



Online Ethics Center
FOR ENGINEERING AND SCIENCE

Chapter 8: Climate Change

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Description

Chapter 8 of "An Instructor's Guide to Ethical Issues in Physics."

Body

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Section 8.1: Introduction

Climate science draws heavily on a wide range of STEM fields. Physicists play a role in understanding how to apply fundamental principles, especially those of thermodynamics and fluid dynamics, to a very complex system. The expertise physicists have in computational modeling is also relevant. Because of the importance of the issues surrounding climate change, physicists need to have a sufficient understanding of the fundamental technical issues so that they can provide meaningful input into public policy debate.

While students taking a course on ethics in physics will likely be familiar with climate change, instructors may want to assign a reading to make sure everyone approaches the topic with a basic understanding of the history of climate change studies as well. A *Physics Today* article by Weart will serve this purpose.[\[1\]](#)

One could easily teach an entire course on climate change, but it is more likely that physics instructors will be able to devote at most a few class sessions on it in courses on ethics, thermodynamics, or fluid mechanics. The wealth of information provides a range of choices for reading selections. This chapter looks first at observational data, then covers elements of climate modeling and the results of combining these elements into complex models, before concluding with a discussion of possible actions that can be taken in response to climate change. Two important points to convey through these readings are that climate modeling is a complex problem and a strong consensus exists in the scientific community that humans have already influenced the climate in measurable ways and will continue to do so for the foreseeable future. See Section 9.2 of this Instructor's Guide for issues related to communicating with the public about climate change.

Discussion Prompts:

1. Discuss the sources of information you currently draw on for information about climate change. What evidence do you have for the reliability of these sources?
2. Discuss the similarities and differences in the role played by physicists as the possibility of nuclear weapons emerged in the mid 1900s and as human-induced climate change emerged as a possibility in the late 1900s.
3. Do you think there are ethical obligations related to climate change shared by *all* physicists? If so, are these obligations reflected in the APS Guidelines on Ethics?

Section 8.2: Observational data

Measuring temperature, interpreting historical temperature data, and determining regional or global average temperatures are all significantly more involved processes than most students expect. Since one of the key climate variables is temperature, it is important that students have an understanding of how challenging it can be to work with this quantity that on the surface seems so straightforward. The three activities mentioned above—measuring, interpreting, and averaging temperature data—are all their own areas of specialization. For a quick introduction to land-based temperature measurements, see the advice given by the National Weather Service on choosing a location for a personal weather station.[\[2\]](#)

Richard and Elizabeth Muller entered the field of analysis of historical temperature data with a skeptical view of existing methodologies. They launched the Berkeley Earth Surface Temperature project, which became the fourth major research group to compile and analyze global temperature data. The ***Physics Today*** article on this study provides both a summary of their results (mostly similar to results from the other three groups) and an overview of some of the issues that must be dealt with when analyzing historical temperature data.[\[3\]](#)

A good understanding of ocean temperatures is needed in climate models since oceans store a huge quantity of thermal energy and are involved in large heat flows. An article by Sabra et al. describes the challenges of these temperatures, including the inability to anchor measuring devices in fixed locations and the problems with monitoring temperatures far below the surface.[\[4\]](#) A portion of the article describes an acoustical technique for measuring water temperature; this may resonate with students who have studied some acoustics or other wave theory.

In addition to monitoring temperature patterns, one can make other environmental observations to detect climate change. One of the most discussed observations is the melting of the polar ice caps. ***Physics Today*** has had several articles on this topic during the past decade. One of the more recent articles provides statistics on the increased rate of melting in the Arctic region and discusses some of the implications of this melting.[\[5\]](#) The latter part of the article focuses more on the impact on shipping lanes, which might not be of direct relevance to a discussion of observational data related to climate change.

The increased CO₂ content in the atmosphere has led to more absorption of CO₂ by the oceans, causing them to become acidic. While this change in the acidity of oceans may not strictly speaking be a climate change, it is often addressed under this heading due to its root cause being CO₂. A ***Physics Today*** article describes the problem of acidification and then briefly discusses one proposed solution.[\[6\]](#) That proposed solution can be classified as a form of geoengineering, a topic that will be addressed in Section 8.5.

Discussion Prompts:

1. Discuss some of the challenges in acquiring and analyzing historical temperature data. How would you respond to someone who argues that with all of these challenges, we cannot draw any meaningful conclusions about whether

global warming is real?

2. Does an understanding of how climate data is acquired give you more or less confidence in global warming data?
3. Discuss the physics of weather-related feedbacks that arise with the melting of polar ice caps.
4. Discuss some negative environmental impacts of the polar ice caps melting.
5. What are some of the ethical concerns about dealing with ocean acidification by chemically treating ocean water?

Section 8.3: Some elements in a climate model

One of the challenges in climate modeling is the need to account for many different natural features and how they interact with each other. A particularly prominent feature in global climate models is heat transfer by radiation. While it seems likely most intermediate physics students understand what the greenhouse effect is, instructors might want to have them review the basics of this phenomenon.

Numerous reliable websites offer brief summaries. The National Weather Service has a page that includes a nice graphic depicting radiation inflows and outflows for our planet.[\[7\]](#) For a much more detailed discussion of the effect, at a level appropriate for an advanced undergraduate student, see Pierrehumbert's article in *Physics Today*.[\[8\]](#)

Students in a physics class will likely know that CO_2 is a greenhouse gas released when fossil fuels are burned, but they may not know what happens to the released CO_2 . Natural processes lead to significant uptake of CO_2 by living organisms, the ground, and the oceans. Graven describes the carbon cycle and how it both influences and is influenced by the global climate.[\[9\]](#) She also describes the role of modeling in increasing our understanding of the carbon cycle and guiding society on environmental policy issues. Another illustration of the interplay between CO_2 and the climate is discussed in a short article on the role of CO_2 in glacial retreat 20,000 years ago.[\[10\]](#) The article introduces the concept of proxies for acquiring historical temperature information and shows how models can provide evidence that variations in solar flux alone cannot explain that glacial retreat. Sarmiento and Gruber take a detailed look at carbon sinks in an article that does a particularly good

job of impressing upon the reader the complexity of modeling the carbon cycle in a dynamic environment.[\[11\]](#) Among other insights, the authors point out that some previously farmed areas in the eastern US have been allowed to return to forest, resulting in a significant carbon capture from the atmosphere. Once this carbon sink becomes saturated, we should expect to see global warming accelerate in response to CO₂ production.

Ocean currents are responsible for moving vast quantities of thermal energy around the globe. Hence understanding them is essential to climate modeling. A news article in *Nature* describes the circulation system in the North Atlantic and the evidence that this system is slowing down.[\[12\]](#) A news article in *Physics Today* highlights a new approach to modeling ocean currents. The model indicates that the ocean's ability to act as a carbon sink has increased in recent years.[\[13\]](#) Another news article describes new techniques in measuring ocean currents and how that has provided an improved understanding of the way these currents are changing.[\[14\]](#) Even a seemingly minor process such as production of ocean spray can have a significant effect on the climate while being very difficult to model, as an article by Richter and Veron indicates.[\[15\]](#) Although some passages may be technically challenging to undergraduate readers, the overall picture that emerges will be clear.

Discussion Prompts:

1. What other elements do you think should be considered in developing a good global climate model, aside from those you have read about for this course?
2. How would you describe the greenhouse effect to someone without much scientific background? What common situations allow one to experience the greenhouse effect directly?
3. What are the important components of heat flow by radiation that influence the earth's climate? Which of these processes might be significantly influenced by human activity?
4. Describe what can happen to CO₂ produced by burning fossil fuel that makes it harder to predict how much of that gas will remain in the atmosphere.
5. Discuss the impact of the ocean circulation on the environment, considering effects directly related to climate as well as those that are not.
6. Why should you be skeptical of someone who claims a "back of the envelope" estimate shows that the observed global warming can be attributed to an increase in the solar flux?

Section 8.4: Global Climate Models

Building a Global Climate Model (GCM) requires pulling together a wide range of physical phenomena, some of which were addressed in the previous section, and accounting for the various feedback loops among these phenomena. A concise introduction is found in an article by Schmidt.[\[16\]](#) This article also points out the success of earlier versions of the models in predicting the impact of the 1991 Mount Pinatubo eruption on the climate. A more technical article on the Mount Pinatubo prediction is available on the USGS website.[\[17\]](#)

The Intergovernmental Panel on Climate Change (IPCC) produces a comprehensive climate report approximately every eight years. The Synthesis Report of 2014 is likely too long for a reading assignment, but the thirty-page “Summary for Policymakers” makes for a data-intensive but otherwise nontechnical summary of global climate research.[\[18\]](#) Alternatively, “Topic 1: Observed Changes and Their Causes” focuses more on data analysis. While the nearly twenty pages of two-column text may be a bit overwhelming for undergraduates, the topics addressed in this section will likely be readily understood. “Topic 2: Future Climate Changes, Risk and Impacts” is about as long as Topic 1 but focuses more on GCMs. Even without reading the entire section, students can get a feel for a few of the features of the models by reading some of the blue-box inserts.

GCMs can be used to look at the influence of particular phenomena on climate. An article by Overland explores an example by describing research into the question of whether there is a cause and effect relationship between the loss of ice cover in the Arctic and the polar vortex phenomenon.[\[19\]](#)

Discussion Prompts:

1. What analogy might you use to explain to someone without a technical background that although climate modeling is very complex, it is still possible to develop useful global climate models?
2. What evidence supports the quality of current global climate models?
3. Discuss some of the sources of information the IPCC report draws on. What evidence is there for their reliability?
4. What are some examples of how global warming can actually cause some locations to be colder at certain times of the year?

5. Try to distill some the scientific information found in any one of the articles in this section down to the point where it can be explained to someone without a strong background in science.

Section 8.5: Focused action

Climate change has had and will continue to have wide-ranging impacts on society. Specific actions to address these impacts can be broken up into three categories: (1) Adaptation—dealing with the changes in climate, (2) Geoengineering—actively trying to modify the climate, and (3) Mitigation—minimizing the human-created sources of climate change. Higgins summarizes these strategies and adds a discussion on the need for further research and on the political environment in which crucial decisions will be made.[\[20\]](#) A Letter to the Editor and the response by Higgins debate the relative merits of the three approaches.[\[21\]](#) While the Higgins article provides a good overview of actions that can be taken, the resources that follow dive more deeply into some of these issues.

Adaptation

Two administrators from the National Atmospheric and Oceanographic Administration discuss the need for environmental intelligence in a 2012 *Physics Today* article that reviews data on the increasing number of extreme weather events. [\[22\]](#) The article describes environmental intelligence as being based on collecting data, analyzing the data, and taking action in response to the analysis. Kramer reports on actions and proposals for action to help Norfolk, Virginia deal with sea level rise.[\[23\]](#) This region of two million people is already experiencing increased incidence of inundated streets and other forms of flooding.

The IPCC report on *Impacts, Adaptation and Vulnerability* has extensive information on adaptation.[\[24\]](#) The Technical Summary alone runs about sixty pages. However, useful segments can be extracted for a reading assignment. For instance, in the Technical Summary, see Boxes TS.2 (pp. 39-40) and TS.3 (p. 41) for definitions of terms used in IPCC reports. Table TS.2, beginning on page 52 and concluding with a final segment on page 55, highlights some prior experience with adaptations. Box TS.6 (p. 63) summarizes global scale consequences of significant warming of the Earth. Table TS.4 (pp. 64-65) describes emerging risks and possible

adaptation strategies.

Geoengineering

Geoengineering refers to large-scale interventions in Earth processes to achieve a specific outcome. Carbon capture and storage can either be classified as mitigation, since it reduces greenhouse gases in the atmosphere, or geoengineering, since it removes a substantial amount of carbon from one part of the earth, the atmosphere, and places it in another, the ground. In this chapter it will be classified as geoengineering, which places more emphasis on the environmental impact of underground storage and the long term effectiveness of such storage. A paper by Medvecky et al. explores in depth the ethical issues associated with carbon capture and storage.[\[25\]](#) While heavy on formal ethics and light on technical details, the paper is nevertheless accessible to physics students since key terms are defined and concepts are described before they are applied to the discussion of carbon capture and storage. Among other issues, the authors spend some time exploring existing ethical theory regarding “rights and duties towards future generations.”

A news article in ***Physics Today*** reports on the possibility that sequestering CO₂ underground may lead to minor earthquakes.[\[26\]](#) A letter to the editor a few issues later comments that a relatively easy way to sequester carbon is to bury, rather than burn, scrap wood from construction projects.[\[27\]](#) A more recent article discusses the economics of carbon capture from the air and describes the technology behind the various carbon-capture systems that are being developed.[\[28\]](#)

Kramer reports on more general ethical issues related to geoengineering and then uses as concrete examples proposals for atmospheric experiments investigating the feasibility of modifying the atmosphere to help regulate the Earth’s temperature.[\[29\]](#) At the time the article was written, no international regulations or ethical standards had been agreed upon, but movement had started towards trying to establish such standards. The Carnegie Climate Governance Initiative has been pursuing this goal.[\[30\]](#)

A 2015 National Research Council study suggests that the term “geoengineering” in the context of climate change strategies is too broad. They instead focus on two groups of climate intervention strategies, Carbon Dioxide Removal[\[31\]](#) and Albedo Modification.[\[32\]](#) The *Report Briefs* provide easy to read overviews, but students

interested in the technical details of various strategies can read the third chapter of each report.

Mitigation

While mitigating the effects of climate change can take on many forms, if one were to focus on CO₂, then mitigation could be broken down into two categories: managing our resources in a way that would improve the Earth's ability to sequester carbon and reducing the amount of CO₂ emitted into the atmosphere by changing our fuel consumption practices.

The role of land as a carbon sink is explored in a previously discussed article by Bertram (Ref. 10). An article by Pielke et al. discusses other ways that land, and in particular land use, can influence the climate.[\[33\]](#) While most of the article focuses on the influence and the importance of accounting for it in climate models, the article also looks at how careful attention to land use issues might mitigate some of the effects of climate change.

Another strategy towards mitigation is replacing fossil fuels with other energy sources. A proposal for concentrated solar power is discussed along with some ethical issues the proposal raised in a *Physics Today* news article[\[34\]](#) and accompanying letters to the editor.[\[35\]](#)[\[36\]](#)

Some considerations in wind farm design are described in an article by Dabiri.[\[37\]](#) A particular focus of the article is research into vertical-axis wind turbines and whether their efficiency can be improved by strategically arranging them on a wind farm. This article may be of particular interest to students with a background in fluid dynamics, though that background is not essential for comprehension. A paper by Bolin et al. provides a concise overview of noise generated by wind turbines and how it affects humans.[\[38\]](#) Elliott's commentary published on the *Physics World* website takes a look at the debate over whether wind turbines are having a serious impact on bird populations.[\[39\]](#)

Geothermal heating systems are becoming more common in the United States. Such systems take advantage of the fact that one only needs to dig a couple of meters below the ground in most places to find soil that stays at a fairly steady temperature of around 10°C all year. If one drills down a couple of kilometers instead, one finds much hotter rock with a correspondingly greater potential for energy extraction. The

process requires drilling multiple holes and cracking the hot rock to create more surface area for heat transfer. Circulating water through the system then brings the thermal energy to the surface. This is known as an engineered geothermal system and is discussed in a news article by Toni Feder, who reports on a test site in Utah. [\[40\]](#) The article also reports on concerns that this form of geoengineering could trigger earthquakes.

Hydrogen has been considered as a source of energy for vehicles for quite a while. Students will need to understand that, in terms of the global energy budget, hydrogen is best viewed as an energy storage system, not an energy source. The Earth does not have much readily accessible, naturally occurring reserves of hydrogen gas, so if it were to be relied on for a large number of vehicles, it would need to be created from chemical reactions that require energy input (usually exceeding the energy later extracted in the vehicle) and that sometimes lead to CO₂ emissions. An update on the status of research into and development of hydrogen-powered vehicles is given in an article by Kramer. [\[41\]](#)

Finally, to give students a broad sweep of current research into renewable energy sources and energy conservation technology, direct them to the National Renewable Energy Laboratory's web page describing its research areas. [\[42\]](#)

Discussion Prompts

1. One important area of public debate is who should bear some responsibility (and how much) for taking action in response to climate change? This responsibility can be viewed from an individual perspective or a collective perspective. For instance, which countries bear more responsibility? Which sectors of society within those countries bear more responsibility? What are the responsibilities of individuals within a country that bears some responsibility? Is there any aspect of this debate where scientists can make a particularly helpful contribution?
2. Choose any one of the strategies for dealing with climate change that are described in readings in this section. For that strategy, discuss both intended consequences and potential unintended consequences and whether, on balance, you think that strategy should be pursued. What additional information would be helpful in order to gain more confidence in your conclusion?

3. What other strategies are you aware of for taking action regarding climate change? Consider the three categories, adaptation, geoengineering, and mitigation.
4. Will all three categories of action (adaptation, geoengineering, and mitigation) be necessary to deal with climate change as we currently understand it, or do you think the problem can be addressed with just one or two of these categories?

Section 8.6: Broader action on climate change

News media coverage has followed international efforts to reach agreement on broad strategies for dealing with climate change. Since these efforts are ongoing and, at times, in rapid flux, no effort will be made to cover them in this Instructor's Guide. The focus instead will be on various ideas and forces that underlie these international efforts.

To give international efforts regarding climate change some context, it is helpful to look at a case study that has progressed much further. Mégie and McGinn describe international agreements that were hammered out in response to the recognition that chlorofluorocarbons were damaging the ozone layer.[\[43\]](#) They perform some modeling to address what would have happened had these agreements been enacted several years earlier. Finally, they draw an analogy between this case and the present efforts to create international agreements on responding to climate change. This paper was written in 2006, so students may want to know the present status of the ozone layer. They can be directed to a 2014 *Physics Today* article[\[44\]](#) and a NASA webpage that has current, technical details about the status of the ozone layer.[\[45\]](#)

A physicist in the New Hampshire legislature took the lead in creating a comprehensive energy plan for the state. In an article describing his efforts he writes, "During my undergraduate and graduate studies at the University of Heidelberg, Germany, our physics professors repeatedly underscored the message (perhaps because of the history of sciences in Germany) that as scientists we have a moral duty to ensure that our science is used primarily to improve people's lives and not just for commercial benefit."[\[46\]](#) The plan focuses on reducing energy use and

includes estimates of the impact on energy usage if all of the proposed measures were to be adopted.

A philosophical discussion of responsibility and blame regarding climate change is found in a paper by van de Poel et al.[\[47\]](#) They describe the “problem of many hands” as one in which it is difficult to assign blame to individuals when undesirable effects result from group action. They consider the possibility that in some cases there may be a collective responsibility even when no individual responsibility exists. While the paper is somewhat lengthy, it nevertheless treats a problem in ethics not generally covered in professional codes. Their discussion has applications to a wide range of other situations involving collective action.

Professional societies often enter the public debate on technical issues by issuing statements. A 2007 American Physical Society statement on climate change identified aspects of human activity that can impact the earth’s climate and then stated, “The evidence is incontrovertible: Global warming is occurring.”[\[48\]](#) The use of the word “incontrovertible” generated controversy in the physics community—some argued that it was unscientific in that it appeared to close off any possibility that future data could lead one to a different conclusion. In 2015, the APS revised the statement on climate change, using terms like “compelling” to describe the evidence.[\[49\]](#) A 2017 statement calls for more research to promote the transition to carbon-neutral energy sources.[\[50\]](#) Each of these statements is concise and could be used to supplement the reading of a longer paper.

Discussion Prompts:

1. In what ways has input by scientists been important in how the ozone problem has been addressed?
2. What other issues facing society fit the model of the many hands problem?
3. What do you believe your individual forward-looking responsibilities are, if any, regarding climate change? Do any of these responsibilities exist primarily because you are a scientist?
4. Do you agree or disagree with the use of “incontrovertible” in the 2007 APS climate statement?

[Continue to Chapter 9: Communicating Science to the General Public](#)

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[1] Spencer Weart, “Climate change impact: The growth of understanding,” *Physics Today* **68** (9) 46 (2015). <https://doi.org/10.1063/PT.3.2914>

[2] National Weather Service, Personal Weather Station—Siting, <https://www.weather.gov/media/epz/mesonet/CWOP-Siting.pdf> (accessed November 12, 2019).

[3] Barbara Gross Levi, “Earth’s land surface temperature trends: A new approach confirms previous results,” *Physics Today* **66** (4), 17 (2013). <https://doi.org/10.1063/PT.3.1936>

[4] Karim G. Sabra, Bruce Cornuelle, and William A. Kuperman, “Sensing deep-ocean temperatures,” *Physics Today* **69** (2), 32 (2016). <https://doi.org/10.1063/PT.3.3080>

[5] David Kramer, “Climate change in the Arctic accelerates,” *Physics Today* **70** (9), 24 (2017). <https://doi.org/10.1063/PT.3.3688>

[6] David Kramer, “Scientists, White House say ocean acidification is well under way,” *Physics Today* **67** (8), 20 (2014). <https://doi.org/10.1063/PT.3.2474>

[7] National Weather Service, “The Earth-Atmosphere Energy Balance,” <https://www.weather.gov/jetstream/energy> (accessed October 29, 2019).

[8] Raymond T. Pierrehumbert, “Infrared radiation and planetary temperature,” *Physics Today* **64** (1), 33 (2011). <https://doi.org/10.1063/1.3541943>

[9] Heather Graven, “The carbon cycle in a changing climate,” *Physics Today* **69** (11), 48 (2016). <https://doi.org/10.1063/PT.3.3365>

[10] Bertram M. Schwarzschild, “Carbon dioxide drove the ending of the last glacial epoch,” *Physics Today* **65** (6), 16 (2012). <https://doi.org/10.1063/PT.3.1588>

[11] Jorge L. Sarmiento and Nicolas Gruber, “Sinks for Anthropogenic Carbon,” *Physics Today* **55** (8) 30 (2002). <https://doi.org/10.1063/1.1510279>

[12] Summer K. Praetorius, "North Atlantic circulation slows down," Nature News and Views April 11, 2018, <https://www.nature.com/articles/d41586-018-04086-4> (accessed October 30, 2019).

[13] Sung Chang, "Why the ocean's carbon sink has gotten stronger," Physics Today **70** (4), 21 (2017). <https://doi.org/10.1063/PT.3.3515>

[14] Johanna L. Miller, "Ocean currents respond to climate change in unexpected ways," Physics Today **70** (1), 17 (2017). <https://doi.org/10.1063/PT.3.3415>

[15] David Richter and Fabrice Veron, "Ocean spray: An outsized influence on weather and climate," Physics Today **69** (11), 34 (2016).
<https://doi.org/10.1063/PT.3.3363>

[16] Gavin Schmidt, "The physics of climate modeling," Physics Today **60** (1) 72 (2007). <https://doi.org/10.1063/1.2709569>

[17] Stephen Self, et al., "The Atmospheric Impact of the 1991 Mount Pinatubo Eruption," <https://pubs.usgs.gov/pinatubo/self/> (accessed October 30, 2019).

[18] IPCC, *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. (IPCC, Geneva, Switzerland, 2014), <https://www.ipcc.ch/report/ar5/syr/> (accessed October 31, 2019).

[19] James Overland, "Is the melting Arctic changing midlatitude weather?," Physics Today **69** (3), 38 (2016). <https://doi.org/10.1063/PT.3.3107>

[20] Paul Higgins, "How to deal with climate change," Physics Today **67** (10), 32 (2014). <https://doi.org/10.1063/PT.3.2548>

[21] Brian Cluggish and Paul Higgins, "Many approaches to climate change policy," Physics Today **68** (5) 10 (2015). <https://doi.org/10.1063/PT.3.2762> and <https://doi.org/10.1063/PT.3.2763>

[22] Jane Lubchenco and Thomas Karl, "Predicting and managing extreme weather events," Physics Today **65** (3), 31 (2012). <https://doi.org/10.1063/PT.3.1475>

[23] David Kramer, "Norfolk: A case study in sea-level rise," Physics Today **69** (5), 22 (2016). <https://doi.org/10.1063/PT.3.3163>

[24] C. B. Field, et al., *IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, (Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2014). <https://www.ipcc.ch/report/ar5/wg2/> (accessed October 31, 2019).

[25] Fabien Medvecky, Justine Lacey, and Peta Ashworth, "Examining the Role of Carbon Capture and Storage Through an Ethical Lens," *Science and Engineering Ethics* **20** (4) 1111-1128 (2014). [DOI 10.1007/s11948-013-9474-z](https://doi.org/10.1007/s11948-013-9474-z)

[26] David Kramer, "Scientists poke holes in carbon dioxide sequestration," *Physics Today* **65** (8), 22 (2012). <https://doi.org/10.1063/PT.3.1672>

[27] Philip Ugorowski, "Simple, low-tech option for carbon sequestration," *Physics Today* **66** (1), 11 (2013). <https://doi.org/10.1063/PT.3.1838>

[28] David Kramer, "Can carbon capture from air shift the climate change equation?," *Physics Today* **71**(9), 26 (2018). <https://doi.org/10.1063/PT.3.4018>

[29] David Kramer, "Geoengineering researchers ponder ethical and regulatory issues," *Physics Today* **66** (11), 22 (2013). <https://doi.org/10.1063/PT.3.2174>

[30] Carnegie Climate Governance Initiative, <https://www.c2g2.net/c2g2-mission/> (accessed January 17, 2020).

[31] National Research Council. 2015. *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/18805>.

[32] National Research Council. 2015. *Climate Intervention: Reflecting Sunlight to Cool Earth*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/18988>.

[33] Robert A. Pielke Sr, Rezaul Mahmood, and Clive McAlpine, "Land's complex role in climate change," *Physics Today* **69** (11), 40 (2016). <https://doi.org/10.1063/PT.3.3364>

[34] Toni Feder, "Scientists help make deserts into solar-energy hubs," *Physics Today* **64** (7) 21 (2011). <https://doi.org/10.1063/PT.3.1157>

- [35] Andrew Ochadlick Jr, "Desert solar hubs not new but risky," *Physics Today* **64** (12) 10 (2011). <https://doi.org/10.1063/PT.3.1344>
- [36] Morris Hirsch, "Thoughts on concentrated solar power," *Physics Today* **65** (7) 12 (2012). <https://doi.org/10.1063/PT.3.1624>
- [37] John Dabiri, "Emergent aerodynamics in wind farms," *Physics Today* **67** (10) 66 (2014). <https://doi.org/10.1063/PT.3.2559>
- [38] Karl Bolin et al., *Environmental Research Letters* **6** 035103. <https://doi.org/10.1088/1748-9326/6/3/035103>
- [39] Dave Elliott, "Wind turbine impacts deplored," *Physics World* (online) August 28, 2019, <https://physicsworld.com/a/wind-turbine-impacts-deplored/> (accessed November 1, 2019).
- [40] Toni Feder, "Engineered geothermal systems have wide potential as a renewable energy source," *Physics Today* **71** (9) 22 (2018). <https://doi.org/10.1063/PT.3.4017>
- [41] David Kramer, "Hydrogen-powered vehicles: A chicken and egg problem," *Physics Today* **70** (9) 31 (2017). <https://doi.org/10.1063/PT.3.3690>
- [42] National Renewable Energy Laboratory, "Research Areas," <https://www.nrel.gov/research/areas.html> (accessed November 1, 2019).
- [43] Gérard Mégie and Robert McGinn , "From Stratospheric Ozone to Climate Change: Historical Perspective on Precaution and Scientific Responsibility," *Science and Engineering Ethics* Volume 12 (4) pp. 596-606 (2006). <https://doi.org/10.1007/s11948-006-0060-5>
- [44] Anne Douglass, Paul Newman, and Susan Solomon, "The Antarctic ozone hole: An update," *Physics Today* **67** (7), 42 (2014). <https://doi.org/10.1063/PT.3.2449>
- [45] National Aeronautics and Space Administration, "NASA Ozone Watch," <https://ozonewatch.gsfc.nasa.gov/> (accessed November 1, 2019).
- [46] Peter Somssich, "A Physicist Politician and Renewable Energy," *Physics and Society*, January 2019, <https://www.aps.org/units/fps/newsletters/201901/politician.cfm> (accessed

November 5, 2019).

[47] Ibo van de Poel, et al., “The Problem of Many Hands: Climate Change as an Example,” *Science and Engineering Ethics* **18** (1) 49-67 (2012). doi: [10.1007/s11948-011-9276-0](https://doi.org/10.1007/s11948-011-9276-0)

[48] American Physical Society, “07.1 Climate Change (Archived Statement),” adopted November 18, 2007, https://www.aps.org/policy/statements/07_1.cfm (accessed November 1, 2019).

[49] American Physical Society, “15.3 Statement on Earth’s Changing Climate,” adopted November 14, 2015, https://www.aps.org/policy/statements/15_3.cfm (accessed November 1, 2019).

[50] American Physical Society, “17.1 Addressing the Global Energy Challenge: Accelerating the Transition to Carbon-Neutral Energy sources,” adopted April 22, 2017, https://www.aps.org/policy/statements/17_1.cfm (accessed November 1, 2019).

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Use of Materials on the OEC

Resource Type

Instructor Materials

Topics

Climate Change

Energy

Geoengineering

Discipline(s)

Computer, Math, and Physical Sciences

Physics

Research Ethics

Teaching Ethics in STEM