

**October/November 2016 Teacher's Guide for**

***Vertical Farming: Does It Stack Up?***

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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 <http://tinyurl.com/o37s9x2>.

# Student Questions

**Vertical Farming: Does It Stack Up?**

* 1. What is vertical farming?
	2. Describe an advantage of vertical farming for the consumer.
	3. Describe an advantage of vertical farming for the farmer
	4. Why is the productivity of a vertical farm surface four to six times greater than an open-field farm?
	5. Compare aeroponics to hydroponics.
	6. Compared to open-field farming, how much less water does vertical farming use?
	7. Identify a challenge of growing plants indoors under artificial grow lamps.
	8. What are the peak wavelengths of light and their associated colors absorbed by chlorophyll?
	9. List two advantages LED lights have over grow lamps.
	10. What are some examples of bulk crops and why is it not practical to grow these crops in a vertical farm?
	11. How does red light affect the behavior of plants?
	12. Name and give the chemical formulas of the end products of photosynthesis.

# Answers to Student Questions

**(taken from the article)**

**Vertical Farming: Does It Stack Up?**

1. **What is vertical farming?**

*In vertical farming, plants are grown indoors in vertically stacked layers. They are grown in nutrient-rich water and with artificial light sources.*

1. **Describe an advantage of vertical farming for the consumer.**

*An advantage to consumers: since the food is grown locally, crops can be picked, packed, and delivered to market within two to eight hours, so there’s no need to store and ship the food. Also, because the plants are kept at stable temperatures, they are available year round.*

1. **Describe an advantage of vertical farming for the farmer.**

*An advantage of vertical farming to farmers is that they can reduce their use of chemical fertilizers and pesticides.*

1. **Why is the productivity of a vertical farm surface four to six times greater than an open-field farm?**

*In vertical farms, crops are stacked in layers, so more can be grown in less open space.*

1. **Compared to open-field farming, how much less water does vertical farming use?**

*Vertical farming uses up to 70% less water than open-field farming.*

1. **Compare aeroponics to hydroponics.**

*With hydroponics plants are grown in nutrient rich solutions, while plants grown through aeroponics are suspended in the air and a fine mist containing nutrients is sprayed directly to the plants’ root structures. Aeroponics uses 70% less water than hydroponics which uses 70% less water than open-field farming.*

1. **Identify three challenges of growing plants indoors under artificial grow lamps.**

*Three challenges of vertical farming are:*

1. *growing crops indoors requires artificial light that uses electricity, which is expensive (sunlight to grow crops is free), and*
2. *grow lamps give off heat. The heat requires that the vertical plants be more spread out.*
3. *costs are high, partly due to the cost of land in the city, and the cost of LED lamps.*
4. **What are the peak wavelengths of light and their associated colors absorbed by chlorophyll?**

*Chlorophyll absorbs two peak wavelengths of light, 450 nanometers (blue light) and 650 nanometers (red light).*

1. **List three advantages LED lights have over grow lamps.**

*The three advantages LEDs have over grow lamps are:*

1. *LEDs can be designed to give off only the wavelengths of light that plants use, thus saving electricity,*
2. *LED lamps are less expensive than grow lamps, and*
3. *LEDs produce little or no heat so plants can be stacked closer together.*
4. **What are some examples of bulk crops, and why is it not practical to grow these crops in a vertical farm?**

*Grains, corn, and soybeans are examples of bulk crops. It costs about $2.50 per pound to grow plants in these underground farms. Cost per yield is too high.*

1. **How does red light affect the behavior of plants?**

*Red light causes plants to flower.*

1. **Name and give the chemical formulas of the end products of photosynthesis.**

*Sugar (C6H12O6) and oxygen (O2) molecules are produced in photosynthesis.*

# 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. Plants can grow indoors if provided with nutrient-rich water and artificial light.
 |
|  |  | 1. Through stacking, vertical farms usually increase the productivity of a surface by a factor of 10.
 |
|  |  | 1. Plants grown without soil use more water than open-field agriculture.
 |
|  |  | 1. Plants grown with their roots suspended in the air use more water than open-field agriculture.
 |
|  |  | 1. The heat produced by artificial light sources is desirable to help plants grow.
 |
|  |  | 1. Plants can be placed closer together if LEDs are used to produce artificial light.
 |
|  |  | 1. Plants absorb all colors in the visible light spectrum in photosynthesis.
 |
|  |  | 1. Currently, bulk crops such as grains, corn, and soybeans are being grown in vertical farms.
 |
|  |  | 1. Light colors can be used to tell a plant to grow in a specific way.
 |
|  |  | 1. Photosynthesis produces carbohydrates and oxygen.
 |

# Reading Strategies

These matrices and 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 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 (for entire October/November 2016 issue):***

* Links to **Common Core Standards for Reading**:
	+ ELA-Literacy.RST.9-10.1:Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
	+ ELA-Literacy.RST.9-10.5: Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).
	+ ELA-Literacy.RST.11-12.1:Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
	+ ELA-Literacy.RST.11-12.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.
* Links to **Common Core Standards for Writing**:
	+ ELA-Literacy.WHST.9-10.2F: Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
	+ ELA-Literacy.WHST.11-12.1E: Provide a concluding statement or section that follows from or supports the argument presented.
* **Vocabulary** and **concepts** that are reinforced in this issue:
	+ Forensic science
	+ Molecular structures
	+ Polar and nonpolar molecules
	+ Wavelengths of light
	+ Chemical reactions
	+ Personal and community health
	+ Heavy metals
	+ Conservation of matter
	+ Consumer choices
* Some of the articles in this issue provide opportunities for students to consider how understanding chemistry can help them make informed choices as consumers.
* 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. The Background Information in the *ChemMatters* Teachers Guide has suggestions for further research and activities.
* In addition to the writing standards above, consider asking students to debate issues addressed in some of the articles. Standards addressed:
	+ **WHST.9-10.1B** Develop claim(s) and counterclaims fairly, supplying data and evidence for each while pointing out the strengths and limitations of both claim(s) and **counterclaims** in a discipline-appropriate form and in a manner that anticipates the audience’s knowledge level and concerns.
	+ **WHST.11-12.1.A** Introduce precise, knowledgeable claim(s), establish the significance of the claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that logically sequences the claim(s), counterclaims, reasons, and evidence.

**Directions**: As you read the article, complete the graphic organizer below to describe vertical farming, including some advantages and challenges.

|  |  |
| --- | --- |
| **What is it? Where is it being tried?** | **Vertical Farming****What are some advantages?** |
| **Examples of light used** | **What are some challenges?** |

**Summary**: On the back of this paper, write a tweet (140 characters or less) describing what you learned about vertical farming.

# Connections to Chemistry Concepts

**(for correlation to course curriculum)**

1. **Energy transfer**—There are several examples of energy transfer in this article. Traditional grow lamps convert heat energy to light energy, while LEDs convert electrical energy to light energy.The process of photosynthesis converts light energy to chemical energy.
2. **Solutions**—Because hydroponics and aeroponics use nutrient solutions, students have an opportunity to explore percent solutions by mass.
3. **Electromagnetic spectrum**—The article provides students with information about the role of the various colors of light within the electromagnetic spectrum in processes that regulate plant growth.
4. **Semiconductor**—LEDs used for grow lights are examples of semiconductors.
5. **Light emitting diode**—Students will understand that light emitting diodes can produce monochromatic light with minimal heat production.
6. **Sustainability**—Sustainable chemistry and food sustainability are related in that both conserve natural resources that are used to meet human needs.

# Possible Student Misconceptions

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

1. **“Vertical farming can supply most of our food needs.”** *Vertical farming has a limited range of crop species (e.g., lettuce and leafy vegetbles). It is impractical to grow tall plants in vertical farms and the cost is too high for bulk crops.*
2. **“Vertical farming is less dependent on fossil fuels than open field farming because the produce doesn’t have to be shipped long distances*.”*** *While this statement is partially true, it doesn’t tell the whole story. If fossil fuels will be used to provide lighting, heating, and power to the vertical farms, the net effect may be negative.*

# Anticipating Student Questions

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

1. **“The article states that, with aeroponics, nutrient solutions are sprayed on the plant roots and the process uses 70% less water than hydroponics. What happens to the excess spray?”** *Nutrients not absorbed by the roots are returned to a reservoir and recycled.*
2. **“I know that LED lights are more expensive than regular (incandescent or fluorescent) light bulbs—I tried to buy one in the store—yet they’re supposed to be cheaper. So, now I’m confused. Are LEDs more or less economical than other light sources?”** *LEDs have a higher initial (purchase) cost, but require no upkeep. Fluorescent and HID lights require ballasts which may need to be replaced during the life of the bulb. Also, the lifetime of an LED is 4 times that of typical HID lamps, 7 times that of fluorescent lamps, and 100 times that of incandescent bulbs.*

# Activities

**Labs and Demos**

1. **Demonstration to investigate how ultraviolet light from a black lamp causes various objects to glow:** This demonstration will show students that phosphors found in common materials can convert ultraviolet light into visible light just as the phosphors in a fluorescent lamp can convert UV light into visible light. Materials that can be used for the demonstration include: tonic water with quinine, petroleum jelly, ink from yellow highlighter pen, newer $20, $50, or $100 bills. Informal procedures for observing fluorescence, ideas for further explorations, and explanations are outlined in the three links: (<http://www.scientificamerican.com/article/shining-science-explore-glow-in-the-dark-water/>,

<http://www.sciencekids.co.nz/experiments/glowingwater.html>, and

<http://www.webexhibits.org/causesofcolor/11F.html>)

1. **Demonstration investigating light emitting diodes:** This activity requires liquid nitrogen.For safety reasons, this activity should be done as a demonstration instead of a lab. Students will relate the color and excitation voltage of LEDs to their composition and periodic trends of the elements. In addition, they will observe how electrical resistance of a metal changes with temperature and how electrical resistance of a semiconductor changes under illumination. A key objective of this experiment is to relate the solid-state structure to physical properties of these materials. Information about purchasing the LEDs can be found at the link cited in the reference. (<http://chemconnections.org/nanotech/Light%20Emitting%20Diodes%20Activity.doc>)
2. **Laboratory activity—Spectral analysis of common light sources:** Students will use *SpectraSnapp*, a free app for the iPhone developed by the American Physical Society, which turns the phone into a hand held spectroscope to analyze common sources of light. The app provides directions for building a spectroscope from black construction paper and a diffraction grating and includes a spectral library. Students will use different light sources, such as fluorescent lights, street lamps, sunlight, incandescent light, etc., to collect data and compare their spectra to the spectral library. This activity relates to the Electron Energy and Light inquiry lesson and helps students better understand emission spectra. Search SpectraSnapp in the app store and download to your iPhone. Directions for building the spectroscope, and using the app can be found in this YouTube video: <https://www.youtube.com/watch?v=FJ1xOWl5Axk>.

**Simulations**

1. **Exploring plants, photosynthesis and light:** The Molecular Workbench’s simulation, “Harvesting Light” allows students to explore, through a series of activities, how molecules in plant cells capture light energy from the sun, compare absorption and reflection of light in plant pigments, identify molecules that absorb light, explore a light harvesting system, and design an artificial photosynthetic system: Open [http://mw.concord.org/modeler/](http://mw.concord.org/modeler/%20), scroll down to “Selected Curriculum Modules” and click on “Harvest Light” to download the simulation.

**Media**

1. **Video clip to explain vertical farming:** “Cities of the Future May Eat Plants Grown in the Air”(4:34) was filmed in one of several vertical farms located in Newark, NJ and can be shown in class to introduce vertical farming. The video describes how plants are grown in a vertical farm and compares this farming method to open field agriculture. (<https://www.youtube.com/watch?v=EXwMM5ra_mU>)
2. **Animated tutorial that describes the light and dark phases of photosynthesis:** Students can review the process of photosynthesis and observe, step by step, the chemical changes that take place in both the light and dark phases of photosynthesis. Students control the time needed to study the chemical reactions of photosynthesis. (<http://www.johnkyrk.com/photosynthesis.html>)
3. **Video to explain photosynthesis: “**Photosynthesis—Converting Light Energy to Chemical Energy” (7:26) can be used as a homework assignment for students to review photosynthesis. This YouTube video uses animations to explain the role of sunlight in photosynthesis, the chemical reactions that take place during the light reaction and the Calvin cycle, and the electron transport system. Students who have taken biology will be familiar with the chemistry of photosynthesis and the electron transport system. (<https://www.youtube.com/watch?v=iLDbW_XvxHQ>)
4. **Video clip that explains how a light emitting diode works:** from Teaching Innovation Projects (9:10) ”The LED—How LEDs work?” defines and describes the p-n junction, the relationship between valence bands, conduction bands, and band gaps, and explains how LEDs can be made to give off different colors of light. (<https://www.youtube.com/watch?annotation_id=annotation_1237083617&feature=iv&src_vid=JBtEckh3L9Q&v=4y7p9R2No-4>)

**Lessons and Lesson Plans**

1. **A lesson plan using the 5E instructional model for modeling photosynthesis:** Students will model the molecules used in the process of photosynthesis. They will describe how light is absorbed and what happens to this light energy. They will then develop an analogy between photosynthesis and some process from everyday life. Procedures and lab questions are provided. (<http://www.cfep.uci.edu/cspi/docs/lessons_secondary/Modeling%20Photosynthesis.pdf>)
2. **Electron energy and light—a POGIL activity:** In this inquiry based activity, students will work in groups of three or four to explore models of white light, emission spectra of hydrogen and boron, and the Bohr model of the atom to develop the concept of electron energy transitions and apply this concept. (<https://pogil.org/uploads/media_items/electron-energy-and-light-student.original.pdf>)

**Projects and Extension Activities**

1. **Experiments in hydroponics:** This activity can be done as an in-class project or a homework assignment and allows students to demonstrate the principles of hydroponic growing. There is an opportunity for students to experiment with different water-nutrient concentrations, different water-nutrient mixes, pots of varying depths, different types of plants, and different sizes of perlite. The students’ data can include pictures of the plants at regular intervals and the height of the plants at three day intervals after germination. (<http://www.schundler.com/hydroexp.htm>)
2. **Experiment with factors that affect the rate of photosynthesis:** While this is an experiment that would normally be done in a biology class, this is an activity that reinforces good experimental design. Students will use critical thinking to design an experiment and analyze the collected data. They will also need to determine if the variable they choose to study is indeed testable. Students will learn that the rate of photosynthesis is influenced by such environmental factors as temperature, the amount of CO2 available, the amount of water available, the pH of the water and the amount and wavelength(s) of light available. (<http://serc.carleton.edu/sp/mnstep/activities/26481.html>)

# 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 directly under the *ChemMattersonline* 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, *“ChemMattersonline”*.**

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Graham, T. Light Emitting Diodes—Tune into the Blues. *ChemMatters*, 2001, *19* (2), pp 4–5. This article contains information on the chemistry and electronics of LEDs.

 Pickett, M. Dirt? Who needs it? How Hydroponics is Poised to Change the World. *ChemMatters*, 2015, *33* (1), pp 14–15. This article contains information about hydroponic agriculture as a possible alternative to growing plants in soil.

# Web Sites for Additional Information

**(Web-based information sources)**

**Open-field agriculture**

For some historical information on open-filed farming, go to <http://historylink101.com/lessons/farm-city/middle-ages.htm>.

**Vertical farming**

This article from food columnist Tamar Haspel, “Will Indoor, Vertical Farming Help Us Feed the Planet—Or Hurt It? Comes from the food section of the June 17, 2016 edition of *The Washington Post*. It discusses in detail the benefits of vertical farming (not so much about the “hurt us” part). In the end, its utility as a food source in the future seems to come down to the cost of electricity in the future. (<https://www.washingtonpost.com/lifestyle/food/will-indoor-vertical-farming-help-us-feed-the-planet--or-hurt-it/2016/06/16/f1faaa98-3332-11e6-8ff7-7b6c1998b7a0_story.html>)

The article “How Vertical Farming is Revolutionizing the Way We Grow Food”, from Gizmodo’s 9/14/2015 issue, provides a thorough discussion of the topic. It includes several nice photo examples of present-day industrial vertical farming. (<http://io9.gizmodo.com/how-vertical-farming-is-revolutionizing-the-way-we-grow-1730550597>)

This short video clip (2:32) from AeroFarms, located in New Jersey, shows their industrial facility for vertical farming. (<http://www.reuters.com/article/us-new-jersey-vertical-farming-idUSKCN0ZE24L>)

This 5:29 video clip shows VertiCrop, an industrial vertical farm, growing lettuce and herbs on the rooftop of a parking garage in the city of Vancouver. (<http://grow.verticrop.com/vertical-farming/>)

**Photosynthesis**

 The Royal Society of Chemistry provides teacher background material on many topics. This one on photosynthesis is from the Biochemical Society and includes nice detail on the chemistry of photosynthesis, including condensation reactions and oxidation-reduction reactions. There are several PowerPoint slides that you can use with your students to help them understand the chemistry involved at each step. If you don’t have PowerPoint, you can download a free version of PowerPoint Viewer to open the slides. (<http://www.rsc.org/Education/Teachers/Resources/cfb/Photosynthesis.htm>)

**LEDs**

This article, “Plant Productivity in Response to LED Lighting”, describes the potential of LEDs as a light source for plants.

(<http://hortsci.ashspublications.org/content/43/7/1951.full>)

**Sustainable food**

This site helps students understand the role food plays in the economy and in their health: <http://www.chgeharvard.org/resources>

 Learn what effect your food choices have on the local economy. Visit <http://www.buylocalfood.org/>.

**Hydroponics**

Could hydroponics solve agricultural challenges in deserts—and even on Mars? What are the innovations of some of the hydroponic visionaries? (<http://www.truth-out.org/speakout/item/35885-solar-powered-hydroponics-could-be-the-future-of-agriculture>)