ACS Green Student Chapter Activity: Scavenger Hunt

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Scavenger hunts. They're one of those activities that give rise to nostalgia in any age group. The fun memories and possibilities of winning prizes will most likely help students overcome hesitation about participating in an activity involving the word "chemistry", which makes a scavenger hunt the perfect choice for engaging an interdisciplinary group.

Students at Alvernia University celebrated Green Chemistry Week with a scavenger hunt involving a variety of activities such as singing about green chemistry in the cafeteria, teaching someone in the mall about the 12 principles of green chemistry and taking a picture in front of the first LEED certified house in Berks County, Pennsylvania.

In this guide you'll find step-by-step instructions, checklists, activity ideas and more to host a successful green chemistry themed scavenger hunt at your college or university.

Sustainable and green chemistry in very simple terms is just a different way of thinking about how chemistry and chemical engineering can be done. Over the years different principles have been proposed that can be used when thinking about the design, development and implementation of chemical products and processes. These principles enable scientists and engineers to protect and benefit the economy, people, and the planet by finding creative and innovative ways to reduce waste, conserve energy, and discover replacements for hazardous substances.

It's important to note that the scope of these green chemistry and engineering principles go beyond concerns over hazards from chemical toxicity and include energy conservation and waste reduction, as well as life cycle considerations such as the use of more sustainable or renewable feedstocks and designing for end of life or the final disposition of the product.

By incorporating sustainable and green chemistry into your student chapter's activities you can:

- Become a spokesperson on your campus for sustainability and the solutions chemistry can bring through green chemistry
- Start a movement of sustainability across your campus and in the community
- Make a difference through chemistry
- Have a positive impact on human health, the environment & the future
- Improve the "image" of chemistry

Chapters who engage in at least three green chemistry outreach and educational activities during the school year are eligible to win a Green Chemistry Student Chapter Award.

Green Chemistry Themes to Consider[1]

It is better to:
Prevent waste than to treat or clean up waste after it is formed
Minimize the amount of materials used in the production of a product
Use and generate substances that are not toxic
Use less energy
Use renewable materials when it makes technical and economic sense
Design materials that degrade to innocuous products at the end of their usable life

[1] Middlecamp, Catherine, ed. *Chemistry in Context: Applying Chemistry to Society*. 8th ed. New York: McGraw Hill, 2014. Print

Building a Scavenger Hunt

Activities and events don't just happen on their own. They require structure, organization and, in the case of a game, a consistent set of rules. The guidelines provided here are only a suggestion but keep in mind that complicated or confusing instructions will frustrate participants and the more important message about green chemistry may be lost.

The Basics: Logistics

A time, date, and place (plus rain location/date if the selected area is outdoors) are essential for hosting any event. An afternoon on a weekend in the Fall or Spring would likely be ideal for maximizing the number of student participants. Consider whether or not the selected **date** is convenient for members of your ACS student chapter to dedicate time. Then think about scheduling the event around the midterms, exams, holidays, major campus events, etc. for potential attendees.

If the **location** is to be indoors, a quad, or other reservable locations, be sure to inquire about its availability at least a couple weeks in advance (i.e. before the event is advertised). Even if the scavenger hunt is spread out over a large area, consider whether or not any of the spaces you plan on using will need to be booked in advance. Suggested locations are parks, malls, around town or campus, etc.

A **time** estimate will be needed for advertising, making reservations, and keeping the event on track. It's worth having members of the student chapter go through the clues and see how long it takes before holding the actual scavenger hunt. Plus, if there's a problem such as a missing clue, confusing type-o, etc. it can be fixed so the actual event runs smoothly.

Advertising is an important part of hosting any campus event but simply asking people to participate can also help. Invite professors to be judges (if judges are needed) or participants and be sure to ask them or your chemistry department about **funds** that may be available for materials or prizes. Some organizations on campus, such as student government, may also give money for student-run events. Getting faculty sponsors or participants can also encourage students to attend if only to see their instructor(s) outside the classroom. Do some research on green chemistry before speaking to a faculty member so you can confidently explain why the event is important to the department, students, and the community.

If possible, get people to **sign up** with their email addresses a few days beforehand in a high-traffic, low-stress area such as a dining hall. Then it's possible to email details and scavenger hunt rules in advance plus those who signed up are more likely to come.

Even if the rules are emailed out beforehand, it’s important to go through them step-by-step when participants have gathered for the event so there’s no misunderstanding about winning prizes, time limits, etc. And of course, be sure to **thank everyone** for their participation.

Advertise

Who will participate in the scavenger hunt if no one knows about it? One of the most important parts of hosting an event is advertising. Here are a few tips for getting better attendance when designing posters or spreading the word online.

1. Remember, you will know the material you’re presenting better than anyone looking at your flyers, posters, or probably even in attendance. Sometimes it’s best to take a step back when you’re very familiar with the information. Think of how participants who have never heard of green chemistry might perceive it and tailor your message around the perceptions of the intended audience. Do some research to find out what they are most likely to care about and adjust the program to fit their needs. In an interdisciplinary group, for example, some students might be interested in the economic benefits of green chemistry; others may be interested in the politics involved, and so on.
2. Always approach advertising in a way that is SIMPLE, DIRECT, and RELEVANT. You don't need a sassy/witty marketing push to get a message across.
3. Make sure you have information access points for your program, such as a Facebook page, Tumblr or WordPress site, etc. to give a more behind-the-scenes views. Also try to get your own website and URL and make it as short as possible so it can be remembered when read on your ads.
4. If you have an online presence, make sure all the facts are straightforward and easy to find. A simple page with the main details (time, date, place, description) and contact information should suffice. Find a tech-savvy friend to help you set up a website if you aren’t sure how. There are a number of fairly simple drag and drop webpage builders.

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Ensuring that Green Chemistry Remains the Focus

Most participants will just want to get to the game. Therefore, the introduction to green chemistry should be very to-the-point. Remember, an interdisciplinary group of students is prone to "zoning out" when listening to information about chemistry simply because it's a subject most are not familiar with. Cover topics that are relevant to anyone and everyone and ask questions that really get to the core of the message.

The majority of people don't realize that essentially everything they own, eat and use is designed on a molecular level. This introduction shouldn't be technical but rather an overview to allow participants to begin their scavenger hunt with an understanding of what green chemistry is and why they should care.

Below are a few questions that might be on the minds of those in attendance. Of course, you don't have to cover everything listed here, but keep the information in the back of your mind in case questions do arise.

How to Talk About Green Chemistry Without it Feeling like a Lecture[2]

- *What is chemistry?*
  Really, everything we experience is a result of chemistry. Remind the participants that everything is made of chemicals: the ground they're standing on, their clothes, the food they eat, the air they breathe. Chemicals are modified and combined by chemists to improve their effectiveness whether that means making a red shirt stay red longer, improving the shelf-life of a sponge cake, or enabling a cancer-treating drug to better target a tumor. Chemicals are not "good" or "bad" but sometimes the ways in which they are used or manufactured can pose risks to human health and safety for the environment.
  Such an introduction to the subject will help show chemistry's wide applications during the transition to talking about greening chemistry.

- *What is "green" chemistry?*
  The manufacture of goods – everything from cars to paint to pesticides – involves chemical processes. "Green Chemistry" was developed as a means to re-think past and current processes, many of which have posed significant risk to human health and safety or the environment. Green Chemistry takes into consideration the effects of a chemical through its entire "life" from the time it is extracted from the earth to the time it is disposed of as waste. This includes the risks involved in its transportation, effects when it enters wastewater, and potential harm caused to those who are working with it. Green chemistry is also a way in which businesses can reduce their expenses by spending less money on waste treatment and using

[2] Hill, J.W., McCreary T.W., Kolb, D.K. (2012) *Chemistry for Changing Times*: Prentice Hall. Ch. 1.

fewer chemicals in general. Some green chemists consider there to be twelve guiding principles for greener chemistry while others feel the scope is much broader. A few key ideas in green chemistry are to prevent waste instead of treating or cleaning it, use as few materials as possible, make and use non-toxic substances, reduce energy use, take advantage of renewable materials, and design things to be harmless even when they reach the end of their useful life.[3] Seems pretty obvious, right?

- *How is "green chemistry" different from just "green"?*

  Many students will be familiar with sustainability and environmental friendliness initiatives such as recycling, using less paper, and cleaning up litter . They also will likely have an awareness of the need to slow global warming, reduce carbon dioxide emissions, etc. It's easy to get these kinds of activities confused with green chemistry because in certain respects they overlap significantly. It is essential, however, to make a distinction between the two.

  Although a goal of green chemistry is to create more sustainable practices it's a specific area of the sustainability movement. For example, recycling plastic is a great sustainability practice. However, a green chemist might consider designing plastic that is more biodegradable, doesn't require petroleum or contain potentially harmful chemicals like BPA, or how to improve the efficiency of the recycling process itself. Another example of a sustainability project would be "going electronic" for a newsletter to reduce paper. A green chemist might consider how to reduce the environmental impact of the paper production process such as eliminating the use of bleach as a whitener or how to re-use chemicals that become waste during the paper production process.

  Green chemistry is a tool for building a sustainable society.

- *How might a world without greener chemistry affect me?*

  Although we often treat resources like petroleum and precious metals as if they are unlimited, they are, in fact, finite and often environmentally and socially costly as well as dangerous to extract. There are countless ways in which chemical practices affect everyone and those effects are likely to be negative if left unchecked. Numerous government agencies and private regulatory/certification groups around the world try to protect consumers, workers, and the planet by encouraging innovation and enforcing regulations based in green chemistry.

  Without green chemistry, the earth and its inhabitants are likely to experience more chemical disasters, polluted water, increased risk of cancer and disease, and could face a shortage of critical resources (everything from fuel to food and from clean air to materials needed for cell phones). Current chemical practices are often not sustainable enough to continue providing the standard of living many people have come to expect.

[3] Middlecamp, Catherine, ed. *Chemistry in Context: Applying Chemistry to Society*. 8th ed. New York: McGraw Hill, 2014. Print

Types of Scavenger Hunts

There are a number of scavenger hunt variations such as item, task, photo, video, or a mixture of activities.

Item: An item-based scavenger hunt means that participants are following clues to gather physical objects. Each group will bring back the objects they've collected in a given time period and the group which has found the most objects wins.

For this type of hunt, it's necessary to have a time limit. The limit should be slightly less than the length of time it would take for multiple groups to find all the objects. This is more easily determined if you conduct a test-run. Additionally, a penalty such as discounting an object for each late minute can be imposed for groups that don't return promptly. The intent is that groups will not purchase any items.

Task: A task-based scavenger hunt is one in which participants must complete an action and the group that successfully completes the most tasks wins. This type of activity often overlaps with photo/video scavenger hunts since they provide proof of completion (and are often entertaining). Make sure any information about the event mentions that students need to bring a camera if they won't be provided.

Photo – In this version, a photo of each task completed must be taken and shown to judges who at the end of the scavenger hunt will decide whether or not it was completed satisfactorily

Video – likewise, this version requires that a video is taken as evidence of each task completed. Again, the videos will be judged for satisfactory completion.

Judges can be members of the ACS student chapter or, if they are willing to participate, faculty members.

QR Code: Tech-savvy student chapters might consider a QR code based scavenger hunt. These hunts involve the use of smart phones to scan QR codes that provide clues. Programs are available online to create your own QR code scavenger hunt.

Additional Tips:

- If the clues are fact-based (particularly in an item-based hunt) it's a good idea to prohibit the use of cell phones or collect them at the beginning of the event.
- For item-based hunts, it's better to count the number of items each team manages to find in a given time limit than to give first place to the team that finishes first (i.e. finds all items quickest). This way the time is controlled and won't end up dragging out longer than participants expected. If participants provide their cell phone numbers, they can be texted at intervals throughout the game or with a five minute warning before time is up.
- Groups of 3 to 4 are ideal. If the scavenger hunt is part of a larger event such as a conference or workshop it can be used as an "icebreaker" exercise where the group members are selected at random (such as pulling numbers out of a hat).

- If the scavenger hunt is video-based having a follow-up event in which the videos are shown can be both very constructive and entertaining. Provide snacks and use the occasion as a forum for generating discussion about green chemistry topics.
- Scavenger hunts in the dark can be unsafe and aren't recommended.

Choosing Prizes

A jug of biodegradable laundry detergent might not be what the winning team is hoping for, but keep the green theme going when selecting prizes. What items will best communicate your commitment to green chemistry while demonstrating that consumers have the ability to advocate with their choices? Be creative and choose something that will be useful and exciting to whoever receives it (including participants who are not necessarily interested in chemistry).

In addition, it's great to give unique prizes that get people talking and asking questions. This generates buzz about green chemistry and the event, so if it's hosted annually more and more people will come along.

Brainstorm ideas within your student chapter and do a little research before deciding on prizes.

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Practical Check-List

- ☐ Advertise, advertise, advertise!
- ☐ Ask for faculty participation
- ☐ Assign responsibilities to members of your chapter
- ☐ Have a trial run of the scavenger hunt
- ☐ Reserve a location (if needed)
- ☐ Chose a rain location or date
- ☐ Printout/email lists of rules/clues to all participants
- ☐ Hide the items
- ☐ Purchase prizes

Below are a few **suggestions for scavenger hunt items and tasks**. Be creative and come up with some of your own but remember to keep the focus on green chemistry and to create clues and tasks that can be completed in the given time limit. If items are hidden, don't make them impossible to find or dangerous to retrieve. If you've ever participated in a scavenger hunt think of what worked and didn't work there.

Notes on Choosing Items

There's more than one way to do an "item" scavenger hunt.

Clues can be written that lead participants to the first location where an item is hidden and the next clue can be found. This method requires starting groups off in different locations equidistant from the first clue so they don't simply follow one another. If the clues are challenging, groups may interpret them differently and head in various directions anyway. This can be done by gathering everyone in one place for the introduction and then having members of the ACS student chapter lead each group to new starting spots. In this case, some clues might lead to stationed chapter volunteers who can ask the group questions or pose prompts about green chemistry before delivering the next clue. The group that makes it through the most clues or finishes first wins.

Another "item" method is to simply create a list of (usually very specific) items and groups must race to find them. The group that gathers the most items wins. Group members should not be allowed to split up.

After an item scavenger hunt, it's easy to go through a few of the items and explain what about each one is "green chemistry"-related. If you've gone over the principles of green chemistry at the beginning and emphasized the subject's importance, all you have to do is give a quick explanation of how these items are relevant at the end and answer any questions.

Notes on Assigning Tasks

Keep any tasks short, simple, and entertaining. Don't have teams do anything that will give observers a negative impression about the event or student chapter or that could disrupt academic activities. Again, if a camera or video camera will be needed by each team be sure to include this in the advertisements.

Engaging Participants Through Tasks and Clues: Why it Matters to Them

Green Chemists seek to improve the reputation of chemistry by learning from the past and looking to things like chemical incidents and spills as opportunities for innovation. This means designing processes that prevent problems rather than fix them after the fact.

The information following and linked to the charts will clarify any questions that arise regarding the relationship between items, clues, and tasks and green chemistry as well as highlighting several real-world scenarios where greener chemistry is already helping out. Even if no one asks, be sure to include a few brief explanations at the end of what you think are the most interesting connections.

Don't forget your audience when writing clues. If the participants aren't familiar with the concept of green chemistry they certainly won't be able to piece together a clue about supercritical CO_2 with a bag of coffee beans. Likewise, don't go overboard on the explanations. There are more details included here in case questions arise, to inspire ideas for clues, or if members of your student chapter want to learn more - but they aren't necessary to mention during this activity.

Keep the clues lighthearted and fun while saving the details for questions and discussion after the event.

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Suggested Items and Tasks

#	Item/Task	Description	Green Chemistry Concept(s)
1	Item	An article of clothing, purse, bracelet, etc. that is made from hemp or bamboo	*Lower Energy Input*
2	Item	Something solar-powered, such as a calculator	*Lower Energy Input*
3	Item	Something you could make biofuel from (judges may be needed for this one)	*Use Renewable Resources*
4	Task	Repurpose an item found in a recycling bin and give it to someone as a gift. (For example, a glass bottle with flowers in it. Be creative.)	*Use Renewable Resources*
5	Item	A soy-based product, such as a candle, tofu, oil, etc.	*Use Renewable Resources, Atom Economy, Safer Solvents*
6	Item	Something recyclable rescued from a garbage can	*Avoid Waste*
7	Item	Something made with at least 50% post-consumer content	*Avoid Waste*
8	Item	Ibuprofen	*Economize on Atoms*
9	Item	A feather	*Critical Materials*
10	Item	Decaffeinated Coffee: instant, brewed, or a bag of coffee beans	*Find Safer Solvents*
11	Item	Non-toxic nail polish – must be Dibutyl Phthalate, Toluene, and Formaldehyde free	*Find Safer Solvents, Design Safer Products*
12	Item	Paint	*Find Safer Solvents, Design Safer Products, Design for Degradation*

13	Item	Citrus Fruit or Juice	*Find Safer Solvents, Use Renewable Resources, Avoid Waste*
14	Item	A package of candy that does not contain any artificial food colors (Lakes, Dyes, FD&C no.)	*Design Safer Products*
15	Item	BPA-free plastic container	*Design Safer Products, Return Safe Substances to the Environment*
16	Task	Make green frosting (recipe and info below)	*Design safer products, use renewable resources*
17	Item	Hand Sanitizer	*Design Safer Products, Use Renewable Resources*
18	Task	Write a clue instructing a team to go to a [designated] laundry room. There you will have hidden a bottle of "green" laundry detergent with facts about how it applies to the principles of green chemistry. Have the teams intercept someone who is about to do a wash and tell them about the scavenger hunt, one fact that came on the bottle, and ask them if they'll substitute their detergent for the one provided by the team.	*Less Hazardous Chemical Synthesis, Returning Safe Substances to the Environment*
19	Task: video	If anyone on a team is wearing green, or if someone volunteers to put green clothes on, get a random student to dump a bucket of water on them	*Greenwashing*
20	Task	Get a random student to tape the 12 principles or the "chemistry of nature" pocket guides to their dorm room or apartment door	*General*
21	Task	staple the pocket guides to at least 5 bulletin boards around campus (in different buildings)	*General*
22	Task	Explain the twelve principles of green chemistry to a random person	*General*
23	Task	If you can get a hold of magnets with the 12 Principles of Green Chemistry, have teams get 3 strangers to put them on their cars	*General*

24	Task	Have each team come up with a short song about green chemistry and sing it in a campus eatery	*General*

Suggested Items and Tasks

A Few Favorite Things: Details on How the Suggested Items and Tasks Relate to Green Chemistry

1. **Hemp or Bamboo**

Growing hemp or bamboo generally has a smaller environmental footprint than either growing textile crops like cotton or processing synthetic fabrics like polyester. Having teams find an article of clothing or accessory that is made from hemp can open the follow-up remarks to a discussion about energy efficiency, use of renewable resources, and the shades of grey in using green alternatives.

Although polyester production requires petroleum and uses processes involving volatile organic solvents that create occupational and environmental hazards, the water used is often re-used in a closed-loop system. Cotton production, on the other hand, not only requires water that is irrigated to crops and cannot be recycled, but also requires large amounts of pesticides.[4] For example, according to the Better Cotton Initiative it takes about 2,700 liters of water to make a single t-shirt. Some researchers consider hemp-based products to be better designed because of the reduced amount of land, water, and chemicals needed to grow and process the renewable raw material.[5] Of course, none of these options are completely ideal. A green chemistry perspective would consider how to make clothing manufactures more energy and resource efficient throughout the entire *life cycle* - the consecutive and interlinked stages of a product or service system from the extraction of natural resources to the final disposal. One example of a newer polyester manufacturing process is using recycled PET plastic to make products like fleeces and carpets.

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2. **Solar Powered Object (such as a calculator)**

This item provides a chance to discuss renewable energy sources in terms of green chemistry: are they efficient, pollution preventing, and less hazardous?

Solar energy is the energy given off by the sun. Because it is free and abundant, solar energy is a viable alternative to petroleum-based fuels. An important note to make on the subject of renewable fuels is that while the current processes and products have faults, they still play major roles as steps in a general movement towards sustainability. In addition, note that many industrial-scale bio-processes, such as the use of lignocellulosic material to create fuel, are still in the early phases of development and won't necessarily be as efficient as something like the petrochemical industry's processes which have been evolving since the 19th century.

[4] Claudio, L. Waste Couture: Environmental Impact of the Clothing Industry, Environ. Health Persp., 2007, 115(9), 448-454 http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1964887/pdf/ehp0114-a00449.pdf

[5] Cherret N., Barrett J., Clemett A., Chadwick M., Chadwick M.J. (2005) *Ecological Footprint and Water Analysis of Cotton, Hemp, and Polyester*, Stockholm Environment Institute. http://sei-international.org/mediamanager/documents/Publications/SEI-Report-EcologicalFootprintAndWaterAnalysisOfCottonHempAndPolyester-2005.pdf

Industrial processes require large amounts of energy and fossil fuels have long been the standard for meeting these demands due to their relatively high energy output and low cost. However, these materials are non-renewable, the energy cost to extract them from the earth is high, and they release greenhouse gases when burned that would otherwise remain stored in the earth. According to the U.S. EPA, "Fossil fuel-fired power plants are responsible for 70 percent of the nation's sulfur dioxide emissions, 13 percent of nitrogen oxide emissions, and 40 percent of carbon dioxide emissions from the combustion of fossil fuels. These emissions can lead to smog, acid rain, and haze." Such processes as mining, drilling, and hydraulic fracturing for extraction of non-renewable resources do not return safe substances to the environment as would be preferred for a green chemistry process but rather they input materials known to be hazardous to ecosystems and which might pollute ground water.

Solar energy has advantages over non-renewables. For example, when generating energy, solar panels do not have emissions and transporting solar panels is less risky than transporting oil. Generating energy from renewable resources is, of course, not without its problems. In some cases, the manufacture and disposal of photovoltaic (solar) cells requires more energy than the cells will ever produce. In addition, some scarce elements are frequently used in photovoltaic cells, such as cadmium which is highly toxic and creates difficult-to-manage waste. The amount of land needed for solar farms is also a concern, but it has been proposed that areas such as deserts, which have no agricultural value, could be utilized. Although these environmental impacts of solar energy are not of the same magnitude as those caused by non-renewables, the cost of solar power is not yet competitive on a large scale for the problems it does create. Green chemists see this as an opportunity for innovation and improved design.[6]

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3. **Something to Make Biofuel From**

This item can be a huge variety of things. Examples would be corn, soybeans, vegetable oil, sunflowers, grass, woodchips, etc. The principle of green chemistry to touch on for this item is the use of renewable resources/feedstocks. Rather than depleting the earth's reserves of fossil fuels, nearly carbon-neutral biofuel is made from plants that can be harvested and re-grown over and over.

There are some pros and cons to discuss on the subject of biofuels; despite ever-better designs for biofuel production there is still a lot of room for improvement. For an interdisciplinary group this is a good place to discuss economics. Crude oil prices fluctuate unexpectedly and depend on foreign markets. Biofuels, on the other hand, can be produced domestically and demand for ethanol has created an economic boon in American Midwestern rural communities. In contrast to their economic benefit, however, is the possibility of a global rise in food prices.[7]

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4. **Repurposing a Recycled Object**

Again, the use of renewable resources is the key idea behind this item but the efficiency of current recycling processes is also relevant. If recycling an object means using additional hazardous chemicals (possibly made from non-renewables) to degrade it or lots of energy for heating and cooling (provided by burning fossil fuels), there's little benefit to re-using a material except that no virgin materials were needed for the thing itself.

One question that arises that can be addressed with participants: is it better to recycle plastic or design it to have a smaller environmental footprint? It makes economic and environmental sense to

[6] Jimenez-Gonzalez, C., Constable, D. J. C. (2011) *Green Chemistry and Engineering: A Practical Design Approach.* Hoboken, New Jersey: John Wiley & Sons, Inc. Ch. 22.
[7] Lange, Marty (ed.) (2012) *Chemistry in Context* New York, N.Y.: McGraw Hill, p.185

minimize the amount of material used to produce plastic. For example 1-gallon milk jugs decreased in weight on average by 30% from 1999 to 2009.[8] Still, petroleum-based plastics are stretching thin a resource used in many products including cell phones, contact lenses, DVDs, and artificial hearts and continues to provide the vast majority of our energy. Research is being done to develop more sustainable bio-polymers, or raw materials for plant-based plastic production. Read more on the pros and cons of bio-based plastics here.

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5. **A Soy-Based Product**

Soy is a renewable and biodegradable raw material that is being used as a "green" replacement for a variety of materials. Having each team collect a soy-based item provides an opportunity to discuss renewable feedstocks. In addition to its use for biofuel, green chemists have found many other applications for soy because of its physical and chemical properties, from plastic cups to carpets – items that would conventionally be made with non-renewable petroleum products.

The energy-intensive process of soybean oil extraction developed in the 1930's and recent improvements in extraction methods provide a great example of chemists working to economize on atoms and use safer solvents. Hexane – a solvent which can cause nerve damage and persists in the environment - has long been used as the extracting solvent with losses of about 1kg per ton of beans (i.e. really poor atom economy: lots of waste generated in proportion to the amount of product obtained).[9] Research for better extraction methods using safer chemicals such as supercritical CO_2 is being conducted.

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6. **Something recyclable rescued from a garbage can**

In order to create a sustainable society waste must be minimized. In green chemistry, avoiding waste is a key consideration in the design of a process for both environmental and economic reasons. Some industries are able to recover a significant portion of the input materials through innovative design. Plastics have conventionally been made from non-renewable petroleum sources. PET, for example, is a type of plastic made from (among other chemicals) ethylene glycol. Ethylene glycol is produced from ethylene, a hydrocarbon purified from crude oil.[10]

There is growing interest in biopolymers, or plastics made from renewable materials. These include thermoplastic starch (TPS) and poly(lactic acid) (PLA) which are created from things like corn and rice.[11] A small business example in this industry is Florida-based U.S. Bioplastics which created a process to use what was previously a waste byproduct from sugar production, known as sugar bagasse, to be processed and converted into a bio-renewable plastic comparable to PET (marketed as Gatoresin™).

Such emerging materials are promising for a sustainable future, but the chemistry involved must

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[8] Ibid., p.394

[9] Kerton, F.M., Marriot, R. (2013) *Alternative Solvents for Green Chemistry*, Cambridge, UK: The Royal Society of Chemistry, p.2

[10] Eldridge, R.B. Olefin/Paraffin separation technology: a review. *Ind. Eng. Chem. Res.* 1993. 32. 2208-2212 http://pubs.acs.org/doi/pdf/10.1021/ie00022a002

[11] Jimenez-Gonzalez, C., Constable, D. J. C. (2011) *Green Chemistry and Engineering: A Practical Design Approach.* Hoboken, New Jersey: John Wiley & Sons, Inc. pp.605-606

be considered in addition to the renewability. For example, plastic production is often a hazardous process that involves the use of toxic chemicals or waste. The complete life cycle of a product, renewable or not, is an important consideration in green chemistry.[12]

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7. **Something made with at least 50% post-consumer content**[13]

Naturally, more recycled material equals more waste avoided. There are four main labels which appear on products with relation to recycling/recyclability:

Recycled-content – these are products made from what would otherwise have entered the waste stream

Postconsumer content – this label will appear on something made from second-hand materials, from industry or consumer products that would otherwise have entered the waste stream

Pre-consumer content – made from waste generated during manufacturing

Recyclable- products that can be recycled but aren't conditionally made from anything that's been recycled

As mentioned in example 6, traditional plastic manufacturing relies on non-renewable petroleum. An innovation in recycling PET (indicated by the number 1 inside the recycling symbol on packaging) was developed by the Petretec Company. The process converts used, contaminated PET back into high quality plastic thus avoiding the use of raw materials and preventing waste such as landfill contributions or air emissions through incineration. Plastic made through this process would be labeled as "post-consumer" and "recyclable." The PET in this process is converted back into ingredients needed to make it – dimethyl terephthalate and ethylene glycol. Ethylene glycol is petroleum based, so this recycling process not only prevents waste but also reduces the reliance on non-renewable resources.[14]

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8. **Ibuprofen**[15]

One of the themes of green chemistry is economizing on atoms. This means designing chemical processes so that most or all of the input materials end up in the final product rather than becoming waste. The pharmaceutical industry has historically had a high product to waste ratio with an average of 16 times as much waste generated as desired product. This is different from reaction yield. A reaction could give 99% yield but only include 20% of all the atoms used in the ingredients.

The traditional Boots Company synthesis of ibuprofen was not very atom-economic; 60% of all the reagent atoms became waste which translates to a 40% atom economy. In the early 1990's, the BHC Company developed a synthesis of ibuprofen with only three steps (rather than six) with an atom economy of 77%-99% depending on whether or not certain reagents are recovered. This greener synthesis reduced waste and allowed for more ibuprofen to be produced more quickly and for less money. Cha-ching!

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[12] *Ibid.,* pp.607-608

[13] Lange, Marty (ed.) (2012) *Chemistry in Context* New York, N.Y.: McGraw Hill, p.396

[14] Cann, M.C. and Connelly, M.E. (2000) *Real World Cases in Green Chemistry,* A publication in conjunction with the University of Scranton, U.S. Environmental Protection Agency, and the American Chemical Society pp.25-28.

[15] *Ibid*., pp.19-23

9. **A Feather**[16]

As technology progresses so does our consumption of endangered elements: the 44 critical materials which will soon face supply limitations. These limitations can stem from factors such as geographic concentration, political motivations, regulatory laws, or consumer demand. Some green chemists are researching more abundant alternatives, more efficient syntheses where alternatives are not found, diversifying the supply and better recycling and recovery programs for these scarce materials. A smartphone, for example, usually contains over 80 elements, many of which are considered "endangered," for everything from the touch screen (dysprosium, europium, etc.) to the color display (yttrium, terbium, and more). To manufacture computer chips, many chemicals, large amounts of water, and energy are required. In a study conducted in 2003, the industrial estimate of chemicals and fossil fuels required to make a computer chip was a 630:1 ratio! That means it takes 630 times the weight of the chip in source materials just to make one chip. Compare that to the 2:1 ratio for the manufacture of an automobile. This is an example of very poor atom economy.

Affordable Composites from Renewable Sources (ACRES) program at the University of Delaware, found a way to use chicken feathers to make computer chips. The protein, keratin, in the feathers was used to make a fiber form that is both light and tough enough to withstand mechanical and thermal stresses. The result is a feather-based printed circuit board that actually works at twice the speed of traditional circuit boards. Although this technology is still in the works for commercial purposes, the research has led to other uses of feathers as source material, including for biofuel.

Note: If the scavenger hunt is aimed specifically at science students the activities can be slightly more involved and even include the lab. Check out these two examples of creating pH indicators from renewable, biodegradable products: cabbage and hibiscus flowers. While not quite as technologically advanced as computer chips, it still demonstrates the applications of green chemistry to conventional methods.

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10. **Decaffeinated coffee: instant, brewed, or a bag of coffee beans**

Many people are surprised to learn that even what they eat is a product of chemical design. Decaffeination is just one example of a food-industry process that green chemistry principles have been applied to with success. The solvents used in many industrial processes – including those related to food – are highly hazardous to human health and the environment. Decaffeination of coffee beans using dichloromethane, a suspected carcinogen, was the accepted process for about 70 years. However, greener methods have been developed and applied on an industrial scale. The Swiss water process and the use of supercritical CO_2 are both the result of green chemical innovation. The Swiss water process uses water, green bean extract and a difference of caffeine concentrations. No harmful solvents are used and very little waste is produced as the water is easily recycled. Decaffeination by supercritical CO_2 is also a safer and more environmentally friendly method because it is a very low-waste process using a relatively non-toxic substance. The carbon dioxide is made using CO_2 sequestered from the environment

[16] http://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry/examples.html

and is recycled throughout the process, while the caffeine solution produced is sold to other manufacturers.[17]

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11. **Non-toxic nail polish** – must be Dibutyl Phthalate, Toluene, and Formaldehyde free ("toxic trio")

Producing safer products is a goal of green chemistry. The average consumer knows very little about what chemicals have actually been used to make products on the shelves. That's not to say it's the consumer's fault – many companies are very reluctant to be transparent, although initiatives like the Campaign for Safer Cosmetics and the Good Guide are trying to change that. (Even labels are not necessarily reliable, of course – nail polish is a cosmetic and therefore not completely regulated by the FDA.[18])

Some companies have changed their formulas, but many nail polishes still contain chemicals like Dibutyl phthalate, toluene, and formaldehyde. These ingredients are included to enhance the properties of the polish, such as adherence to the nail, flexibility to reduce chipping, for thickening, and faster drying.[19] Phthalates are endocrine disrupting chemicals: they can change hormone signaling and could affect a variety of biological functions like the metabolism, nervous system, and reproduction.[20] Both toluene and formaldehyde can be absorbed through the skin; toluene is known to affect the nervous and respiratory systems with repeated exposure, such as in the workplace, and formaldehyde is a known carcinogen.[21,22]

Green chemistry has resulted in nail polishes that are less hazardous for human health. Designing around this flaw – the inclusion of harmful substances – is possible and, in fact, has already been done. For example, a nail company called Acquarella Nail Polish uses water as the base solvent, an ingredient which of course is non-toxic to humans and the environment.[23]

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12. **Paint**[24]

Oil-based "alkyd" paints give off large amounts of volatile organic compounds (VOCs). These volatile compounds evaporate from the paint as it dries and cures. Many VOCs have one or more environmental impacts, such as reacting with nitrous oxides in the air to produce smog. Procter & Gamble partnered with Cook Composites and Polymers to create a mixture of soya oil and sugar that replaces fossil-fuel-derived paint resins and solvents, cutting hazardous volatiles by 50 percent. Chempol® MPS paint formulations use these biobased Sefose® oils to replace petroleum-based solvents and create paint that is safer to use and produces less toxic waste. Sherwin-Williams developed water-

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[17] Jimenez-Gonzalez, C., Constable, D. J. C. (2011) *Green Chemistry and Engineering: A Practical Design Approach.* Hoboken, New Jersey: John Wiley & Sons, Inc.

[18] http://www.fda.gov/aboutfda/transparency/basics/ucm262353.htm

[19] Drahl, C. (2008) *Nail Polish.* Retrieved from http://cen.acs.org/articles/86/i32/Nail-Polish.html

[20] Dodson, R.E., Nishioka, M., Standley, L.J., Perovich, L.J., Brody, J.G., Rudel, R.A., Endocrine disruptors and asthma-associated chemicals in consumer products, *Environ Health Persp,* 2012, 120(7), pp.935-943.

[21] https://www.osha.gov/SLTC/toluene/health_hazards.html

[22] http://www.niehs.nih.gov/health/materials/formaldehyde_508.pdf

[23] Drahl, C. (2008) *Nail Polish.* Retrieved from http://cen.acs.org/articles/86/i32/Nail-Polish.html

[24] http://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry/examples.html

based acrylic alkyd paints with low VOCs that can be made from recycled soda bottle plastic (PET), acrylics, and soybean oil. These paints combine the performance benefits of alkyds and low VOC content of acrylics. In 2010, Sherwin-Williams manufactured enough of these new paints to eliminate over 800,000 pounds, or 362,874 kilograms, of VOCs.

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13. **Citrus fruit or citrus fruit juice**

Have participants retrieve a lemon, orange, grapefruit, etc. or the juice of one of these fruits to touch on the topics of safer solvents, use of renewable resources, avoid waste and creating safer consumer products. A chemical called D-Limonene is an essential oil found in the rinds of citrus peels. Chemically classified as a *monocyclic monoterpene* it is a major component of the flavor and fragrance of citrus fruits. It is GRAS, or Generally Recognized as Safe by the U.S. Food and Drug Administration, meaning it has relatively low toxicity. One estimate found that the average American consumes about 16mg of d-Limonene a day through citrus fruit consumption.[25]

D-Limonene is used in a variety of consumer goods for its cleaning (degreasing) capability and pleasant odor. These include things like detergents, shampoos, cosmetics, and flavor enhancers for everything from ice cream to baked goods. It has also been used in a few medical applications such as breaking up gallstones and as part of cancer treatment.[26] D-Limonene is also a less hazardous solvent that can be used in place of halogenated chemicals (some of which can deplete the ozone layer) or those with health risks, like n-Hexane (known to affect the nervous system). Some manufacturers of d-limonene use the byproducts of orange juice manufacture to make the chemical, thus minimizing waste.

If you're tailoring the scavenger specifically to chemistry students and you're able to get faculty supervision, consider having the participants make their own d-limonene as a task. You can find the materials needed and the procedure in the ACS Green Student Chapter guide for demonstrations.

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14. **A package of candy that does not contain any artificial food colors (Lakes, Dyes, FD&C no.)**

Even though food additives are regulated in the U.S. by the Food and Drug Administration the products may have negative human health impacts (although this has been widely debated since the 1970's). The U.S. FDA has rejected evidence that these food colors pose a risk to the general population, but independent studies have shown that food coloring chemicals – particularly those in red food dye - correlate to neuro-behavioral toxicity.[27]

Titanium Dioxide (TiO_2) is a common food additive for its whitening effects, like in icing, powdered donuts, and chewing gum, but it is also used to enhance other colors, particularly for sweets,

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[25] Hakim, I.A., Harris R.B. and Ritenbaugh C. (2000) Citrus peel use is associated with reduced risk of squamous cell carcinoma of the skin. *Nutrition and Cancer*. 37(2), 161-168. http://69.164.208.4/files/Citrus%20Peel%20Use%20Is%20Associated%20With%20Reduced%20Risk%20of%20Squamous%20Cell%20Carcinoma%20of%20the%20Skin.pdf

[26] Sun, Jidong (2007) D-Limonene: Safety and Clinical Applications. *Altern. Med. Rev.* 12(3), 259-264. http://www.anaturalhealingcenter.com/documents/Thorne/articles/Limonene12-3.pdf

[27] Weiss, B. Synthetic food colors and neurobehavioral hazards: the view from environmental health research, *Environ Health Persp.,* 2012, 120(1), 1-5.

such as in M&Ms® and Good&Plenty®. In addition, TiO_2 is an anticaking agent for things like powdered mixes. The list of foods containing this chemical goes on and on and yet the effects on the environment and human health are not known with any certainty. However, it is often found in water samples, particularly downstream from wastewater processing plants.[28]

A point to discuss here with participants would be: should we continue to use chemicals without knowing how they affect human health and the environment? How much research must be done before a chemical is deemed "safe?" Metrics and tools are being developed by organizations such as the U.S. EPA to help objectively and consistently measure the impact of chemical use, but is it enough to have the metrics or are regulatory laws needed?

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15. **BPA-free plastic container**

Teams can retrieve any food container, water bottle, canned good, etc. labeled "BPA-free" to connect to the topic of designing safer products. BPA, or bisphenol-A, acts like the hormone estrogen in the body and has been linked to increased health risks for cancer, diabetes, and hypertension. It has been used in food and drink packaging, electronics, medical devices and more as a lightweight, shatter-reducing additive since the 1950's, but research has shown that it leaches out of plastics to act as an endocrine disrupting chemical, or EDC.[29] This chemical is produced in huge quantities worldwide; 5.5 million metric tons were manufactured in 2011.[30]

Consumer awareness and demand, however, has caused some companies to reconsider their plastic formulations. In Canada, the substance was declared toxic and products containing it were removed from stores.[31] Tools for testing endocrine disrupting activity are being developed by biologists, chemists, and toxicologists to prevent such chemicals from entering the marketplace by determining their toxicity early.[32] Part of green chemistry is developing better materials through trial and error, creating tools that quantify their safety, and designing benign products and processes, but being a knowledgeable consumer helps create demand for these safer products.

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16. **Make Green Frosting**

This green activity might seem a little out of the blue but food additives, like everything, are chemicals. See item 14 for more information on food colors and chemistry.

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[28] Weir, A., Westerhoff, P., Fabricius, L., Hristovski, K., von Goetz, N. Titanium dioxide nanoparticles in food and personal care products, *Environ Sci. Technol.,* 2012, 46, 2242-2250 http://pubs.acs.org/doi/pdf/10.1021/es204168d

[29] *Consumer Affairs; Canada Lists Plastic Chemical as Toxic; Other Development*, Facts on File World News Digest: loaded May 14, 2008, 461 of 631 documents, pg. 306F1

[30] Pupo M, Maggiolini M (2014) Bisphenol-A: A Powerful Endocrine Disrupting Chemical . J Biofertil Biopestici 5: e124 http://omicsonline.org/open-access/bisphenola-a-powerful-endocrine-disrupting-chemical-2155-6202.1000e124.pdf

[31] *Consumer Affairs; Canada Lists Plastic Chemical as Toxic; Other Development*, Facts on File World News Digest: loaded May 14, 2008, 461 of 631 documents, pg. 306F1

[32] http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3553450/

As a task, assign the teams the "burden" of creating frosting and coloring it green with a completely natural product: avocado. Have the ingredients ready for when the team(s) solve the clue and arrive at the mixing station (you may want to have some cookies nearby for them to decorate!).

Here's a green frosting recipe from the Food Network. Consider the logistics before having the teams set off: have mixer ready, utensils out, and sugar sifted. Each team does *not* need to make a whole batch of frosting!

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17. **Hand Sanitizer**

Micro-organisms are everywhere, even in our clothes. They cause odors, wearing, and color changes to fabrics in textiles. To reduce the number and effects of micro-organisms on our clothes, antimicrobial textiles have been developed. Unfortunately, some of these synthetic agents have toxic effects on humans. For example, silver antimicrobial agents have caused dermatitis, some synthetic dyes have been found to cause cancer, and still others like zinc pyrithione are neurotoxic. Not only are these compounds harmful to humans, they are often not biodegradable and the waste created by their manufacture is difficult to treat and sometimes they become ineffective over time.

Green chemistry approaches have created benign antimicrobial textile solutions. These include materials called biopolymers that are made from a huge variety of renewable materials found in nature such as chitosan from crustaceans and fungi, cyclodextrin from starch, and alginate from brown sea weeds. Antimicrobial agents made from these ingredients are less harmful to the environment, have lower toxicity, are renewable, and still highly functional.[33]

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18. **Green laundry detergent**[34]

Dry Cleaning: dry-cleaning processes have conventionally used the chemical perchloroethylene (perc). Several organizations have stated that perc is a hazardous substance to human health. The International Agency for Research on Cancer (IARC) concluded that perc is a "probable human carcinogen" meaning it is likely to cause cancer in addition to its short term effects like dermatitis. Workers in a dry-cleaning facility can be exposed to perc in a number of ways from cleaning the machine to simply loading clothing.[35] In addition, perc is categorized as a hazardous air pollutant by the U.S. EPA's Clean Air Act and it may contaminate groundwater when it is disposed.[36]

Applying green chemistry to this situation has resulted in a markedly improved process using liquid carbon dioxide – a substance that is essentially non-toxic and is equally effective at removing grease and dirt from fabric. This simple innovation of replacing a hazardous chemical for a benign one is a perfect example of green chemistry at work in everyday life.

Another, more technical, angle that this task could be seen from is the benefits of selective catalysts over stoichiometric chemistry. At the Institute for Green Oxidation Chemistry at Carnegie

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[33] Shahid-ul-Islam, Shahid, M., Mohammad, F. Green chemistry approaches to develop antimicrobial textiles based on sustainable biopolymers – a review. *Ind. Eng. Chem. Res.* 2013, 52, 5245-5260.

[34] Ryan, M. (ed.), Tinnesand, M. (ed.) (2002*) Introduction to Green Chemistry*, American Chemical Society: U.S.A. pp.23-29

[35] https://www.osha.gov/dsg/guidance/perc.html

[36] http://yosemite.epa.gov/opa/admpress.nsf/0/e99fd55271ce029f852579a000624956

Mellon University, catalysts have been developed as an alternative to bleach-based cleaners and disinfectants. Tetraamido macrocyclic ligand (TAML) activators perform the same chemical function as chlorinated bleaches, but they act in water, are effective in low concentrations, reduce pollution and can be designed for high selectivity based on the stain or contaminant.[37]

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19. **Greenwashing**[38]

This task involves each team selecting someone from their group to wear green and have water dumped on them: literally a task of "green washing." Greenwashing is "a term used to describe the perception of consumers that they are being misled by a company about its environmental practices or the environmental benefits of a product or service." Greenwashing can result in increased consumer skepticism of environmental claims and reduced motivation for companies to take steps towards environmental friendliness. The term can also refer to the misinformation itself as presented by a company or organization in an attempt to project a greener image. Explain to the student that has been selected to dump the water what the activity represents.

Just as it is important not to dump buckets of water on your friends too often lest they stop trusting you, greenwashing should be minimized in order to gain consumer trust and advance sustainable practices.

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20-24. **General Green Chemistry Tasks: Teaching, Singing, Telling, Yelling**

These tasks are simply to introduce non-participants to green chemistry. Be sure teams are provided with resources and examples with which to spread the word. Printouts from the ACS Green Chemistry Institute website are available here in this document. Information on the GCI website, examples from the items and tasks listed above, and information in Appendices A and B are great places to start for finding materials to give to the teams.

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[37] https://www.acs.org/content/dam/acsorg/greenchemistry/education/resources/bleaching-with-green-oxidation-chemistry.pdf

[38] Jimenez-Gonzalez, C., Constable, D. J. C. (2011) Green Chemistry and Engineering: A Practical Design Approach. Hoboken, New Jersey: John Wiley & Sons, Inc. p.507

Appendix A: Introduction to Green Chemistry

What is green chemistry and why is it important?[39]

The concept of greening chemistry is a relatively new idea which developed in the business and regulatory communities as a natural evolution of pollution prevention initiatives. In our efforts to improve crop protection, commercial products, and medicines, we also caused unintended harm to our planet and humans.

By the mid-20th century, some of the long-term negative effects of these advancements could not be ignored. Pollution choked many of the world's waterways and acid rain deteriorated forest health. There were measurable holes in the earth's ozone. Some chemicals in common use were suspected of causing or directly linked to human cancer and other adverse human and environmental health outcomes. Many governments began to regulate the generation and disposal of industrial wastes and emissions. The United States formed the Environmental Protection Agency (EPA) in 1970, which was charged with protecting human and environmental health through setting and enforcing environmental regulations.

Green chemistry takes the EPA's mandate a step further and creates a new reality for chemistry and engineering by asking chemists and engineers to design chemicals, chemical processes and commercial products in a way that, at the very least, avoids the creation of toxics and waste.

We are able to develop chemical processes and earth-friendly products that will prevent pollution in the first place. Through the practice of green chemistry, we can create alternatives to hazardous substances we use as our source materials. We can design chemical processes that reduce waste and reduce demand on diminishing resources. We can employ processes that use smaller amounts of energy. We can do all of this and still maintain economic growth and opportunities while providing affordable products and services to a growing world population.

This is a field open for innovation, new ideas, and revolutionary progress.

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[39] http://www.acs.org/content/acs/en/greenchemistry/what-is-green-chemistry.html

How is green chemistry different from sustainability?

Many people are familiar with sustainability and environmental friendliness initiatives such as recycling, using less paper, and cleaning up litter and have an awareness of the need to slow global warming, reduce carbon dioxide emissions, etc. It's easy to get these kinds of activities confused with green chemistry because in certain respects they overlap significantly. It is essential, however, to make a distinction between the two.

Although a goal of green chemistry is to create more sustainable practices it's a specific area of the sustainability movement. Green chemistry is a tool for building a sustainable society. For example, recycling plastic is a great sustainability practice. However, a green chemist might consider designing plastic that is more biodegradable, doesn't require petroleum or contain potentially harmful chemicals like BPA, or how to improve the efficiency of the recycling process itself. Another example of a sustainability project would be "going electronic" for a newsletter to reduce paper. A green chemist might consider how to reduce the environmental impact of the paper production process such as eliminating the use of bleach as a whitener or how to re-use chemicals that become waste during the paper production process.

Appendix B: Everyday Examples of Green Chemistry

Below are a few more interesting examples of how green chemistry affects everyone.

- *Have you ever eaten food?*
  - Consider everything vanilla-flavored you've ever eaten or vanilla-scented candles, soaps, and more that you've used. The production of synthetic vanillin, the main flavor component of natural vanilla extract, has undergone several changes through industry attempts to improve efficiency, reduce waste, and increase the quality as demand grows at a faster rate than vanilla bean production. In the 1930's, use ligninsulfonates (organic material from wood pulp production) became the conventional starting material for vanillin production but were eventually replaced by a petrochemical starting material due to the large amounts of waste created through the wood-production by-product process[40]. New research has found that vanillin molecules can be collected and purified using ionic solvents which are often greener than the solvents they replace (less volatile) and can be derived from renewable resources unlike petrochemicals[41]. Although this synthesis is still in development the pathway towards greener production is being paved.
- *Have you ever used plastic?*
  - Several companies have been working to develop plastics that are made from renewable, biodegradable sources.
  - NatureWorks of Minnetonka, Minnesota, makes food containers from a polymer called polylactic acid branded as Ingeo. The scientists at NatureWorks discovered a method where microorganisms convert cornstarch into a resin that is just as strong as the rigid petroleum-based plastic currently used for containers such as water bottles and yogurt pots. The company is working toward sourcing the raw material from agricultural waste.
  - BASF developed a compostable polyester film that called "Ecoflex®." They are making and marketing fully biodegradable bags, "Ecovio®,"made of this film along with cassava starch and calcium carbonate. Certified by the Biodegradable Products Institute, the bags completely disintegrate into water, CO_2, and biomass in industrial composting systems. The bags are tear-resistant, puncture-resistant, waterproof, printable and elastic. Using these bags in the place of conventional plastic bags, kitchen and yard waste will quickly degrade in municipal composting systems.
- *Have you ever taken a medication?*
  - Merck and Codexis developed a second-generation green synthesis of sitagliptin, the active ingredient in Januvia™, a treatment for type 2 diabetes. This collaboration lead to an enzymatic process that reduces waste, improves yield

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[40] Calvo-Flores, F.G., Dobado, J.A. Lignin as a renewable raw material, *Chem Sus Chem.,* 2010, 3, 1227-1235. http://onlinelibrary.wiley.com/enhanced/doi/10.1002/cssc.201000157/

[41] http://www.sciencedirect.com/science/article/pii/S1383586610002789

and safety, and eliminates the need for a metal catalyst. Early research suggests that the new biocatalysts will be useful in manufacturing other drugs as well.

- Originally sold under the brand name Zocor®, the drug, Simvastatin, is a leading prescription for treating high cholesterol. The traditional multistep method to make this medication used large amounts of hazardous reagents and produced a large amount of toxic waste in the process. Professor Yi Tang, of the University of California, created a synthesis using an engineered enzyme and a low-cost feedstock. Codexis, a biocatalysis company, optimized both the enzyme and the chemical process. The result greatly reduces hazard and waste, is cost-effective, and meets the needs of customers.

- *Have you ever painted something?*
  - Oil-based "alkyd" paints give off large amounts of volatile organic compounds (VOCs). These volatile compounds evaporate from the paint as it dries and cures and many have one or more environmental impacts.
  - Procter & Gamble and Cook Composites and Polymers created a mixture of soya oil and sugar that replaces fossil-fuel-derived paint resins and solvents, cutting hazardous volatiles by 50 percent. Chempol® MPS paint formulations use these biobased Sefose® oils to replace petroleum-based solvents and create paint that is safer to use and produces less toxic waste.
  - Sherwin-Williams developed water-based acrylic alkyd paints with low VOCs that can be made from recycled soda bottle plastic (PET), acrylics, and soybean oil. These paints combine the performance benefits of alkyds and low VOC content of acrylics. In 2010, Sherwin-Williams manufactured enough of these new paints to eliminate over 800,000 pounds, or 362,874 kilograms of VOCs.

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Pocket Guide Print Outs: Technical

Green Chemistry Pocket Guide

The 12 Principles of Green Chemistry

Provides a framework for learning about green chemistry and designing or improving materials, products, processes and systems.

1. Prevent waste
2. Atom Economy
3. Less Hazardous Synthesis
4. Design Benign Chemicals
5. Benign Solvents & Auxiliaries
6. Design for Energy Efficiency
7. Use of Renewable Feedstocks
8. Reduce Derivatives
9. Catalysis (vs. Stoichiometric)
10. Design for Degradation
11. Real-Time Analysis for Pollution Prevention
12. Inherently Benign Chemistry for Accident Prevention

www.acs.org/greenchemistry

ACS Chemistry for Life™

ACS Green Chemistry Institute®

The Chemistry of Nature

Green Chemistry Definition: *The design, development and implementation of chemical products and processes that reduce or eliminate the use and generation of hazardous substances.*

Green Chemistry is doing chemistry the way nature does chemistry – using renewable, biodegradable materials which do not persist in the environment.

Green Chemistry is using catalysis and biocatalysis to improve efficiency and conduct reactions at low or ambient temperatures.

Green Chemistry is a proven systems approach.

Green Chemistry reduces negative human health and environmental impacts.

Green Chemistry offers a strategic path way to build a sustainable future.

To catalyze and enable the implementation of green chemistry and engineering throughout the global chemical enterprise

Contact us: gci@acs.org

Green Chemistry Print-Outs: Non-Technical

Submitting Your Green Student Chapter Activity

Once your ACS student chapter has completed a green activity it's time to fill out the student report with details about what's been done. Please send along photographs or a mention of your work in the university or college news.

See this webpage for information on deadlines, submission requirements, and the report form.