



**Acidic Seas:**

**How Carbon Dioxide  
is Changing the Oceans**

*February/March 2018*

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

**Teacher’s Guide**



**Teacher's Guide for**

***“Acidic Seas: How Carbon Dioxide   
is Changing the Oceans”***

**February/March 2018**

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# Connections to Chemistry Concepts

|  |  |
| --- | --- |
| **Chemistry Concept** | **Connection to Chemistry Curriculum** |
| **Greenhouse effect** | The study of the electromagnetic spectrum provides a good opportunity to investigate where the specific wavelengths involved in the greenhouse effect are located on the EMS and to consider their role in global warming and its impact on the health of coral reefs. |
| **Molecular polarity** | The slow acidification of the oceans from increased CO2 in the atmosphere shows the relatively low solubility of the gas due to its molecular structure and lack of polarity. |
| **Equilibrium** | The chemical equations in this article can be used to explain how human activities that produce CO2 emissions can set up a chain of equilibrium reactions that can do immeasurable harm to aquatic life. |
| **Limiting reagent** | Carbonate in the oceans is an example of a limiting reagent in coral and mollusk shell-forming reactions. |
| **Common Ion effect** | The common ion effect can be used to explain how dissolved atmospheric CO2 sets up equilibriums that consume available CO32 – ions, increasing the ocean’s acidity that inhibits the formation of coral and shellfish structures. |
| **Weak acids** | The effect of weak acids on coral reefs exposed to acidic seas can be used as an example of how even weak acids can cause environmental destruction. |
| **pH scale** | While a change in pH from 8.2 to 8.1 may not seem significant, its effects on ocean life can be devastating, and it suggests an increasingly acidic ocean. |

# Teaching Strategies and Tools

## Standards

Links to **Common Core Standards for Reading**:

* + ELA-Literacy.RST.9-10.1:Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
  + ELA-Literacy.RST.9-10.5: Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).
  + ELA-Literacy.RST.11-12.1:Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.
  + ELA-Literacy.RST.11-12.4: Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.

Links to **Common Core Standards for Writing**:

* + ELA-Literacy.WHST.9-10.2F: Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).
  + ELA-Literacy.WHST.11-12.1E: Provide a concluding statement or section that follows from or supports the argument presented.

In addition to the writing standards above, consider asking students to debate issues addressed in some of the articles. Standards addressed:

* **ELA-Literacy.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.
* **ELA-Literacy.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.

## Vocabulary

**Vocabulary** and **concepts** that are reinforced in this issue:

Physical properties

States of Matter

Structural Formulas

pH

Oxidation & Reduction

Enzymes

Intermolecular forces

* Some of the articles in this issue provide information about carbon dioxide and its role in the environment.
* 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 consumer choices. Also, ask them if they have questions about some of the issues discussed in the articles.

# Reading Supports for Students

The pages that follow include reading supports in the form of an Anticipation Guide, a Graphic Organizer, and Student Reading Comprehension Questions. These resources are provided to help students as they prepare to read and in locating and analyzing information from the article.

The borders on these pages distinguish them from the rest of the pages in this Teacher’s Guide—they have been formatted for ease of photocopying for student use.

* **Anticipation Guide (p. 8):**  The Anticipation Guide helps to 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.

*NEW! Instead of using the aforementioned anticipation guide, consider these ideas to engage your students in reading.*

* Ask students to describe the importance of coral reefs around the world, and how we can protect them.
* As they read, ask students to add to the list they began before reading.
* **Graphic Organizer (p. 9):**  The Graphic Organizer is provided to help students locate and analyze information from the article. 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 article. The use of bullets helps them do this.

|  |  |  |
| --- | --- | --- |
| **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 |

* **Student Reading Comprehension Questions (p. 10-11):** The Student Reading Comprehension Questions are designed: to encourage students to read the article (and graphics) for comprehension and attention to detail; to provide the teacher with a mechanism for assessing how well students understand the article and/or whether they have read the assignment; and, possibly, to help direct follow-up, in-class discussion, or additional, deeper assignments.

Some of the articles in this issue provide opportunities, references, and suggestions for students to do further research on their own about topics that interest them.

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 “Web Sites for Additional Information” section of the Teacher’s Guide provides sources for additional information that might help you answer these questions.

“Acidic Seas: How Carbon Dioxide is Changing the Oceans”, *ChemMatters*, February/March 2018

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

## Anticipation Guide

“A Close-up Look at the Quality of Indoor Air” (*ChemMatters*, April/May 2016 Issue)

**Directions:**  ***Before reading the article*,** 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. Unhealthy corals are faded and crumbling. |
|  |  | 1. Coral reefs make up 10% of the earth’s surface. |
|  |  | 1. Without carbon dioxide, the earth would be cold and inhospitable. |
|  |  | 1. When corals are stressed, they expel algae they need for food. |
|  |  | 1. Most of the carbon dioxide in seawater forms bicarbonate ion (HCO3-). |
|  |  | 1. When carbon dioxide from the atmosphere dissolves in ocean water, the pH of the ocean is lowered. |
|  |  | 1. Increased carbon dioxide in the ocean helps shells form more readily. |
|  |  | 1. Ocean water is slightly acidic. |
|  |  | 1. About one-fourth of ocean species live in coral reefs. |
|  |  | 1. Coral reefs around the world are affected equally by ocean acidification. |

## Graphic Organizer

Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

“Acidic Seas: How Carbon Dioxide is Changing the Oceans”, *ChemMatters*, February/March 2018

**Directions**: ***As you read***, complete the graphic organizer below to describe the effect of carbon dioxide on the world’s oceans.

|  |  |  |
| --- | --- | --- |
| 3 | **Ways carbon dioxide is affecting the oceans** |  |
| 2 | **Reasons we should be concerned about ocean life** |  |
| 1 | **Number or statistic from the article that surprised you (and why)** |  |
| Contact! | **What can you do to reduce the impact of carbon dioxide on the world’s oceans?** |  |

## Student Reading Comprehension Questions

“Acidic Seas: How Carbon Dioxide Is Changing the Oceans”, *ChemMatters*, February/March 2018

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Name

**Directions**: Use the article to answer the questions below.

1. Complete the following table to describe unhealthy signs of and threats to ocean coral.

|  |  |
| --- | --- |
| **Signs of Unhealthy Coral** | **Threat Responsible for Those Signs** |
|  |  |
|  |  |

1. Give two reasons why researchers are concerned about the health of coral reefs that make up less than 1% of the Earth’s surface.
2. What causes ocean warming and acidification?
3. Why is the term “greenhouse effect” misleading when used to describe ocean warming and acidification?
4. How do (a) greenhouses and (b) atmospheric gases trap heat?
5. Why are human activities that release carbon dioxide into the atmosphere causing concern?

**Student Reading Comprehension Questions, cont.**

“Acidic Seas: How Carbon Dioxide is Changing the Oceans”, *ChemMatters*, February/March 2018

1. What happens after warm oceans cause stressed corals to expel the symbiotic algae living in their tissues?
2. How does the water chemistry change as carbon dioxide gas is dissolved in the ocean water?
3. What does a drop in ocean pH from 8.2 to 8.1 mean?
4. How do coral reefs help protect the shore during storms?
5. What are two economic risks of ocean acidification?
6. According to the author, what two things will ocean scientists in the future need to understand?

## Answers to Student Reading Comprehension Questions

1. **Complete the following table to describe unhealthy signs of and threats to ocean coral.**

|  |  |
| --- | --- |
| **Signs of Unhealthy Coral** | **Threat Responsible for Those Signs** |
| *faded colors* | *stress from warming ocean water* |
| *weakening or crumbling* | *acidic ocean water decreases the ability of coral to obtain materials needed for their growth* |

1. **Give two reasons why researchers are concerned about the health of coral reefs that make up less than 1% of the Earth’s surface.**

*Researchers are concerned about the health of coral reefs because*

* 1. *they play a crucial role in the ocean ecosystem and*
  2. *they provide shelter for perhaps a quarter of the ocean’s species.*

1. **What causes ocean warming and acidification?**

*Ocean warming and acidification are caused by an increase in carbon dioxide (and other gases) in the atmosphere.*

1. **Why is the term “greenhouse effect” misleading when used to describe ocean warming and acidification?**

*The term greenhouse effect is misleading because, while both atmospheric gases and a greenhouse produce higher temperatures, they work in different ways.*

1. **How do (a) greenhouses and (b) atmospheric gases trap heat?**
   * + - 1. *Light from the sun passes through the glass roof of the greenhouse to heat plants and the ground inside the greenhouse. These objects then emit infrared radiation, that is, heat. This thermal energy is trapped in the greenhouse, keeping the building warm.*
         2. *“Heat radiates from Earth toward space. Some of this heat is trapped by greenhouse gases in the atmosphere.”*
2. **Why are human activities that release carbon dioxide into the atmosphere causing concern?**

*Human activities are increasing the amounts of greenhouse gases such as carbon dioxide in our atmosphere. These gases trap extra heat, causing Earth’s temperature to rise, leading to environmental changes such as melting glaciers and ice sheets and warming our oceans.*

1. **What happens after warm oceans cause stressed corals to expel the symbiotic algae living in their tissues?**

*After the coral expels the symbiotic algae living in its tissues, the coral loses its major source of food, turns white or very pale, and is more susceptible to disease.*

1. **How does the water chemistry change as carbon dioxide gas is dissolved in the ocean?**

*As shown in the first equation on page 11, gaseous carbon dioxide [CO2 (g)] dissolves in ocean surface water to produce aqueous carbon dioxide [CO2) (aq)]. Then, in the second equation, the CO2 (aq) reacts with water to form unstable carbonic acid [H2CO3 (aq)] that immediately dissociates adding a hydrogen ion (H+) (aq) that increases the acidity of the water.*

1. **What will happen if man continues to release carbon dioxide into the atmosphere?**

*A drop in ocean pH from 8.2 to 8.1 shows that continuing to release carbon dioxide at the current rate will result in the oceans’ continuing increase in acidity.*

1. **How do coral reefs help protect the shore during storms?**

*Coral reefs help protect the shore during storms by blocking and deflecting some of the energy of ocean waves, meaning that water between the shore and the reef is calmer.*

1. **What are two economic risks of ocean acidification?**

*Economic risks of ocean acidification include*

* 1. *harming fish and shellfish that humans eat, and*
  2. *eliminating commercially valuable species of fish.*

1. **According to the author, what two things will ocean scientists in the future need to understand?**

*Future ocean scientists will need to understand*

*how pollution, warming, and ocean acidification affect marine life, and*

*how to develop ways to reduce atmospheric carbon dioxide and its impact on oceans.*

# Possible Student Misconceptions

1. **“I heard that hurricanes are the major cause of ocean coral reef destruction.”** *Although hurricanes may cause some mechanical damage (i.e., breaking up the coral), ocean corals actually receive benefits from summer hurricanes. These storms alleviate thermal stress on corals by absorbing thermal energy from surface water, churning the ocean to bring cooler water from the depths up to the surface, and by shading (think cloud cover) the ocean surface from the sun.*
2. **“I read that the ocean dissolves about 26% of the carbon dioxide released by human activities such as fossil fuel burning. So, I assume that we really don’t need to worry about environmental damage due to carbon dioxide.”** *Much of the carbon dioxide released into our atmosphere is dissolved by oceans. Yet during the absorption process, the seawater becomes increasingly acidic, harming corals and other aquatic species.*
3. **“I’ve been to the Virgin Islands, where the coral reefs are beautiful, so I think that current risks are probably exaggerated. They’ll be fine if we just reduce the atmospheric carbon dioxide a bit.”** *Actually, the risks to coral reefs are probably underestimated because the data show that ocean warmth and acidity are not the only stresses placed on the coral reefs. They also face damage from other factors, such as water pollution, stronger storms, and overfishing.*
4. **“Since coral reefs are complex and a part of a whole reef system, they can probably resist environmental changes such as bleaching and acidic oceans.”** *Although the coral reef ecosystems are very complex, they are seldom able to resist a combination of the severe stress of warming oceans and the loss of their calcium shells due to ocean acidity.*
5. **“When you touch a coral, it seems like a big colorful rock. Are they actually ancient fossils, or just chunks of minerals?”** *Although corals may appear to be non-living minerals, fossils or rocks, coral reefs are composed of marine animals that attach their exoskeletons to underwater rocks and shipwrecks. They have tentacles with stingers that they can use to capture and then eat tiny fish and zooplankton (small floating sea animals).*

# Anticipating Student Questions

1. **“Why can’t damaged coral reefs just replenish themselves by forming more shells?”** *In some cases, damaged coral reefs can rebuild, but severe stressing caused by a combination of several environmental situations such as acidified and warmer ocean water, pollution and excessive tourism causes slower growth and interferes with polyp reproduction.*
2. **“What is the composition of a coral reef?”** *A coral reef is composed of thin layers of a calcium carbonate base. Millions of tiny coral polyps that feed on plankton and algae form a living mat over this skeleton and add the beautiful shapes and colors of the reef.*
3. **“Why are healthy corals so colorful?”** *The skeletons of most corals are white because they are composed of calcium carbonate, a white-colored compound. The brilliant colors of coral reefs come from the tiny algae that live inside their tissues. These pigments are visible through the clear polyp body of the corals.*
4. **“How many different types of coral are there?”** *There are* approximately 2,500 species of coral. About 1,000 of these form hard shells and build coral reefs; the others are soft shelled.
5. **“Is ocean acidification the only danger to coral reefs?”** *No, evidence shows that, in addition to ocean acidification, the complex interaction of various environmental stresses working at the same time causes greater damage than acidification alone.*

# Activities

**Labs and demos**

**13 hands-on experiments on ocean acidification:** The European Project on Ocean Acidification (EPOCA) asked leading European scientists to design labs for 10–18 year-olds. Lab titles include: “Atmospheric Carbon Dioxide Can Produce Ocean Acidity” and “pH Regulation of Seawater”: The Role of Carbonate (CO32–) and bicarbonate (HCO3–)”; links take you to complete directions, materials, and equipment diagrams, plus sample data. (<http://www.epoca-project.eu/index.php/what-do-we-do/education/educational-activities/hands-onexperiments.html>)

**Demo: “Ocean Acidification in a Cup”:** Short videos illustrate the concept and the demo using vinegar, baking soda, and acid/base indicator. Consider this extension: note the destruction shown when seashells (or eggshells) are submerged in increasingly acidic water (like the sea butterfly experiment shown on page 12 of the Hale “Acidic Seas” article). (<https://www.exploratorium.edu/snacks/ocean-acidification-in-cup>)

**Simulations**

**“CO2, Shell Building and Ocean Acidification”:** Produced by the Woods Hole Oceanographic Institution, this simulation uses chemical reactions to show where organisms must use energy to expel hydrogen ions (H+) from bicarbonate ions (HCO32–) to release carbonate ions (CO3–2) needed for shell building. Under the “Multimedia” box on the right side of the project page, click on the “Interactive” clamshell icon for the simulation (requires Adobe Flash). (<http://www.whoi.edu/ocean-acidification/>)

**Media**

**“Ocean Acidification” video (3:01):** This terrific video uses cartoon characters as molecules and ions to demonstrate the consequence of excess carbon dioxide in oceans, including reduction of carbonate ions and shell destruction. The program accompanied by lesson plans and activities is produced by the Smithsonian National Museum of Natural History (NMNH); the video is from *The Alliance* (between the American and the German chemical societies) *for Climate Education*. (<http://ocean.si.edu/ocean-acidification>)

**PBS video (8:50) “Coral Reefs”:** Excellent photography shows the formation and structure of different types of coral reefs. The text describes how coral reefs provide food and shelter for aquatic life and the process of bleaching that leads to their death. (<https://ca.pbslearningmedia.org/resource/bfe7f0ea-8cd1-4392-aed6-1708cd9edf0e/coral-reefs/?#.WhXyTXmWxjo>)

**NOVA video (4:07), “What is Ocean Acidity?”:** After a short description of how carbon dioxide dissolved in ocean water changes water’s chemistry, this excellent video uses structural formulas of the molecules and ions to show the series of five reactions given in the Hale article and explains that the carbonate ion is the limiting reagent required to form calcium carbonate shells for aquatic life. (<https://ca.pbslearningmedia.org/resource/nvls-sci-acidification/what-is-ocean-acidification/?#.WhXrBXmWxjo>)

**Lessons and lesson plans**

**“Effect of Acidification on Coral Reefs” (two-50-minute class periods):** This multi-section lesson plan produced by Gustavus/Howard Hughes Medical Institute Outreach Program includes readings, a hands-on lab with pre-lab, student questions, and a video. See a list of links at the end for additional resources. (<https://gustavus.edu/events/nobelconference/2012/teachers/files/EffectofAcidificationonCoralReefs_000.pdf>)

**Inquiry lesson—why do we explore? (two 45-minute class periods):** “Ocean Health”, a lesson based on exploration and research from the NOAA ship Okeanos, asks, “What factors tend to resist changes in ocean pH?” Students seek answers during a hands-on laboratory activity; the site contains thorough answers to questions and lab preparations that include how to make artificial sea water, with supplementary links provided for the teacher. (<http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/09offbase>)

**Projects and Extension Activities**

**Research project on “Ocean Acidification”:** This investigation, from Carleton College, MN, of “the other carbon dioxide problem” involves the study of the long-term effects of carbon dioxide acidification on aquatic animals. Suggested materials include articles, discussion questions, videos, and a virtual (data based) lab exercise on sea urchins. (<https://serc.carleton.edu/eslabs/carbon/7b.html>)

**“Slowing Down an Amplifying Greenhouse Effect” project:** This site provides an evaluation and risk/benefit study of technologies designed to reduce atmospheric carbon dioxide. The project includes student research, articles to read, a NOVA video, and questions to address. (<https://serc.carleton.edu/eslabs/carbon/lab8.html>)

# References

**The reference 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”*.**



***30* Years of *ChemMatters !***

Available Now!

The Teacher’s Guide for the April 2009 *ChemMatters* article on algal blooms contains some interesting information about the adverse effect of ocean acidity on the ability of clownfish larvae to locate coral reefs through “tasting” (smelling).

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

"Compound Interest" is a blog created by Andy Brunning, a chemistry teacher in the UK, who uses his site to post graphics that he designs to highlight and explain the uses, reactions, and impacts of everyday chemicals. His choice of carbon dioxide for the infographic in the link below produced a perfect fit for the topic of this Acidic Seas article: note that the three columns on the graphic focus on how atmospheric carbon dioxide affects pH, the subsequent chemical reactions that produce acidic seas, and the results of ocean acidification.

([http://www.compoundchem.com/wp-content/uploads/2017/01/Carbon-Dioxide-and-Ocean-Acidification.png)](http://www.compoundchem.com/wp-content/uploads/2017/01/Carbon-Dioxide-and-Ocean-Acidification.png)

All of the chemistry infographics he has created are posted on the *Learn Chemistry* Web page of the Royal Society of Chemistry Web site at [http://www.rsc.org/learn-chemistry/resource/listing?Keyword=KCN00000015&reference=compoundinterest#](http://www.rsc.org/learn-chemistry/resource/listing?Keyword=KCN00000015&reference=compoundinterest).

# Web Sites for Additional Information

**Characteristics and development of ocean corals**

This article from the Smithsonian NMNH contains excellent photos of ocean corals with details of their structure and formation, including the symbiotic relationship between coral reefs and the colorful algae that grow within the reef structure, and a description of the reproductive behavior of coral polyps, accompanied by photos and a short video (2:10) of polyps spawning. Current work at the Smithsonian’s Caribbean research station is described and illustrated.

(<http://ocean.si.edu/corals-and-coral-reefs>)

The Coral section of The “Marine Life Photography of Hawaii and Beyond” site has a “Coral Index” of 25 pictures of species of coral, a physical description of each type, and other facts such as the location of colonies (country, depth in the ocean, ocean temperature, etc.). (<http://www.marinelifephotography.com/corals/corals.htm>)

**Endangered ocean coral**

The World Wildlife Federation (WWF) explains why ocean corals are considered an endangered species, one whose survival goes beyond simply conserving their habitat. The site provides a map\*, suitable for PowerPoint or whiteboard displays, showing the worldwide location of coral reefs, in warm and in cold waters, and a brief description of each of the major threats to coral reefs and their inhabitants; many listed threats also contain a WWF link to a more extensive description of that threat.

(<http://wwf.panda.org/about_our_earth/blue_planet/coasts/coral_reefs/>)

\*This is a link to a clearer enlargeable view of the warm/cold map listed above. The author (Hugo Ahlenius) gives permission for classroom use if his URL and name are given credit. (<https://farm1.staticflickr.com/734/32357568885_5c8f0d1551_o.jpg>)

*The Conversation,* published by the University of Australia, discusses the scale and reasons for the massive loss of coral from the Great Barrier Reef, and embedded links take you to maps of coral loss. (<https://theconversation.com/how-will-the-barrier-reef-recover-from-the-death-of-one-third-of-its-northern-corals-60186>)

**Ocean warming**

In this article, ocean warming is described as “the most powerful evidence of global warming” due to the release of heat-trapping gas emissions as fossil fuels are burned. Excellent charts and graphs appropriate for classroom use show how the rate and depth of ocean warming are increasing due to the oceans’ absorption of 2/3 of the excess heat trapped by greenhouse gas emissions.

(<https://insideclimatenews.org/news/03102017/infographic-ocean-heat-powerful-climate-change-evidence-global-warming>)

The International Union for Conservation of Nature and National Resources (IUCN), based in Switzerland, has prepared an extensive (560 pages) report, *Explaining Ocean Warming: Causes, Scale, Effects and Consequences*. On the premise of ocean warming as the “greatest hidden challenge of our generation,” sections of this document report on the impacts and effects of ocean warming on various marine organisms, their habitats, and ecosystems.

(<https://portals.iucn.org/library/sites/library/files/documents/2016-046_0.pdf>)

**Ocean acidification**

This URL takes you to a clear explanation of the carbonate/bicarbonate buffer system that includes chemical equations, and a diagram that is suitable for classroom use. (<http://strippolichemistry.weebly.com/uploads/9/7/8/2/9782140/the_carbonate_buffering_system.pdf>)

“Ocean Chemistry” from the *ACS Science Toolkit* uses five equations to thoroughly and clearly explain the ocean carbonate buffer system, using Le Châtelier’s principle to discuss ocean pH and equilibrium shifts as additional environmental carbon dioxide is absorbed by the ocean and places a stress on the system. The margin presents an easy demonstration; this article is appropriate for student reading.

(<https://www.acs.org/content/acs/en/climatescience/oceansicerocks/oceanchemistry.html>)

**The greenhouse effect**

This National Aeronautics and Space Administration (NASA) site on “Global Climate Change,” includes an explanation of how the greenhouse effect has always warmed the planet, but that recent human activities have led to dramatic increases in the amounts of greenhouse gases released to the atmosphere. This is an amazing site that includes several articles based on NASA research, with interactive videos and suggestions of ways to mitigate climate change. (<https://climate.nasa.gov/causes/>)

“Threats to Coral Reefs” (due to climate change) contains an “Infographic” that could easily be shown and discussed in class. The text lists threats to coral reefs by climate change and describes ways that people can help reduce their contributions to ocean warming due to their activities.

(<https://oceanservice.noaa.gov/facts/coralreef-climate.html>)

**Loss of coral reefs**

On this site, *National Geographic* studied the effects of dredging the seafloor to expand Australian ports to accommodate large tankers. The Great Barrier Reef suffered as huge plumes of sediment from the seafloor blocked sunlight, thus preventing algal photosynthesis, the source of food and energy for coral reefs.

(<https://news.nationalgeographic.com/news/2014/07/140716-australia-coral-reef-dredging-sediment-disease-environment-ocean/>)

Oceana, an international organization devoted to the protection of the oceans, reports that coral reefs serve as the first line of defense against strong tropical storms for coastal communities. This article describes the economic and humanitarian necessity of careful worldwide monitoring of human activities to obtain targeted data as the basis for developing programs to reduce global threats to coral reefs.

(<http://oceana.org/marine-life/marine-science-and-ecosystems/coral-reef>)

**Recovery of coral reefs?**

According to a report in *LiveScience* of a study led by James Gilmore at the Australian Institute of Marine Science, published in *Journal of Science*, researchers were amazed to watch the recovery of a bleached coral reef; self-regeneration was not expected, nor was healing in years rather than decades. This article explains the scientific findings and what they suggest for the care of the environment.

(<https://www.livescience.com/28440-coral-reefs-can-regenerate.html>)

This BBC article contains beautiful photography, including a short (1:03) underwater video of corals. “The Corals that came back from the Dead” explains coral death from bleaching and provides possible explanations for their recovery.

(<http://www.bbc.com/earth/story/20140916-the-corals-that-come-back-from-the-dead>)

**New approaches to coral reef research**

The open access paper *Frontiers in Marine Science,* March 2016, contains excellent illustrations suitable for the classroom. Findings of the Duke University Nicholas Institute suggest that multiple stressors interact in complex ways leading to more rapid and stronger negative effects on coral ecosystems.

(<https://nicholasinstitute.duke.edu/ocean/publications/multiple-stressors-and-ecological-complexity-require-new-approach-coral-reef-research>)

The Marine Institutes of Australia, Florida, and Hawaii are working on an approach to restoring coral reef colonies through genetic research by attempting to grow hardy corals—ones that will resist ocean warming—in their labs and then implant them at sea. However, this work creates ethical questions regarding the use of selective breeding techniques. (<https://www.nytimes.com/2017/09/20/climate/coral-great-barrier-reef.html>)

**International efforts to stem ocean acidification**

*The Monaco Declaration*—2008: A group of 155 scientists from 26 countries reviewed the threats to the marine ecosystem posed by chemical changes in the ocean due to increasing worldwide carbon dioxide emissions. In an effort to prevent further damage, they launched initiatives to improve understanding and communications between scientists and economists and policymakers. (<http://www.fpa2.org/pdf/declaration_monaco.pdf>)

This United Nations (UN) slideshow covers the conference details: (<http://www.un.org/depts/los/consultative_process/ICP14_Presentations/HILMI_ICP_Presentation.pdf>)

*Paris Agreement*—2017: Representatives from 197 nations met to address the common cause of combating climate change and adapting to its effects through development of the UN Framework on Climate Change; 170 of the nations ratified the agreement to reduce their carbon dioxide emissions, with the ultimate goal of reducing emissions to reach climate neutrality (net zero carbon footprint) by the end of the century. (<http://unfccc.int/2860.php>)

# About the Guide

Teacher’s Guide team leader William Bleam and editors Pamela Diaz, Steve Long and Barbara Sitzman created the Teacher’s Guide article material.

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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, beginning 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>.