more interdisciplinary education on campus by Academic Futures. The Academic Futures Interdisciplinary Committee report emphasizes that “interdisciplinarity can develop student agency and provide the education that students (and their future employers) want.” Green chemistry by its very nature is interdisciplinary. For example, it forms bridges between chemistry and biology, engineering, and business, fostering studies of topics such as toxicology, environmental engineering, and the economic and social impacts of sustainable practices by companies.



In fact, in the Green Chemistry survey described earlier in the paper, many students from these majors expressed interest in the subject - demonstrating the interdisciplinary nature of green chemistry and the wide range of majors served by courses in the Chemistry Department (see graph to left).

When asked about the relevance of the Green Chemistry Scholarship program, senior student Spencer Bajcar (Chemistry & Sociology major) noted that it was “really interesting to see a coursework that not only tied in the physical and environmental sciences but also tied in more of the social sciences as well.” This course allowed him to better visualize the “linkage of physical

and social sciences coming together and get a better understanding of what green chemistry is.” Embracing green chemistry education at CU Boulder would provide campus with opportunities to grow connections between different departments to enhance interdisciplinary academics at CU Boulder.



## Recommended Actions for the University

This report sheds light on the various ways that green chemistry education can add value on campus and bolster the university's role as a leader in sustainability. There are many different ways that the university can provide opportunities for students to engage with the subject in enriching and impactful ways. We believe that incorporating the following recommendations will provide students and the campus community with valuable opportunities to learn about green chemistry, explore the subject as it relates to different areas of society, fosters interdisciplinary learning that stirs interest and engages students, benefits reputation, and attracts talent.

### 1. *Make the Green Chemistry Commitment*

CU Boulder should sign on to the [Green Chemistry Commitment](#), joining the 60+ academic institutions that are demonstrating leadership to meet the growing need for "world class chemists whose skills are aligned with the needs of the planet and its inhabitants in the 21st century, and design and develop innovative, efficient, and environmentally sound chemical solutions to the health, safety and effectiveness of chemical products and processes."

CU Boulder can commit to implementing Green Chemistry Student Learning Objectives in its own unique way and on its own timeline; the commitment is voluntary and flexible. Departments and universities are not expected to be perfect or immediate in their green chemistry implementation, they only need to commit to continual improvement.

The CU Boulder Chemistry Department has already been leading through actions described within this report and deserves recognition for being a leader among these other academic institutions.

### 2. *Offer courses with an emphasis on Green Chemistry or a complete Green Chemistry course for both graduate and undergraduate students*

The survey results shared in this report show that CU Boulder students want opportunities for green chemistry education. By offering courses that emphasize, or directly address, green chemistry concepts, students will have access to academic material that empowers them to make tangible, positive impacts on society by using their deeper understanding of responsible, regenerative, and sustainable chemical practices. It will enhance their resumes and keep students fulfilled by CU Boulder's education rather than looking or needing to go elsewhere.

### 3. *Highlight Green Chemistry actions that are already going on in the Chemistry Department and on campus to both current and prospective students as well as the campus and greater community*

As described in this report, there are various efforts taking place that reflect the university's and the Chemistry Department's commitment to a cleaner, safer, and more sustainable future. Highlighting

these efforts and initiatives is a powerful way to continue to foster a culture of stewardship, further develop its reputation, as well as show current and prospective students the importance that CU Boulder and the Chemistry Department places on sustainability and innovation.

*4. Integrate Green Chemistry professionals/speakers into seminar series or on-campus events*

67% of global executives agree that sustainability strategies are necessary to be competitive, especially as many businesses face increasing pressure to use less toxic chemicals in their processes and products<sup>3</sup>. Various industries are in need of professionals who can help provide these sustainable solutions. Providing educational events and networking opportunities that explore green chemistry as it relates to different career paths can highlight how different companies utilize green chemistry concepts as well as what these companies look for in early-career scientists looking to pursue careers in the field.

*5. Engage students to help grow green chemistry in the department*

ACS offers a [Green Chemistry Student Chapter Award](#) that recognizes “ACS student chapters who have shown outstanding commitment to incorporating green chemistry into their annual activities”. Already the CHEMunity graduate student group is partnering with CU Green Labs on the Green Chemistry Certificate Scholarship Program discussed in this paper. That partnership also extends to include the Undergraduate Chemistry Club who is the host of the final presentations given by the scholarship recipients. As of October 2019, CU Boulder is not listed as an institution having an ACS student chapter. The ACS Green Chemistry Student Chapter Award requires three green chemistry activities during an academic year to be considered for an award. A focus on green chemistry for CU Boulder students could renew student interest chapter status and also help grow student engagement and availability of activities for students in the Chemistry department.

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<sup>3</sup> Brokaw, Leslie. “Five Ways That Sustainability Commitment is Up— Dramatically.” MIT Sloan Management Review. 27 Nov 2012. Web. 15 Oct 2012





## Resources for Educators and Institutions

Below are some valuable resources that can guide institutions when making plans to incorporate green chemistry education into their curriculums.

### AMERICAN CHEMICAL SOCIETY

Textbook Recommendations  
Lab Manuals  
Activities and Experiments  
Webinars



[CLICK HERE](#)

### CENTER FOR GREEN CHEMISTRY & ENGINEERING AT YALE

Lesson Plans  
MoDRN Modules for Undergraduate Chemistry, Biology, and Environmental Sciences



[CLICK HERE](#)

### BEYOND BENIGN

Downloadable Lesson Plans  
Webinars (including "Green Chemistry = Social & Environmental Justice")



[CLICK HERE](#)

### MY GREEN LABS

Comprehensive Teaching Guide



[CLICK HERE](#)

### UNIVERSITY OF TORONTO GREEN CHEMISTRY INITIATIVE

General Tips  
Additional Resources



[CLICK HERE](#)



## Appendix

### 1. Detailed Experiment Changes in Chemistry Teaching Labs at CU Boulder

#### Minimization of Toxic Chemicals in Teaching Labs

##### *Alternative Mole Ratios Lab*

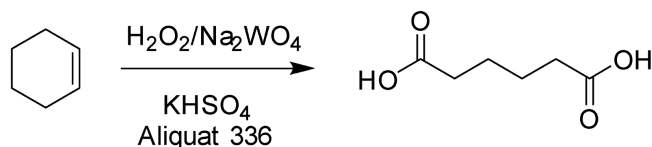
The general chemistry teaching labs implemented an alternative version of the mole ratios lab. This lab now uses acids and bases that labs already have on hand for other experiments, while the old version of the mole ratios lab used bleach. Because of the concern regarding chlorine gas generated by the old experiment, the lab was modified to address safety and sustainability.

##### *Lithium Battery Lab<sup>4</sup>*

The Marshak Lab in the chemistry department created a lithium battery with inexpensive and non-toxic materials for teaching purposes. Soon, this process will be implemented as a lab procedure in the CU-Boulder course CHEM 4021, enabling 16 students to be the first undergraduates in the world to make and test a functional lithium battery as part of their education.

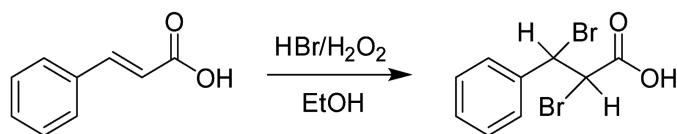
##### *Synthesis and Recrystallization of Adipic Acid Lab*

The traditional procedure used for this experiment was unable to be performed in an organic chemistry teaching lab due to reagents. Common industrial procedures use nitric acid or carbon monoxide, both of which are unfavorable reagents as the former is an explosive if accidentally mixed with organic solvents while the latter has obvious inhalation hazard.



##### *A Greener Bromination of Stilbene Lab—used with trans-cinnamic acid<sup>5</sup>*

Previously this organic chemistry teaching lab experiment required bromine solution, dichloromethane as a solvent and large volumes of aqueous sodium thiosulfate used to neutralize Br<sub>2</sub>. Now, Br<sub>2</sub> is generated in situ with hydrogen peroxide and HBr. Ethanol, a greener solvent, replaced dichloromethane use. And no aqueous sodium thiosulfate is needed.

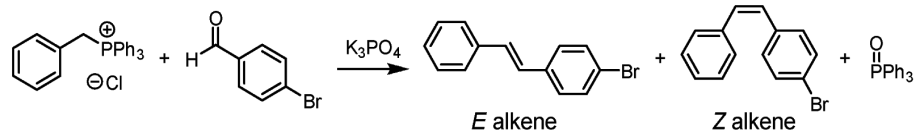


<sup>4</sup> Exploring Real-World Applications of Electrochemistry by Constructing a Rechargeable Lithium Ion Battery, Maharaj, F. D. R.; Wu, W.; Zhou, Y.; Schwanz, L. T.; Marshak, M. P. J. Chem. Educ. 2019. DOI: 10.1021/acs.jchemed.9b00328

<sup>5</sup> Doxsee, K.; Hutchison, J. *Green Organic Chemistry: Strategies, Tools, and Laboratory Experiments*; Cengage Learning, 2003.

### Solvent-Free Wittig Coupling Lab<sup>6</sup>

Two noxious-smelling, toxic chemicals were replaced with three inert chemicals. This also results in a better product for teaching double bond isomers in the organic chemistry teaching labs.



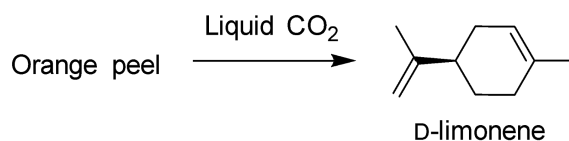
### Waste Reduction in Teaching Labs

#### Adjusted Microtitration Lab

In the general chemistry teaching labs, the microtitrations experiment was adjusted for CHEM 1134. Instead of using hundreds of mL of acid/base to perform a titration, students now use less than 5 mL. This greatly reduces the amounts of chemicals used and waste generated.

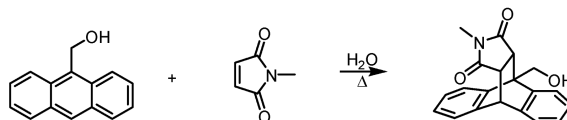
#### $\text{CO}_2$ Liquid Extraction of Limonene Lab<sup>7</sup>

The previous experiment used steam distillation for the extraction procedure in the organic chemistry teaching labs. Now the digital polarimeter allows lower detection of limonene, reducing the number of oranges used by a factor of five.



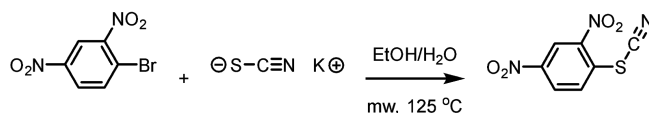
#### Green Diels-Alder Lab<sup>8</sup>

Use of this alternative experiment in the organic chemistry teachings labs eliminated an energy-intensive cyclopentadiene distillation and the large amounts of water and energy required to purify the product.



#### Microwave Assisted Chemistry Lab<sup>9</sup>

Use of this alternative experiment in the organic chemistry teaching labs eliminated a week-long reaction requiring large solvent volumes, & reflux condenser use. The microwave assisted experiment takes 30 min &  $\text{EtOH}/\text{H}_2\text{O}$  are good microwave absorbers.



<sup>6</sup> Leung, S. H.; Angel, S. A. *J. Chem. Educ.* **2004**, *81*, 1492–1493.

<sup>7</sup> McKenzie, L. C.; Thompson, J. E.; Sullivan, R.; Hutchison, J. E. *Green Chem.* **2004**, *6*, 355–358.

<sup>8</sup> McKenzie, L. C.; Huffman, L. M.; Hutchison, J. E.; Rogers, C. E.; Goodwin, T. E.; Spessard, G. O. *J. Chem. Educ.* **2009**, *86*, 488–493.

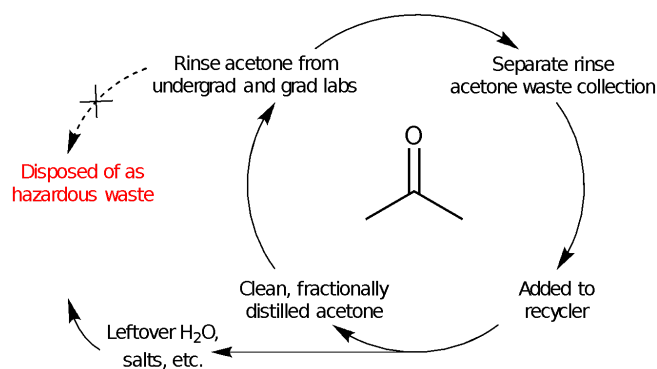
<sup>9</sup> Leadbeater, N.; McGowan, C. *Clean, Fast Organic Chemistry: Microwave-Assisted Laboratory Experiments*, CEM Publishing, 2006 / Horta, J. E. *J. Chem. Educ.* **2011**, *88*, 1014–1015.

### Glove Recycling Pilot

It was estimated that general chemistry would go through about 100,000 gloves in one semester. All chemistry teaching labs in general chemistry, organic, upper division and biochemistry are now recycling their gloves to divert this waste from the landfill.

### Solvent Recycling Program

CU Boulder has implemented a program dedicated to the recycling of solvents collected from research and teaching labs. The most success thus far has been with acetone and ethanol. Most acetone distillation is done by the organic chemistry teaching lab director as part of an effort in collaboration with EH&S. A fractional distillation unit is currently being used to recycle acetone from research and teaching laboratories. Between 2013-2019 the director of the organic chemistry teaching labs, Jacquie Richardson, PhD, reported that this program recycled 1,791 gallons with 74% efficiency, saving \$19,325 in the process.



## Water Efficiency in Teaching Labs

### Water Saving Measures

- The inorganic chemistry teaching labs now only use waterless condensers to eliminate water use during reflux. Waterless condensers are also used in some research labs across campus for reactions involving solvents with higher boiling points.
- The general chemistry teaching labs have eliminated the use of water aspirators for vacuum filtration, avoiding the need for water that was previously used to pull vacuum. Gravity filtration is now used instead which takes more time but requires no energy and no water use.
- The organic chemistry teaching labs are using recirculating chillers with their rotary evaporator condensers rather than cooling with single use tap water. A local central vacuum system, that is serving the organic teaching labs, is also used in place of water aspirators to pull vacuum for rotary evaporators, filtration, and other needs. This is resulting in very large water savings.

## 2. Examples of Green Chemistry Investigations in CU Boulder Chemistry Research Labs

### **Sustainable Recycling of PET plastic**

The Oana Luca Lab is working on new, less toxic methods to recycle PET plastics through the use of chemistry and electrochemistry.<sup>10</sup>

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<sup>10</sup> Myren, T. H. T.; Stinson, T. A.; Mast, Z. J.; Huntzinger, C. G.; Luca, O. R. *Molecules*. **2020**, *25*, 2742.