Green Chemistry

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1. Purpose

To provide guidance on the use of Green Chemistry and support the University to achieve objectives set out in the Environmental Policy and maintain compliance with the ISO 14001:2015 environmental management system.

2. Scope

This document is relevant to all laboratory users that work with chemicals.

3. Procedure

'Green Chemistry is the design of chemical products and processes that reduce and/or eliminate the use or generation of hazardous substances'

Anastas, P. T.; Warner, J. C. Green Chemistry: Theory and Practice; Oxford University Press: New York, 1998

Green Chemistry is an umbrella approach that encompasses all divisions of science, not just chemistry. It applies the principle that it is better to prevent waste during the design and development stage than to handle, treat and dispose of waste and hazardous chemicals after the process.

For a comprehensive guide to Green Chemistry and all its principles and sub divisions see this guide in collaboration with My Green Lab, Beyond Benign and Merck Millipore.

See the Appendix for a poster labs can use to promote the use of Green Chemistry.

3.1 The 12 Principles of Green Chemistry

The 12 principles of green chemistry are a framework for evaluating and minimizing the impacts of a product or process. Some of the principles also incorporate tools for calculating efficiency or minimizing waste.

1. Prevention

Prioritise the prevention of waste rather than cleaning up and treating waste after it has been created. Plan ahead to minimise waste at every step.

2. Atom Economy

Reduce waste at the molecular level by maximising the number of atoms from all reagents that are incorporated into the final product. Use atom economy to evaluate reaction efficiency.

3. Less Hazardous Chemical Synthesis

Design chemical reactions and synthetic routes to be as safe as possible. Consider the hazards of all substances handled during the reaction, including waste.

4. Designing Safter Chemicals

Minimise toxicity directly by molecular design. Predict and evaluate aspects such as physical properties, toxicity and environmental fate throughout the design process.

5. Safer Solvents and Auxiliaries

Choose the safest solvent available for any given step. Minimise the total amount of solvents and auxiliary substances used as these make up a large percentage of the total waste created.

6. Design for Energy Efficiency

Choose the least energy-intensive chemical route. Avoid heating and cooling, as well as pressurised and vacuum conditions (i.e. ambient temperatures and pressure are optimal.

7. Use of Renewable Feedstocks

Use chemicals which are made from renewable (i.e. plant based) sources, rather than other equivalent chemicals originating from petrochemical sources.

8. Reduce Derivatives

Minimise the use of temporary derivatives such as protecting groups. Avoid derivatives to reduce reaction steps, resources required, and waste created.

9. Catalyst

Use catalytic instead of stoichiometric reagents in reactions. Choose catalysts to help increase selectivity, minimise waste and reduce reaction times and energy demands.

10. Design for degradation

Design chemicals that degrade and can be discarded easily. Ensure that both chemicals and their degradation products are not toxic, bio accumulative or environmentally persistent.

11. Real-time pollution prevention

Monitor chemical reactions in real-time as they occur to prevent the formation and release of any potentially hazardous or polluting substances.

12. Safer Chemistry for Accident Prevention

Choose and develop chemical procedures that are safer and inherently minimise the risk of accidents. Know the possible risks and assess them beforehand.

Useful links:

12 Principles of Green Chemistry - American Chemical Society

Green Chemistry Principles

Compound Interest: The Twelve Principles of Green Chemistry: What it is, & Why it Matters

3.2 Greener Solvent Selection

Greener solvent selection is the process of choosing solvents that minimize their environmental impact. Green solvents are environmentally friendly chemical solvents that are designed to be less toxic and conserve energy resources.

Solvent selection guides are used to rank solvents and can help find solvents with low toxicity, minimal safety concerns and little environmental impact. There is no universal approach to solvent selection, these guides are resources that should be used by labs to make the right choice for their specific methods.

Here are a few examples of solvent selection guides:

3.2.1 Beyond Benign Greener Solvent Guide

This is a guide of classically used solvents is based on select solvent selection guides and greener solvent alternatives. Curr Green Chemistry Organic Resource Guide Downloads - Beyond Benign

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Greener Solvent Guide

For more resources for Green Chemistry in chemistry education: http://bit.ly/gc-resources

Key: | Hazardous | Problematic | Preferred |

* Indicates Highly Hazardous

Undesirable Solvents	Alternative
Pentane, Hexane(s)	Heptane
DMF, DMAc, NMP, DMSO	Acetonitrile, Cyrene[c], Cyclopentyl methyl ether (CPME)[a], dimethyl carbonate[c]
Tetrahydrofuran, Methyl tert-butyl ether (MTBE)	2-Methyltetrahydrofuran (2-MeTHF), CPME
Di-isopropyl ether or diethyl ether*	2-MeTHF or tert-butyl methyl ether, CPME
Dioxane or dimethoxyethane	2-MeTHF or tert-butyl methyl ether, CPME
Chloroform*, dichloroethane* or CCl_4*	Dichloromethane
Pyridine (as a base)	Triethylamine (Et_3N)
Dichloromethane (in extractions)	Ethyl acetate (EtOAc), MTBE, toluene, 2-MeTHF
Dichloromethane (in chromatography)	EtOAc/heptane[b], 3:1 EtOAc/EtOH[b]
Benzene*	Toluene
Acetone	Ethyl lactate[a]

For a review of organic reactions in **water**: http://bit.ly/org-rx-water
For a review of **solvent-free** organic reactions: http://bit.ly/solvent-free-org-rx

References:
Prat, D., *et al.*, *Green Chemistry*, **2016**, *18*, 288–296; Dunn, P. J., *et al.*, *Green Chemistry*, **2008**, *10*, 31–36.
a. MilliporeSigma Greener Solvent Alternatives [https://www.sigmaaldrich.com/technical-documents/articles/analytical/solvents-and-reagents/greener-solvent-alternatives.html].
b. Taygerly, J.P., *et al.*, *Green Chemistry*, **2012**, *14*, 3020–3025.
c. Byrne, F.P., *et al.*, *Sustain Chem Process*, **2016** *4*; 7 1–24.

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3.2.2 Chem21 Solvent Selection Guide

This offers a more comprehensive look into greener solvent selection that ranks solvents based on their hazard level. [The CHEM21 Solvent Selection Guide – ACS GCI Pharmaceutical Roundtable]

3.2.3 Merck Greener Solvents

This guide offers green alternatives to Alcohols, Ethers, Esters and other solvents offered by Merck. [Greener Solvents | Merck]

3.2.4 A survey of solvent selection guides

For a comprehensive overview of different solvent selection guides see this [Article] by the Royal Society of Chemistry.

3.3 Chemical Inventory

Maintaining a chemical inventory can help prevent the over-purchasing of chemicals and reduce the amount of chemical waste. Make inventories available to other labs to enable the sharing of chemicals. Make sure the inventories are kept up to date when chemicals are purchased or finished.

3.4 Plan in Advance

Plan work in advance to minimise the use of chemicals and reduce as much waste as possible. Plan to make up the smallest volumes of any solutions required to minimise the amount of waste. If any chemicals are required check the inventory to see if they are already available before purchasing new.

4. Changes to the procedure

Version	Reason for change	Date
1.0		December 2024

GREEN CHEMISTRY

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Plan work in advance to minimise the use of chemicals and reduce as much waste as possible.

Look for **less harmful alternatives**, this will reduce the generation of hazardous waste and your exposure to hazardous chemicals.

Dispose of Chemicals in the correct way.

beyondbenign green chemistry education

Greener Solvent Guide

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