Curriculum Guide to *From Knowledge to Power: The Comprehensive Handbook for Climate Science and Advocacy*

A resource for students and instructors

by John Perona

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Introduction

This curriculum guide to *From Knowledge to Power* (K2P) is offered with the intention of optimizing use of the book in college and university classroom settings and in other adult education venues.

I first conceived of K2P as a resource for the US climate advocacy movement, especially my friends and colleagues in the Citizens' Climate Lobby (CCL), from whom I learned a great deal about advocacy strategies and how to engage with individuals from across the political spectrum. The main premise of K2P is that these climate conversations with business, community and government leaders can yield better outcomes when advocates possess intellectual reserves that they can bring into play at key junctures. Since most citizen advocates are not experts in climate matters, it seemed important to offer a comprehensive handbook that would explain the science and policy in enough detail to enable them to feel more empowered and confident in their goals. All climate advocates must also confront the realities of US politics - and since policy and politics are closely intertwined, I recognized that K2P would need to address this area as well. This requires that I be forthright about my own political orientation.

Some readers of K2P have noted that while I call the work a *handbook*, it bears more than a passing resemblance to a *textbook*. Yet to be fully useful in classroom settings a text should include supplementary material providing a more thorough platform for students and instructors to engage with the material. I have provided many such resources on the book website at www.fromknowledgetopower.com, including guides to reliable internet sites on climate science and policy, a comprehensive glossary, an introduction to national and Oregon-specific advocacy groups, and a climate bookshelf with capsule summaries of recommended titles. This curriculum guide complements these resources by offering a chapter-by-chapter catalog for working through the material. For more perspectives on K2P, see the Author Q&A and the blog piece "Introducing K2P" on the book website, and the reviews that have appeared on Goodreads and Amazon.

Each chapter of this guide is organized into four sections. *Key messages* provide capsule summaries of the most important takeaways for each chapter, and are organized approximately in step with the text. *Review and comprehension questions* test the student's understanding of many of the important ideas in the chapter. Most of these questions are answerable by directly consulting the text alone, although they may certainly open up avenues for further inquiry. *Research* *and discussion questions* are more open-ended, and are intended as springboards for students and instructors to delve more deeply into selected aspects of the material, often including personal reflection. Finally, *Resources for further learning* offer jumping off points for those interested in diving deeper. Some of these resources are included in the Endnotes (print and e-book versions), but I have also cited other works as well as new materials that have appeared since I surrendered the completed manuscript to the publisher for layout and design purposes, in early 2021.

Visualizations and modeling of climate and energy systems add a valuable dimension to learning. The En-ROADS modeling system from Climate Interactive is particularly useful as a K2P supplement, as it supports a thoughtful and engaging dialog in which students interactively experiment with different policies to see their effects on key climate, energy and economic variables. The climate and carbon cycle models supporting David Archer's fine *Global Warming* book are also valuable, especially the MODTRAN and GEOCARB modules examining Earth's energy balance and carbon cycle, respectively. Finally, my colleague Frank Granshaw at Portland State has created the Climate Toolkit (pdxscholar.library.pdx.edu/pdxopen/28/), a collection of online climate education exercises that is an excellent complement to K2P.

K2P is appropriate for college and university courses at the undergraduate or graduate level, where the intention is to provide a comprehensive overview of climate change for those who recognize the increasing importance of attaining literacy in the field. Students concentrating in green business, law, social sciences and the environmental humanities are among those who will benefit from engaging with the full scope of the material. The book requires no specific background in any aspect of science or mathematics, but the semi-quantitative approach, abundant scientific data and high information density may nonetheless challenge some readers. K2P is not intended for students concentrating in earth or environmental sciences, but it may be useful as a policy supplement to accompany detailed texts in these fields, which often omit or give short shrift to this area. With proper supplementation, including the modeling programs listed above, K2P is also suitable for upper division elective courses taken by undergraduates concentrating in fields such as molecular cell biology, chemistry, physics and engineering.

My colleague at Portland State, Dr. Rachel Slocum, has observed that the underlying paradigm of K2P is ecological modernism. In her review of K2P for *Geographical Review*, she defines this as a framework in which "...human ingenuity can improve existing institutions, technologies and capitalist markets, enabling society to manage and overcome human-environment ‘challenges’ such as climate change." Indeed, a great deal of K2P is devoted to unpacking the details of how this might be done, with the recently published US energy transition roadmaps to net zero emissions providing essential context. For humanities and social science students, this information provides critical factual grounding to shape their development of cultural and political paradigms in response to the climate crisis. Students majoring in business, law and engineering, in contrast, will recognize themes from their core disciplines in these parts of K2P. My hope is that K2P may inspire some of these talented students to apply their technical skill sets to whatever aspect of the climate challenge they feel most drawn to.

K2P was written with the broadest possible audience in mind, consistent with my training in CCL's bipartisan approach to climate advocacy and my own background and sensibilities - as a scientist interested first and foremost in solving the carbon pollution problem, and a citizen with a mix of liberal and centrist political views that naturally lead me toward inclusivity and viewpoint diversity. K2P certainly reflects my firm belief that all political identity groups with a genuine desire to contribute solutions, from progressives to center/right conservatives, should be welcome at the negotiating table. Excluded, however, are the individuals and groups, including a prominent part of the US fossil fuel industry, who fund climate denialism and exploit weaknesses in our laws and institutions to attack science, promote the fossil fuel-dominant status quo, and neglect our obligation to leave a healthy climate for future generations. In K2P, climate change denialism is discussed in several of the early science chapters and in the chapter dedicated to the fossil fuel industry.

While K2P's stand against climate denialism meets no resistance in academic circles, the same cannot be said of its primary emphasis on technical and policy solutions. For a good number of climate advocates and academics on the progressive Left, addressing social inequity is of overriding importance and its solutions must always be prioritized in climate policy. In contrast, in K2P I offer a balanced treatment that recognizes the clear relevancy of social equity in many climate policy contexts, yet consistently advocates for compromise. The need for climate advocates of all political persuasions to find common ground is particularly urgent in view of the need to oppose the well organized, denialist hard Right. I also note that the equity triangle is not limited to social equity but includes intergenerational equity and legal standing for objects in the natural world. On these latter equity dimensions there is little or no daylight between K2P and its critics on the progressive Left.

I thank again my many friends and colleagues in the climate advocacy community for their unremitting support for this book project; it would not have been possible without them. Special thanks are due to Professor Frank Granshaw, who developed the Climate Toolkit and adopted K2P for his undergraduate class at Portland State University in Winter 2022. I am also indebted to the student publishing team led by Callie Brown at Ooligan Press, who conceived of "K2P" as an effective rubric to designate the book and, in turn, its approach to climate education. Full acknowledgments for the K2P project may be found in the text.

Chapter 1 – Earth’s Climate System

1. Describing the Earth
2. The Sun and the greenhouse effect
3. The Carbon Cycle
   Carbon movements through land, ocean and atmosphere
   Short and long timescales of the carbon cycle

Key messages

A strong working knowledge of climate science and policy can make advocacy work much more effective. It empowers climate advocates to become a resource for lawmakers and community leaders who make the key decisions, giving them a seat at the table.

The Earth’s climate system consists of the atmosphere, oceans, ice (cryosphere), land surface, and biosphere. It is in constant motion. Natural processes such as ice melting, water evaporation and wildfires lead to continuous interchange of material and energy among these five parts of the system.

Naturally occurring greenhouse gases (GHGs) in the atmosphere – water vapor, carbon dioxide, methane, nitrous oxide and ozone - trap solar heat through the natural greenhouse effect, raising the surface temperature and making the Earth ideal for human flourishing.

The Sun and the deep underground each influence Earth’s climate system. The major cause of global warming is our rapid transfer of the carbon in fossil fuels from the deep underground into the surface climate system.

The atmospheric blanket of greenhouse gases is thickening because of fossil fuel burning and other human activities such as land use change. This causes the *anthropogenic greenhouse effect*, which has increased the average surface temperature by 2°F since the mid 19^{th} century.

Before the Industrial Revolution, Earth was approximately in an energy balance with Space: incoming sunlight was balanced by outgoing Earthlight. This kept the average surface temperature roughly constant. Today, Earth is far out of energy balance – much more heat enters than leaves – and temperatures are steadily increasing.

Human carbon dioxide emissions are responsible for the largest share of the anthropogenic greenhouse effect. As part of Earth's carbon cycle, the land and oceans absorb roughly equal amounts of this emitted carbon dioxide from the atmosphere. A little over half the emissions are absorbed within a decade, partly by plant photosynthesis.

The remaining carbon dioxide emissions persist in the atmosphere for up to several hundred thousand years, giving rise to *climate inertia*. This means that, unless we carry out large scale removal of carbon dioxide, warmer temperatures will persist for a very long time after emissions are halted.

In the past few decades atmospheric carbon dioxide levels have increased by 1-3 parts per million (ppm) each year. Complex natural variations in the *land carbon sink* account for why the amount of increase each year varies so much, despite the fact that anthropogenic carbon dioxide emissions have been rising at a steady rate. Incomplete understanding of land carbon dynamics limits our ability to project what the future climate will be like.

Review and comprehension questions

1. *Why is it important to distinguish between the climate system and the two key elements that lie outside of this system?*

2. *Carbon dioxide is only the fifth most abundant gas in Earth's atmosphere. What are the top four, and which of these are greenhouse gases? Has human activity changed the relative abundance of any of these gases?*

3. *Figure 1.1 shows a conceptual map of Earth's climate system. Which components in the figure belong to each of the five major parts of the system? In which parts of the system do you find the six forms of carbon depicted in Figure 1.3?*

4. *What is the fate of biomass on the Earth's surface if oxygen begins to build up in the atmosphere, as actually occurred early in Earth's history?*

5. *How does the "bare rock" model of Earth's climate illustrate the importance of the greenhouse effect?*

6. *Deforestation is an important cause of anthropogenic climate change. Given the principles of Earth's energy balance, however, is there any way that deforestation promotes <u>cooling</u> of surface temperature?*

7. *Although fossil fuel emissions have been rising steadily, the rate of atmospheric carbon dioxide buildup is very uneven from year to year. How is this explained?*

8. *How would the Keeling curve (Figure 1.4) differ if Earth's land masses were evenly distributed between the North and South hemispheres, rather than being concentrated in the North? Explain as thoroughly as you can.*

9. *How is biological respiration similar to human burning of fossil fuels? How does it differ?*

10. *Suppose a large slug of carbon dioxide, say 1 Gigaton, is suddenly emitted today. About how much remains in the atmosphere after 10 years? 1000 years? 10^5 years?*

Research and discussion questions

1. *Using Figure 1.1 as an initial guide, draw from your own experience to suggest as many ways as you can in which the five parts of the climate system are interconnected.*

2. *Adding the atmosphere to the "bare rock" model improves its estimate of Earth's surface temperature, but the resulting model is still very crude. What other aspects of the climate system might be important to add to the model? Is there anything you would leave out? (see chap. 3)*

3. *Do you agree that the phenomenon of climate inertia poses a challenge for climate advocates? If so, how would you address this challenge in advocacy conversations with business, community or government leaders?*

4. *Mars and Venus are composed of similar materials compared to Earth, yet carbon dioxide is by far the most abundant atmospheric gas on both these planets. Do some research on the question of why Earth differs. Why has the carbon cycle on Earth operated to make CO_2 only a minor component of the atmosphere? Is it related to the "Goldilocks" principle mentioned on p. 13?*

Resources for further learning

An excellent recent review of the carbon cycle by The Royal Society is: *The carbon cycle: Better understanding carbon-climate feedbacks and reducing future risks*, see https://royalsociety.org/-/media/policy/projects/climate-change-science-solutions/climate-science-solutions-carbon-cycle.pdf

An easy-to-run interactive model (MODTRAN) simulating the greenhouse effect is available at http://climatemodels.uchicago.edu/modtran/ The GEOCARB model of Earth's carbon cycle is available at http://climatemodels.uchicago.edu/geocarb/. Both models are available from the University of Chicago.

More detailed descriptions of the carbon cycle and the greenhouse effect, including some basic mathematical treatment, are available in Prof. David Archer's fine primer: *Global Warming, Understanding the Forecast* (2nd ed., 2010) This text is suitable for undergraduate students who have completed a few terms of college chemistry, and includes exercises using the models described above.

A thorough list of reliable web resources on climate change is available on the K2P book website; see https://www.fromknowledgetopower.com/science-resources/

Chapter 2 – Earth Out of Balance

1. Natural influences on climate
2. Carbon dioxide and temperature
   Denial of the data
3. Paleoclimatology
4. Human influences on climate: greenhouse gases
   Methane and nitrous oxide
   Ozone, halocarbons and short-lived pollutants
5. Aerosols and clouds
6. Land use change

Key messages

Climate change drivers, or forcings, are natural or human influences that shift Earth's energy balance. Most drivers, like greenhouse gases, affect how fast Earthlight is emitted into space. However, some drivers work by changing the reflectivity (albedo) of Earth's surface, while changes in sunlight intensity alter the rate of energy input.

The natural drivers are sunlight and volcanoes, which transfer material from the deep underground into the climate system when they erupt. Aerosols and dust from volcanic eruptions cool the planet, and sunlight intensity has been nearly constant in the past century. Natural forces cannot account for global warming.

The Earth's average surface temperature has increased by about 1.1°C since the mid-19th century. The amount of warming varies considerably from year to year, and is always significantly higher on land compared to ocean.

The Arctic has warmed twice as fast as most other parts of the Earth. As reflective white ice melts, more of the surface becomes dark blue ocean, which absorbs sunlight rather than reflecting it. In turn, the absorbed solar heat melts more white ice, and so on. This is called the *ice albedo effect*, an example of a *positive feedback loop*.

Over 90% of the excess heat from global warming has gone into the oceans, which, because of their high heat capacity, can take up a great deal of heat without undergoing a large increase in temperature.

Numerous aspects of the temperature record compiled by climate scientists have been attacked by climate change denialists, who operate in well organized groups that do the bidding of the fossil fuel industry.

Study of Earth's past climates reveal that surface temperatures and sea levels can be either much higher or lower than today. The way Earth's past climate has varied in response to changes in sunlight intensity or geologic forces provides a potent warning of the potential consequences if greenhouse gas emissions are not stopped.

Human activity, mainly through greenhouse gas emissions, has caused an energy imbalance of about 1% - more energy is entering the climate system than is radiated away. This imbalance amounts to about 60 times the annual energy output of humanity.

In addition to carbon dioxide, methane, nitrous oxide, ozone and halocarbons are also all greenhouse gases that trap heat. The potency of each gas compared to carbon dioxide depends on its concentration, its longevity in the atmosphere, and the extent to which its specific infrared absorption bands are saturated.

Agriculture and livestock industries are the primary anthropogenic sources of both methane and nitrous oxide. Leakage of methane from industrial operations, especially fossil fuel mining, refinement, and transport, is another major source of this pollutant.

Halocarbons, which comprise chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs) and related molecules, are used as refrigerants and in other industrial processes. Although their atmospheric concentrations are low, these gases are extremely potent global warming agents.

In contrast to the other greenhouse gases, ozone is not well-mixed in the atmosphere, and its residence time is quite short. In the lower atmosphere, ozone is mainly produced by chemical reactions of smog pollutants under the influence of sunlight.

A band of ozone exists in the stratosphere, where it protects surface life (including humans) by absorbing harmful ultraviolet radiation. CFCs react to destroy stratospheric ozone, creating the ozone hole. While CFCs and HFCs are being phased out worldwide, the slow repair of the ozone hole will increase warming.

Aerosols generated by human activity, mainly fossil fuel burning, result in cooling, a phenomenon dubbed global dimming. Aerosols also influence cloud formation, with complex consequences that can result in either warming or cooling, depending on cloud type. Uncertainties in our understanding of cloud dynamics is a major uncertainty in the projections of climate models.

Anthropogenic land use change primarily affects climate through disruption of the natural carbon and nitrogen cycles, and secondarily by changing the albedo, or reflectivity, of Earth's surface. Cumulatively, land use change has contributed about 30% to the total energy imbalance, although its contribution today is less than half that.

Review and comprehension questions

1. *Why do climate scientists express Earth's energy balance using units of power rather than energy?*

2. *Which drivers of Earth's energy balance (color plate 2) are best understood by climate scientists? For which drivers is the uncertainty greatest?*

3. *The land surface of Earth has warmed considerably more than the ocean (Fig. 2.1). Yet oceans take up more than 90% of the trapped heat from the greenhouse effect. How do you explain this apparent discrepancy?*

4. *Volcanic eruptions result in the direct transfer of carbon dioxide from underground deposits to the atmosphere. How do we know that these natural eruptions are not a major source of atmospheric* CO_2*?*

5. *Define the term "radiative forcing" and explain its connection to global warming.*

6. *Though there is a correlation between changes in atmospheric* CO_2 *and surface temperature, it is not always consistent. What factors complicate this relationship?*

7. *How do climate scientists explain the apparent sharp slowdown in global warming from 1998-2014? Answer in terms of Earth's energy balance.*

8. *What is cherry picking? How do climate change denialists use this strategy to claim that global warming is due to increased solar radiation?*

9. *Atmospheric carbon dioxide levels vary naturally over geologic time. Before the industrial era, where did the excess atmospheric carbon dioxide come from during periods when its concentration increased?*

10. *Ice core data for the past 800,000 years shows that higher atmospheric carbon dioxide levels are correlated with higher surface temperatures, but detailed analysis also often reveals that the increased CO_2 lags the temperature rise by some hundreds of years. What is the explanation?*

11. *Define the term "climate proxy" and provide a few examples, explaining how each is used to give information useful to our understanding of global warming.*

12. *Which short-lived greenhouse gas is not the direct product of any industrial process yet still has very substantial warming impact? How is this gas generated? Will putting a stop to fossil fuel burning eliminate all the gas from the atmosphere? Would that be desirable?*

13. *Why are many sources of methane and nitrous oxide emissions particularly difficult to control? Which of these gases has a greater warming impact over a 20 year time frame? Over 100 years?*

14. *Why is it important to report methane's global warming impact over both 20 and 100 year time frames?*

15. *What determines the potency (global warming potential) of a particular greenhouse gas compared to carbon dioxide?*

16. *Carbon dioxide has the lowest global warming potential of any greenhouse gas, yet it makes the largest contribution to the Earth's energy imbalance. How is this explained?*

17. *Banning of CFCs by the 1988 Montreal Protocol is considered a huge success of international diplomacy because it removed the cause of the ozone hole over Antarctica. However, the treaty also affected global warming, and not always in positive ways. How did the Montreal Protocol mitigate warming? How did it worsen it? Are all its effects correctable?*

18. *What causes global dimming? Distinguish between the natural and anthropogenic causes of this phenomenon. What will happen to global dimming as the use of fossil fuels is phased out in the coming decades?*

19. *Wildfires in the far northern boreal forests of Canada and Siberia are of concern beyond their effects on the carbon cycle. What additional global warming driver do these fires implicate? How does this driver work?*

Research and Discussion questions

1. *Watch the interview of the conservative Australian politician Nick Minchins by climate scholar Naomi Oreskes, available at https://www.youtube.com/watch?v=7ZQNiDIBxO4. Why does Mr. Minchins accept the findings of science in other fields, but not climate change? Do you find his position reasonable? Persuasive? Why or why not?*

2. *Eliminating fossil fuel burning would dramatically curb further increases in atmospheric CO_2. How else do you think this action would affect the Earth's energy balance? Does fossil fuel burning affect any of the other drivers? As necessary, do some research to look into how all the various drivers depicted in color plate 2 may (or may not) be linked to fossil fuel burning.*

3. *Consider some of the main ways in which humans alter the natural landscape, including deforestation, industrial agriculture, removal of wetlands, and urbanization. How do these land use changes affect the Earth's climate by way of altering natural carbon and nitrogen cycles? How do they directly affect Earth's energy balance with space?*

Resources for further learning

In addition to detailed debunking of the many false claims of climate change denialists, the Skeptical Science group also spearheads an effort called The Consensus Project, theconsensusproject.com, which offers accessible graphics explaining the overwhelming scientific consensus for climate change. The group's seminal publication is found at https://iopscience.iop.org/article/10.1088/1748-9326/8/2/024024

For remarkably thorough weekly updates on key new scientific findings about climate change, see https://skepticalscience.com/ and scroll down to Latest Posts, in the column on the left side of the page.

An updated version of Color Plate 2, Drivers of Climate Change, can be found in chapter 7 of the Working Group I contribution to the IPCC6 report (2021). See https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter_07.pdf As might be expected, this shows worsening of the Earth's energy imbalance with space, compared to the IPCC5 report from 2013.

More information about the different types of clouds and their effects on global warming is available at https://ec.europa.eu/research-and-innovation/en/horizon-magazine/qa-why-clouds-are-still-one-biggest-uncertainties-climate-change

A thorough list of reliable web resources on climate change is available on the K2P book website, see https://www.fromknowledgetopower.com/science-resources/

The Real Climate website is dedicated to blogs by climate scientists, often concerning papers in the recent literature that have received popular attention. See https://www.realclimate.org

Chapter 3 - Climate Models & Carbon Budgets

1. A cornucopia of fossil fuels
    Reserves and resources
2. Climate models and carbon budgets
    Basics of climate modeling
    Climate models: simple and complex
    Reliability of climate models
    Carbon budget estimates
3. Pathways for decarbonization

Key messages

Fossil fuels are all hydrocarbons, and comprise coal, oil and natural gas. The ratio of carbon to hydrogen in these fuels determines the amount of CO_2 emitted when a given quantity is burned. Coal burning emits nearly twice the CO_2 compared to natural gas, while petroleum is intermediate.

Coal formed from abundant plants on land during Earth's Carboniferous Period, while oil and gas formed together from marine phytoplankton. Reflecting these origins, the companies mining coal are distinct from those drilling oil and gas in marine (or formerly marine) environments.

The reserve to production ratio (R/P) indicates the amount of a fossil fuel reserve that remains at current mining rates. R/P has remained constant over time because reserves increase when new resources are found and become viable to develop.

Fracking technology allows previously inaccessible oil and gas resources to become minable reserves. Far more reserves are available than can be safely mined, for global warming to be limited to 1.5°C or 2.0°C above preindustrial levels.

1.5°C to 2.0°C above preindustrial levels is the amount of warming thought manageable and (perhaps) preserving of Earth's climate system as experienced since the last Ice Age ended 12,000 years ago. These temperature targets are embodied in international diplomacy through the 2015 Paris Agreement.

Carbon budgets are based on detailed computer models of Earth's climate system that include descriptions of the carbon cycle. The budgets indicate the amount of CO_2 that can be emitted while limiting temperature increases since the preindustrial era to a given level, such as 1.5°C or 2.0°C.

Climate models incorporate physical and chemical laws that govern the climate, and detailed descriptions of many aspects of the Earth system. They are tested against experimental measurements of Earth's climate in both the recent past and over geologic time. Models are becoming more reliable and show that global warming unquestionably arises from human activity, not natural variation.

Climate models are essential because they incorporate negative and positive feedback loops. Positive feedbacks amplify warming and include the ice albedo effect (chap. 2) and the greater capacity of warmer air to hold water vapor, a potent greenhouse gas. Negative feedbacks dampen warming and include increases in heat radiation from Earth's surface and the greater efficiency of plants to fix carbon as CO_2 levels rise.

Earth's climate sensitivity, ΔT_{2x}, is a key parameter that indicates the increase in average surface temperature when atmospheric CO_2 levels are doubled. The best current estimate for ΔT_{2x} is 2.6°C-3.9°C, reached at a CO_2 level of 560 ppm.

At present emission levels, the carbon budget for a 1.5°C world will likely be exceeded within 10-15 years. There is somewhat more tolerance for near-term emissions to maintain a 2.0°C world, but either scenario requires sharp emissions decreases. The rate of global emissions increase slowed in the second decade of the 21st century, but a clear plateau has not yet been reached.

Representative concentration pathways (RCPs) are model-based scenarios in which future GHG emissions levels are projected to peak in different years and then decrease at varying rates until net-zero emissions are attained. Because some emissions are difficult to eliminate, to reach net zero the models incorporate atmospheric carbon removal methods, termed *carbon negative*.

Review and comprehension questions

1. *How does the way fossil fuels formed over geologic time embody the popular notion of these fuels as "buried sunlight"?*

2. *Distinguish clearly between fossil fuel reserves and fossil fuel resources. What triggers the reclassification of a fossil fuel deposit from a resource to a reserve, and how does this explain why R/P values often remain constant over time?*

3. *Carbon taxes (see chap 7) are levied according to the amount of carbon dioxide emitted from burning a given quantity of fossil fuel. By this criteria, which fossil fuel should be taxed at the highest rate, and which at the lowest?*

4. *Explain how isotope analysis of carbon dioxide demonstrates that the elevated atmospheric levels of this gas come from burning fossil fuels.*

5. *What makes the Paleocene Eocene Thermal Maximum (PETM) a particularly good analog for present day climate change?*

6. *Distinguish clearly between climate and weather. How is it that weather forecasts are unreliable beyond a few weeks or less, while climate projections decades into the future are thought to be reliable?*

7. *What are two key reasons why climate models - computer simulations - are absolutely necessary as a complement to experimental measurements of the various parts of the climate system?*

8. *Very early climate models included the energy balance of the Earth with space, but were missing a great deal of detail about many other aspects of the climate system. What key elements needed to be added to early climate models to make them useful in formulating carbon budgets?*

9. *Which of the positive and negative climate feedbacks in Table 3.2 directly implicate the functioning of Earth's carbon cycle? How do they do so?*

10. *How does data from the past climate record, including the ancient Earth as recorded in ice cores (chap 2), help improve climate models?*

11. *Carbon budgets for limiting warming to* 1.5°C or 2.0°C *are often expressed in terms of* CO_2 *emissions alone. What is missing from these budget calculations?*

12. *Climate scientists model representative concentration pathways (RCPs) together with carbon budgets. What do RCPs contribute that is complementary to the carbon budget numbers, and why is this important?*

Research and Discussion questions

1. *About 20 years ago, the notion of "peak oil" garnered a great deal of popular attention, driven in part by the early work of geologist M. King Hubbert, who accurately predicted a US peak in oil production in the 1970s. Do some research on the peak oil concept. What essential aspect of fossil fuel production dynamics did Hubbert's analysis fail to account for? What technology has been most crucial to debunking the peak oil idea today?*

2. *Do you think that carbon budgets and representative concentration pathways are useful in formulating responses to anthropogenic climate change? How might you use these concepts in advocacy work?*

3. *The National Oceanic and Atmospheric Administration (NOAA) has a very useful information page on climate models, see https://www.climate.gov/maps-data/climate-data-primer/predicting-climate/climate-models Links from this page lead to other, more detailed resources. With this information in hand, how would you describe the principal components of a general circulation climate model? What most limits the predictive capacities of these models today, and how do we know that the models are reliable in spite of their limits?*

Resources for further learning

Prof. Kerry Emanuel at MIT has written an excellent primer on climate science, with particular attention to climate modeling. See *Climate Science and Climate Risk: A Primer*; https://climateprimer.mit.edu/climate-primer.pdf

Readers wishing to lend their unused personal computer power to help model Earth's climate can sign up at www.climateprediction.net to join a team of Oxford, UK climate scientists.

An excellent resource to learn about climate modeling from very first principles is The Climate Modelling Primer (Fourth Edition) by Kendal McGuffie and Ann Henderson-Sellers (Wiley-Blackwell, 2014).

Chapter 4 - Impacts of Climate Change

1. Evitable and inevitable impacts
    Climate tipping points
2. Ice loss and sea level rise
3. Extreme weather
    Earth's hydrological cycle
4. Ecology and biodiversity
    Endangered species
    Fragile marine ecosystems
    Forests and terrestrial ecosystems
5. The human world
    Food and water
    Health
    Economy
    Intergenerational equity

Key messages

The Intergovernmental Panel on Climate Change (IPCC) uses a framework called Reasons for Concern (RFC) to describe the impacts of climate change. Five RFCs encompass the full range of impacts, including unique and threatened systems, extreme weather, disproportional effects on vulnerable groups, global aggregates such as the economy, and large-scale singular events (tipping points).

A watershed 2018 IPCC report on climate impacts showed that nearly all impacts are substantially worsened as warming increases from 1.0°C to 1.5°C to 2.0°C. Prior to this report the deleterious effects of just a half-degree of additional warming had not been well appreciated.

Tipping points reflect the potential for all or part of Earth's climate system to cross irreversible boundaries, locking in damages. Tipping points include large permafrost methane releases, slowing/stopping of key global ocean currents, runaway tropical deforestation, and ice sheet collapse. An extreme potential outcome is creation of a "hothouse Earth" with much higher temperatures and sea levels.

Sea level rise comes from expansion of water volume at higher temperature, and from melting of glaciers and polar ice sheets on land. Human activities have raised sea level by 8 inches so far, with a worst-case projection of 8 feet by 2100 if emissions are not curtailed. In addition to existential threats to coastal communities, sea level rise also worsens nuisance flooding and storm surges on the coasts.

Attribution science is a new branch of climate science that uses increased computer power in models that allow assignment of the human contribution to specific extreme weather events. This is particularly useful in detailing the human role in heat waves, hurricanes and intense rainfalls.

Extreme weather events such as hurricanes, wildfires, floods and droughts can all be related to the way higher temperatures intensify Earth's hydrological cycle. Through global circulation patterns, this intensification creates more extremes of moisture and dryness, and also drives larger scale phenomena like increased desertification.

Climate change is a threat multiplier to ecosystems, augmenting the severe damages that humans have already caused by indiscriminate removal of minerals, fiber, and other commodities. Deforestation caused by human encroachment poses a severe threat to these unique ecosystems, especially in tropical regions.

Human impact on the biosphere, including through climate change, is driving the sixth major extinction of species in Earth's history. Extinction rates have sharply risen across all major groups of animals, including mammals, birds, fish and reptiles.

The unique coral reef habitat is severely stressed by climate change, through ocean warming and acidification. Oceans are 30% more acidic than at the start of the industrial revolution, caused directly by their uptake of atmospheric CO_2. This has widespread detrimental effects on ocean ecology.

Climate change is impacting food and water resources in the US. While large industrialized farms have so far adapted, effects on small farms and tribal communities are more significant. Increased dryness of the southwest and altered rainfall patterns elsewhere drive droughts and floods throughout the country.

Human health effects from climate change include illness and death from heat waves, increased prevalence of bacterial and viral disease and worsened air pollution from higher rates of ground-level ozone production. Health effects are substantially worse in low income communities and communities of color.

Both adaptation and mitigation of climate change are costly, and both will be needed in the upcoming decades. Yearly costs of extreme weather events are rising sharply and may soon impact the national economy.

The question of intergenerational equity embodies our obligation to preserve a stable climate for future generations. The requirement that costs be borne now for the sake of future generations is the key political dilemma posed by climate change.

Review and comprehension questions

1. *Some aspects of the natural world are already severely threatened by the 1.1°C warming experienced to date. What do these elements of the global ecosystem share that makes them so vulnerable?*

2. *How do the IPCC findings on climate impacts argue for an urgent need to spend on adaptation measures? Which parts of the US are particularly vulnerable to the most economically costly impacts of climate change? Are these regions leading adaptation efforts?*

3. *What aspects of US society have not yet experienced significant climate change impacts? Name at least two such aspects and explain why they have so far been resilient.*

4. *What is meant by a climate change tipping point? Does reaching a tipping point always imply a large-scale global effect? Does it always imply irreversibility?*

5. *What factors are most important to determining sea level rise? Which parts of the cryosphere can melt without causing sea levels to rise?*

6. *All the worlds oceans mix through global circulation, yet sea level rise differs substantially at coastlines around the world. What factors contribute to this variation? Which US coasts are most vulnerable, and why?*

7. *What is the goal of attribution science? Summarize the approach used by climate scientists working in this new subdiscipline.*

8. *How might rising sea levels impact supplies of groundwater used for drinking, irrigation and other purposes?*

9. *How does global warming drive more intense hurricanes, floods, droughts and wildfires? Consider your answer in terms of the operation of the hydrologic cycle.*

10. *Explain how heat is transferred from the Earth's surface into the troposphere.*

11. *What is causing desertification in the American Southwest? How does this phenomenon impact the lives and livelihoods of people in this region? What dimensions of this problem are exacerbated by existing social inequities?*

12. *CO_2 fertilization provides a negative feedback that helps mitigate the impact of global warming (chapter 3). How does this phenomenon work at the level of the photosynthesizing plant cell, and what is the associated impact that worsens the spread of wildfires?*

13. *How does biodiversity contribute to the health of human society?*

14. *What are the factors contributing to the rapid demise of coral reefs in recent decades? What are the consequences of coral reef loss for biodiversity and human economies?*

15. *What is the root cause of ocean acidification? Can you find a way to explain this phenomenon without invoking details of the chemistry involved?*

16. *The impacts of climate change extend far beyond those of more localized environmental damages. How does climate change impact food and water resources, public health and the economy? Give at least two example for each of these aspects.*

17. *How do the US federal and state governments bear responsibility for increasing the economic damages from climate change? Can you think of examples beyond those mentioned in the text?*

Research and discussion questions

1. *The field of attribution science is receiving attention by environmental lawyers who are bringing lawsuits against companies in the fossil fuel industry. Why might the findings of attribution science be helpful to these individuals? See chapter 6 for ideas.*

2. *The impact of dryer, hotter weather on wildfire damages is self-evident, but some people see another factor at work - one that is often also invoked with respect to the damages caused by sea level rise and coastal hurricanes. What might these particular, seemingly disparate events have in common at a social or governance level? Is it possible to assign responsibility?*

3. *Periods of rapid climate change are often associated with major mass extinctions. In fact, it is commonly said that Earth is now in the throes of its sixth major extinction. How is the present extinction event distinguished from some of the earlier events? What does it have in common with them? Consider both the causes and the consequences for Earth's biosphere.*

4. *Discuss why the notion of intergenerational equity is so fundamental to the climate problem. What rationale is given in the text for why the discount rate should be low (1%) rather than high (5%)? Do you agree?*

Resources for further learning

The single best resource for learning about the detailed impacts of climate change in the US is volume II of the fourth National Climate Assessment (NCA4), published in 2018. See https://nca2018.globalchange.gov NCA4 explains overall impacts and also delves into regional effects across the country. The Trump administration attempted to weaken this document before publication, but was unsuccessful.

Two of the best popular books by journalists on climate impacts are *The Sixth Extinction*, by Elizabeth Kolbert (on biodiversity), and *The Water Will Come*, by Jeff Goodell (on sea level rise).

A good resource on the new field of extreme weather attribution to anthropogenic causes is the world weather attribution website, at https://www.worldweatherattribution.org This site includes summaries of the studies that have been done on individual extreme events. A very readable book-length description of this new field is Angry Weather, by Friedericke Otto.

Issued annually by the National Oceanic and Atmospheric Association (NOAA), the Arctic Report Card offers detailed tracking of the profound changes in the Arctic environment brought about by anthropogenic climate change.

The International Union for the Conservation of Nature (IUCN) harnesses the expertise of over 1400 member organizations to offer a comprehensive view of human impacts on the global environment and the role of climate change in exacerbating those impacts. See https://www.iucn.org/

Interlude - The Renewable Energy Transition

The present situation
Social and cultural dimensions
Roadmaps for the US
An advocacy agenda for the 2020s

Key messages

Restraining global warming below 1.5°C would require greenhouse gas (GHG) emissions reductions of approximately 10% per year, beginning immediately. This would demand an unprecedented worldwide movement to intentionally restrict economic growth, and is likely out of reach.

Nonetheless, climate stability at or below 1.5°C is attainable by rapidly expanding carbon-free energy, curtailing fossil fuels, and developing negative emissions technologies. Key elements of US roadmaps are: a nationally unified carbon-free electricity grid, electrification of end uses, green fuels, improved materials and energy efficiency, and aggressive curtailment of climate pollutants beyond CO_2.

The United Nations Emissions Program (UNEP) and the International Energy Agency (IEA) estimate that the temperature rise will stabilize between 2.5°C and 3.0°C given present trajectories and international commitments. Modest achieved decoupling of economic growth from GHG emissions offers a basis for optimism.

Shared socioeconomic pathways (SSPs) offer models for how social cohesion and international norms affect how the carbon-free energy transition may play out. SSPs are integrated with RCPs (projected emissions scenarios; chap 3) to examine how dozens of possible futures may emerge. Preliminary data suggest that scenarios that give specific attention to reducing socioeconomic inequality are more efficient in fostering the green transition.

The Princeton Net Zero America modeling effort offers perhaps the most thorough, granular US roadmap for reaching net zero emissions by 2050. The key messages from this work are that the energy transition is readily affordable and can be accomplished using already existing technologies.

The Climate Crisis Action Plan developed by US House Democrats is largely embodied in the Build Back Better agenda of the Biden administration. Enactment of all or a significant part of this plan would be a major step forward. Many avenues exist for climate advocates to bring the agenda to fruition, especially at state and local levels.

Review and comprehension questions

1. *International climate meetings, such as the UN Glasgow conference in Fall 2021, often yield apparently conflicting messages about global progress on the climate problem. Why is it reasonable to be optimistic about our ability to limit warming to under 2.0°C? Why are some people pessimistic?*

2. *Is it plausible to meet the 1.5°C target without overshoot? If we do go above 1.5°C compared to preindustrial temperatures, how do we get back below this target without waiting for the natural carbon cycle to operate over centuries, milleniums, and longer?*

3. *Explain how the shared socioeconomic pathways (SSP) framework intersects with the relative concentration pathway (RCP) analysis described at the end of chapter 3. What are the key early findings of this new work? How might they bolster arguments from political progressives, regarding the importance of connecting climate policy with social justice?*

4. *What are some of the key challenges that must be overcome to meet the climate goals articulated in the US roadmaps? Which of these are purely technological and which are more political in nature?*

5. *Why was the report from the US House Select Committee on the Climate Crisis significant? Is it a visionary document? Is it proposed legislation? Something in between? Was it bipartisan, with input from both Republicans and Democrats?*

Research and discussion questions

1. *The initial paragraphs of the Interlude emphasize how the US energy transition is linked to similar transitions underway in other countries, all under the auspices of the 2015 Paris Agreement. Do some research on the Paris Agreement and its antecedent, the Kyoto Protocol. What distinguishes these two international accords? Will the Paris Agreement be successful in*

wake of the Kyoto failure? What do you think are the strengths and weaknesses of the Paris Agreement?

2. *For each of the five key elements found in comprehensive roadmaps for the US energy transition (p. 88-89), pose a substantive question asking how the challenge of implementing this element will be met. It will be helpful to consult materials in other chapters of the book or elsewhere. For example, given the major sources of methane and nitrous oxide emissions (chap 2), how much reduction is likely to be practical in the short term, and what would it take to achieve more? Detailed consideration of these elements is taken up in chapters 7-10.*

3. *Look up the Princeton Net Zero America roadmap at https://netzeroamerica.princeton.edu/?explorer=year&state=national&table=2020&limit=200. The NZA actually consists of five different roadmaps. How are they similar and different from each other? Are you particularly drawn to some solutions and not to others? For solutions that you do not favor, how much (if at all) are you willing to compromise to get the job done?*

4. *Table i.3 lists some suggested advocacy actions by decade. Which of these actions might impact your present or possible future vocation, either positively or negatively?*

Resources for further learning

The CarbonBrief website is an excellent resource hosting articles by experts that explain climate science and future emissions scenarios. As an example, the third and last portion of the sixth IPCC report contains emissions scenarios that have been subject to substantial misinterpretation. See https://www.carbonbrief.org/guest-post-how-not-to-interpret-the-emissions-scenarios-in-the-ipcc-report/ for a short article that clarifies how these scenarios should be properly understood.

The United Nations Emissions Gap report, published yearly, documents progress in emissions reduction and reports on the gap between existing progress and commitments, and what would be needed to constrain warming to under two degrees Centigrade compared to preindustrial temperatures. See https://www.unep.org/resources/emissions-gap-report-2021

Chapter 5 - Climate Advocacy

Key messages

The impact of climate change can be understood as the product of three variables: population, affluence and technology. In the US, however, projected future impacts of climate change are largely insensitive to population growth. Globally, population growth is expected to significantly impact climate change only in sub-Saharan Africa.

Some people feel that climate change should be addressed by rejecting economic growth and returning to small, local economies of scale. This is the underlying idea spurring the *degrowth* movement, which would address climate change by reducing affluence. However, the political constituency for this approach is very small.

A strong consensus exists that climate change must be tackled by reducing emissions in the context of sustained economic growth. This requires decarbonizing the energy economy by applying green technology at massive scale.

Climate advocacy groups in the US span the political spectrum from progressive through center-right. The Eco-Right movement advocates solutions consistent with conservative principles of limited government. Although distinguished from climate denialists, many Eco-Right groups do not embrace the comprehensive net-zero roadmaps that climate scientists call for.

"Big Green" groups are well-funded organizations addressing climate change, typically with roots in traditional areas of environmental stewardship. They are distinguished from grass-roots, citizen organizations. The latter are typically very progressive, linking climate change solutions with promotion of social equity.

Political divisions among climate advocacy groups reflect the Democratic party split between progressive and moderate factions. Disagreements exist regarding the extent that equity should be linked to policy solutions. Further, while moderates often take a science-based, all-of-the-above approach, the rejection of nuclear power, carbon capture and carbon pricing by some progressives can also be a source of conflict.

Progressive climate groups, led by the youth-based Sunrise Movement, have recently catalyzed an enormous, promising shift in political awareness, placing climate change among the top issues before the US Congress. Maintaining this focus while forging consensus among moderates and progressive is a major challenge in the 117th Congress and beyond.

Many resources are available to citizens who wish to play an active role in climate advocacy. Local advocacy networks, often with connections to national organizations, play a key role in fostering community and providing education. Development of local climate action plans, engagement in state government processes, and targeted opposition to fossil fuel developments are among the key areas of work.

A great deal of social science research supports the decisive role of creating empowering narratives when advocating for a healthy climate. Tailoring of narratives to the particular social and moral values of the audience is an essential aspect of this work.

Review and comprehension questions

1. *Why is climate change considered a wicked problem? What are the key characteristics of such problems? What other contemporary challenges might fit the criteria?*

2. *Explain why, with the exception of Sub-Saharan Africa, population growth is not likely to be a key determinant of future climate change.*

3. *What are the key distinctions between Big Green advocacy groups and the grass roots climate advocacy movement?*

4. *Why do you think that EcoRight advocacy groups often do not embrace the full spectrum of actions advocated by climate scientists, as articulated in roadmaps like that put forward by Princeton Net Zero America?*

5. *Both the Sunrise Movement and Citizens' Climate Lobby are grass roots groups, but their memberships are very different. How would you describe the distinctions in style and strategy between the Sunrise Movement and CCL? Is there an important role for both types of advocacy? What might be the advantages and disadvantages of each approach?*

6. *What are some of the reasons given by progressives for tackling social justice and climate change together? Is there a downside to this approach with respect to assembling a political coalition that can win against entrenched opposition by fossil fuel interests? What ideas are offered in the text for how a compromise among climate advocates with differing political views might be reached?*

7. *How is the En-ROADS modeling program useful in climate advocacy? What types of audiences might be most responsive to the use of this tool?*

Research and discussion questions

1. *Write the Kaya identity in a more mathematical form, indicating the units involved in each term, and showing how they cancel. Do some research on this concept as it applies to climate change. How can the technology term be separated into two parts, and why is that separation useful in further elaborating the problem?*

2. *The text makes the claim that climate change can only be solved by working within the economic system that we have. Do you agree? Why or why not? Which groups in the contemporary political spectrum would be more or less likely to go along with this view?*

3. *Many US citizens engaged in the climate movement describe themselves as activists, but "I'm not an activist" is often given as a reason by Americans who care about the climate yet nonetheless do not get involved. K2P uses the term "advocate" instead of "activist". How do you understand the meanings of*

these labels? Do they have particular cultural connotations? Do you identify more with one or the other?

4. *A key aspect of the Jemez Principles for democratic organizing is a process by which goals and values of other groups are incorporated into one's own work. Do some research on the respective goals and values of EcoRight and grass roots progressive groups. Choosing the orientation closest to your own, how would you incorporate the other group's values in a policy proposal?*

5. *Consider the five moral axes of individual development identified by evolutionary psychologist Jonathan Haidt (p. 127-128). Which of these moral axes motivate you the most strongly? Which do not? Do some research on Professor Haidt's work. Do you think it might be helpful in forging consensus among climate advocates?*

6. *Consider the Global Warming's Six Americas study, and do some research on the potential messaging strategies developed by the Yale and George Mason University researchers who created this typology. Do you see this framework as useful in climate advocacy work? Why or why not?*

Resources for further learning

The underpinnings of moral foundations theory are described by Professor Jonathan Haidt in The Righteous Mind: Why good people are divided by politics and religion (2012).

A review of the research and underpinnings of the influential Global Warming's Six Americas study can be found at Leiserowitz et al., Current Opinion in Behavioral Sciences, DOI: 10.1016/j.cobeha.2121.04.007

Many books are available that can provide inspiration for climate advocates. Although what inspires us is usually very personal, two books that stand out for me are: Katharine Hayhoe: Saving Us (2021) and Carla Wise, Awake on Earth: Facing climate change with sanity and grace (2016).

Chapter 6 - Fossil Fuels: Business and Politics

1. The business of fossil fuels
    - *The demise of coal*
    - *Oil and gas production*
    - *Business strategies of oil and gas firms*
    - *Advocacy: divestiture*
2. Fossil fuel politics
    - *Subsidies*
    - *Promotion of climate change denialism*
    - *Advocacy: lawsuits*
3. The role of government
    - *Federal emergency powers*
    - *Basics of environmental regulation*
    - *Regulation of carbon dioxide emissions*
    - *Regulation of methane emissions*
    - *State and local actions*
    - *Transporting and exporting fossil fuels*

Key messages

Because US energy demand continues to increase, specific attention to reducing fossil fuel use and retiring infrastructure is necessary to meet climate targets. "All of the above" schemes that add both fossil fuel and renewable resources do not suffice.

Fossil fuel firms plan new infrastructure investments that would overrun carbon budgets for 1.5°C or 2.0°C worlds if executed. This is referred to as the *production gap*.

Coal's contribution to the electricity grid has decreased from 50% to 20% in the last decade, because coal mining is uneconomical compared to natural gas, solar and wind power. All major coal companies have sought bankruptcy protection. Because coal communities are so hard hit, policies eliminating this energy resource should be accompanied by programs for worker retraining and other assistance.

The US leads the world in both oil and natural gas production, and ranks third in coal reserves. A decisive US shift away from fossil fuels could spur a global movement toward carbon-free energy.

The fossil fuel industry, through mining, refining and shipping operations, is a large source of carbon dioxide and methane emissions - quite apart from the carbon dioxide produced when the fuels are later burned.

Fracking technology has driven large increases in US oil and natural gas production in the past decade, spurring a new liquified natural gas industry by which gas is shipped worldwide in liquid form on refrigerated tankers.

Oil and gas companies are beginning to develop new business models in response to pressure from governments and climate advocates. European oil majors are well ahead of US firms in their plans to reconfigure operations to reduce climate pollution.

Recent actions by US companies include greater investment in plastics, voluntary efforts to shift to more climate-friendly practices, and support for modest carbon taxes. US companies' advocacy for modest carbon taxes reflects a bias against regulation, but it does not include support for any specific legislative proposal (see chap 7).

Divestment from fossil fuel companies is driven in part by the firms' overinvestment in new infrastructure, potentially leaving trillions of dollars of stranded assets and liabilities in the event of a climate change-driven flight from the industry. Financial regulators have begun highlighting the risks of climate change, and some insurers will no longer underwrite some of the worst polluting operations.

Both green banks and shareholder pressure for transparency and climate-related disclosures complement direct divestiture. Green banks foster investment into climate resiliency and green business, and have the capacity to target local, underserved communities.

Fossil fuel companies and related interests lobby heavily against government initiatives on climate change, exploit new laws enabling "dark money" funding of supportive candidates, and fund climate denialist groups such as the Heartland Institute, which carry out disinformation campaigns.

Actions by fossil fuel companies to deliberately mislead the public are now the subject of a myriad of lawsuits. In particular, the high-profile case *Juliana vs. United States* has spawned many similar suits. Juliana plaintiffs base their case on the public trust doctrine, and demand that the US fund a national Climate Recovery Plan.

US federal and state governments have many ways to limit the fossil fuel industry agenda and promote the carbon-free energy transition. Declaration of a climate emergency by the President could spur a federally led effort to build renewable energy infrastructure, and justify a halt to fossil fuel extraction on federal land.

Industry regulation by the Environmental Protection Agency (EPA) and other entities has been effective in curtailing conventional pollutants and can play an important role in reducing methane, nitrous oxide and HFC pollution. However, EPA regulation of carbon dioxide emissions appears unlikely to win judicial approval under the Clean Air Act. New legislation will be needed to provide the authority for such regulation.

The legal process of *notice and comment* affords climate advocates an excellent opportunity to make their voices heard by state and federal agencies implementing environmental regulations. It is not uncommon for agencies to significantly revise regulations in response to thoughtful public input.

States regulate fossil fuels in diverse ways, including onshore and near-offshore oil and gas production, use of gas and coal-powered electricity, and construction of new infrastructure for transport and export. Local zoning and building ordinances to restrict fossil fuels are also gaining ground. These initiatives offer many opportunities for engagement by climate advocates.

Conservative state governments are increasingly responding to local advocacy by issuing preemptive state orders blocking local climate friendly actions. However, preemption can sometimes be successfully challenged on the grounds that local interests should outweigh state authority.

Review and comprehension questions

1. *The text (p. 135) suggests that there is no reason to consider carbon capture and storage (CCS) for coal-fired electricity power plants. What might be the rationale for this assertion, given that CCS can prevent carbon dioxide from reaching the atmosphere?*

2. *What two aspects of the trends in primary energy consumption account for the decrease in US carbon dioxide emissions since 2005 (Figure 6.1)?*

3. *Why are some domestic oil and gas companies struggling financially, in spite of the tremendous recent growth in US oil and gas exports due to fracking technology?*

4. *Can you perceive any common dynamic among the different responses of the US fossil fuel industry to the intensification of public concern about climate change? What do you think is the ultimate goal of the leading players in the industry, such as ExxonMobil and Chevron?*

5. *Many US climate advocates believe that divestment is an effective approach toward defanging the fossil fuel industry, but others disagree. What do you think are the pros and cons of dedicating efforts to this approach?*

6. *How can federal and state governments use the influence of financial institutions in the fight against climate change?*

7. *How does the largely private ownership of the US fossil fuel industry affect the ability of government to set the course toward a net-zero economy?*

8. *Why is it important to separate skepticism about the findings of climate science from climate change denial? What distinguishes these points of view?*

9. *How does the media help to transmit and validate the claims of climate change deniers, even when they have no direct intention to do so? How does this undermine the authority of scientific institutions and culture?*

10. *What are some of the ways in which the fossil fuel industry is subsidized by US taxpayers? Would the elimination of these subsidies work synergistically with a national carbon tax?*

11. *What characterizes the "new" climate change denialism? How has it arisen as a consequence of recent political shifts in the US?*

12. *What legal theories are available to hold fossil fuels companies liable for their deliberate misrepresentations of climate science and climate change impacts?*

13. *What limits the use of federal emergency powers in the fight against climate change in the US? How might the invocation of a climate emergency by the President be helpful to spur action?*

14. *What are the roles of the Environmental Protection Agency (EPA) and the federal courts in the fight against climate change? In general, why is it necessary for administrative agencies to hold a share of the power with respect to implementing environmental law? Contrast how the legal proceedings play out when either Democrats or Republicans hold the White House and/or Congress. What happens when there is single party control of the Presidency and both houses of Congress?*

15. *What are the drawbacks of the Clean Air Act as a vehicle to bring about large-scale reduction of atmospheric carbon dioxide concentrations? Are there similar limitations in writing regulations to control methane emissions? What accounts for the differences?*

16. *What arguments are available to climate advocates to persuade fossil fuel-rich states to seek other sources of revenue?*

17. *Give some general examples of local ordinances that could be enacted with the rationale of promoting a healthy climate. Can you think of other benefits to such ordinances that could help build broad support for their enactment?*

18. *The National Environmental Policy Act (NEPA) was enacted in 1970, before climate change became a concern. What does NEPA require, and of whom? How can it be used to build awareness about climate change?*

Research and discussion questions

1. *What are the political implications of the sharp drop in US coal production since 2009? Consider which states produce the most coal and the current partisan composition of the US Congress. Do you think that further contraction of the industry is inevitable? What policies would you suggest to mitigate the negative consequences of this decline for coal mining communities?*

2. *Different countries have widely disparate responses to the fossil fuel "production gap": some large producers are taking little action, while others are discussing and beginning to enact measures for a managed transition away from these fuels. Research this issue with a view toward which strategies are being considered. Which approaches do you think are most viable? See https://productiongap.org*

3. *The Russian invasion of Ukraine has led European governments to stop purchasing natural gas from Russia. What aspect of the global fossil fuel industry will likely grow as a consequence of this decision? How do you think the US should respond to the European policy? Do you think that the European decision will ultimately be a net positive for the global climate?*

4. *Progressive groups such as 350 and the Sunrise Movement have been leading advocacy efforts for fossil fuel divestment, elimination of fossil fuel subsidies, and curtailment of new infrastructure buildout. In view of these efforts, why do you think these groups also often oppose carbon pricing initiatives? Do the reasons given in Table 6.3 (p. 141) fully explain their stance? Consider your answer in view of the nature of these groups and how the pricing might be implemented (chapters 5 and 7).*

5. *The Clean Power Plan (CPP) was the Obama administration's signature effort to control climate change by way of regulating emissions of carbon dioxide. Do some research on the CPP. How much of the US economy's CO_2 emissions were covered? Would it have made a difference if it had been upheld by the courts? What does the demise of the CPP tell us about the potential for federal regulation of CO_2 emissions?*

6. *The authorities to regulate production, siting and transport of fossil fuels are divided among local, state and federal governments in a way that is often inconsistent and confusing. Use the text, notes, and other research to make a table of where the main authority is located for siting, operations and transport for coal, petroleum and natural gas. Which types of projects come under both federal and state jurisdiction? What are the advantages and disadvantages of national versus local jurisdiction for climate advocacy work?*

Resources for further learning

An excellent collection of resources on green banks has been made available by the Green Bank Network. See https://greenbanknetwork.org

An informative and extensively documented article on the Obama and Trump administration initiatives to regulate carbon dioxide emissions is available from the Union of Concerned Scientists. See: What is the Clean Power Plan? https://www.ucsusa.org/resources/clean-power-plan

A recent article explaining fossil fuel subsidies and proposing ways that the US can exert global leadership to end this practice is available from the Brookings Institution. See https://www.brookings.edu/research/reforming-global-fossil-fuel-subsidies-how-the-united-states-can-restart-international-cooperation/

Carbon Tracker is a think tank that researches the impact of climate change on financial markets. Detailed policy articles may be accessed on the fossil fuel industry, carbon markets and the energy transition.

The Sabin Center for Climate Change Law provides up to date resources on key topics in climate change law and regulation, and tracks all the climate change lawsuits in the US. See https://climate.law.columbia.edu

Chapter 7 - Carbon Pricing

1. Why price carbon?
2. Approaches to carbon pricing
3. US emissions trading systems
    Cap and trade in California
    The Northeast's Regional Greenhouse Gas Initiative (RGGI)
    Advocacy: expanding the state and regional programs
4. Prospects for federal carbon taxes
    Federal carbon tax proposals
5. Carbon pricing politics

Key messages

Climate pollution is a classic global commons problem. Polluters benefit from emitting greenhouse gases at no cost, while the impact of the pollution is felt by others as a negative externality. Carbon pricing solves this problem by requiring fossil fuel emitters to pay for their pollution, thus driving adoption of low-carbon technologies.

Carbon pricing underlies other climate policies, making them more effective by incentivizing the shift away from carbon-intensive fuels in direct proportion to the amount of carbon emitted when those fuels are burned. It also provides businesses with certainty that long-term investments in green technology will bear fruit.

Carbon pricing is most effective in the electricity sector, where inexpensive alternatives to fossil fuels are available. A robust carbon price can green the electricity grid rapidly, in turn making electrification of end uses more effective.

Carbon may be priced through either a direct tax or a "cap and trade" program that caps emissions. Carbon taxes often start low but increase yearly, while the driver for change under cap and trade is a steadily decreasing cap on emissions. Both pricing systems have been widely used, and a great deal is known about how to implement them effectively.

Two regional cap and trade programs exist in the US - a California program that also includes the Canadian province of Quebec, and a consortium of 11 Northeast states known as the Regional Greenhouse Gas Initiative (RGGI). In 2021 Washington state also passed legislation to implement a cap and trade program.

Key features in any cap and trade program include the overall scope of covered industries, and the design of rules by which allowances to emit below the cap are allocated and traded. Both the RGGI and California programs have been effective in modestly reducing emissions.

Carbon offsets are another feature of both US cap and trade programs. These are investments made by the regulated companies to catalyze emissions reductions outside the program's jurisdiction, which count towards meeting their obligations under the program.

Carbon taxes are more transparent than cap and trade programs, avoiding both the need to auction or distribute allowances, and the use of offsets. They are also faster to implement, and cover all large and small emitters economywide. In contrast, cap and trade programs exempt small emitters and may cover only a subset of the economy (RGGI applies only to the electric power sector).

A key feature of federal carbon tax proposals is a border carbon adjustment. This protects US companies by providing rebates when they ship carbon-intensive goods for sale to countries with no carbon tax or a lower tax. Similarly, imports from those countries are subject to tariffs to level the playing field for sales in the US.

Both carbon tax and cap and trade programs generate very substantial revenues, which may be dedicated to clean energy development, programs to remedy the inequitable impacts of climate change, and/or dividend return to US households (to offset higher energy prices). How revenues should be used has been a major area of political disagreement.

Despite many years of advocacy by various groups, including the grass roots Citizens' Climate Lobby, implementation of a US federal carbon tax has proven elusive so far. Most opposition comes from fossil fuel interests, but a minority of progressives in Congress also oppose carbon taxes.

Review and comprehension questions

1. *What crucial concept from economics underlies the notion of the "tragedy of the commons?" How does it apply to anthropogenic climate change?*

2. *How does carbon pricing work in synergy with other, more specific policies to mitigate climate change from different sectors of the economy?*

3. *Why does the effectiveness of carbon pricing in reducing emissions vary in different sectors of the economy?*

4. *What are the most important features to look for in assessing the merits of a cap and trade program? Which features are most crucial in a carbon tax law?*

5. *What aspects of cap and trade programs make this approach to carbon pricing less transparent than a carbon tax? Are these features related to the large difference in development times required between enactment of the laws and implementation of the programs? Are they related to the higher administrative costs of a cap and trade program?*

6. *Why should states that already pursue aggressive climate mitigation policies in many specific sectors, such as Oregon and Washington, also want to enact a carbon pricing program?*

7. *Why are carbon taxes usually perceived as less certain to bring about emissions reduction as compared to cap and trade programs? How is this issue addressed in recent federal legislation such as the Energy Innovation and Carbon Dividend Act?*

8. *What would be the likely response of fossil fuel companies to the imposition of a federal carbon tax? How would this response lead to emissions reductions on a national scale?*

9. *How are emissions allowances distributed in cap and trade programs? Could some approaches to allowance distribution undermine the perceived fairness and integrity of the program?*

10. *Why have offsets in cap and trade programs generated political opposition, especially among progressive climate advocates?*

11. *How does emissions allowance trading in cap and trade programs lead to lowest-cost emissions reductions within the jurisdiction?*

12. *What are the key distinctions between the RGGI and California emissions trading systems? Are both programs open to new members? Is there any*

geographical restriction on which US states or foreign regions can join either program?

13. *How do cap and trade programs limit the range of prices for allowances in trading markets? How would such limitations make a cap and trade program more closely resemble a carbon tax?*

14. *What are the key provisions of the Energy Innovation and Carbon Dividend Act? How does the legislation incorporate protection for domestic manufacturing? Does that protection create any favorable incentives for other countries to adopt their own tax?*

15. *What is meant by a revenue neutral carbon tax? Give two ways in which revenue neutrality could be achieved.*

16. *How might a federal carbon tax work synergistically with state cap and trade programs, leading to more rapid emissions reductions than either program would be likely to achieve on its own?*

Research and discussion questions

1. *Why might discomfort with a capitalist global economic system drive some climate advocates to oppose carbon pricing, despite its broad support among mainstream climate scientists and economists?*

2. *In cap and trade programs, what justification is typically offered for distributing free allowances? Discuss the pros and cons of this approach. Is it possible to come up with a clear criterion for deciding how many free allowances to distribute, and to which regulated parties?*

3. *Research some ways that carbon tax proposals use the substantial revenues from the policy. What revenue uses would likely be favored by conservatives? Climate scientists who want to reduce emissions as aggressively as possible? Progressives? Can you see why allocation of revenues is politically fraught? What are some of the other political dynamics that come into play when a federal carbon tax is on the table?*

Resources for further learning

A recent article that persuasively lays out the case for carbon pricing is: Max Roser, *The argument for a carbon price*, https://ourworldindata.org/carbon-price?utm_source=OWID+Newsletter&utm_campaign=dd84ae84a6-biweekly-digest-2022-05-20&utm_medium=email&utm_term=0_2e166c1fc1-dd84ae84a6-537017410

A clearinghouse for resources about carbon taxes all around the world is the Carbon Tax Center, see https://www.carbontax.org

For a book-length analysis of the policy and politics of carbon pricing in the US and abroad, see Barry Rabe, *Can We Price Carbon?* (MIT Press, 2018). A valuable book that focuses on contrasting carbon taxes with cap and trade programs is Shi-Ling Hsu, *The Case for a Carbon Tax* (Island Press, 2011).

Chapter 8 - Carbon-Free Power

1. Powering the US electricity grid
   Solar power
   Wind power
   Hydropower
   Geothermal power
   The nuclear option
2. A net carbon-free grid by 2040
3. Policies for renewable electricity
   Renewable and clean energy standards
   Advocacy: influencing state electricity policy
   Modernizing the electricity grid
   Distributed solar power

Key messages

Electricity is an energy carrier generated from primary energy sources: natural gas, coal, nuclear fission, and renewables such as wind, solar, geothermal and hydroelectric dams. Coal use has fallen sharply since 2010, and the coming years will be dominated by competition between the ascendant natural gas and renewable energy sources.

The US electricity grid is presently divided into Eastern, Western and Texas subgrids, with few connections between them. This limits operational flexibility and impedes the transition to a fully carbon-free system.

Sharp increases in solar photovoltaic (PV) and wind power are required in all projections for the carbon-free energy transition. Because these sources are intermittent, their expansion will also require new ways to store electrical energy at very large scale, over long timeframes.

Batteries can store electricity but are discharged within hours. Water kept in elevated reservoirs for hydropower is presently the only option for long-term storage, but is limited in geographic scope. Low-carbon or fully renewable hydrogen may be the best long-term storage solution, but will require decades to implement (see chap 9).

A key feature of primary electricity sources is *dispatchability* - the ability to meet consumer demand by rapidly turning the source on or off. Natural gas is highly dispatchable, but wind and solar are not. This highlights the need for long-term storage in a renewables-dominated grid.

The *capacity factor* of an electricity source reports the percentage of time it operates to generate power. Nuclear fission plants have very high capacity factors and are optimal for meeting baseload power needs. Maintaining nuclear power at its present 20% share is crucial for achieving a carbon-free grid in the next decades.

Wind and PV solar, including offshore wind, are economically competitive and technologically ready, with high expansion potential. However, new small modular reactors are needed to maintain nuclear's share of the grid, as large old plants are retired. While hydropower, geothermal and concentrated solar power (CSP) plants are largely carbon-free, their expansion capacities are limited.

Energy from coal, natural gas, nuclear fission, geothermal and CSP plants is used to boil water, generating steam to drive electrical generators. The excess heat from these operations can be captured and used, increasing efficiency and allowing coupling to other processes, such as manufacturing or heating of buildings (see chap 9). PV solar, wind and hydrothermal power sources produce electricity without generating usable heat.

All electrical power sources face environmental and sociopolitical challenges. Land use demands and ecological impacts produce opposition to hydropower, wind and solar from conservationists and nearby communities. Concerns about nuclear power include waste disposal and high water demands. Buildout of PV solar and energy storage creates the need for rare metals and other raw materials that are often in short supply or only available as imports.

The future of natural gas is the subject of a great deal of debate. Capture and safe sequestration of CO_2 emissions could make these power plants up to 90% carbon free, but upstream methane leaks cannot be fully eliminated. High social and environmental costs also attend the mining and transport of the gas.

Production and investment tax credits and funding of research have been the main federal contributions to renewable energy growth. Most policies are conceived in the states, creating a patchwork that largely follows partisan political lines.

Renewable and clean energy portfolio standards are state mandates that require increasing percentages of carbon-free electrical power over time. Renewable energy credits are associated with clean power generation and provide a convenient way to commodify these energy sources.

State public utility commissions (PUCs) regulate profit-making electric utilities that deliver electricity to consumers. In some regions, utilities also own the power sources, but two-thirds of consumers live in areas where electricity markets are deregulated. This has allowed more rapid growth of renewable power. Climate advocates can participate in PUC planning as regards the nature of the future power mix.

Home and business PV solar power, also known as *distributed solar*, has received a large boost from state *net metering* policies, which allow customers to sell back excess power to the grid. This is one aspect of a large-scale required grid infrastructure buildout that can contribute greatly to cutting energy demand and decreasing the need for long-term storage.

Review and comprehension questions

1. *Why is an emissions-free electricity grid always paramount in roadmaps to achieve net-zero US emissions by 2050? What fraction of the US grid is presently powered by zero-carbon sources? Are all of these also considered renewable?*

2. *What is meant by a primary source of energy? An energy carrier? How many truly distinct natural resources providing exploitable power are there? Would you classify wind as a primary source? Biofuels?*

3. *Describe the key components of the US electricity grid. In what ways is it helpful or accurate to conceive of the US grid as a single entity?*

4. *Distinguish between baseload and peaking power. Which power sources on the contemporary grid are best suited to provide each of these functions?*

5. *Describe the trends in how the US electricity grid has been powered for the last 70 years. What key competitions among power sources do you think will*

most clearly define the speed and effectiveness of the US electric power transition over the next few decades?

6. *Why is dispatchability an important feature of the electricity grid? Which power sources are the most dispatchable? Could a well-designed demand response policy help to mitigate dependence on these sources?*

7. *Which electric power sources generate heat as a byproduct of electricity production? Which do not? What is the common mechanism by which the heat is generated? How might heat production be useful in the context of power generation?*

8. *What are the most important ways in which today's physical electricity grid limits the rapid dissemination of intermittent wind and PV solar power? What other challenges must be met to maximally enable growth of these technologies?*

9. *Why does concentrated solar thermal power generation play such a limited role on today's US electricity grid?*

10. *Why are the capacity factors of wind and solar electricity generation so low? What are the implications of this for a future grid that relies heavily on these two resources?*

11. *List some of the disadvantages of nuclear fission alongside the disadvantages of continuing to power the grid with fossil fuels. Does this exercise help illuminate why nuclear power has divided climate advocates? What do you think the root of the disagreement might be?*

12. *What are the key challenges facing the offshore wind industry as it strives to contribute a greater fraction of power to the US electricity grid?*

13. *Is hydropower properly classified as a renewable resource? Give two reasons why this common classification could be challenged.*

14. *What limits the geothermal resource from providing more power to the electricity grid? In addition to electricity generation, how else can geothermal energy help fuel the renewable energy transition?*

15. *What might be the most reasonable arguments for retaining a small share of natural gas power on the US electricity grid for the forseeable future?*

16. *Why is the development of innovative energy storage technologies such as new batteries crucial to a green electricity grid? What other policies, if enacted, might lessen the need for large amounts of storage?*

17. *What have been the key policies that the US federal government has used to promote the carbon-free energy transition? In what ways has federal leadership fallen short?*

18. *State renewable portfolio standards (RPS) and clean energy standards have played a major role in promoting low carbon electricity. How do these two types of standards differ from each other? What range of power sources can qualify under one or both standards?*

19. *Distinguish between bundled and unbundled renewable energy credits (RECs). What role do RECs play in the transition to a grid predominantly powered by renewable sources?*

20. *What is the role of state public utility commissions (PUC) in regulating electricity production? How is the electricity price paid by consumers central to this process? How can climate advocates influence the way old electricity sources are retired and new ones commissioned in their state?*

21. *Why is improved electricity grid connectivity crucial to promoting the growth of solar and wind power?*

22. *How does net metering policy assist the growth of PV solar power? Why might consumers who install home solar panels benefit from the purchase of a solar battery as well?*

23. *Why is it important for cities to foster community solar projects? Beyond a healthy climate, what other societal goals do you think might be promoted by this policy?*

Research and discussion questions

1. *What do you see as the main advantages and disadvantages of nuclear fission as an electricity power source? Do some research into how the proposed next generation of nuclear reactors will differ from the present fleet. Does the new technology address any of the disadvantages that are widely cited as reasons to oppose nuclear power?*

2. *What do you think is the best mix of resources for powering a largely carbon-free US electricity grid in the year 2040? Using the text and other resources, develop a realistic plan that considers the advantages and disadvantages of each potential resource. Include practical and political considerations to help justify your recommendations.*

3. *The 117th Congress (2021-2022) considered both a national clean energy standard (CES) and a national economywide carbon tax as cornerstone policies to drive the green energy transition. The CES was part of a large bill called the Clean Future Act. Research the comparative merits of a CES and a carbon tax (see the EICDA bill; chap 7). Which would be likely to drive faster emissions reductions? Which political constituencies are more or less likely to support either bill?*

Resources for further learning

Two noteworthy recent books that offer deep dives into the workings of the electricity sector are Peter Fox-Penner, *Power After Carbon* (Harvard, 2020), and Leah Stokes, *Short-Circuiting Policy* (Oxford, 2020).

Americans for a Clean Energy Grid is a public interest advocacy coalition that promotes grid modernization and conversion to carbon-free power sources. The group has compiled a useful set of recent studies on grid expansion and resiliency. See https://cleanenergygrid.org/publications-news/publications/

Tap into informative updates and interviews with experts - basically, all things electricity in the US - with a subscription to *Volts*. Volts covers many aspects of decarbonization in the US, including all aspects of electricity technology and policy at the federal and state levels. See https://www.volts.wtf

Chapter 9 - Carbon-free Lifestyles

1. Industry
    Steel, cement and petrochemicals
    Policies to reduce industry emissions
    Refrigeration: hydrofluorocarbons (HFCs)
    Waste management: methane
2. Renewable hydrogen and carbon
3. Transportation fuels
    Crop biofuels and their discontents
    Carbon intensities and climate impacts
    The growing reach of the LCFS
    Biofuels: policy and advocacy
4. Electric vehicles
    Electric vehicle technology
    Policy and advocacy
5. Cities
    Urban climate plans

Key messages

Industry generates over 20% of US emissions through electricity use, heating needs, specific aspects of manufacturing processes (*process emissions*), and product disposal. The steel, cement and petrochemical industries are the largest US sources of process emissions.

Two general approaches to reducing industry emissions are improved energy efficiency and combined generation of heat and power (cogeneration). Efficiency can be improved by implementing principles of a circular economy to minimize material inputs, prolong product life, and recycle product components.

The cement industry generates 8% of worldwide CO_2 emissions. Process emissions are very high because the limestone carbonate is released as CO_2 during manufacturing.

Policies to reduce industry emissions include funding of public-private partnerships between government and industry. This can help new technologies overcome a shortfall in funding for translating basic research findings into product development.

Improper disposal of refrigerants and other products containing hydrofluorocarbons (HFCs) leads to escape of these potent greenhouse gases. A recently enacted international treaty specifies phaseout of HFCs; this mandate is mirrored in a new US law that also requires substitution of HFCs with alternative products.

Microbial processes inside landfills cause emission of *biogas*, a 50:50 mixture of methane and CO_2. New US regulations have begun to require biogas capture, and the methane recovered is now a major source of *renewable natural gas* (RNG). Potentially available amounts of RNG, however, can only substitute for a small fraction of fossil natural gas.

Hydrogen (H_2) is a crucial industrial commodity presently manufactured from natural gas, with high CO_2 emissions. However, the CO_2 can be captured (blue hydrogen), and H_2 can also be made by electrolysis using carbon-free power (green hydrogen). Blue hydrogen is available now, while green hydrogen requires a great deal of development to optimize the process and attain economies of scale.

Green hydrogen and CO_2 capture from the ambient air (see chap 10) are the key elements of a future *circular carbon economy*. In this vision, electricity is made in abundance from solar and wind power. Hydrogen from solar-driven electrolysis is then combined with CO_2 from the air to generate *syngas* - a mixture of H_2 and carbon monoxide that can be used to synthesize green fuels and commodities, without any fossil fuel input.

Transportation is the largest source of US GHG emissions. Electric vehicles (EVs) powered by a greening grid can go a long way towards reducing these emissions. The technology to electrify light duty cars and trucks, buses and rail is available now, while batteries powerful enough for heavy-duty trucking, shipping and aviation are still in development.

Electrification of the vehicle fleet is under way, but public assistance is still required to fund construction of the charging infrastructure and to provide tax credits to spur purchases. Because the shift away from gasoline and diesel vehicles will take several decades, stringent federal gas mileage requirements remain crucial for reducing emissions in the short term.

Biofuels offer another approach to cut transportation emissions, especially when electrification of the end use application is not yet available. Although high-profile failures such as corn ethanol and imported palm oil have soured some on this approach, careful modeling of carbon emissions over the full life cycle of the biofuel is able to distinguish which biomass sources can offer climate-friendly solutions.

The *carbon intensity* of a biofuel (CI) measures CO_2 emissions per unit of energy produced. CI's for biodiesel produced from some oil-rich crops, waste oil, and rendered animal fats are quite low, offering good potential for replacing fossil diesel in both the industry and transportation sectors.

California's low carbon fuel standard (LCFS) ranks alternative fuels according to their CIs, and requires fuel refiners and importers to reduce carbon emissions over time. It creates markets in which renewable fuel producers can acquire and sell fuel credits to the regulated companies. The LCFS includes hydrogen, renewable gas and other technologies, rewarding innovation of all kinds in proportion to the climate benefit of the approach.

Transportation emissions can also be cut by reducing vehicle miles traveled (VMT). VMT can be reduced in cities by including well-designed public transportation in urban climate plans. Typical city plans also incorporate low-carbon building codes, efficient appliance standards, incentives for electrification and decreased use of natural gas, and promotion of rooftop solar. Urban climate plans usually pay particular attention to ensuring that considerations of social equity are embedded throughout the policy design.

Review and comprehension questions

1. *What are some of the general challenges associated with electrifying heavy industry operations such as cement manufacture, steelmaking and production of petrochemicals?*

2. *Which electric power sources are amenable to use in heat and power cogeneration systems? Which are not? What is the key distinction?*

3. *In what ways does the concept of the circular economy extend the familiar practice of recycling?*

4. *The IPAT formula (chap 5) can be rewritten to include the concepts of energy efficiency and carbon intensity: Emissions = Population x GDP/Capita x*

Energy/GDP x Emissions/Energy. Which terms represent carbon intensity and energy emissions, respectively? Classify the policies discussed in this chapter into one or both of these categories.

5. *What is meant by the "valley of death"? What policies are available to overcome this critical barrier?*

6. *The recent comprehensive phaseout of HFCs internationally and in the US was a big victory for the climate. Why do you think that Congressional Republicans, usually unsupportive of far-reaching climate policy, voted in favor of this law?*

7. *What is the distinction between biogas and renewable natural gas (RNG)? How valuable is RNG as a replacement for fossil natural gas? Why do you think some progressive climate advocacy groups are wary of this technology?*

8. *Hydrogen is a crucial commodity used in many industrial processes, but its production from natural gas entails substantial CO_2 emissions. How might hydrogen be produced with lower or even zero emissions? Which of these technologies are presently available?*

9. *What is meant by the circular carbon economy? How does it support the notion of a net-zero energy system despite continued emissions of carbon dioxide? Where does the carbon come from?*

10. *Name three biofuels whose production is incentivized by the federal renewable fuel standard. What does this law require, and of whom? What were some of the unintended negative consequences of this law?*

11. *What are the advantages of lifecycle analysis as a tool for estimating the climate impact of biofuels? Which components of a biofuel's life cycle are typically included? What quantitative metric is used to compare the climate impacts of different biofuels and their distinct production pathways?*

12. *What biofuel impacts does lifecycle analysis fail to consider?*

13. *How does California's Low Carbon Fuel Standard (LCFS) incentivize the production of alternative, low-carbon biofuels? What are some of the ways in which this program has expanded to accommodate other technologies in addition to liquid biofuels?*

14. *Distinguish among the common modes of transportation according to the ease with which they can be electrified. What is the key technological barrier preventing rapid electrification of the more difficult modes?*

15. *What environmental impacts are associated with electric vehicle technology?*

16. *How can local, state and federal governments incentivize the adoption of electric vehicles? What are some laws or policies that could be enacted to forward this aim at each level?*

17. *Why is it important to maintain and strengthen the corporate average fuel economy (CAFE) standards for vehicle emissions during the energy transition?*

18. *What are the advantages of using wood for new building construction? What safeguards for the climate would be appropriate in regulating the practice?*

19. *Most US urban building and transportation policies incorporate social equity. What are the rationales for doing this? Which specific policies do you see as most important to furthering this aim?*

Research and discussion questions

1. *With the exception of mini-mills using recycled steel, rapid electrification is presently not possible in cement manufacture, steelmaking and production of petrochemicals. Do some research to supplement the text narrative (p. 204-206). How might emissions be reduced in these industries? Are there any approaches that are common to two or all three industries? How much reliance is there on technologies that are not yet available?*

2. *The clean products standard proposed by the Rhodium group appears to be an innovative approach to reducing industry emissions. See https://rhg.com/research/clean-products-standard-industrial-decarbonization/How does this approach differ from conventional regulation of industrial pollutants by the EPA? What does it have in common with cap and trade carbon pricing programs?*

3. *Biodiesel can be produced as either a fatty acid methyl ester (FAME) or as a hydrogenated product (renewable diesel). These two diesel fuels have remarkably different properties. Read the K2P blog on renewable diesel at https://www.fromknowledgetopower.com/renewable-diesel-for-oregon/. What are the advantages of renewable diesel over FAME biodiesel? Beyond the Oregon Clean Fuels Program (similar to California's LCFS), what policies might incentivize renewable diesel expansion in this or other states that enact similar laws? Can you anticipate some likely objections? How would you address these?*

4. *The climate advocacy community is divided on the question of biofuels. Consider the sources and uses of biomass listed in Table 9.3 (p. 213). Which sources and uses would be acceptable to you? Which would not? Discuss the reasons for your decisions. What values apart from climate, having to do with equity, economy, or other environmental concerns, come into play?*

5. *Some US towns and cities are contemplating partial or complete bans on the use of natural gas in homes and businesses. Do some research on how the implementation of these policies is going. What impacts do they have? Which groups are questioning or opposing the policies, and on what grounds?*

Resources for further learning

An excellent review article on the prospects for decarbonizing the industry sector is Jeffrey Rissman et al., *Technologies and policies to decarbonize global industry: review and assessment of mitigation drivers though 2070*, Applied Energy, 266, 15May2020, 114848, https://www.sciencedirect.com/science/article/pii/S0306261920303603

For a review of the role of hydrogen in the net-zero carbon energy transition, see Carbon Brief, *In-depth Q&A: Does the world need hydrogen to solve climate change?* https://www.carbonbrief.org/in-depth-qa-does-the-world-need-hydrogen-to-solve-climate-change/

Resources to learn about the potential of renewable natural gas are compiled by the Environmental Protection Agency, see https://www.epa.gov/lmop/renewable-natural-gas For a perspective emphasizing the downsides of RNG, see Sightline Institute, The four flaws of renewable natural gas, https://www.sightline.org/2021/03/09/the-four-fatal-flaws-of-renewable-natural-gas/

An informative blog about the distinctions between biodiesel and renewable diesel, and the potential of the renewable diesel industry to cut into transportation emissions, is available on the K2P website; see https://www.fromknowledgetopower.com/renewable-diesel-for-oregon/

A good short review on the challenges and opportunities of electric vehicles is available from the Environmental and Energy Study Institute (EESI). See https://www.eesi.org/articles/view/on-the-move-unpacking-the-challenges-and-opportunities-of-electric-vehicles. For more articles, see https://www.eesi.org/topics/electric-vehicles

To learn more about California's Low Carbon Fuel Standard, the state of the art policy for reducing transportation sector emissions, see LCFS basics, https://ww2.arb.ca.gov/resources/documents/lcfs-basics

Chapter 10 - Carbon Removal & Solar Geoengineering

1. The carbon removal challenge
2. Natural land management
    Afforestation and forest restoration
    Forests: policy and advocacy
    Agriculture and grasslands
    Sustainable agriculture: policy and advocacy
    Livestock management
3. Carbon capture technologies
    Carbon capture and storage in industry (CCS)
    Carbon capture and utilization (CCU)
    Direct air capture and storage (DACS)
    Accelerated weathering
    Bioenergy with carbon capture and storage (BECCS)
    Carbon removal: policy and advocacy
4. Solar geoengineering

Key messages

The two approaches to atmospheric carbon removal are natural land management and industrial-scale sequestration. Earth's land surface has a limited capacity to absorb additional carbon, so natural approaches alone will probably not be able to stabilize climate if warming significantly exceeds 1.5°C above pre-industrial temperature.

Tree restoration and effective forest management are the most promising paths for sequestration of carbon on the land. Two general principles for maximizing carbon sequestration in forests are maintenance of a complex and diverse tree canopy, and use of native vegetation to build ecological resiliency.

Because most US forests are privately owned, policies promoting healthy family-owned tracts and sustainable harvesting by timber companies are crucial. Amending federal laws to include carbon storage as a key aspect of forest management would also be beneficial.

Enhanced planting of cover crops represents perhaps the most cost-effective approach to preserving carbon stores in agricultural soils. Conservation tillage, effective nutrient management, agroforestry and silvopasture are other approaches that can reduce emissions of CO_2, CH_4 and N_2O from farmlands.

Livestock are a large source of methane emissions, especially for cattle and other animals kept in concentrated animal feeding operations (CAFOs). Trapping methane and CO_2 as biogas emanating from CAFO lagoons is an effective means of mitigation, since the recovered gas reduces the need for fossil gas mining.

CO_2 capture and sequestration (CCS) from industry smokestacks is a key technology that can both mitigate present emissions and provide innovation to help drive cost reductions for direct air capture (DAC). Common elements of CCS and DAC include CO_2 pipeline infrastructure and development of safe sites for geological sequestration.

CCS is best when employed at manufacturing plants, including glassmaking, petrochemicals, cement manufacture, fertilizer production and ethanol fermentation. This is because electrification of these industries is often difficult, so presently CCS offers the only good way to decrease CO_2 emissions.

While DAC may ultimately hold the most promise for atmospheric carbon removal, accelerated weathering (AW) is an alternative approach that can absorb large amounts of CO_2 directly into crushed rock aggregate. This mineralization could also generate economically valuable materials. However, both AW and DAC still require decades of development.

Bioengineering with carbon capture and storage (BECCS) is ready now. It involves transporting excess biomass to power plants, burning or other use of the biomass, and CCS. Regrowth could result in "negative emissions" at large scale - if supply chains can be established and the operations carried out sustainably.

Some advocates oppose CCS because of moral hazard: it is feared that the approaches will blunt the urgency for aggressive emissions mitigation. However, the urgency of the climate problem is such that the CCS approach is no longer optional. Federal tax credits are now in place and expected to drive growth of the technology.

Although carbon removal and solar radiation management (SRM) are sometimes both considered forms of geoengineering, SRM is effectively adaptation and does not address the root cause of global warming.

SRM comprises a set of methods that seek to increase the reflectivity of Earth. Sulfur aerosol injection is the most commonly discussed approach. It would require continuous application and strong international governance, and poses largely unknown risks to the integrity of the climate system.

Review and comprehension questions

1. *What is meant by the term "negative emissions"? How does it connect to the carbon budgets discussed in chapter 3?*

2. *Most climate scientists think that the proportion of our carbon emissions taken up by the land is likely to decrease in the coming decades. Thinking back to the carbon cycle and climate feedback loops (chaps 1-3), what might be some of the reasons for this?*

3. *Industry-scale technologies for carbon removal from the atmosphere focus almost entirely on carbon dioxide. Methane, however, is also a significant driver of Earth's energy imbalance. Why is atmospheric methane removal not also emphasized by climate scientists?*

4. *What key distinctions are considered by natural resource managers when they recommend ways of storing carbon on the land?*

5. *Distinguish among afforestation, reforestation and forest restoration. In what ways does climate change affect the ability of forests to take up atmospheric carbon and store it over decade to century timeframes?*

6. *In what way does deforestation contribute to <u>restoring</u> Earth's energy balance? How does this principle influence thinking about where afforestation and reforestation efforts should be focused?*

7. *How could federal land management laws be amended to more directly address climate change? Why is it important to amend the laws instead of making changes to administrative regulations under the existing laws?*

8. *What are some ways in which governments could induce private forest land holders to maintain healthy, carbon-dense forests? What values besides climate are implicated by the commercial use of forests to provide commodities for human use?*

9. *What are some of the climate and other environmental impacts of the post WWII industrialization of agriculture and livestock production? Identify which greenhouse gases are emitted from both types of operations, and their principal sources.*

10. *How does biochar technology fundamentally differ from many other practices to retain carbon in agricultural soils, such as the use of cover crops, conservation tillage or silvopasture?*

11. *Among (i) carbon capture and storage (CCS) from industry smokestacks, (ii) atmospheric carbon removal approaches such as DACS, and (iii) solar radiation management, which constitute mitigation of climate change? Which are forms of adaptation? Which get at the root causes of the climate crisis?*

12. *How does bioenergy with carbon capture and storage (BECCS) resemble biochar technology for soil carbon sequestration? What concern is common to both approaches?*

13. *In what ways does CCS as applied to industry smokestacks help pave the way for direct air capture of carbon dioxide (DACS)? What is the fundamental technological barrier that makes DACS so much more costly and energy intensive?*

14. *What is the most challenging technological barrier presently preventing the widespread implementation of accelerated weathering?*

15. *Can a useful policy distinction be drawn between the use of CCS in industries such as cement manufacture and petrochemicals, as compared with CCS in the electric power sector? What would be the argument for supporting CCS in manufacturing but not electric power generation?*

16. *From an economic point of view, what is the most challenging aspect of large scale atmospheric carbon removal coupled to safe geologic sequestration? What policies might stimulate growth of the CCS industry in spite of this issue?*

17. *Do you support federal tax credits for enhanced oil recovery, as recently enacted into law with bipartisan support? What arguments can you offer either for or against public subsidies for this technology?*

18. *What risks would be associated with the planet-wide implementation of solar radiation management (SRM)? Do these risks depend on which SRM technology might ultimately prevail? How do you think the program could be paid for?*

Research and discussion questions

1. *Take a look at Figure 1 in the Fargione et al. paper, published in Science in 2018, available at https://www.science.org/doi/10.1126/sciadv.aat1869. If you were to recommend a select few approaches for natural atmospheric carbon removal from farms and forests, which would they be? Don't forget to consider costs.*

2. *The Growing Climate Solutions Act (Box 10.2, p. 241) passed the US Senate with a 92-8 bipartisan vote in June 2021, and is supported by a wide array of groups. However, as of May 2022 it had not yet received a vote in the US House. Read a summary of the law at https://www.braun.senate.gov/sites/default/files/2020-06/Growing%20Climate%20Solutions%20Act%20One%20Pager.pdf Why do you think that many progressives are lukewarm to this legislation? Do you agree with them? Offer some arguments for and against the law.*

3. *Some climate advocates oppose carbon capture technology based on moral hazard. Do some research on the basis for this opposition. Do you agree that the risk of committing resources to carbon capture outweighs the potential benefits of the technology? Does the support of CCS by fossil fuel interests influence the strength of the opposition to the technology? Should it?*

Resources for further learning

A comprehensive analysis of the role of the land sink in the carbon cycle can be found in the IPCC special report on Climate Change and Land (2019). The Summary for Policymakers offers a concise review. See https://www.ipcc.ch/srccl/

The World Resources Institute focuses on atmospheric carbon removal as part of its detailed science/policy analyses of climate change. To access this large collection of resources, see https://www.wri.org/initiatives/carbon-removal WRI publications on carbon removal are available at https://www.wri.org/resources/tags/carbon-removal-19048

An analysis of the potential for carbon sequestration in the US by natural land management approaches, especially with respect to forests and farms, can be found in Fargione et al., Natural climate solutions for the United States, 2018, *Sci Adv 4, eaat1869,* see https://www.science.org/doi/10.1126/sciadv.aat1869

The National Sustainable Agriculture Coalition, which advocates for policy to support small family farms, also compiles a large database of resources on this subject; see https://sustainableagriculture.net

The National Academy of Sciences (NAS) publishes regular technical analyses of new technologies relevant to carbon capture and geoengineering. A research strategy for ocean-based carbon dioxide removal and sequestration is available at https://www.nationalacademies.org/our-work/a-research-strategy-for-ocean-carbon-dioxide-removal-and-sequestration.

A comprehensive NAS study on solar geoengineering is available at https://nap.nationalacademies.org/catalog/25762/reflecting-sunlight-recommendations-for-solar-geoengineering-research-and-research-governance

Much information about carbon capture and storage is compiled by the Global CCS Institute, a nonprofit advocacy group. See https://www.globalccsinstitute.com