



**Tools and Resources**

***“Clean & Green”***

February/March 2019

<http://www.acs.org/chemmatters>

**Teacher’s Guide:**



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**Table of Contents**

[Connections to Chemistry Concepts 3](#_Toc524368421)

[Teaching Strategies and Tools 4](#_Toc524368422)

[Standards 4](#_Toc524368423)

[Vocabulary 5](#_Toc524368424)

[Possible Student Misconceptions 6](#_Toc524368425)

[Anticipating Student Questions 7](#_Toc524368426)

[Activities 8](#_Toc524368427)

[References 10](#_Toc524368428)

[Web Resources for More Information 11](#_Toc524368429)

# Connections to Chemistry Concepts

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| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Scientific processes** | Preparation for chemistry lab work provides an excellent place in the curriculum for students to compare the differences between the processes of standard procedures and green laboratory procedures, as shown in this article. |
| **Sublimation** | While studying phase changes, the extraction of essential oils discussed in this article provides a great example of real-world application of sublimation. |
| **Phase changes** | As described in the article, the odors emitted by essential oils can be attributed to the important nature of their volatile molecules that easily undergo the liquid/gas phase change. |
| **Greenhouse gases** | While studying how greenhouse gases affect our atmosphere and climate, this article provides information through an industrial example of ways to reduce the presence of carbon dioxide in the atmosphere. |
| **Carbon footprint** | Information from this article can be used to show the importance of considering energy use when calculating the carbon footprint of a laboratory procedure. |
| **Triple point** | When phase changes and triple points are studied, industrial use of these chemical concepts, as described in this article, can enhance student interest. |
| **Separation techniques** | The extraction of essential oils mentioned in this article is an example of a separation process—one which can be done either by steam distillation or the use of supercritical carbon dioxide. |

# Teaching Strategies and Tools

## Standards

* Links to **Common Core Standards for Reading**:
  + **ELA-Literacy.RST.9-10.1:** Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
  + **ELA-Literacy.RST.9-10.5:** Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).
  + **ELA-Literacy.RST.11-12.1:** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
  + **ELA-Literacy.RST.11-12.4:** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
* Links to **Common Core Standards for Writing**:
  + **ELA-Literacy.WHST.9-10.2F:** Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
  + **ELA-Literacy.WHST.11-12.1E:** Provide a concluding statement or section that follows from or supports the argument presented.

## Vocabulary

**Vocabulary** and **concepts** that are reinforced in the February/March 2019 issue:

Mixtures

Structural formulas

Environmental impacts of personal and societal decisions

Nanoparticles

Periodic properties

Phase changes

Green chemistry

* Consider asking students to read “Open for Discussion: Unpacking the Paleo Diet” on page 4 before they read “Making Sense of Milk” to learn why some people might choose not to consume dairy products.
* To help students engage with the text, ask students which article **engaged** them most and why, or what **questions** they still have about the articles, and what they would like to explore further.
* Ask students if they have questions about some of the issues discussed in the articles.
* Encourage students to watch the videos and try the simulations suggested in some of the articles.

# Possible Student Misconceptions

1. **“To make our world greener, I understand how important it is to ban the use of all the chemicals that are hazardous to the environment and to humans.”** It will not be practical to stop using all hazardous chemicals, as some are essential ingredients for reactions to make medicines and other necessary products. However, whenever possible, hazardous chemicals should be replaced by alternatives that have been proven safe.
2. **“Industry should use only biodegradable chemicals.”** Actually, it is important to avoid using chemicals that stay as waste in the environment or bio-accumulate. However, many chemicals that are not biodegradable can be considered valuable resources if they can be removed from waste by recycling or reusing.
3. **“We should be using water as a solvent for almost everything.”** While water is an excellent green solvent for polar materials, when used in reactions with nonpolar organic compounds it may affect the reactivity of the reactants and the catalysts. Moreover if some of the organic material dissolves in the water, it may be very difficult to remove by water treatment processes. So while water is a good solvent, it should not be taken for granted that it is the best solvent for all situations.
4. **“When staying in a hotel, I tell my family to always follow the instructions on the card with large GREEN letters asking us to join the effort to save the environment by using the ‘green’ choice to ‘opt out’ of washing sheets and towels.”** This claim is misleading in terms of green chemistry because probably little or nothing has been done by the hotel to “green” the process of cleaning the laundry. This practice often called ‘greenwashing’ doesn’t save the environment; it just saves money for the hotel because they wash linens less frequently.
5. **“As a priority, we really need to look at producing less waste from chemical reactions.”** Yes, this is important, but actually it would be wiser to carefully consider the contents of the waste. Perhaps some of the waste products can be recycled or used again. This will prevent them from polluting the environment as well as further reducing the waste.
6. **“Wow, I really found the *chemistry* involved in producing essential oils exciting!”** In the lab, removing essential oils from citrus zest is a *physical*, not a *chemical* change. The oil in the zest was not chemically produced; it was just separated from the zest. The liquid supercritical CO2 penetrated the zest and merely dissolved the essential oil to physically remove it from the zest.

# Anticipating Student Questions

1. **“Why is green chemistry important?”** Green chemistry practices are important because they promote a healthier, safer, and cleaner environment by creating alternatives to hazardous substances. This is done through the design of chemical processes that reduce waste, use less energy, and reduce the use of limited resources.
2. **“Why does Kiersi need to wear gloves when she holds the test tube of dry ice?”** Kiersi must wear gloves to protect her hands from the very cold dry ice. Carbon dioxide freezes at –78.5 oC (water freezes at 0 oC). So, dry ice is very dangerous to your bare skin; it can burn, freeze, and cause your skin cells to die.
3. **“What does it mean when you refer to a product’s ‘carbon footprint’?”** A product’s carbon footprint is a calculation that represents the total amount of greenhouse gases (which include carbon dioxide) released during the production of a substance. The footprint is calculated as carbon dioxide equivalents and expressed in tons of carbon dioxide (CO2 e) released to the environment. Carbon footprints can also refer to an individual or an event. Students can use this EPA site to calculate their carbon footprints based on their current life style: (<https://www3.epa.gov/carbon-footprint-calculator/>)
4. **“Why is the oil from an orange peel called essential?”** Essential oils are so named because their aromas represent the “essence” of the fragrance of the plant from which they were extracted. For example, the oil extracted from orange peel smells like an orange.
5. **“Why do some substances sublime?”** When the vapor pressure of the compound is greater than the total pressure of the atmosphere, and the temperature is below the melting point, the substance can change directly from a solid to a gas. This process is called sublimation.
6. **“Besides dry ice, what other substances undergo sublimation?"** Examples include

* If you watch Ice and snow on a cold day when the temperature is below freezing, you can sometimes see “steam” (really condensed water vapor forming a “cloud” of tiny water droplets) rise directly from the solid.  
  [Note that we can’t actually *see* steam, because steam is water in the gas phase—a colorless gas, just like carbon dioxide or carbon monoxide; we can’t see them, either.]
* Naphthalene (mothballs) also undergoes sublimation. Its vapor is poisonous to moths; however, clothes stored with mothballs are not “wetted” by melted mothball liquid (because there *is* no liquid phase).
* Iodine crystals in a closed, clear glass bottle will soon sublime into a purple gas in the bottle, with some crystals remaining, but no liquid present.

# Activities

**Labs and demos**

**“Reactions Lab”:** In this Beyond Benign chemistry lab, students identify the type of chemical reaction and then choose between two procedures, one traditional and the other a green chemistry alternative. Finally, students will analyze their experiments against the 12 principles of green chemistry. [Note: The URL for the lab described in the Lim green chemistry article is given in the “Lessons” section below.] (<https://www.beyondbenign.org/lessons/reactions-lab/>)

**“Wet Dry Ice Lab”:** Students actually see the triple point of dry ice! This Flinn Fax lab includes a description of the relevant phase diagram. (<https://www.flinnsci.com/api/library/Download/cc3f4560edb447c693d6ad631f971ff3>)

**Media**

**“Extraction of D-Limonene/Dry Ice”, video (4:20):** This video demonstrates the extraction described in the Lim article. Beginning with an explanation of the method using the phase diagram for CO2, all steps of the laboratory procedure including safety are shown and explained as the experiment progresses to the final product. (<https://www.youtube.com/watch?v=4OU65Y6KG00>)

**“How to Make Dry Ice with a Fire Extinguisher”, video (1:53):** This silent video clearly shows how to use a carbon dioxide fire extinguisher to make dry ice, collect it in a pillow case and dump it into a metal bowl. Note the safety precaution: the demonstrator wears gloves throughout the procedure, including (especially) while handling the dry ice; goggles should also be worn. (<https://www.youtube.com/watch?v=WleXk7eu1tU>)

**Lessons and lesson plans**

**“Essential Oil Extraction Using Liquid CO2” lesson plan:** This Beyond Benign lesson plan includes two complete oil extraction experiments: steam and CO2 (as described in the Lim article. Students are asked to compare the two methods and write how they relate to the “Principles of Green Chemistry”. (<https://www.beyondbenign.org/lessons/essential-oil-extraction-using-liquid-co2/>) (Lesson download available at this URL)

**“The safer chemical design game. Gamification of green chemistry and safer chemical design concepts for high school and undergraduate students”:** Students use this free, downloadable green chemistry computer game to design laboratory exercises that are greener and safer than those used traditionally. (<https://www.tandfonline.com/doi/full/10.1080/17518253.2018.1434566>)

**Projects and extension activities**

**“Chemistry Project on Green Chemistry: Bio-Diesel and Bio-Petrol”:** This project includes three activities: the first and second are lab-based—making (1) and testing (2) bio-diesel—while the third involves using market data to analyze the use of bio-diesel. An introduction to green chemistry is followed by a discussion of its principles and their application during the production of bio-diesel. (<https://www.scribd.com/document/47324592/Chemistry-Project-on-Green-Chemistry-Bio-Diesel-and-Bio-Petro>)

**“Green Chemistry in the General Chemistry Laboratory”:** For extension activities or student projects, consider using (and comparing with standard procedures) the Beyond Benign general chemistry experiments that are greened versions of university level introductory chemistry labs, which use safer, less toxic replacements for most of the original hazardous chemicals. The site provides an excellent resource especially for the AP Chemistry lab program. (<https://www.beyondbenign.org/bbdocs/curriculum/higher-ed/CS_General_Chemistry.pdf>)

# References

**The references below can be found on the *ChemMatters* 30-year DVD, which includes all articles published from the magazine’s inception in October 1983 through April 2013; all**

**available Teacher’s Guides, beginning February 1990; and 12 *ChemMatters* videos. The DVD is available from the American Chemical Society for $42 (or $135 for a site/school license) at this site:** [***http://ww.acs.org/chemmatters***](http://www.acs.org/chemmatters)**. Click on the “Teacher’s Guide” tab to the left, directly under the “*ChemMatters Online"* logo and, on the new page, click on “Get 30 Years of *ChemMatters* Magazine!” (the icon on the right of the screen).**

**Selected articles and the complete set of Teacher’s Guides for all issues from the past three years are available free online at the same Web site, above. Click on the “Issues” tab just below the logo, *“ChemMatters Online”*.**



“The Supercritical Clean Machine” describes the chemistry behind the polymer surfactant design and the ability of supercritical carbon dioxide to “green” the dry-cleaning process that won the 2000 ACS Presidential Green Chemistry Challenge Award. (Kirchoff, M. The Supercritical Clean Machine. *ChemMatters*. 2000, *18* (2), pp 14–15)

“The Swoosh Goes Green: Interview with John Frazier, Environmental and Sustainable Chemist at Nike” discusses the ways that Nike has reduced the release of volatile organic compounds (VOCs) and pesticides to the environment. (Brownlee, C. The Swoosh Goes Green: Interview with John Frazier, Environmental and Sustainable Chemist at Nike. *ChemMatters*. 2008, *26* (3), pp 18–19)

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The ACS “Chemistry in the Community” (ChemCom) textbook integrates green chemistry throughout the curriculum via icons for brief references and study of the principles of green chemistry through a biodiesel lab used as a green alternative to petroleum for a major energy source. (<https://www.acs.org/content/acs/en/education/resources/highschool/chemcom.html>; free review and electronic or print copies can be ordered at this site.)

# Web Resources for More Information

**History of green chemistry**

Green chemistry advances are described for each decade from the 1960s to the present. There is much information here as well as links to more.

(<https://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry/history-of-green-chemistry.html>)

This article is separated into three green chemistry sections: Origins, Present, and Future; the future section focuses on the importance of an interdisciplinary approach to product design for the field of toxicology.

(<https://greenchemistry.yale.edu/about/history-green-chemistry>)

**12 principles of green chemistry**

Each principle is described and denoted by an appropriate icon. The authors suggest that the principles can be grouped as either reducing risk or minimizing environmental impact.

(<https://www.sigmaaldrich.com/chemistry/greener-alternatives/green-chemistry.html>)

A reproducible, full-color bookmark listing the 12 principles can be downloaded here: <https://www.epa.gov/sites/production/files/documents/green-chemistry-bookmark_1.pdf>.

“Green chemistry: deliverance or distraction?” questions green chemistry principles and includes a good section for classroom use: a table with four headings: “Green chemistry principles”, “Useful questions for discussion”, “What can chemistry tell us”, and “What chemistry cannot tell us”.

(<https://link.springer.com/article/10.1007/s10098-016-1118-y>)

**Essential oils**

This history from *The Essential Oils Academy* describes the use of essential oils around the world, from fragrances for Cleopatra and Egyptian Priests to aromatherapy. The site also includes their use on wounds in WWI and how they are currently applied as natural remedies for health conditions.

(<http://essentialoilsacademy.com/history/>)

The URL below takes you to a very comprehensive site that includes the chemistry of essential oils and their components. A description of the types of compounds that compose various essential oils is followed by links to their uses: as alternative medicines (with recipes); safety concerns; manufacturing methods; and a list of those sold in the U.S.

(<https://essentialoils.co.za/components.htm>)

**Classroom applications**

Knowing the science curriculum is already packed, during this NSTA webinar Michael Tinnesand and Barbara Sitzman present ways to integrate, rather than add, green chemistry into lesson plans. During a lab activity, attendees learn to calculate and compare energy use in a traditional lab with that of a greener version. (<https://learningcenter.nsta.org/products/symposia_seminars/ACS/webseminar2.aspx>)

This review of green chemistry pedagogy suggests that the green chemistry field offers the best way to make chemistry relevant to a wide audience, through programs such as the ACS National Chemistry Week outreach. Along with an extensive bibliography, there is a section on pages 4–5 that focuses on placing green chemistry into the high school curriculum.

(<https://www.researchgate.net/publication/313829252_Green_Chemistry_Pedagogy>)

**Climate change**

The United Nations Climate Change Conference produced the *Paris Agreement* where nations pledged to reduce their greenhouse emissions. This BBC article summarizes the key elements of the agreement.

(<https://www.bbc.com/news/science-environment-35073297>)

Considering “green” as vital for meeting climate targets, three industrial partners from the Amsterdam area are studying the feasibility of forming a very large “green” hydrogen cluster. They plan to cluster (arrange) their industries to form a circular, recyclable process, driven by off-shore wind, which uses emissions from steel companies to produce hydrogen and oxygen for producing new products.

(<https://www.portofamsterdam.com/en/press-release/nouryon-tata-steel-and-port-amsterdam-partner-develop-largest-green-hydrogen-cluster>)

**Supercritical carbon dioxide**

This article describes the importance of using supercritical carbon dioxide as a green replacement for flammable and often toxic traditional solvents. A phase diagram is used to explain formation of supercritical carbon dioxide; it also includes details of CO2’s use for extraction; and text includes information about chemical reactions.

(<https://www.chemengonline.com/supercritical-co2-a-green-solvent/?printmode=1>)

Here is an extensive bulleted summary of the advantages of oil extraction by supercritical carbon dioxide. While most involve the health and environment advantages of avoiding organic solvents, taste testing shows that the flavor of extractions by carbon dioxide is closer to that of the real material than extraction by distillation or other procedures.

(<http://web.ist.utl.pt/ist11061/fidel/flaves/sec5/sec5431.html>)

**Beyond Benign**

Beyond Benign provides open access to green and sustainable chemistry curriculum. They have developed over 200 lesson plans and units; they also offer teacher training and workshop presentations.

(<https://www.beyondbenign.org/about/>)

Beyond Benign was one of the collaborators in writing a green-chemistry supplement to the ACS Guidelines for Bachelor’s Degrees in ACS-approved chemistry programs. The supplement “Green Chemistry in the Curriculum” is divided into specific examples of how to integrate green chemistry into basic chemistry courses, including general chemistry topics (similar to topics in the AP Chemistry program), and into the other fundamental bachelor’s degree courses.

(<https://www.acs.org/content/dam/acsorg/about/governance/committees/training/acsapproved/degreeprogram/green-chemistry-in-the-curriculum-supplement.pdf>)