

**February/March 2017 Teacher's Guide for**

***62 Endangered Elements***

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# About the Guide

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Articles from past issues of *ChemMatters* and related Teacher’s Guides can be accessed from a DVD that is available from the American Chemical Society for $42. The DVD contains the entire 30-year publication of *ChemMatters* issues, from February 1983 to April 2013, along with all the related Teacher’s Guides since they were first created with the February 1990 issue of *ChemMatters*.

The DVD also includes Article, Title, and Keyword Indexes that cover all issues from February 1983 to April 2013. A search function (similar to a Google search of keywords) is also available on the DVD.

The *ChemMatters* DVD can be purchased by calling 1-800-227-5558. Purchase information can also be found online at:

<https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/products.html>.

# Student Questions

**Iron in the Diet: Power on Your Plate?**

* 1. What are the ten elements with the highest risk of running out in the next 100 years?
  2. What rare, endangered element is used to make touch screens?
  3. What are the properties of indium tin oxide that make it useful in the manufacture of touch screens?
  4. Explain what is wrong with the statement, “The total amount of indium on earth is diminishing”.
  5. Use the law of conservation of matter to explain why, unlike animals, elements are not in danger of becoming extinct.
  6. Why isn’t helium recovered from the air?
  7. Where is the U.S. National Helium Reserve located?
  8. How is helium produced on earth?
  9. State the uses of helium mentioned in the article, with an alternative element for each use.
  10. How is phosphorus important for life?
  11. Where do we get our supply of phosphorus, and how long before our reserves have been depleted?
  12. Where does a lot of the phosphorus that is unused by plant crops end up in the environment?

# Answers to Student Questions

**(taken from the article)**

* + 1. **What are the ten elements with the highest risk of running out in the next 100 years?**

*The ten elements with the highest risk of running out in the next 100 years are helium, zinc, gallium, indium, tellurium, hafnium, europium, terbium, dysprosium, and ytterbium.*

* + 1. **What rare endangered element is used to make touch screens?**

*Indium is a rare endangered element that is used to make indium tin oxide that is used in computer touch screens.*

* + 1. **What are the properties of indium tin oxide that make it useful in the manufacture of touch screens?**

*Indium tin oxide is transparent and highly conductive to electricity which makes it useful in the manufacture of touch screens.*

* + 1. **Explain what is wrong with the statement, “The total amount of indium on earth is diminishing”.**

*The total amount of indium on earth is not diminishing, it is just being spread all over the globe and is no longer as concentrated in a few locations. It is our indium reserves that are running low, but the total amount of indium is constant.*

* + 1. **Use the law of conservation of matter to explain why, unlike animals, elements are not in danger of becoming extinct.**

*The law of conservation of matter states that matter is neither created nor destroyed. Therefore, the amount of a particular type of atom is constant and is not being destroyed, it’s just being dispersed. With animals, once their ability to reproduce ceases, the species dies out, ceasing to exist.*

* + 1. **Why isn’t helium recovered from the air?**

*Helium is not recovered from the air because “… the total amount of helium in the air is so small that it is not technologically feasible to recover it.”*

* + 1. **Where is the U.S. National Helium Reserve located?**

*The U.S. National Helium Reserve is located in Amarillo, Texas.*

* + 1. **How is helium produced on earth?**

*“Helium is produced underground by the decay of thorium and uranium, two radioactive elements, as follows”:*

* + 1. **State the uses of helium mentioned in the article, with an alternative element for each use.**

*The uses of helium and their alternatives are:*

1. *birthday balloons. Alternative could be hydrogen, though flammable.*
2. *shielding gas used by welders to protect the vulnerable molten metal from contamination by oxygen and water vapor in the atmosphere. Alternative could be argon.*
3. *coolant in magnetic resonance imaging (MRI) machines that take pictures of the inside of organs, tissues, and tumors using magnetic fields. Helium cools the magnets that make these fields. Alternative could be liquid nitrogen.*
   * 1. **How is phosphorus important for life?**

*Phosphorus is an ingredient of DNA, the genetic blueprint of all cells. It is also an important component of teeth and bones, and plants require it for growth.*

* + 1. **Where do we get our supply of phosphorus, and how long before our reserves have been depleted?**

*Phosphorus is mined from rock. Scientists “… estimate that in 30 to 40 years there will not be enough phosphorus left in reserves to meet agricultural demand.”*

* + 1. **Where does a lot of the phosphorus that is unused by plant crops end up in the environment?**

*Excess phosphorus from crop fertilizers ends up in the runoff that flows into nearby bodies of water. (Students might also mention that human and animal waste contains phosphorus which also eventually finds its way into the bodies of water.)*

# Anticipation Guide

Anticipation guides help engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss students’ responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

**Directions:**  *Before reading*, in the first column, write “A” or “D,” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article. In the space under each statement, cite information from the article that supports or refutes your original ideas.

|  |  |  |
| --- | --- | --- |
| **Me** | **Text** | **Statement** |
|  |  | 1. We are at risk of running out of some elements in the coming century because the elements are being transformed into other elements. |
|  |  | 1. Indium, used in touchscreens, may run out in less than 20 years. |
|  |  | 1. Indium tin oxide conducts electricity very well. |
|  |  | 1. Helium is the second most abundant element in the universe. |
|  |  | 1. Helium can be recovered from the Earth’s atmosphere. |
|  |  | 1. Helium is a product of radioactive decay. |
|  |  | 1. Modern agriculture relies on fertilizers containing phosphorus. |
|  |  | 1. Phosphorus compounds are very soluble in water. |
|  |  | 1. Recycling would help solve the problem of endangered elements. |
|  |  | 1. No other elements can replace helium in medical and industrial uses. |

# Reading Strategies

These graphic organizers are provided to help students locate and analyze information from the articles. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher if students are struggling. Encourage students to use their own words and avoid copying entire sentences from the articles. The use of bullets helps them do this. If you use these reading and writing strategies to evaluate student performance, you may want to develop a grading rubric such as the one below.

|  |  |  |
| --- | --- | --- |
| **Score** | **Description** | **Evidence** |
| 4 | Excellent | Complete; details provided; demonstrates deep understanding. |
| 3 | Good | Complete; few details provided; demonstrates some understanding. |
| 2 | Fair | Incomplete; few details provided; some misconceptions evident. |
| 1 | Poor | Very incomplete; no details provided; many misconceptions evident. |
| 0 | Not acceptable | So incomplete that no judgment can be made about student understanding |

***Teaching Strategies:***

* Links to **Common Core State 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** and **concepts** that are reinforced in this issue:
  + Chemical and physical properties
  + Chemical reactions
  + Viscosity
  + Personal and community health
  + Oxidation states
  + Elements
  + Conservation of matter
  + Consumer choices
  + Recycling
* Most of the articles in this issue provide opportunities for students to consider how understanding chemistry can help them make informed choices as consumers. The articles also connect chemistry and engineering.
* Consider asking students to read “Open for Discussion” on page 4 to extend the information in “The Drive for Cleaner Emissions” on pages 5-7.
* The infographic on page 19 provides more support for the article “Brush Up on Toothpaste!” on pages 14-15.
* 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.
* You might also ask them how information in the articles might affect their choices as consumers. Also ask them if they have different ideas to solve some of the problems discussed in the articles.
* The Background Information in the *ChemMatters* Teachers Guide has suggestions for further research and activities.

***Directions*:** As you read the article, complete the graphic organizer below to describe what you learned about how we might run out of elements in the next 100 years.

|  |  |  |  |
| --- | --- | --- | --- |
| **Element** | **Indium** | **Helium** | **Phosphorus** |
| **Estimated years remaining** |  |  |  |
| **Where do we use it?** |  |  |  |
| **How can it be recycled?** |  |  |  |
| **Alternatives** |  |  |  |

**Summary**: On the back of this page, explain how endangered elements are not the same as endangered animals. You may use a Venn diagram if you wish.

# Connections to Chemistry Concepts

**(for correlation to course curriculum)**

1. **Conservation of matter**—Matter is neither created nor destroyed. The elements are not being destroyed, though the ores from which some of them are extracted are being depleted. This could be used as an example of the law of conservation of matter.
2. **Nuclear decay**—Helium production by decay of uranium and thorium is a great example to use in a discussion of alpha decay in nuclear chemistry.
3. **Chemical and physical properties of elements and compounds**—Elements and their compounds have specific properties which make them suitable for various uses. Endangered elements of every level of risk have unique properties.
4. **Biochemistry**—In addressing the “elements” of life, phosphorus as an element in DNA is a key component in living matter.
5. **Periodic Table**—The Periodic Table of Endangered Elements could be emphasized during a unit on the periodic table.
6. **Entropy**—If you want another example of entropy besides the teenager’s messy room analogy, the endangered elements in this article would be great examples of nature tending to maximum entropy, as they are being dispersed through use.

# Possible Student Misconceptions

**(to aid teacher in addressing misconceptions)**

1. **“Endangered means the element may become extinct.”** *Endangered means that the source of the element is becoming more difficult to secure. Sometimes the element is scarce, but sometimes it is abundant but inaccessible. There is a constant, finite number of atoms of each element with the exception of helium and uranium and the other radioactive elements. In theory, helium and the radioactive elements could become extinct on earth. The radioactive elements would stop decaying when they reach a stable isotope or element. All the helium could escape the atmosphere.*
2. **“Helium can just be extracted from the air.”** *The air contains 5.2 ppm of helium. At that concentration, it would be extremely difficult to extract helium from the air. When helium is extracted from natural gas, it is present in quantities as high as 7%, though most deposits have less than 2%.*
3. **“Helium comes from underground, so we can never run out.”** *Helium IS found underground, usually with natural gas deposits, but it is NOT inexhaustible. Eventually, if we keep “mining” the natural resources in a natural gas field, we will run out of the resources—natural gas AND helium—just like oil fields that have been tapped and have run dry.*
4. **“Since there’s a shortage of helium on Earth, no one should even think about buying helium-filled balloons.”** *The editor has actually pondered this question when purchasing a party balloon. Even though the amount of helium used in balloons is miniscule compared to the amounts used in industries around the world, merchants buying helium for balloons are under the same market pressure. As the price of helium increases, the price of your balloon will increase. Some retailers, in order to keep the price of balloons low, are already using a mixture in the balloons that contains less helium while some are putting the balloons on sticks to give the illusion of buoyancy.*

# Anticipating Student Questions

**(answers to questions students might ask in class)**

1. **“Why is the U.S. National Helium Reserve in Texas?”** *The U.S. National Helium Reserve is in Amarillo, Texas because the gas reservoirs that are richest in helium are near there. Gas deposits from the Texas and Oklahoma panhandles, as well as southern Kansas, are rich in Helium. The reserves are stored in an underground geological formation named the Bush Dome.*
2. **“What happens to the helium that is released into the air?”** *Helium that is released into the air leaves the earth’s atmosphere and goes into space. The density of helium is much less than that of air, so it will rise above the air layer that surrounds the earth.*
3. **“Why don’t we have airships that use helium?”** *The airship industry fizzled out shortly after the Hindenburg crashed and burned. There are many applications where airships would be beneficial today in delivering large items to remote locations that don’t have airport runways. They are also more environmentally friendly. Several countries, including Canada, UK, Brazil, China, and the U.S. either have designs for an airship or have recently built one. Three projects that are receiving attention now are: the Airlander 10, in England; Lockheed Martin’s LMH-1 in the U.S.; and an airship named Aeroscraft, developed by a private citizen. The U.S. legislature established the Cargo Airship Caucus last year with the purpose of expediting development and production of cargo airships. For an article that appeared in The New Yorker about one man’s dream of building airships, go to* <http://www.newyorker.com/magazine/2016/02/29/a-new-generation-of-airships-is-born>.
4. **“What did farmers do before we started manufacturing fertilizer?”** *Before commercial fertilizer was used, farmers used animal manure, tilled dead plant material into their soil, composted food scraps, and rotated their crops. Some crops take more from the soil than others while some plants like legumes actually help enrich the soil. Corn generally taxes soil more than soy beans and other legumes. With food products being shipped so far away from where they were grown, the cycle of the plant waste being returned to the field it was grown in ceases to be a possibility. Food waste now ends up in a landfill or in the water sewage system.*
5. **“What could be used instead of indium tin oxide in our smart phones?”** *There is a variety of materials that may be substituted for ITO in touch screens, though few of them have been developed enough to make the substitution. The following are materials that have been proposed as possible substitutes: Graphene, carbon nanotubes, thin metal films, silver nanowires hybrid materials, aluminum-doped zinc oxide (AZO),and gallium-doped zinc oxide (GZO). However, just as in the case of ITO, as we see demand for these materials increase, their price and availability will be affected as well.*

# Activities

**Labs and Demos**

1. **Solar cell lab:** A thorough lesson plan for guiding students to make their own solar cells using indium tin oxide coated slides and berry juice can be found at this Web site. Excellent instructions, discussion, and resources are included. Students could use the basic instructions for the cell and then devise their own experiment to test different berry juices or other variables. <http://teachers.egfi-k12.org/berry-organic-solar-energy/>
2. **Electroplating lab or demo:** As electrolysis is used to purify many of the metals that are discussed in this article, you could either demonstrate electroplating or have the students do the lab. Instructions for a microscale electroplating lab can be found here: <https://www.flinnsci.com/microscale-electroplating-lab/dc91454/>. Another macroscale option that includes a video can be found at this site: <http://www.hometrainingtools.com/a/electroplating-science-project>.
3. **Helium density lab**: A lesson plan that explores the density of helium is an option, particularly if you are teaching chemistry as part of a physical science course. There are teacher instructions as well as student instructions included in this packet. You will need approximately 50 minutes to complete the lab activity. (<https://www.teacherspayteachers.com/Product/Helium-Balloon-Density-Lab-Lesson-Plan-372698>)
4. **Determine the amount of phosphorus in fertilizer lab:** If you have access to the *Journal of Chemical Education*, there is a lab experiment presented by Solomon, Lee, and Bates in a 1993 issue, volume (5), p 410. Access to the complete article requires a subscription but the abstract can be accessed here: <http://pubs.acs.org/doi/abs/10.1021/ed070p410?journalCode=jceda8>.  
   If this is not an option, a modification of the lab can be found here: <https://www.emich.edu/chemistry/genchemlab/documents/10-phosphorus.pdf>.
5. **“Colorimetric Determination of Phosphate in Fertilizer” lab:** This is a lab that uses a reaction of phosphate with molybdate to produce a color complex that can be measured using a colorimeter. (<http://www.rsc.org/learn-chemistry/content/filerepository/CMP/00/001/176/RSC%20Phosphate%20by%20molybdate%20assay%20student.pdf?v=1363788564234>)
6. **The effects of phosphorus on plant growth lab:** This lab could be modified to use varying concentrations of phosphorus to demonstrate the effects phosphorus has on plant growth. (<http://www.rsc.org/learn-chemistry/content/filerepository/CMP/00/001/084/Effect%20of%20nutrients%20on%20plant%20growth%20soil%20student.pdf?v=1363791316232>)

**Simulations**

1. A PhET simulation for the alpha decay of polonium to lead can be found here. Instructions and lesson ideas are also available at this site. (<https://phet.colorado.edu/en/simulation/legacy/alpha-decay>)
2. A PhET simulation for beta decay of tritium to He-3 can be found here: Lesson ideas and instructions are included in links on the same page. (<https://phet.colorado.edu/en/simulation/legacy/beta-decay>)
3. This PhET simulation of how an MRI works may be too advanced for general chemistry but for advanced classes it would be useful in showing how electron spin is used in an MRI. (<https://phet.colorado.edu/en/simulation/legacy/mri>)

**Media**

1. **Helium video:** A Sci-show video (3:53) covering the properties of helium and also the facts surrounding the claims that we are running out of helium are presented in this fast paced presentation. (<https://sharemylesson.com/teaching-resource/all-about-helium-257333>)
2. **University of Nottingham video on helium** (4:45): An Einstein looking university professor talks about helium while graduate students demonstrate its properties. (<http://www.rsc.org/periodic-table/video/2/helium?videoid=a8FJEiI5e6Q>)
3. **How a touch screen works video:** A 2:44 YouTube video explains how a capacitance touch screen with TIO works. This video has a nice graphic that is used in the explanation. (<https://www.youtube.com/watch?v=FyCE2h_yjxI>)
4. **ITO coated plastics demonstration:** This 54 second video shows how plastics coated with ITO can be used with LEDs. (<https://www.youtube.com/watch?v=mHKuA5OZdmU>)
5. **Graphene, the next wonder material:** This is the video that accompanies the *ChemMatters* article by the same name. It would be good to show if graphene is mentioned as a future replacement for ITO as a semiconductor in cell phones or solar cells. Select Episode 10 from the videos available at the following link: <https://www.acs.org/content/acs/en/education/resources/highschool/chemmatters/videos.html>.
6. **How does a semiconductor work?** This 4:45 minute video produced at MIT explains how a semiconductor works, using the electron band gap theory in the explanation. Animations and visual examples make this explanation easy to follow.

(<https://www.youtube.com/watch?v=gUmDVe6C-BU>)

1. **The Hindenburg crash:** For students who do not know anything about The Hindenburg, this short (1:30) video gives information about the crash. (<https://www.youtube.com/watch?v=rWeO1q0gHJE>)
2. **The Hindenburg crash documentary**: This video documents the entire last flight of the Hindenburg and follows several of the passengers with actors and interviews of survivors. (<https://www.youtube.com/watch?v=_R7GoRcuDzA>)

**Lessons and Lesson Plans**

1. A lesson plan about the periodic table can be found here. It contains an element scavenger hunt, an essay about the history of the periodic table and an interactive periodic table. The scavenger hunt could be modified using the endangered elements. <http://oeta.pbslearningmedia.org/resource/phy03.sci.phys.matter.lp_pertable/the-periodic-table-of-the-elements/>
2. Hunting the Elements is the theme of this collection of materials. At this site you will find a collection of short video clips, periodic table handouts which you could have your students mark the endangered elements, ipad apps, and a lesson plan for teaching out the elements. <http://www.pbs.org/wgbh/nova/education/physics/hunting-the-elements-collection.html>
3. Many of the metals have to be purified by electrolysis in order to isolate them from their ores. A lesson plan for teaching electrolysis can be found at this Web site. Video clips and power point presentations are among the resources provided in these lesson plans. (<http://grade12uchem.weebly.com/lesson-8-electrolysis-and-electrolytic-cells.html>)

**Projects and Extension Activities**

1. Students could research the possible substitutes for the endangered elements and report on their findings to the class. This could be an individual report or the students could be divided into small groups with each group assigned a number of elements.
2. “Where in the World is …?” could be the title of this activity. Students could prepare a large map of the world indicating where each of the endangered elements is located, raising awareness of the interdependence of the nations of the world.

# References

**(non-Web-based information sources)**

**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 the past 30 Years of *ChemMatters* on DVD!” (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”*.**



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This article covers the use of tantalum (one of the endangered elements) in cell phones but also reveals the unstable supply of the element due to wars in the Congo over mining operations. (Michalovic, M. Tantalum, Congo, and Your Cell Phone. *ChemMatters,* 2007, *25* (3), pp 16–18).

A deeper discussion on the geopolitics of mining Tantalum in the Congo as well as a great deal of information about tantalum can be found in the October 2007 Teacher’s Guide for the above article.

When looking for a replacement for indium tin oxide, graphene is often mentioned. In this *ChemMatters* article, author Tinnesand writes about graphene and its possible future use in cell phones. (Tinnesand, M. Graphene: The Next Wonder Material? 2012, *30* (3), pp 6–8)

The Teacher’s Guide for the October 2012 *ChemMatters* issue referenced above contains additional information on flexible, printable solar cells.

A nice infographic on the elements in a cell phone can be found in the February 2014 issue of *ChemMatters*. (As a Matter of Fact. Your Smart Phone Contains Valuable Chemicals. *ChemMatters*, 2014, *32* (1), p 4)

More explanation for students on semiconductors and photovoltaics can be found in an article concerning solar energy. (Warner, J. A Solar Future. *ChemMatters,* 2014, *32* (2), pp 9–11)

The Teacher’s Guide for the April 2014 article mentioned above contains an additional explanation about energy bands and gaps in conductors, semiconductors, and insulators.

The elements found in a smart phone is the topic of this 2015 *ChemMatters* article. Additional explanation of how a touch screen works is also included. (Rohrig, B. Smartphones, Smart Chemistry. *ChemMatters*, 2015, *33* (2), pp 10–12)

The history and extensive information about the rare earth metals and their supply and demand can be found in the April 2015 Teacher’s Guide for the article mentioned above. This Teacher’s Guide also provides links to classroom activities that could apply to the endangered elements.

Plant nutrients such as phosphorus are discussed in a *ChemMatters* article on hydroponics. Also discussed are the pressures for increased food production for an increasing population. (Pickett, M. Dirt, Who Needs It? *ChemMatters*, 2015, *33* (3), pp 14–15)

More information on plant nutrients is discussed in the Teacher’s Guide to the article mentioned above. Links to classroom activities involving growing plants hydroponically are provided. Using this, students could alter the amount of phosphorus provided the plants and document the difference in growth.

# Web Sites for Additional Information

**(Web-based information sources)**

**Endangered elements**

In this article, “Endangered Elements: Critical Thinking”, Emma Davies explains the shortages of various elements and what is being done about their shortage. While she too concentrates on He, In, and P, there is more information about REEs. (<http://www.rsc.org/images/Endangered%20Elements%20-%20Critical%20Thinking_tcm18-196054.pdf>)

An overview of the main elements facing supply restrictions can be found in this whitepaper from the 2013 5th Chemical Science and Society Summit. The ideas of critical elements and energy critical elements are explained here. Several charts and graphics are used. (<https://www.acs.org/content/dam/acsorg/greenchemistry/industriainnovation/cs3-whitepaper2013.pdf>)

This Web site contains information on some of the endangered elements, in particularly helium, indium, and the rare earth metals. The site contains links to other articles with information on endangered elements. (<http://www.compoundchem.com/2015/08/19/endangered-elements/>)

The elements featured in the article originated from the work of Mike Pitts. His work and periodic tables are located at this site. A year after publishing his work he posted an updated periodic table which highlighted 62 elements rather than the original 44. That can be found here as well. (<http://www.thechemicalengineer.com/~/media/Documents/TCE/Articles/2011/844/844elements.pdf>)

The role of chemical sciences in finding alternatives to critical resources is the topic of the material found at this Web site. This link is to chapter 4 of the materials from a National Research Council Chemical Sciences workshop but the entire content of the book is available by selecting the content link. Chapter 5 contains information specific to indium and its use in photovoltaics. Chapter 6 has a good discussion of chemical use in batteries. The use of precious metals in automotive catalytic converters is a particularly interesting discussion in chapter 4 and one that students may relate to. (<https://www.ncbi.nlm.nih.gov/books/NBK100035/>)

“Securing Materials for Emerging Technologies” is the topic of this report by the American Physical Society. The Energy Critical Elements are addressed here. This is a good site for learning more about the geopolitical aspects of the distribution and use of the elements. (<http://www.aps.org/policy/reports/popa-reports/upload/elementsreport.pdf>)

“Element Recovery and Sustainability” is the topic of the book that can be accessed online here. This is a preview of the first 51 pages. There is lots of information on the critical elements in the material available. Nice graphics and another periodic table that could be easily used in power point presentations. There is additional information on the different methods of element extraction from ores. (<https://books.google.com/books?id=QmbfLX4TgGEC&lpg=PR13&ots=zGLXNET-hI&dq=Element%20Recovery%20and%20Sustainability&pg=PP1#v=onepage&q=Element%20Recovery%20and%20Sustainability&f=false>)

**Indium and indium tin oxides**

This site contains information about indium tin oxide as well as multiple links to related topics concerning this compound and its uses: <https://en.wikipedia.org/wiki/Indium_tin_oxide>.

On the Web site of the Indium Corporation, information about indium and indium tin oxide can be accessed. Information about ITO is linked here: <http://www.indium.com/inorganic-compounds/indium-compounds/indium-tin-oxide/>.

This is an interesting blog post from an Indium Corporation employee. It outlines many things that indium is used for that actually have a positive effect on the environment. This might be an interesting read for students that would prompt them to think if the benefits of using indium outweigh the hazards. (<http://www.indium.com/blog/environmental-impact.php>)

Another blogpost about the unsuitability of graphene as a replacement for ITO is found here. This would be a good read for the student who is excited about the future applications of graphene. (<http://www.indium.com/blog/graphene-an-unlikely-candidate-to-replace-ito-in-flat-panel-displays.php>)

Additional information about ITO, its touch screen and other applications, as well as possible alternatives, can be accessed at this Web site: <http://www.azom.com/article.aspx?ArticleID=9634>.

This site presents the health hazards that are beginning to be associated with exposure to inhalation of ITO. The most informative data comes from workers at a processing plant in Japan. ITO when inhaled can produce interstitial lung disease. This is the National Toxicology report. (<https://ntp.niehs.nih.gov/ntp/noms/support_docs/ito060309_508.pdf>)

“Electrons and Holes in Semiconductors” is the name of the chapter of a book at this site. It goes into depth in explaining semiconductors and the chemistry involved. Band gap, valence bands, and conduction bands are explained, as well as many other terms encountered in a discussion of semiconductors and energy transmission. (<https://people.eecs.berkeley.edu/~hu/Chenming-Hu_ch1.pdf>)

**Helium**

This *Popular Mechanics* article addresses the reasons behind the possible Helium shortage and explains the politics behind it. (<http://www.popularmechanics.com/science/health/a4046/why-is-there-a-helium-shortage-10031229/>)

Some interesting facts about superfluid helium and its ability to “climb walls” can be found in this *Scientific American* article: <https://www.scientificamerican.com/article/superfluid-can-climb-walls/>.

General information about helium can be found at this site. There is a good deal of information about the health hazards encountered with helium’s misuse near the end of the article that would be good to share with students. (<https://en.wikipedia.org/wiki/Helium>)

This January 26, 2015 article on the *Live Science* Web site is an up to date article about Helium general facts and current research. (<http://www.livescience.com/28552-facts-about-helium.html>)

The story of the history of helium’s discovery in natural gas can be found here. It could be used as an example of scientific inquiry in solving the mystery behind a puzzling observation. (<https://www.acs.org/content/acs/en/education/whatischemistry/landmarks/heliumnaturalgas.html>)

Information on helium’s use in MRI machines and how an MRI machine works can be found here: <http://summitsourcefunding.com/blog/helium-used-mri-machines/>.

This article provides news of the latest discovery of a helium reservoir in Tanzania. This is the first time helium has been the purpose of the geological exploration. (<https://www.newscientist.com/article/2095196-huge-newfound-deposit-of-helium-will-keep-mri-scanners-running/>)

**Phosphorus**

This is a blog post that discusses whether or not we are truly running out of phosphorus. (<http://blogs.ei.columbia.edu/2013/04/01/phosphorus-essential-to-life-are-we-running-out/>)

A February 2016 article about phosphorus depletion can be found at this site. The phosphorus cycle is illustrated and discussed. (<http://phys.org/news/2016-02-great-phosphorus-shortage-short-food.html>)

This current article on a phosphorus and nitrogen imbalance in the North Sea would be a good read for students interested in environmental chemistry or marine biology. (<http://phys.org/news/2016-01-environmental-policy-imbalance-phosphorus-nitrogen.html#nRlv>)

For a description of phosphorus mining practices and the effects they have on the environment the following article is a good place to start. (<http://www.motherjones.com/environment/2013/05/fertilizer-peak-phosphorus-shortage>)

The supply and demand issues concerning phosphorus are discussed in this MIT report: <http://web.mit.edu/12.000/www/m2016/finalwebsite/problems/phosphorus.html>.

Florida Institute of Phosphate Research provides a wealth of information on phosphate, how it is reclaimed and how it is used. (<http://www.fipr.state.fl.us/about-us/phosphate-primer/chemical-processing-of-phosphate/>)

**Fertilizers**

This Web site contains information about the ingredients in modern commercial fertilizers and the purpose for each ingredient with an emphasis on phosphorus. (<https://www.planetnatural.com/phophorus-fertilizer/>)

Fertilizer labels and what they mean is the topic for the article found here: <http://www.growingagreenerworld.com/the-numbers-on-fertilizer-labels-what-they-mean/>.

# General Web References

**(Web information not solely related to article topic)**

The Los Alamos interactive periodic table can be accessed here: It is a resource about all the elements that can be used throughout the year. (<http://periodic.lanl.gov/index.shtml>)

A Wake Forest professor who has worked extensively in the field of MRI maintains a Web site that entertains questions over all aspects related to MRI. It contains a wealth of current information. His explanations are in depth, yet easy to understand. (<http://mri-q.com/index.html>)