

Application for Large Grant for a  
2.5 Gallon Acetone Redistillation Unit  
for the University of Colorado at Boulder  
Department of Chemistry

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**Participants**

*Research Labs*

- Koch Research Group: Thomas Price Kirby, Graduate Student, Lab Eco-Leader
- George Research Group: Daniel Higgs, Graduate Student, Lab Eco-Leader
- Gin Research Group: Lily A. Robertson, Graduate Student, Chemistry Dept. Green Labs Team Lead; Erin F. Wiesenauer, Graduate Student, Lab Eco-Leader
- Sammakia Research Group: Jacob Greenburg, Graduate Student, Lab Eco-Leader
- Walba Research Group: Mike Springer, Graduate Student, Lab Eco-Leader
- Wang Research Group: Patrick Barbour, Graduate Student, Lab Eco-Leader
- Zhang Research Group: Ryan Denman, Graduate Student, Lab Eco-Leader

*Organic Chemistry Undergraduate Teaching Labs*

- Dr. Jacqueline Richardson, Director of Organic Chemistry Undergraduate Teaching Labs  
Department of Chemistry and Biochemistry University of Colorado at Boulder

*Environmental Health and Safety (EH&S)*

- Mark Lapham, CHMM, Hazardous Materials Program Manager, EH&S, University of Colorado at Boulder

**Supporter\***

Kathryn A. Ramirez-Aguilar, Ph.D.  
CU Green Labs Program Manager  
Facilities Management/Environmental Center

\*NOTE on behalf of Kathryn Ramirez-Aguilar: While 1) acetone recycling is an idea I suggested for the Chemistry Department including my ideas of why and how it could work and 2) I did connect Lily with the Sustainable CU website and with Mark Lapham as a resource for this idea, I want to make sure it is known that the vast majority of the outreach and research for this proposal and all of the writing was done by Lily. Additionally, because the reuse of solvents in something that only EH&S, the labs, and the Chemistry department can collectively permit, this proposal should be viewed more as collaborative project between the Chemistry Dept. and EH&S, where CU Green Labs' role was simply the suggestion of the idea.

Acetone is a very commonly used organic solvent with the chemical formula  $(\text{CH}_3)_2\text{CO}$  (Fig. 1). Often, it is used in organic chemistry labs as a wash solvent to remove excess water from freshly cleaned glassware. The amount of acetone used in the CU Chemistry Department makes it an ideal candidate for solvent recycling via distillation. In 2012 the Chemistry Stockroom sold 310 20 L drums of acetone, which at the current cost of \$62/drum amounts to over \$19,000 of cost. Although some acetone was bought by other departments, a majority stayed in chemistry. There is a high likelihood that much of the solvent bought could be recycled. Also inherent in the ease of acetone recycling is the fact that it does not combine with water to form an azeotrope, which occurs when two liquids of a mixture distill together at a specific boiling point,<sup>i</sup> such as with ethanol and water, which makes separation more difficult. In addition, the purity and recovery of acetone via a distillation unit are extremely high.<sup>ii</sup>



Fig. 1 20-L drums of acetone in ChemStores.



Fig. 2 Undergraduate students in an organic teaching laboratory.

Student involvement will include graduate students as well as undergraduate students. Graduate and undergraduate students in research labs, primarily organic chemistry-focused, in the Chemistry Department who choose to manually separate acetone waste will contribute to this project. Groups who use a large amount of acetone that have shown interest include the Gin, Koch, Sammakia, Walba, Wang, and Zhang research labs. Undergraduate students enrolled in organic chemistry teaching labs (Fig. 2) will also participate by separating acetone waste during wet labs, which use between one and two 20 L drums per week of operation. The redistilled acetone will be reused by these same undergraduate students and will also be distributed to students in research labs who contributed to the acetone recycling stream.

Recycling of wash acetone has been demonstrated at several other United States universities that we know of: Harvard,<sup>iii</sup> Columbia,<sup>iv</sup> Boston University,<sup>v</sup> and Northeastern University.<sup>vi</sup> At Harvard, acetone recycling began in the summer of 2010. Roughly 550 students enrolled in the summer and fall 2010 lab courses collected 161 L of wash acetone that was recycled to give 82 L for reuse, a savings of \$693. The teaching labs anticipate their annual

savings at roughly \$1400 per year.<sup>iii</sup> The program at Columbia has returned nearly 2000 gallons of recycled acetone since it began in 2008, saving thousands of dollars in purchasing and disposal while simultaneously decreasing environmental impact. The program has been so successful that a second recycler was purchased in 2011, and methanol and ethanol are also being recycled.<sup>iv</sup> At Boston University, three recyclers are in operation at the university and their medical center, generating hundreds of gallons of recycled acetone per year.<sup>v</sup> The program at Northeastern University initially worked very well, but recycling decreased when the main contributing laboratory left.<sup>vi</sup> Their recycler is currently in storage, but Steve Brehio, the associate director of EH&S at Northeastern, hopes to rekindle interest in the program this summer.<sup>vii</sup>

A system for collecting the waste acetone will be established by providing each lab with a desired number of recycled 4 L plastic jugs that originally contained wash acetone—empty jugs for this part of the project are currently being collected through Patrick Barbour of the Wang Lab. Dr. Jacqueline Richardson, director of the organic teaching labs, has offered the bench space needed for the acetone recycler in her lab prep room. She will be the primary person running and maintaining the recycler. Once the unit is purchased, we expect that at most it will take a month or two to get the instrument up and running and all the waste collection in labs going.

Recycling of organic solvents will greatly reduce the environmental footprint of a research laboratory. A recent paper from the *Journal of Green Chemistry* demonstrated the feasibility of solvent recycling in the pharmaceutical industry. The researchers first studied the life cycle assessment (LCA) of a variety of common organic solvents, including acetone, in the context of the pharmaceutical industry. The goal of this publication is to demonstrate that “implementing a solvent recovery or reduction system into pharmaceutical manufacturing processes can significantly reduce the emissions associated with the process,” for which solvents include 80 – 90% of total reaction mass and 60% of energy use.<sup>viii</sup> The authors first analyzed the cumulative energy demand (CED) of production of 1 kg of solvent (CED Solv. Prod.) and the carbon emissions of incineration of 1 kg of solvent (CO<sub>2</sub> Incin.). These values are adjusted for energy savings from incineration to give more accurate values for CED and CO<sub>2</sub> emissions, denoted Total CED and CO<sub>2</sub> Offset, respectively. The data for nine solvents are shown in Table 1. The calculations show that for every kilogram of acetone, there is a total CED of 34.3 MJ and 0.574 kg of CO<sub>2</sub> are produced.

Table 1 CO<sub>2</sub> and energy demands/credits associated with the incineration of 1 kg of various solvents, reproduced from Raymond et al.<sup>ix</sup>

Solvent	CO <sub>2</sub> Incin. kg CO <sub>2</sub>	CO <sub>2</sub> Offset kg CO <sub>2</sub> -Eq	CED Solv. Prod. MJ-Eq	Total CED Offset MJ-Eq
Acetone	2.55	0.574	67.3	34.3
Acetonitrile	3.31	0.518	61.5	32.7
Diethyl ether	1.47	0.363	48.0	8.56
Ethanol	1.40	0.290	48.0	16.8
Hexane	1.17	0.346	61.7	7.89
Isopropanol	2.00	0.340	63.2	26.8
Methanol	0.940	0.340	37.6	15.7
Tetrahydrofuran	8.36	0.544	128	90.8
Toluene	2.43	0.910	63.4	15.0

The second analysis step of the authors' research involved case studies with three different pharmaceutical companies, Bristol-Myers Squibb (BMS), Pfizer, and Novartis, and three different solvents, tetrahydrofuran, isopropanol, and methanol, respectively. The studies compared a "base case" and the "addition of a solvent recovery or reduction system" and found that overall emissions were reduced for the BMS case by 94% and for the Pfizer and Novartis cases by 91% each.<sup>x</sup> Although these data are for the pharmaceutical industry, which may have a higher percentage of solvent as total reaction mass as opposed to that for the research level, the percentage of solvents used in research labs will still be high, and this paper gives a good qualitative understanding of how incorporating green solvent solutions may significantly reduce emissions.

An acetone recycler will reduce the environmental footprint of and costs to the University of Colorado at Boulder campus, several ways. Transportation of new chemicals to and of waste solvent from campus will be lessened (Fig. 3). In 2012, 5711 gallons total of flammable solvents were disposed of as hazardous waste from campus—this total is over 100 of the 55 gallon containers shown in Figure 3. 3179 gallons of this total were collected from the Chemistry drums. Chemistry student labs disposed of 244 gallons of solvents, 220 gallons of which were from the organic chemistry undergraduate labs. About 190 gallons of acetone were purchased in 2012 for these labs, so a majority of the waste should be acetone. The acetone recycler project will also reuse empty 4 L and 20 L acetone containers as waste containers for each participating lab to collect their wash acetone. These containers normally cannot be recycled and go in the landfill. Also, once the acetone recycler is generating a large enough solvent stream, labs will be able to simply fill the same carboy-type container repeatedly with clean acetone. Additionally, the organic teaching labs will be able to shift the money previously spent on acetone to other projects such as improving undergraduate student labs and experiences.



Figure 3 55 gallon drums of flammable solvents in the EH&S hazardous waste storage area, awaiting shipment.

Hopefully, the separation of acetone from other organic and aqueous waste in the Chemistry Department will help raise awareness among graduate and undergraduate students in research and organic teaching labs of their ability to make a difference. The undergraduate students in organic teaching labs in particular will see the turn-over effect of their recycling efforts, which may give them inspiration to consider reuse and recycling opportunities in their other classes and departments.

Although acetone recycling has already been demonstrated at a couple other universities, it is still relatively unexplored. With their groundwork, we would like to demonstrate that this project is an effective way to reduce the carbon footprint of and costs to the Chemistry Department. This would be the first solvent redistillation recycling project of its kind on campus. This could eventually lead to the finding of other opportunities for recycling of other solvents.

Ideally, we would like to purchase the 2.5 Gallon Bench Top Supreme Acetone Recycler from CBG Biotech as well as the corresponding five year service contract. In the initial quote from CBG Biotech, the Manual vs. Supreme model was significantly more financially viable. However, CBG was very interested in helping us with this project and have reduced the price of the Supreme Recycler such that now it is only about \$1,000 more than the Manual model. The Supreme Recycler is completely automated from start to finish with an automatic waste drain valve that opens after each cycle. Upon purchase and delivery, CBG will also send a technical specialist to set the unit up and also provide training on the proper



Figure 4 2.5 Gallon benchtop recycler from CBG Biotech.

operation and care of the recycler (these services will be provided free of charge).

The pricing for the 2.5 Gallon Bench Top Acetone Recycler and the five year service contract are shown in Table 2 with both the current and original quotes from CBG included. The desired budgets from Sustainable CU for the Recycler and the service contract are shown in Tables 3 and 4, respectively. Dr. Richardson will contribute \$2,000 from the Organic Teaching Undergraduate Labs budget for this project. She has also agreed to provide the funds for a new service contract or repairs once the original five year plan is expired. In addition, EH&S and Sustainable Action Team (SAT) have agreed to contribute \$5,925 each to this project. The Supreme model comes with three 2.5 gallon collection containers. We would like to purchase five additional containers to have on hand for distribution of clean acetone as needed. The budget for these containers is shown in Table 5. Importantly, CBG has offered us a 20% discount on any containers purchased in their updated quote. The total budget requested from Sustainable CU for the Recycler, replacement plan, and containers is tabulated in Table 6.

Table 2 2.5 Gal. Bench Top Acetone Recycler Pricing from CBG Biotech.

Unit	Discounted Unit Price	5-year replacement package	Total
Supreme	\$19,184	\$8,875*	\$28,059
Manual	\$14,784	\$6,660*	\$21,444
<b>Supreme updated quote</b>	<b>\$15,000</b>	<b>\$7,500†</b>	<b>\$22,500</b>

\* 6 Month replacement policy: no charge

† 6 Month replacement policy **extended to 12 months**: no charge

Table 3 Budget for 2.5 Gal. Bench Top Supreme Acetone Recycler

Original Unit Price (12% discount)	\$19,184
Additional CBG Discount	-\$4,184
Updated Unit Price	\$15,000
Freight Charges	\$775
Additional CBG Discount	-\$375
Organic Teaching Labs	-\$2,000
EH&S	-\$2,500
Sustainable Action Team	-\$2,500
<b>Sustainable CU</b>	<b>\$8,400</b>

Table 4 Budget for 2.5 Bench Top Supreme 5-Year Replacement Package

Original Package Price	\$8,875
Additional CBG Discount	-\$1,375
Updated Package Price	\$7,500
EH&S	-\$3,105
Sustainable Action Team	-\$3,105
<b>Sustainable CU</b>	<b>\$1,290</b>

Table 5 Budget for extra 2.5 gallon containers from CBG Biotech

	Price/container	# Desired	Price Total
Original Price	\$200	5	\$1000
Addition CBG discount (20%)	-\$40		-\$200
Price	\$160	5	\$800
EH&S			-\$320
Sustainable Action Team			-\$320
<b>Sustainable CU</b>			<b>\$160</b>

Table 6 Total Budget requested from Sustainable CU

Item	Cost
2.5 Gallon Supreme Acetone Recycler	\$8,400
5-year Replacement Package	\$1,290
5 - 2.5 gallon containers	\$160
<b>Total Request</b>	<b>\$9,850</b>

Although we are very fortunate to have these large discounts currently offered by CBG, if only partial funding is available, we would consider purchasing a recycler with no replacement warranty or extra containers included. We feel that the replacement warranty would be worth having a total of six years coverage to ensure trouble-free recycling. We also feel it is important to highlight that the Undergraduate Organic Teaching Labs, EH&S, and SAT are committing to almost 60% of the funding we need. Please let us know if you have questions or need additional information. Thank you in advance for your time and consideration.

### Supporting Analysis

We have provided an analysis of the return on investment (ROI) based on the following purchase options:

ROI #1: 2.5 gallon supreme recycler with 1yr. manufacturer warranty + 5yr. extended warranty

$$\$15000 + \$7500 + \$800 + \$400 = \$23,700$$

ROI #2: 2.5 gallon supreme recycler with 1yr. manufacturer warranty and no extended warranty

$$\$15000 + \$800 + \$400 = \$16,200$$

Table S1 shows an analysis of these ROIs based on the total gallons of acetone purchased from Chemistry Stockroom in 2012. However, since it is uncertain how much of this acetone would end up in the recycling stream, an analysis based on contributions from the Gin lab and the Teaching labs is shown in Table S2 with recycling rates of 91% or 87%. From this analysis, ROI #2 is achievable in roughly five years and ROI #1 between seven and eight.

Table S3 shows the commitment needed from the rest of the Chemistry department to achieve ROI #1 within six years. Please Note: The estimate of acetone that the Gin Lab and the Teaching Labs use on an annual basis amounts to less than 20% of what is purchased in the Chemistry Stockroom. Thus, it is likely that if other organic-focused research labs contribute to this effort (there are six others that have expressed interest), they would contribute a large amount based on these sales. Even though our calculations show a need for only about 50 more gallons from these labs to achieve the ROI #1 of six years, it would likely occur much sooner.

Table S1 For Departmental Use - Overall quantity of acetone waste that is recyclable throughout dept. is unknown at this time.

	gallons	Annual Cost Savings	ROI #1 (yrs.)	ROI #2 (yrs.)
Total *	1638		\$23,700	\$16,200
80%	1310	\$17,690	1.3	0.9
60%	983	\$13,268	1.8	1.2
40%	655	\$8,845	2.7	1.8
20%	328	\$4,423	5.4	3.7

Table S2 For Gin lab and Teaching labs use - The quantity of acetone waste that is recyclable is much more certain.

	gallons	Annual Cost Savings	ROI #1 (yrs.)	ROI #2 (yrs.)
Total **	270		\$23,700	\$16,200
***91%	246	\$3,317	7.1	4.9
****87%	235	\$3,171	7.5	5.1

Table S3 In order to achieve a ROI within 6 yrs. on recycler with extended warranty - This is the additional amount of acetone needed from other labs in Chemistry Dept. on top of Gin and Teaching labs operating at recycling rates of 91% or 87%.

	gallons	Annual Cost Savings	ROI #1 (yrs.)
Total		(+ savings above)	\$23,700
2.9%	48	\$3,958	5.99
3.6%	59	\$3,967	5.97

Cost Savings calculated considering cost of new Acetone per gallon = \$11.62 and disposal = \$1.88.

Not adjusted for inflation, for example it is safe to expect disposal costs to increase by 10% next year with the current haz. waste disposal contract ending.

\*- based on 310 - 20 L per year or 6200 L per year.

\*\*- based on 1.25 x 20 L per month or 300 L per year in Gin Lab and 720 L per year in Teaching labs.

\*\*\*- 91% overall rate based on 80% recycling rate in Gin lab and 95% recycling rate in teaching labs.

\*\*\*\*- 87% overall rate based on 80% recycling rate in Gin lab and 90% recycling rate in teaching labs.

## References

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- <sup>i</sup> Carey, F. A.; Giuliano, R. M. *Organic Chemistry* 8<sup>th</sup> Ed.; McGraw-Hill: New York, 2011, 661.
- <sup>ii</sup> CBG Biotech. Benefits of recycling acetone and other solvents from CBG.
- <sup>iii</sup> Email correspondence from Jamie L. Bemis.
- <sup>iv</sup> Columbia University Environmental Health and Safety Dept. Solvent Recycling. <http://ehs.columbia.edu/RecycleSolvent.html> (accessed January 25, 2013)
- <sup>v</sup> Boston University Environmental Health and Safety Dept. Solvent. <http://www.bu.edu/ehs/management-plans/environmental/emissions/solvent/> (accessed January 25, 2013).
- <sup>vi</sup> Brehio, S. Utilizing solvent recycling and other methods to reduce quantities of hazardous waste generated. Abstracts of Papers, 240<sup>th</sup> ACS National Meeting, Boston, MA, United States, August 22-26, 2010 (2010), CHAS-7.
- <sup>vii</sup> Email correspondence from Steve Brehio.
- <sup>viii</sup> Raymond, J. R.; Slater, C. S.; Savelski, M. J. LCA approach to the analysis of solvent waste issues in the pharmaceutical industry. *Green Chem.* **2010**, *12*, 1826.
- <sup>ix</sup> *Ibid.*, 1830.
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