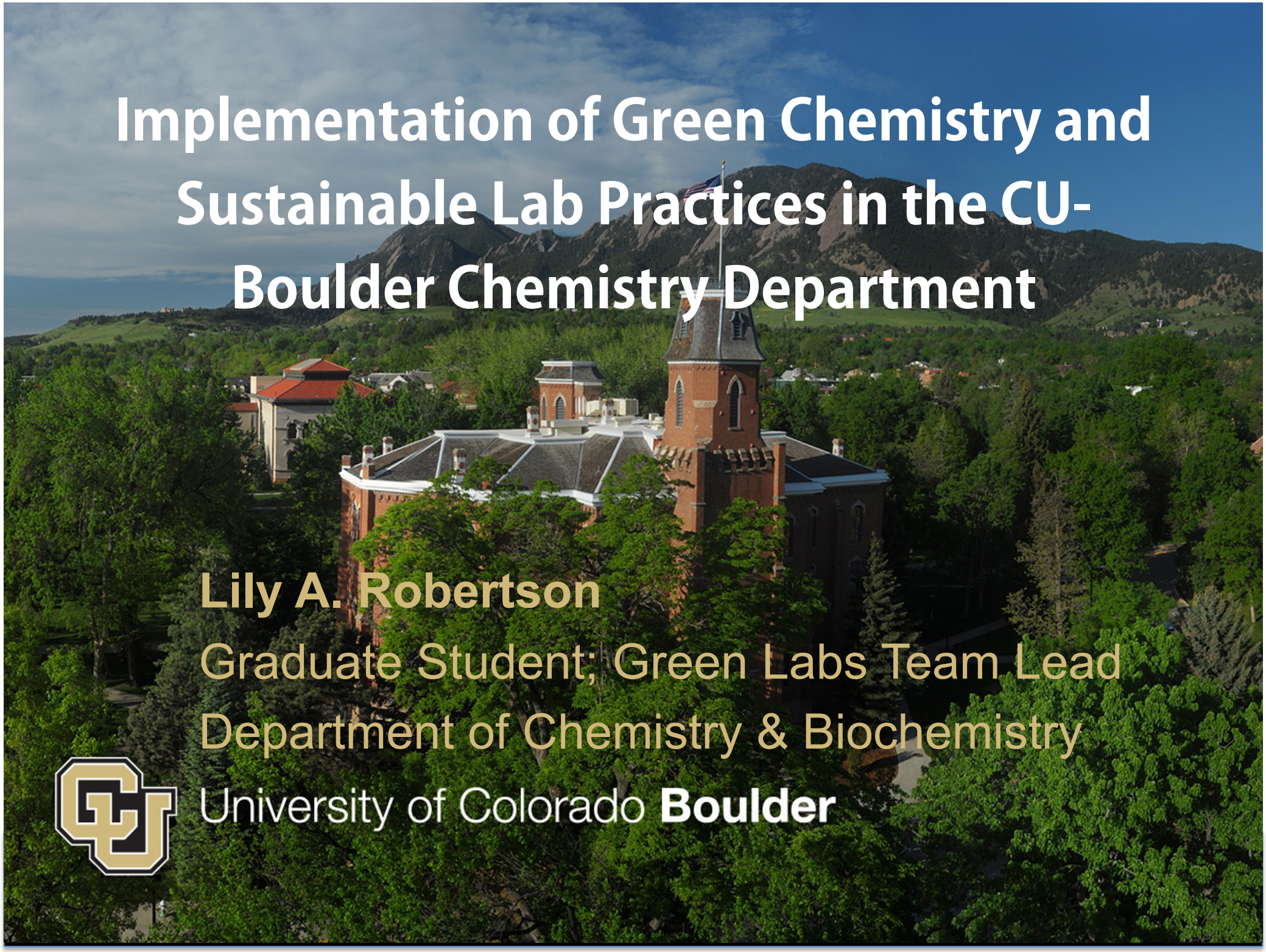

Implementation of Green Chemistry and Sustainable Lab Practices in the CU-Boulder Chemistry Department

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Learning Objectives

- Learn about green chemistry projects implemented at CU.
- Learn about the hazardous waste diversion and dollar savings resulting from those projects.
- Learn about impact those projects are having on raising awareness about green chemistry at CU.

Solvent Recycling

- Fractional distillation unit purchased in June 2013 (CBG Biotech).
- Main target for solvent recycling is acetone, but other commonly used solvents may be addressed in the future

Acetone Recycling: How it works

Rinse acetone from undergrad and grad labs

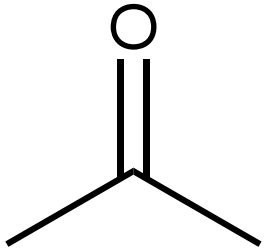
Separate rinse acetone waste collection

Added to recycler

Clean, fractionally distilled acetone

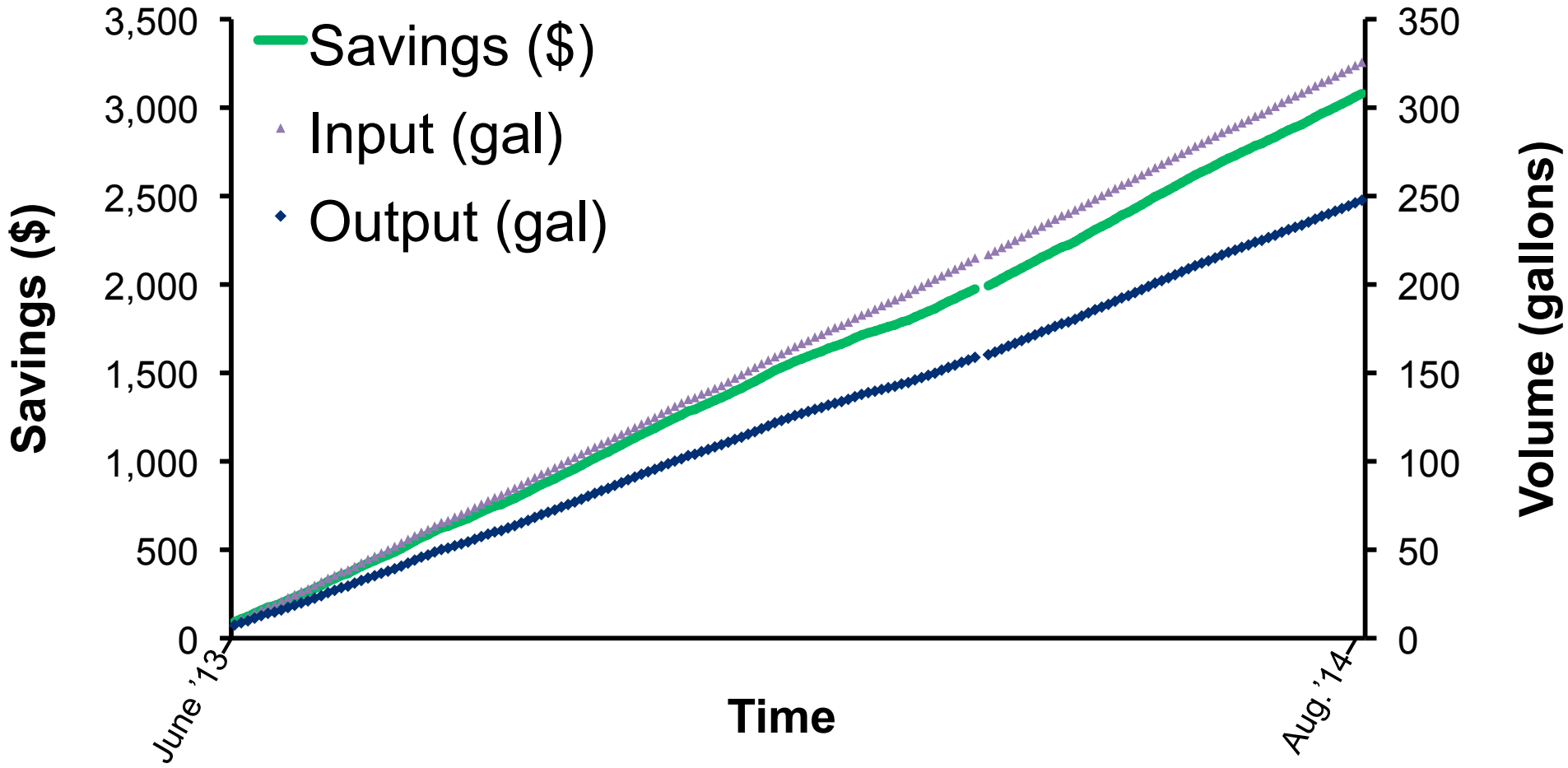
Leftover H_2O, salts, etc.

Disposed of as hazardous waste



Acetone Recycling: Savings

- Overall efficiency = 76.0%; overall savings = $3,079.*



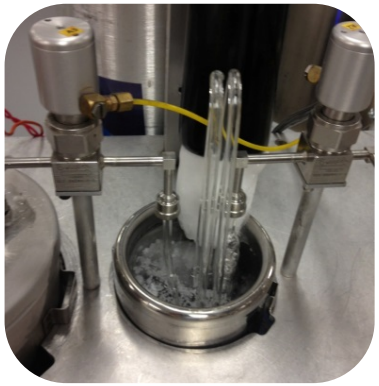
* Not including previous disposal costs

Other Possible Solvents

- Common mixtures from column chromatography
  - Hexanes/ethyl acetate
    - **Testing in progress**
  - Dichloromethane/hexanes
  - Azeotrope formation could be problematic, i.e., resultant product could remain a mixture
- Other rinse solvent streams that are mixtures, i.e., acetone, methanol, and water

Ethanol Reuse Program

- 120 gallons/year of used ethanol from cold traps was being disposed of as hazardous waste
- This volume is equivalent to a purchase price of $1,560!
- Now this ethanol is being diluted and reused to wipe down biosafety cabinets in Biochemistry!



Haz. Waste

Icing

H_2O

Ethanol Cold Trap

Biosafety Cabinet Sterilization

Green Chemistry

The Green Chemistry Commitment
TRANSFORMING CHEMISTRY EDUCATION

Green Chemistry & Engineering:
Innovation for a Sustainable Future

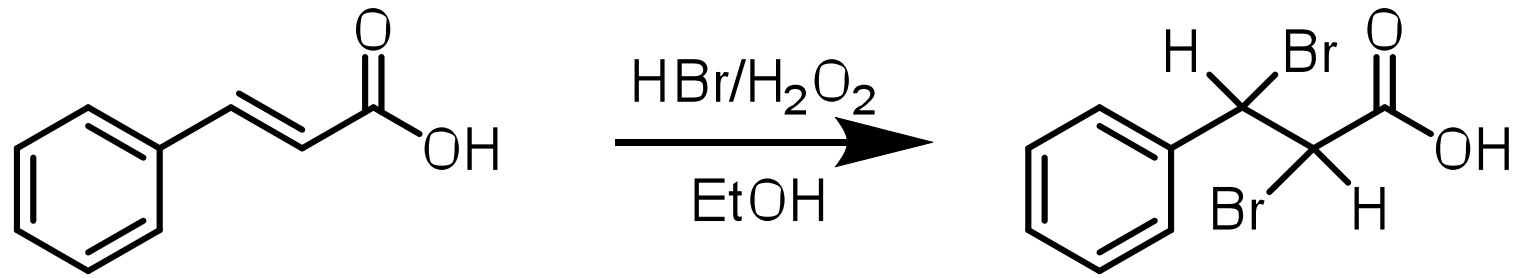
http://www.amazon.com/Green-Organic-Chemistry-Strategies-Experiments/dp/0534388515/ref=sr_1_1?s=books&ie=UTF8&qid=1410027139&sr=1-1&keywords=green+organic+chemistry; http://www.chem.utoronto.ca/green/_shared/images/2014GroupPicture.png; http://greenchemistrycommitment.org/wp-content/themes/gcc/assets/img/logo.png; http://www.acs.org/content/acs/en/greenchemistry/_jcr_content/mainContent/image.img.jpg/1391009610770.jpg

Green Chemistry in Teaching Labs

Endeavors

- Scaling down of reactions
- Replacement of hazardous procedures
- Substitution for less hazardous reagents
- Undergraduate education about hazards, acetone recycling, etc.
- **A handful of reactions have been replaced and/or implemented**
- **Impacting up to 900 students/year**

"A Greener Bromination of Stilbene"



trans-Cinnamic acid

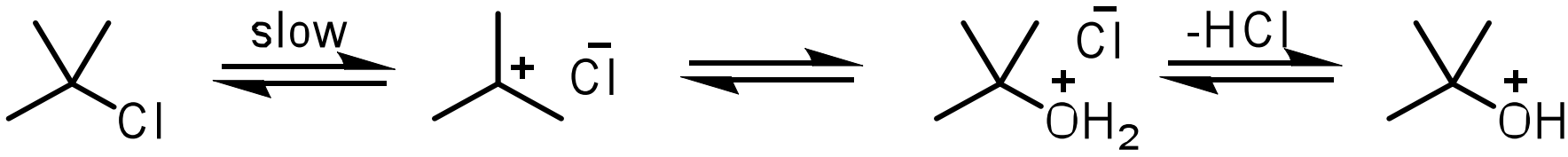
Previously:

- Bromine solution, dichloromethane as solvent
- Large volumes of aq. sodium thiosulfate neutralized Br_2

Now:

- Br_2 generated in situ with H_2O_2 and HBr, ethanol used as solvent, and no aq. sodium thiosulfate needed

"Measuring solvent effects: kinetics of hydrolysis of tert-butyl chloride"



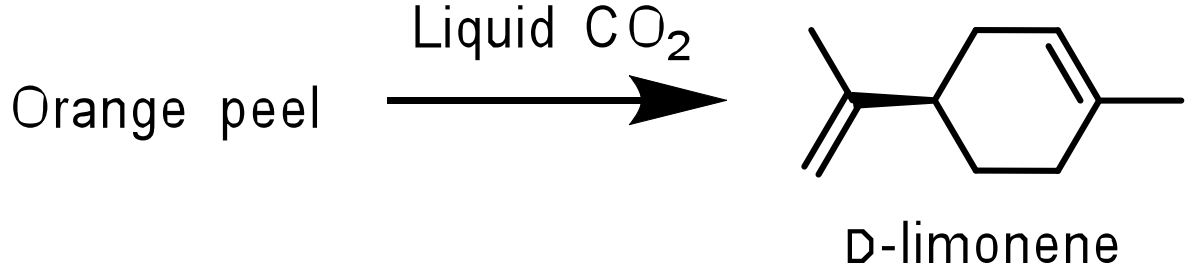
Previously:

- Replaces an old kinetics lab, which generated less volume of waste, but students used more hazardous reagents (KOH pellets, volatile alkylhalides)

Now:

- Milder reagents:
  - Uses recycled acetone and tap water as solvents
  - Prepared 0.04 M NaOH aqueous solution

"CO_2 liquid extraction of limonene"



Previously:

- Energy intensive steam distillation extraction procedure
- Required about 1 orange/student—high volume of discarded oranges

Now:

- Liquid CO_2 is more efficient, new digital polarimeter allows lower detection of limonene → ~1 orange/5 students!

McKenzie, L. C. et al., *Green Chem.* **2004**, *6*, 355–358.

Green Chemistry in Research Labs

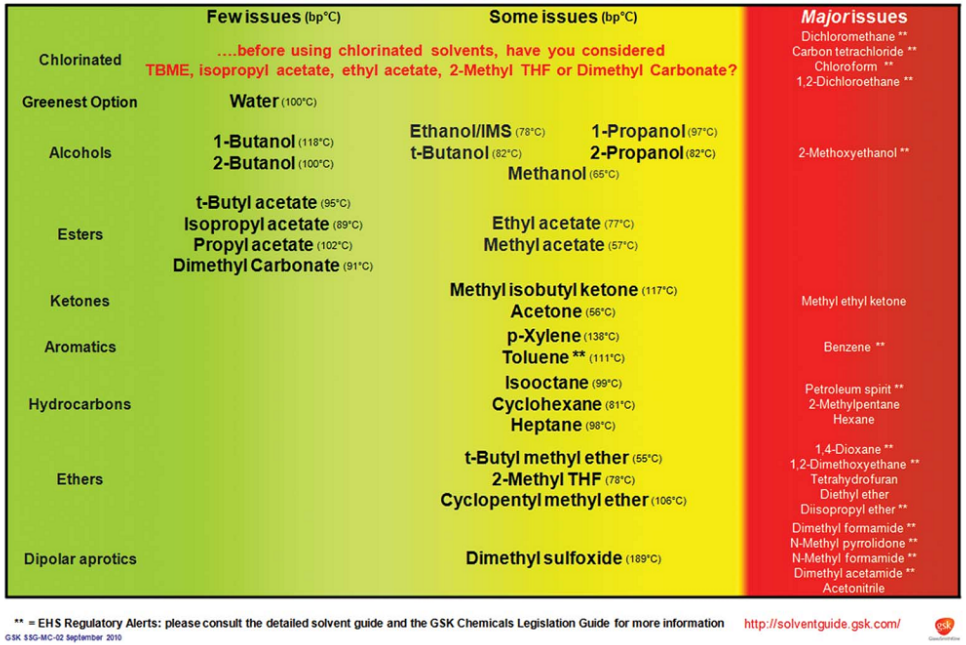
Endeavors

- Solvent substitutions
- Findensers—water-free condensers
- Use of solvents from bio-based feedstocks as opposed to petroleum-based
- Green Chemistry Fund

Solvent Substitutions

- A number of solvent selection guides are available

Glaxo-Smith Kline



Green Chem. **2011**, *13*, 854–862.

Pfizer

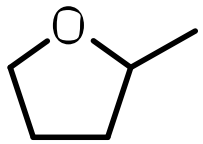
Preferred	Usable	Undesirable
Water	Cyclohexane	Pentane
Acetone	Heptane	Hexane(s)
Ethanol	Toluene	Di-isopropyl ether
2-Propanol	Methylcyclohexane	Diethyl ether
1-Propanol	TBME	Dichloromethane
Ethyl Acetate	Isooctane	Dichloroethane
Isopropyl acetate	Acetonitrile	Chloroform
Methanol	2-MeTHF	NMP
MEK	THF	DMF
1-Butanol	Xylenes	Pyridine
t-Butanol	DMSO	DMAc
	Acetic Acid	Dioxane
	Ethylene Glycol	Dimethoxyethane
		Benzene
		Carbon tetrachloride

Green Chem. **2008**, *10*, 31–36.

Solvent Substitutions

- Solvent substitutions are also available for chromatography, which uses high volumes of solvents, often chlorinated solvents and hexanes or ethyl acetate and hexanes.
- References:
  - *Green Chem.* **2012**, *14*, 3016–3019.
  - *Green Chem.* **2012**, *14*, 3020–3025.
- Also, alternative types of chromatography have been tested that use less solvent:
  - *Synthesis* **2001**, *25*, 2431–2434; *Syn. Lett.* **2014**, *25*, 0058–0063.

Bio-based solvents



2-Methytetrahydrofuran (2-MeTHF)

Advantages

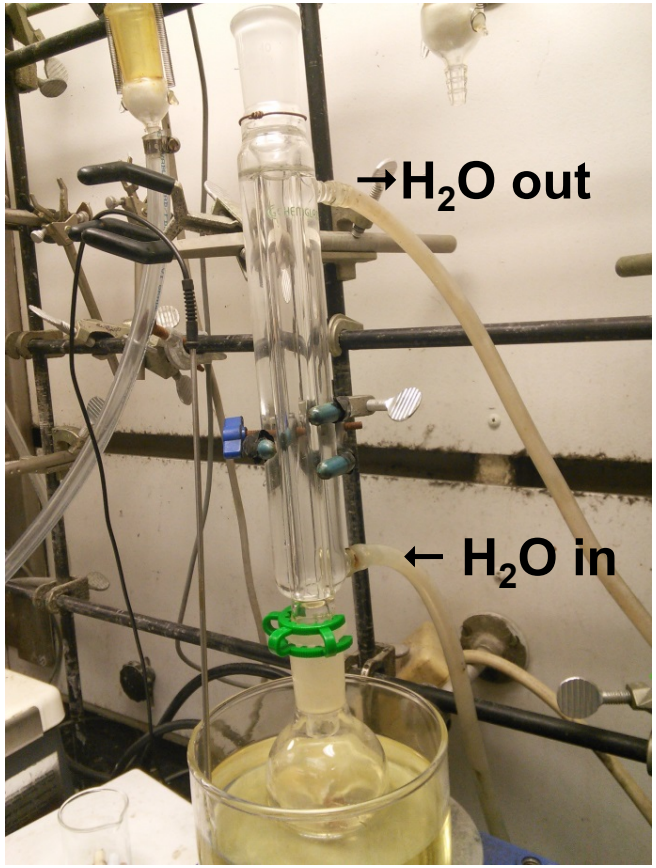
- Substitute for petrol-based tetrahydrofuran (THF)
- Immiscible with water
- Reactions may proceed better

Cons

- Much more expensive
- Not enough demand

Water-free Condensers

- Save water, eliminate flooding



Normal condenser

Water-free "Findenser"

FY '14 - '15 Green Chemistry Fund

- $5,000 fund to cover cost of materials for lab members to try their ideas
- Committee of grad students, EH&S, & CU Green Labs to review requests
- Successes will be publically shared with campus
- Grow the green chemistry culture on campus and get labs involved in coming up with ideas
- Ideas that committee could also promote:
  - Replace EtBr with less toxic products for DNA viewing
  - Safer & greener alternatives to Piranha acid baths
  - Mercury free efforts

Other Recycling

Current recycling

- Carboy, plastic film, pipette tip box, Styrofoam

In progress

- Metal, select brown glass bottles

Carboys

Metal Reagent Cans & Solvent Drums

Brown Glass

Questions?

- Contact info

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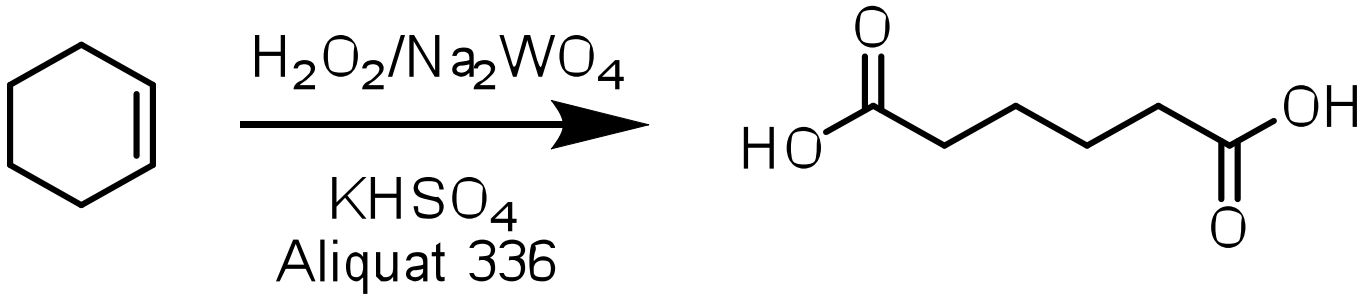
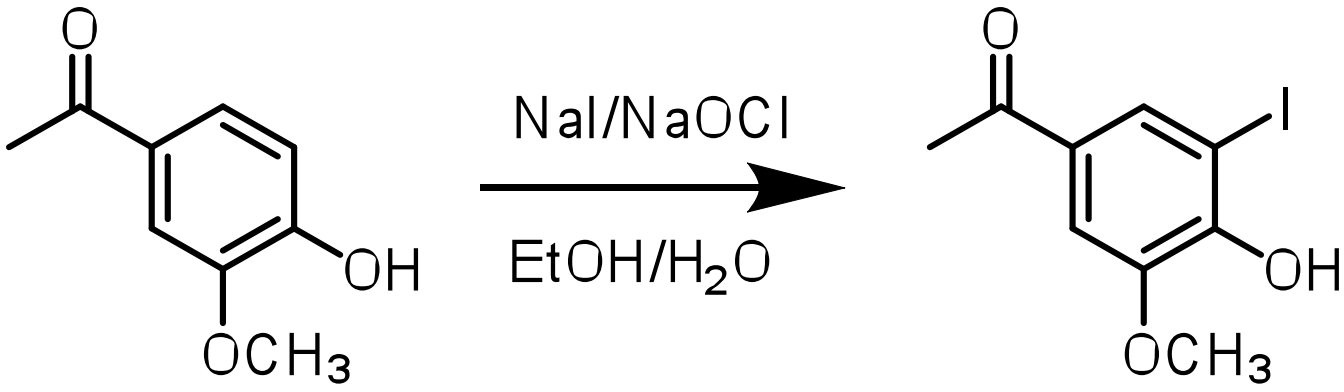
"Synthesis and recryst. of adipic acid"



"Synthesis and recryst. of adipic acid"

- Not a direct replacement for any particular lab at CU
- Affects: Majors OChem I students (~ 40 people/yr).

"Electrophilic Aromatic Iodination"



- Not a direct replacement for any particular lab at CU
- Affects: Majors OChem II students (30-40 people/yr)
- Very successful

"Palladium-catalyzed alkyne coupling"

- Uses product from electrophilic aromatic iodination
- Will be introduced in spring 2015
- Affects: Majors OChem II students (30-40 people/yr)