Greener chemistry in the organic chemistry laboratory: Benefits and lessons learned

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Excellent local examples of green innovation through chemistry in commerce

Are these “chemical” companies? Solutions go far beyond choosing a safer alternative – innovation. They need new chemicals/materials, skilled workforce, leaders..
Hot Academic Jobs of the Future: Try These Fields
By LEE ROBERTS

“The following list is not a bible, and it's certainly not scientific. But here are some of the academic fields our experts believe will be "hot" over the coming decade:

Green chemistry focuses on eliminating the use of toxic chemicals in chemistry without stifling scientific progress. Paul T. Anastas, a Yale University chemist, founded the field in 1991. As it grows in importance, more institutions are expected to offer master's degrees and doctorates. Among the universities with green-chemistry programs are Carnegie Mellon and Yale Universities and the Universities of Oregon, Scranton, and Massachusetts at Lowell.

Terry Collins, a chemistry professor at Carnegie Mellon who heads the university's Institute for Green Science, thinks the intellectual rationale for the field is strong. "It hasn't gotten a lot of federal support, but I think that's going to change," he says. One reason: Mr. Anastas has been nominated by President Obama to head the Environmental Protection Agency's Office of Research and Development.
Need to educate the public (either marketers or consumers) as well as chemists.

“Chem-free Sunscreens

We scrutinize everything we put in our bodies—reading labels, checking food facts and counting calories. But what about what’s going on our bodies? By Victoria Barbatelli

Sunscreens are often made with petrochemical ingredients that are known carcinogens. There’s a move towards chemical-free sunscreens that protect against UVA (there’s not a single chemical-free sunscreen that protects against UVB (which is the type of protection our skin really needs!) and zinc oxide is a natural, mineral reflecting of both UVA and UVB. The best performers are those with the highest concentration of zinc oxide and titanium dioxide. These products also perform well in water resistance tests and on the back of our own testing the only sunscreen that passed was ‘Micronised’

Addressing the risks of deeper penetrating UVA without using chemical absorbers.”

“...chemical-free recipes made with organic minerals such as titanium dioxide and zinc oxide.”
Our organic lab curriculum wasn’t meeting or anticipating these needs

Table 1  Starting Material Employed in Classic Organic Laboratory Syntheses  
1902-1980

<table>
<thead>
<tr>
<th>Date</th>
<th>Author</th>
<th>Acetanilide</th>
<th>4-Bromoacetanilide</th>
<th>Benzoic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Starting Materials Required (grams)</td>
<td>Aniline</td>
<td>Acetanilide</td>
<td>Benzoaldehyde</td>
</tr>
<tr>
<td>1902</td>
<td>Levy, 4th ed.</td>
<td>46.2</td>
<td></td>
<td>50.0</td>
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<tr>
<td>1915</td>
<td>Cohen, 3rd ed.</td>
<td>25.0</td>
<td>5.0</td>
<td>25.0</td>
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<tr>
<td>1933</td>
<td>Adkins</td>
<td>28.0</td>
<td>13.5</td>
<td>10.0</td>
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<tr>
<td>1941</td>
<td>Fieser, 2nd ed.</td>
<td>18.2</td>
<td>13.5</td>
<td>25.0</td>
</tr>
<tr>
<td>1963</td>
<td>Adams</td>
<td>20.0</td>
<td>13.5</td>
<td>16.0</td>
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<tr>
<td>1980</td>
<td>Drust</td>
<td>10.0</td>
<td>5.2</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Adapted from: From Microscale Organic Laboratory by D.W. Mayo, R.M. Pike and S.S. Butcher, 1985

Preparing students to pursue chemical research that brings solutions to sustainability challenges
The green chemistry curriculum pioneered at the UO has changed the way we address those needs.

Modern chemistry, inquiry-based, safer lab, less waste, cheaper, enhanced learning environment, lower energy costs....
19 Green Organic Chemistry Experiments

Plus....

- Introduction
- Identification of Chemical Hazards
- Chemical Exposure and Environmental Contamination
- Evaluation of Chemical Hazards
- Introduction to Green Chemistry
- Alternative Solvents
- Alternative Reagents
- Reaction Design and Efficiency
- Alternative Feedstocks and Products

Target audience: Sophomore-level organic chemistry laboratory

2004 Brooks-Cole
Laboratory curriculum project implementation

**Fall term**
- Synthesis, separations, spectroscopy
  1. Solventless Aldol condensation
  2. Bromination of an alkene
  3. Preparation/distillation of cyclohexene
  4. Synthesis of adipic acid
  5. Oxidative coupling of alkynes
  6. Gas phase porphyrin synthesis
  7. Solvent effects on kinetics
  8. Molecular mechanics modeling

**Winter term**
- Synthesis, spectroscopy, applications
  1. Electrophilic iodination with KI/NaOCl
  2. Palladium-catalyzed aryl halide/alkyne coupling
  3. Polymer-supported oxidation chemistry
  4. Friedel-Crafts acylation of ferrocene
  5. Thiamine-mediated benzoin condensation
  6. Self-assembled monolayers/patterning
  7. Combinatorial synthesis of antibiotics

Bar chart showing the number of students from 1997-1998 to 2001-2002.
Solventless Aldol Condensation

Chemical Concepts:
- Melting point determination and depression
- Aldol condensation reaction
- Recrystallization skills

Green Lessons:
- Solventless reactions
- Atom economical reactions

Raston, C. L.; Scott, J. L. Green Chemistry 2000, 2, 49-52.
The number of resources has grown substantially since 1997. Materials from the ACS, JChEd and from Presidential Green Chemistry Challenge Awards (http://www.epa.gov/greenchemistry/presgcc.html)
GEMs: A living database for green chemistry education

GEMs for Chemists

Greener Education Materials for Chemists

Goal: catalyze the incorporation of green chemistry into the curriculum

http://greenchem.uoregon.edu
Green chemistry appeals to students and builds problem-solving skills

"After taking this course I have a much better opinion of chemistry .... I feel like I am learning something that has an actual important application to the real world."

Assess existing procedure → Identify hazards or inefficiencies → Find/develop alternative methods → Test efficacy of new procedure → Greener alternative

Faculty are engaged by it, too

“(The students) are no longer looking at clock to leave as soon as possible, but staying late to finish what they’re doing. They have embraced the creative process of research that has been incorporated into the green chemistry curriculum.”

“It has completely revitalized my teaching and research interests; it has generated enthusiasm among my students and peers that is unparalleled in my career; it has brought service and outreach possibilities at the local and national level. In short, it's the best thing that's ever happened to my career.”

*Principle based - provides flexibility to innovate
Opportunity for continuous improvement*
There are many benefits for institutions

We are generating less waste and a less hazardous waste stream.
   Winter term 2002 disposal numbers (14.2L of aqueous, 1L of flammable organic and 1kg of solid waste for 180 students)

The project has been great for University public relations
   At least 30 articles have now been published around the world - higher profile has increased research funding

Enhances student recruiting
   We have seen strong interest from undergrads and grads who want to be part of green chemistry - increased chem majors, graduate students

Opportunity to upgrade curriculum and facilities - energy savings ($90k/yr)
   University invested in a showcase lab facility to highlight the program

Improved educational atmosphere
   The new lab setting is an excellent learning environment; multiscale glassware; new experimental techniques
Green Chemistry is Now Infused Throughout Oregon’s Research Community

Education

Research

Policy
1997: Green chemistry education efforts
Thinking about going GREEN?

11th annual
Green Chemistry in Education Workshop

July 16, 2011

Hands-on workshop focusing on implementing green chemistry in the organic lab curriculum:
- try out new experiments
- learn approaches to incorporate green chemistry in your curriculum
- network with other educators in your region

Application deadline for 2011 workshop:
February 15, 2011

Sponsored by the UO, the NSF and the NSF-sponsored Center for Workshops in the Chemical Sciences

For more information see: http://greenchem.uoregon.edu
Today: Universities and colleges across the US (and around the world) are teaching green chemistry.
Regional support for green chemistry educators

22 Institutions
37 Educators
Summary

• Interest in green chemistry is rising in academia and industry

• Green chemistry engages students and faculty – recruits new talent to the discipline

• Green chemistry has been appealing to educators because its principles they put their own stamp on it

• A wide array of greener materials are now available – for organic lab

• Think open source. Use available resources…don’t reinvent the wheel/test tube….share your findings

• Challenge existing assumptions - why is this in the curriculum?

• Develop and test new materials…carefully

• Lean on the community for rapid (and successful) adoption
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