CLIMATE CHANGE CONSIDERATIONS

from GVSU ENS 300 "Climate Horror Wiki" and "Climate Response Wiki" assignments,
and supplementary research in Winter 2020 ff.

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1. What are the key established facts concerning the effects of climate change?

Global average temperatures have increased by 0.7° C since 1850.

The global climate is warming, at a rate 10 times faster than any previous period in the geological record. Since 1981, the rate of warming has been at +0.18° C per decade. The five warmest years in the 1880–2019 record have all occurred since 2015, while nine of the 10 warmest years have occurred since 2005.[1]

Increased atmospheric levels of five greenhouse gases (ghgs) correlate to, and account for, the warming trend.

- Water vapor
- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Chlorofluorocarbons (CFCs)[2]

Human activity is the major contributor to this increase in ghgs and associated warming.[3]

The major predictable effects of warming include:

- Change Will Continue Through This Century and Beyond
- Temperatures Will Continue to Rise
- Frost-free Season (and Growing Season) will Lengthen
- Changes in Precipitation Patterns
- More Droughts and Heat Waves
- Hurricanes Will Become Stronger and More Intense
- Sea Level Will Rise 1-4 feet by 2100 [due to melting glaciers, ice sheets; and to expansion of warmer sea water]
- Arctic Likely to Become Ice-Free[4]

Ocean acidification is not directly a result of climate change, but is a separate, undesirable global effect attributed to the increase in CO_2.[5]

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1. Rebecca Lindsey and LuAnn Dahlman, "Climate Change: Global Temperature," NOAA, January 16, 2020, https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature.

2. "The Causes of Climate Change," NASA Jet Propulsion Laboratory and California Institute of Technology, accessed February 6, 2020, https://climate.nasa.gov/causes/.

3. "The Causes of Climate Change."

4. "The Effects of Climate Change," NASA Jet Propulsion Laboratory and California Institute of Technology, accessed February 6, 2020, https://climate.nasa.gov/effects/.

5. "Science and Climate: Ocean Acidification," University of California, Davis, accessed February 8, 2020, https://climatechange.ucdavis.edu/science/ocean-acidification/.

A. The “when did they know” timeline:

1856: Eunice Foote did experiments to show that atmospheric CO2 increases the absorption of thermal radiation from the sun, raising the temperature of the atmosphere: the greenhouse effect. John Tyndall published similar findings in 1859, apparently independently of Foote’s work.[6]

1912: A New Zealand newspaper published a short article titled “Coal Consumption Affecting Climate” in August, 1912. The article described the connection between burning coal and increased CO_2 levels, resulting in the greenhouse effect and a rise in earth temperatures.[7]

1957-58: The International Geophysical Year. “It’s June 1957, and Prince Philip is addressing the nation, warning about the threat of rising seas caused by melting glaciers.”[8]

1966: James R. Garvey, president of Bituminous Coal Research Inc., a coal mining and processing research organization, published an article in the *Mining Congress Journal.*

“There is evidence that the amount of carbon dioxide in the earth’s atmosphere is increasing rapidly as a result of the combustion of fossil fuels,” wrote Garvey. “If the future rate of increase continues as it is at the present, it has been predicted that, because the CO_2 envelope reduces radiation, the temperature of the earth’s atmosphere will increase and that vast changes in the climates of the earth will result.”

“Such changes in temperature will cause melting of the polar icecaps, which, in turn, would result in the inundation of many coastal cities, including New York and London,” he continued.[9]

1977: “The most-publicized report came from the National Academy of Sciences in 1977. It warned that average temperatures may rise 6 degrees Celsius by 2050 due to the burning of coal.”[10]

1981 (and earlier): Internal documents show that Exxon knew that fossil fuels affected climate change in 1981. They considered regulation around this affect to be a business risk.[11]

Exxon has been accused of funding climate denial research and think tanks in the intervening years.[12]

6. Natasha Ishak, “Meet Eunice Foote, the Mother of Climate Science Whose Work Was Ignored Because of Her Sex,” All That’s Interesting, March 27, 2020, https://allthatsinteresting.com/eunice-foote and Roland Jackson, “Eunice Foote, John Tyndall and a Question of Priority,” *Notes and Records: The Royal Society Journal of the History of Science*, February 13, 2019, https://doi.org/10.1098/rsnr.2018.0066

7. Sustainable Business Network, 2016, “This is from a local newspaper letters column. . .,” Facebook, image, October 12, 2016, https://www.facebook.com/SustainableBusinessNetworkNZ/photos/a.403513914925/10154115514619926/.

7. Alice Bell, “‘Spandex jackets for everyone’ – the International Geophysical Year,” A Short History of Climate Change (blog), May 24, 2017, https://www.climatehistories.com/histories/2017/5/24/spandex-jackets-one-for-everyone-the-international-geophysical-year.

9. Élan Young, “Exxon knew—and so did coal,” Grist, November 29, 2019, https://grist.org/energy/exxon-knew-and-so-did-coal/.

10. Ben Block, “A look back at James Hansen’s seminal testimony on climate, part one,” Grist, June 16, 2008, https://grist.org/article/a-climate-hero-the-early-years/.

11. Suzanne Goldberg, “Exxon Knew About Global Warming More Than 30 Years Ago,” *Mother Jones*, July 9, 2015, https://www.motherjones.com/environment/2015/07/exxon-climate-change-email/.

12. “ExxonMobil’s Funding of Climate Science Denial,” Desmog, accessed February 8, 2020, https://www.desmogblog.com/exxonmobil-funding-climate-science-denial

As of Fall 2019, the New York attorney general's office was suing Exxon, "arguing that one of the world's largest oil and gas companies misled its shareholders and the public by misrepresenting the risks that climate change poses to the value of its oil and gas assets."[13]

1988: James Hansen was an early prominent climate scientist at NASA's Goddard Institute. In 1988, he told a U.S. Senate Committee that he was 99 percent confident that global temperatures were increasing, and that this was due to human activity rather than natural variation.[14]

1988–90: The Intergovernmental Panel on Climate Change is a large body of scientific experts, established by the World Meteorological Organization and the United Nations Environment program in 1988, to research and report on the science of climate change. In the 1990 report, Working Group I reported scientific certainty that human activity was contributing to greenhouse gas increases in the atmosphere, and that this was responsible for over half of the observed enhanced greenhouse gas effect. (Adams, W. M., 2020, *Green Development*, 4th ed, p. 69).

1989: Bill McKibben published *The End of Nature* (Anchor).

1991: Shell Oil produced a 28-minute documentary on climate change, "Climate of Concern," in 1991.[15]

The Climate Accountability Institute reports that half of all CO_2 emissions since 1751 have been emitted since 1988, when "the evidence and risks of human-caused warming first became widely known."[16]

B. "But what about…?" Responding to climate skeptics

How can one respond to dismissive assertions that "Greenland was green!" or "We're coming out of the Little Ice Age" or "It's Pacific Decadal Oscillation"? These and other one-line rejections of climate science pop up in the replies to any report or policy proposal involving climate change. They can come across as being very persuasive, authoritatively implying some esoteric knowledge of science or deep history that has been overlooked by scientists.

Most rely built on the premise that the speaker has access to information that climate experts lack, or that experts are not considering for some (possibly nefarious) reason.

The first response to such assertions is that climate experts *also* have access to the internet, they know how to use Google, and they can in fact read that blog or watch that video you referenced. Your privileged, rare knowledge of some obscure phenomenon is in fact neither privileged nor rare. Anybody can access it in exactly the same place you did.

The second response is that climate experts have, in fact, already looked at these possibilities. If you became aware of and are passionately convinced by one of these explanations, after an hour or

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13. Lee Wasserman, "Did Exxon Deceive Its Investors on Climate Change?," *New York Times*, October 21, 2019, https://www.nytimes.com/2019/10/21/opinion/exxon-climate-change.html.

14. Block, "A look back."

15. Inae Oh, "In 1991, Shell Produced This Alarming Video Warning About Climate Change Dangers," *Mother Jones*, February 28, 2017, https://www.motherjones.com/environment/2017/02/shell-climate-change-documentary/; Jelmer Mommers, "Shell made a film about climate change in 1991 (then neglected to heed its own warning)," The Correspondent, February 28, 2017, https://thecorrespondent.com/6285/shell-made-a-film-about-climate-change-in-1991-then-neglected-to-heed-its-own-warning/692663565-875331f6.

16. "Carbon Majors," Climate Accountability Institute, October 8, 2019. http://climateaccountability.org/carbonmajors.html

two of "doing your own research," you can expect that climate experts have already looked into it. That esoteric-sounding objection you just uttered has been taken seriously. It's not included in the mainstream science because it's already been thoroughly considered and, as a result of that consideration, it has been rejected as an explanation.

Of course no one person has sufficient expertise to handle every objection. The fact that one particular person is unable to refute every such alternative explanation on the spot does not mean these explanations have not been refuted.

Expert responses to such skeptical objections are readily available, however. One comprehensive source is the "Global Warming & Climate Change Myths" page maintained by Skeptical Science, a non-profit science education organization founded by John Cook, a climate scientist. This page was compiled with the input of many, many experts in various fields. It lists 198 common climate objections, and provides both brief and more detailed explanations about why each objection fails.[17]

2. Where are the major areas of uncertainty about the effects of climate change?

2.1 Uncertainty due to lack of scientific knowledge?

- A central question remains about **climate sensitivity**: "the amount of global surface warming that will occur in response to a doubling of atmospheric CO_2 concentrations compared to pre-industrial levels." "Estimates have put climate sensitivity somewhere between 1.5C and 4.5C of warming for a doubling of pre-industrial CO_2 levels. This range has remained stubbornly wide, despite many individual studies claiming to narrow it."[18]
- How **quickly will climate conditions respond** to reductions in ghg emissions?[19]
- There is **general uncertainty about the details of some physical/biological/ chemical laws** that guide natural processes. E.g., cloud dynamics, the persistence of atmospheric aerosols that have a cooling effect[20]
- How stable are **the Antarctic ice sheets**? Are they locked to the land underneath, or not?[21]
- What is the effect of **sulfate aerosols in cooling the atmosphere** ("global dimming")? Effects are short-lived, but there are a lot of these pollutants up there.[22]
- When have/will we reach **peak oil**, and see a decline in petroleum use due to normal economic forces?

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17. "Global Warming & Climate Change Myths," Skeptical Science, 2021, https://skepticalscience.com/argument.php

18. Zeke Hausfather, "Explainer: How scientists estimate 'climate sensitivity'," CarbonBrief, June 19, 2018, https://www.carbonbrief.org/explainer-how-scientists-estimate-climate-sensitivity.

19. Oliver Milman, "Global heating could stabilize if net zero emissions achieved, scientists say," *The Guardian*, January 7, 2021, https://www.theguardian.com/environment/2021/jan/07/global-heating-stabilize-net-zero-emissions; Bob Berwyn, "Many Scientists Now Say Global Warming Could Stop Relatively Quickly after Emissions Go to Zero," Inside Climate News, January 3, 2021, https://insideclimatenews.org/news/03012021/five-aspects-climate-change-2020/

20. Mark Lynas, *Six Degrees: Our Future on a Hotter Planet* (Washington, DC: National Geographic, 2008), 129.

21. Lynas, *Six Degrees*, 188.

22. Lynas, *Six Degrees*, 273.

Tipping points

What and where are the **tipping points** for various systems? A) How many and which systems are vulnerable to abrupt, non-linear change (e.g. sudden changes in ocean currents, collapse of ice shelves) B) What are the physical/chemical mechanisms involved in various locations? C) At what level of warming do they occur? D) At what point in time do they occur?

> "It is likely that the Earth system will experience sharp regional transitions at moderate warming. . . although the prediction of any particular event has a very high uncertainty."[23]

> Several components or phenomena in the climate system could potentially exhibit abrupt or nonlinear changes, and some are known to have done so in the past. Examples include the AMOC [Atlantic Meridional Overturning Circulation, including the Gulf Stream], Arctic sea ice, the Greenland ice sheet, the Amazon forest and monsoonal circulations. For some events, there is information on potential consequences, but in general there is low confidence and little consensus on the likelihood of such events over the 21st century.[24]

> We explore the risk that self-reinforcing feedbacks could push the Earth System toward a planetary threshold that, if crossed, could prevent stabilization of the climate at intermediate temperature rises and cause continued warming on a "Hothouse Earth" pathway even as human emissions are reduced.[25]

Possible tipping points:

- **"Collapse of major ice sheets in Greenland and Antarctica:** Melting of these ice sheets is an ongoing process; however, there are signs that moderate melting may accelerate into a runaway situation that leads to a relatively sudden loss of large amounts of ice. Such a collapse could lead to dramatic changes in sea level, and could also impact ocean circulation." [Greenland's tipping point will be hit at global increase of 1.2° C][26]
- **"Disruption of thermohaline circulation [AMOC]:** If the ocean's circulation changed dramatically or even shut down altogether, the transfer of heat in the climate system would be altered in a huge way."[27]
- **"Sudden release of methane:** If the potent greenhouse gas methane were released rapidly from its stores in Arctic permafrost and special ices beneath the seafloor (called methane hydrates or clathrates), the rate of warming would increase. Methane releases would generate

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23. Chris Mooney, "The biggest question about climate change isn't 'if' or 'when.' It's 'how abrupt?'," *Washington Post*, October 15, 2015, https://www.washingtonpost.com/news/energy-environment/wp/2015/10/15/the-biggest-question-about-climate-change-isnt-if-or-when-its-how-abrupt/.

24. Matthew Collins, et al., "Long-term Climate Change: Projections, Commitments and Irreversibility," in Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, eds. T. F. Stocker, et al. (Cambridge: Cambridge University Press, 2013), 1033, https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf.

25. Will Steffen, et al., "Trajectories of the Earth System in the Anthropocene," ed. William C. Clark, *Proceedings of the National Academy of Science of the United States of America* 115 (August 2018): 8252-8259, doi:10.1073/pnas.1810141115.

26. Lynas, *Six Degrees*, 88.

27. "Predictions of Future Global Climate," University Corporation for Academic Research, 2011, https://scied.ucar.edu/longcontent/predictions-future-global-climate.

a feedback loop of increased greenhouse warming by methane driving further methane emissions. Some scientists suspect that sudden increases in methane may have played a role in major extinction events in the past."[28]

- **"Ocean uptake of carbon:** Today, the ocean is absorbing CO_2 that would otherwise stay in the atmosphere. At some point seawater will become saturated with CO_2 and unable to absorb any more. At that point, anthropogenic emissions of CO_2 would all land in the atmosphere, increasing the rate of greenhouse warming. Acidification of the oceans could also disrupt marine life, causing photosynthesizing plankton to succumb, preventing them from removing CO_2 from the air. Shells of many types of marine organisms might begin to dissolve in the presence of the acidic oceans, releasing the carbon stored within the shells back into the environment."[29]
- **Loss of Arctic sea ice:** Ice and snow reflect 80% of the sun's heat; open ocean can absorb up to 95%. Once a crucial amount of ice is lost, the heating process speeds up and heat is subsequently all trapped in the ocean rather than reflected out.[30]
- **Phytoplankton die-off:** surface phytoplankton absorb a great deal of atmospheric CO_2, as part of the "biological carbon pump." "Marine phytoplankton perform half of all photosynthesis on Earth" "the biological pump takes carbon out of contact with the atmosphere for several thousand years or longer and maintains atmospheric CO_2 at significantly lower levels than would be the case if it did not exist. An ocean without a biological pump. . . would result in atmospheric CO_2 levels ~400 ppm higher than present day."[31]

  Ocean acidification, warming, and changes in circulation will affect various phytoplankton in ways that are presently unpredictable: populations may increase, or decrease, or disappear. If they decrease significantly, diminishing the biological carbon pump system, acidification and warming will accelerate significantly.

  Phytoplankton "absorb half of the carbon dioxide we create. If we wipe them out, that process will stop. We are altering the entire chemistry of the oceans without any idea of the consequences"[32]
- **Desertification of Africa:** the substrate of the lower third of the continent is sand. Somewhere above 2 C, the vegetation begins to die back, exposing the sand, leading to hot, dry, "violently blowing sand"[33]
- **Methane production in the melting Arctic:** (see below on anaerobic bacteria in melting permafrost—this could become a major feedback that leads to runaway warming)
- **Methane hydrate releases from the oceans:** this trapped methane is naturally sequestered at depth in the oceans. At warmer temperatures it becomes unstable and rises, become even less stable at lower pressures. Significant atmospheric methane releases become more likely as the oceans warm.[34] The tipping point is not known.[35]

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28. "Predictions of Future Global Climate."
29. "Predictions of Future Global Climate."
30. Lynas, *Six Degrees*, 48.
31. Samarpita Basu and Katherine R. M. Mackey, "Phytoplankton as Key Mediators of the Biological Carbon Pump: Their Responses to a Changing Climate," *Sustainability* 10, no. 3 (March 2018): 869, https:// doi.org/10.3390/su10030869
32. Lynas, *Six Degrees*, 78.
33. Lynas, *Six Degrees*, 127.
34. Lynas, *Six Degrees*, 223.
35. Lynas, *Six Degrees*, 228.

A 2017 study concluded that "current warming of ocean waters is likely causing gas hydrate deposits to break down at some locations. However, not only are the annual emissions of methane to the ocean from degrading gas hydrates far smaller than greenhouse gas emissions to the atmosphere from human activities, but most of the methane released by gas hydrates never reaches the atmosphere. Instead, the methane often remains in the undersea sediments, dissolves in the ocean, or is converted to carbon dioxide by microbes in the sediments or water column."[36]

Undersea methane release was observed off the eastern coast of Siberia in 2020. "While the methane bubbles are still being absorbed by the ocean, the researchers did measure methane concentrations near the surface that were four to eight times higher than normal, and said this methane would make it into the atmosphere."[37]

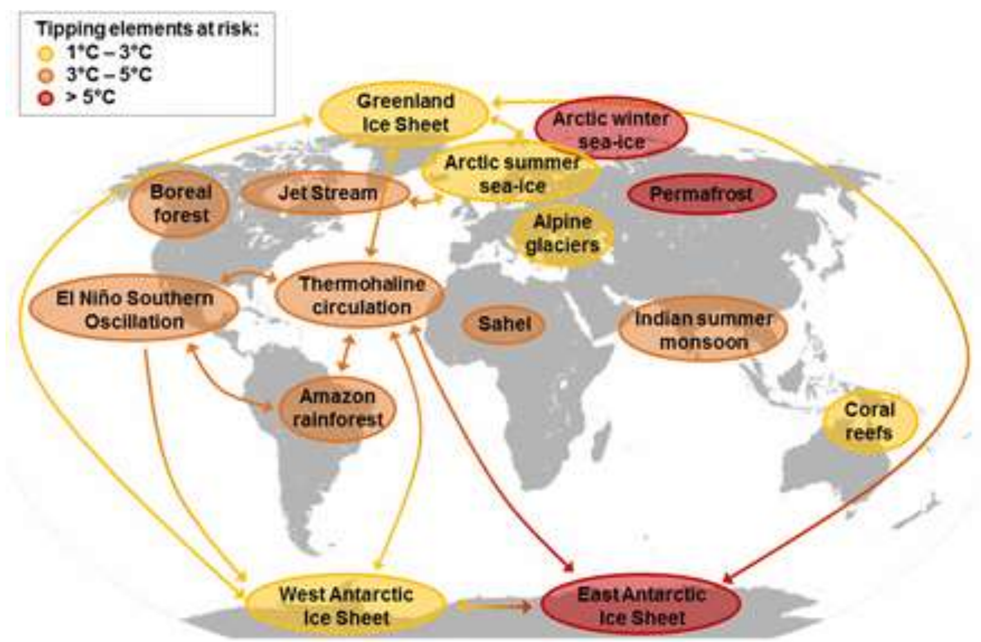

Figure 1 Image from Will Steffen, et al., "Trajectories of the Earth System in the Anthropocene," ed. William C. Clark, *Proceedings of the National Academy of Science of the United States of America* 115 (August 2018): 8252-8259, doi:10.1073/pnas.1810141115.

Other sources:

Andrew D. King, "The drivers of nonlinear local temperature change under global warming," *Environmental Research Letters* 14 (2019), 064005, https://doi.org/10.1088/1748-9326/ab1976.

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36. "Gas Hydrate Breakdown Unlikely to Cause Massive Greenhouse Gas Release," USGS, February 9, 2017, https://www.usgs.gov/news/gas-hydrate-breakdown-unlikely-cause-massive-greenhouse-gas-release.

37. Olivia Rosane, "Scientists Say Methane Release Is Starting in Arctic Ocean. How Concerned Should We Be?" EcoWatch, October 28, 2020 https://www.ecowatch.com/methane-release-arctic-ocean-2648529839.html
See also Jonathan Watts, "Arctic Methane Deposits 'Starting to Release', Scientists Say," The Guardian, October 27, 2020 https://www.theguardian.com/science/2020/oct/27/sleeping-giant-arctic-methane-deposits-starting-to-release-scientists-find

Alan Buis, "Part 2: Selected Findings of the IPCC Special Report on Global Warming," NASA Global Climate Change, June 19, 2019, https://climate.nasa.gov/news/2865/a-degree-of-concern-why-global-temperatures-matter/

"Impacts of a 4°C global warming," GreenFacts, accessed February 8, 2020, https://www.greenfacts.org/en/impacts-global-warming/l-2/index.htm.

Julia Blocher and Richard Betts, "Preparing for a future beyond 'dangerous' climate change," United Nations University (blog), November 25, 2015, https://ehs.unu.edu/blog/articles/preparing-for-a-future-beyond-dangerous-climate-change.html.

Mark S. Williamson, et al., "Combination of impacts information with assessment of likelihood of different climate tipping points to produce first comprehensive risk assessment of climate tipping points under different scenarios," High-End Climate Impacts and Extremes (HELIX) Project, April 25, 2016, https://helixclimate.eu/wp-content/uploads/2018/07/Deliverable-10.2-Comprehensive-risk-assessment-of-climate-tipping-points-under-different-scenarios.pdf.

Feedback loops

Undesirable feedback loops

What and where are there **undesirable feedback loops** (positive system reinforcements) that are likely to be established as temperatures rise and physical/chemical/biological systems change? E.g., deforestation may lead to greater drought which leads to more deforestation. The same questions about specifics arise here as with the tipping points.

- **Plant carbon absorption shutdown:** At higher temperatures, forests and soils cease to absorb carbon from the atmosphere and instead begin to release it.[38] This is especially problematic for the Amazon rain forest,[39] which could go into a runaway desertification mode above 2° C.[40]
- **The mechanical air conditioning cycle:** When it gets hot, people use more air conditioning. As new regions get hotter, people will install air conditioning where it was not used before. AC uses a lot of energy—much derived from fossil fuels.[41]
- **Albedo flip on ice sheets in Greenland, West Antarctica, and elsewhere:** as floating ice sheets melt, they get wet and appear darker, absorbing more heat.[42]
- **Increased petroleum extraction due to warming:** Melting Arctic ice has opened access to previously unreachable petroleum deposits.[43] [The same might eventually occur in Antarctica, but by then we probably won't want to extract any more carbon to burn.]
- **Warmer oceans absorb less CO_2**[44]
- **Drying peat deposits:** warmer temperatures and drier climate over "tens of millions of acres of Southeast Asian and Amazonia" would expose highly flammable, carbon-rich peat to burning.[45]

38. Lynas, *Six Degrees*, 82.
39. Lynas, *Six Degrees*, 139.
40. Lynas, *Six Degrees*, 142.
41. Lynas, *Six Degrees*, 84.
42. Lynas, *Six Degrees*, 93.
43. Lynas, *Six Degrees*, 95.
44. Lynas, *Six Degrees*, 139.
45. Lynas, *Six Degrees*, 141.

- **High altitude ice in Greenland begins to melt**, due to warmer weather, which leads to runoff accumulations, which absorb more heat….
- **Methane production in the melting Arctic:** As permafrost melts, organic matter is exposed and saturated. If the soils are too wet, decomposition is done by anaerobic bacteria, which produce a lot of methane.[46] Thawing permafrost is not figured into all current warming models, and could be a huge unaccounted contributor.[47]
- **Diminished rainfall across "dry belts":** At higher temperatures (4° C), large land areas on either side of the equator will receive less rainfall; the land will dry and heat, evaporation increases, leading to more heat, toward desertification and intense heat.
- **Methane hydrate releases from the oceans:** this trapped methane is naturally sequestered at depth in the oceans. At warmer temperatures it becomes unstable and rises, become even less stable at lower pressures. Significant atmospheric methane releases become more likely as the oceans warm. Significant methane releases dramatically increase the temperature. The oceans could go into runaway warming mode.[48] More recent research suggests this is unlikely, however.

Desirable feedback loops

What and where are there desirable feedback loops (negative system reinforcements).

- **Increased cloud cover due to water evaporation** reduces the amount of solar energy that reaches the earth. It would be fortunate if this effect balanced out the greenhouse effect of that same water vapor trapping heat in the atmosphere. (We should not count on this—the point is that this is a complex system and we literally don't know with certainty.) The same questions about specifics arise here as with the tipping points.
- **Global dimming effect** of sulfate aerosols[49]

2.2 Uncertainty due to indeterminacy of future events (esp. human responses)?

The most likely warming scenario over the next few centuries is between 1.5° and 6.0°C. This is a wide range, and is largely due to **a single indeterminant factor**: how will humans respond to the situation by limiting ghg emissions, and removing ghgs from the atmosphere, starting now?

Other sources of uncertainty:

- Prospect of **new technologies** for energy production, sequestration, mitigation, adaptation.
- Unpredictable/independent **geopolitical events** that may realign economic and industrial activities on a global scale. Such events are likely to be connected to ongoing climate change to some degree (war, mass migration, economic collapse, political revolutions).

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46. Lynas, *Six Degrees*, 210.
47. Lynas, *Six Degrees*, 211.
48. Lynas, *Six Degrees*, 223, 227. See Watts, Rosane for a report on a directly observed methane release in 2020.
49. Lynas, *Six Degrees*, 273.

- **Political leadership can make a difference:** almost immediately after taking office, President Biden took a number of steps to address climate change, including rejoining the Paris Accord.[50]
- **Public attitudes toward ghg mitigation can change:** in the U.S., which is responsible for disproportionate amount of GHG emissions, there has been a powerful climate denial movement that has blocked significant changes. There has been some movement away from this denial position in recent years, though talk of climate change as a scientific or political reality still meets with opposition.[51]
- Unpredictable/independent **natural disasters** that may realign economic, political, and industrial activities on a global scale (earthquakes, volcanic eruptions, sunspot activity, magnetic pole realignment, lethal epidemic(s), even a comet strike [it's happened before…]). Some events, and the scale of their effects, are likely to be connected to ongoing climate change to some degree (esp. the effects of drought cycles, large storms, flooding).
- **The Covid-19 pandemic** has disrupted life everywhere, changing behavior in ways that will likely continue to play out for years. The global lockdown caused a sudden drop in fuel consumption and corresponding emissions, as much as a 17% reduction in emissions.[52] There may be continued emphasis on working from home even after the pandemic is controlled. Other changes from the pandemic will become apparent over time. The crisis may present an opportunity to introduce fundamental, long-term changes to address climate change. The lockdown-induced reduction in ghg emissions in 2020 will not, by themselves, have much impact on global atmospheric CO_2 levels, however.[53]

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50. Valerie Volcovici, "Factbox: Biden Mobilizes The Federal Government To Tackle Climate Change," *Reuters*, January 27, 2021 https://www.reuters.com/article/us-usa-biden-climate-factbox-idUSKBN29W30X, and Bill McKibben, "The Biden Administration's Landmark Day in the Fight for the Climate," *New Yorker*, January 28, 2021 https://www.newyorker.com/news/daily-comment/the-biden-administrations-landmark-day-in-the-fight-for-the-climate

51. R. Schiffman, "Climate Deniers Shift Tactics to 'Inactivism,'" *Scientific American,* January 12, 2021 https://www.scientificamerican.com/article/climate-deniers-shift-tactics-to-inactivism/ This is an interview with Michael Mann, author of *The New Climate War: The Fight to Take Back Our Planet*. See also D. Wallace-Wells, "After Alarmism: The War on Climate Denial Has Been Won. And That's Not the Only Good News," Intelligencer, *New York Magazine*, January 19, 2021 https://nymag.com/intelligencer/article/climate-change-after-pandemic.html

52 Matt McGrath, "Climate Change: Covid Pandemic Has Little Impact on Rise in CO2," *BBC News*, 23 November 2020 https://www.bbc.com/news/science-environment-55018581

53. Mark Dwortzan, "How will COVID-19 ultimately impact climate change?" *MIT News*, January 29, 2021 https://news.mit.edu/2021/how-will-covid-19-ultimately-impact-climate-change-0129.

3. What are the most likely effects of climate change at the various possible temperature increase scenarios?

Current status

We have already seen **0.7° C increase since 1850**; we were at **414 ppm CO_2** concentration as of January 2020, and **415.77ppm** in January 2021.

"Estimates of the equilibrium climate sensitivity (ECS) based on observed climate change, climate models and feedback analysis, as well as paleoclimate evidence indicate that ECS is likely in the range 1.5° C to 4.5° C with high confidence, extremely unlikely less than 1°C (high confidence) and very unlikely greater than 6°C (medium confidence). The transient climate response (TCR) is likely in the range 1°C to 2.5ºC and extremely unlikely greater than 3°C, based on observed climate change and climate models."[54]

"The transient climate response , TCR, is the temperature change at the time of CO_2 doubling and the equilibrium climate sensitivity, T2x, is the temperature change after the system has reached a new equilibrium for doubled CO_2, i.e., after the additional warming commitment has been realised."[55]

An interactive chart at various levels: "The impacts of climate change at 1.5C, 2C and beyond."[56]

Other sources:

Collins, M., R. Knutti, J. Arblaster, J.-L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver and M. Wehner, 2013: Long-term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter12_FINAL.pdf

Arnell, N.W., Lowe, J.A., Challinor, A.J. et al. Climatic Change (2019) 155: 377. https://doi.org/10.1007/s10584-019-02464-z

An additional 1.0° C:

"Changes include increases in both land and ocean temperatures, as well as more frequent heatwaves in most land regions (*high confidence*). There is also (*high confidence*) global warming has resulted in an increase in the frequency and duration of marine heatwaves. Further, there is *substantial evidence* that human-induced global warming has led to an increase in the frequency, intensity and/or amount of heavy precipitation events at the global scale (*medium*

54. Matthew Collins, et al., "Long-term Climate Change," 1033.
55. "Working Group I: The Scientific Basis," accessed February 8, 2020, https://archive.ipcc.ch/ipccreports/tar/wg1/345.htm.
56. Robert McSweeney and Rosamund Pearce, "The impacts of climate change at 1.5C, 2C and beyond," CarbonBrief, October 4, 2018, https://interactive.carbonbrief.org/impacts-climate-change-one-point-five-degrees-two-degrees/?utm_source=web&utm_campaign=Redirect.

confidence), as well as an increased risk of drought in the Mediterranean region (*medium confidence*)."[57]

The major predictable effects of warming include:

- Change Will Continue Through This Century and Beyond
- Temperatures Will Continue to Rise
- Frost-free Season (and Growing Season) will Lengthen
- Changes in Precipitation Patterns
- More Droughts and Heat Waves
- Hurricanes Will Become Stronger and More Intense
- Sea Level Will Rise 1-4 feet by 2100 [due to melting glaciers, ice sheets; and to expansion of warmer sea water]
- Arctic Likely to Become Ice-Free

Effects in the US:

- Northeast. Heat waves, heavy downpours and sea level rise pose growing challenges to many aspects of life in the Northeast. Infrastructure, agriculture, fisheries and ecosystems will be increasingly compromised. Many states and cities are beginning to incorporate climate change into their planning.
- Northwest. Changes in the timing of streamflow reduce water supplies for competing demands. Sea level rise, erosion, inundation, risks to infrastructure and increasing ocean acidity pose major threats. Increasing wildfire, insect outbreaks and tree diseases are causing widespread tree die-off.
- Southeast. Sea level rise poses widespread and continuing threats to the region's economy and environment. Extreme heat will affect health, energy, agriculture and more. Decreased water availability will have economic and environmental impacts.
- Midwest. Extreme heat, heavy downpours and flooding will affect infrastructure, health, agriculture, forestry, transportation, air and water quality, and more. Climate change will also exacerbate a range of risks to the Great Lakes.
- Southwest. Increased heat, drought and insect outbreaks, all linked to climate change, have increased wildfires. Declining water supplies, reduced agricultural yields, health impacts in cities due to heat, and flooding and erosion in coastal areas are additional concerns.[58]

Other effects of warming:

- **Impacts on Ocean Currents:** Large-scale ocean currents called thermohaline circulation, driven by differences in salinity and temperature, may also be disrupted as climate warms. Changes in precipitation patterns and the influx of fresh water into the oceans from melting ice can alter salinity. Changing salinity, along with rising water

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57. IPCC, Global Warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, eds. V. Masson-Delmotte, et al., 2018, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_Low_Res.pdf; Alan Buis, "Part 2: Selected Findings of the IPCC Special Report on Global Warming," NASA Global Climate Change, June 19, 2019, https://climate.nasa.gov/news/2865/a-degree-of-concern-why-global-temperatures-matter/.

58. "The Effects of Climate Change."

temperature, may disrupt the currents. In an extreme case, thermohaline circulation could be disrupted or even shut down in some parts of the ocean, which could have large effects on climate.

- **Changing Severe Weather:** Some climate scientists believe that hurricanes, typhoons, and other tropical cyclones will (and may have begun to already) change as a result of global warming. Warm ocean surface waters provide the energy that drives these immense storms. Warmer oceans in the future are expected to cause intensification of such storms. Although there may not be more tropical cyclones worldwide in the future, some scientists believe there will be a higher proportion of the most powerful and destructive storms. Some scientists believe we are already seeing evidence for an upswing in the numbers of the most powerful storms; others are less convinced.
- **More Clouds:** Clouds are a bit of a wild-card in global climate models. Warmer global temperatures produce faster overall evaporation rates, resulting in more water vapor in the atmosphere... and hence more clouds. Different types of clouds at different locations have different effects on climate. Some shade the Earth, cooling climate. Others enhance the greenhouse effect with their heat-trapping water vapor and droplets. Scientists expect a warmer world to be a cloudier one, but are not yet certain how the increased cloudiness will feed back into the climate system. Modeling the influence of clouds in the climate system is an area of active scientific research.
- **Changes to Life and the Carbon Cycle:** Climate change will alter many aspects of biological systems and the global carbon cycle. Temperature changes will alter the natural ranges of many types of plants and animals, both wild and domesticated. There will also be changes to the lengths of growing seasons, geographical ranges of plants, and frost dates.
  Models of the global carbon cycle suggest that the Earth system will be able to absorb less CO_2 out of the atmosphere as the climate warms, worsening the warming problem.[59]

Yet more:

- Less freshwater will be available, since glaciers store about three-quarters of the world's freshwater.
- Some diseases will spread, such as mosquito-borne malaria (and the 2016 resurgence of the Zika virus).[60]

1.5° C:

With considerable effort, change could be limited to 1.5° C. The IPCC Special Report "Global Warming of 1.5 ºC" indicated what would need to be done, and indicated that changes must be implemented by 2030 in order to restrict warming to 1.5° C.[61]

Writing about the effects of climate change in Australia, a group of scientists previously recognized for their accomplishments by the Australian Research Council (the ARC Laureats) "further increases in extreme fire risk, heat waves and flooding rains; ecosystems degraded and wild species forced to migrate or vanish; agricultural activities moved or abandoned, challenging our food security; and so on. If strong action is *not* taken, environmental degradation and social disruption will be much greater

59. "Predictions of Future Global Climate."
60. "Effects of global warming," *National Geographic*, accessed February 8, 2020, https://www. nationalgeographic.com/environment/global-warming/global-warming-effects/.
61. IPCC, Global Warming of 1.5°C.

and in many cases adaptation will no longer be achievable. It would be naive to assume that such a world will still support human societies in their current form and maintain human well-being."[62]

"Global emissions of greenhouse gases have, however, continued to rise, making it more and more likely that this 2°C 'guardrail' will be exceeded."[63]

2.0° C:

All of the predicted effects will be increased. From the IPCC Special Report:

- *Extreme heat days/waves get 25% worse:* "Extreme hot days in mid-latitudes warm by up to about 3° C at global warming of 1.5°C and about 4°C at 2°C, and extreme cold nights in high latitudes warm by up to about 4.5°C at 1.5°C and about 6°C at 2°C (*high confidence*)."
- *Sea level rise increases by 20%, or about a foot:* "Sea level rise will be higher: 0.26 to 0.77 m by 2100 for 1.5°C, 0.1 m higher at 2.0°C (about one foot)."
- *We lose more of the permafrost, and release more of the methane locked inside:* "Limiting global warming to 1.5°C rather than 2°C is projected to prevent the thawing over centuries of a permafrost area in the range of 1.5 to 2.5 million km2 (*medium confidence*)."
- *We lose more ocean life:* "Limiting global warming to 1.5°C compared to 2ºC is projected to reduce increases in ocean temperature as well as associated increases in ocean acidity and decreases in ocean oxygen levels (*high confidence*). Consequently, limiting global warming to 1.5°C is projected to reduce risks to marine biodiversity, fisheries, and ecosystems, and their functions and services to humans…"
- *The arctic sea ice disappears completely:* "There is *high confidence* that the probability of a sea ice-free Arctic Ocean during summer is substantially lower at global warming of 1.5°C when compared to 2°C."
- *Ocean acidification gets worse:* "The level of ocean acidification due to increasing CO_2 concentrations associated with global warming of 1.5°C is projected to amplify the adverse effects of warming, and even further at 2°C, impacting the growth, development, calcification, survival, and thus abundance of a broad range of species, for example, from algae to fish (*high confidence*)."
- *Tropical diseases move further north:* "Risks from some vector-borne diseases, such as malaria and dengue fever, are projected to increase with warming from 1.5°C to 2°C, including potential shifts in their geographic range (*high confidence*)."
- *Crop yields and the nutritional value of foods decreases even further:* "Limiting warming to 1.5°C compared with 2°C is projected to result in smaller net reductions in yields of maize, rice, wheat, and potentially other cereal crops, particularly in sub-Saharan Africa, Southeast Asia, and Central and South America, and in the CO_2-dependent nutritional quality of rice and wheat (*high confidence*)."
- *The chances of crossing tipping points or of triggering feedback loops increases:* "For global warming from 1.5°C to 2°C, risks across energy, food, and water sectors could overlap spatially and temporally, creating new and exacerbating current hazards, exposures, and vulnerabilities that could affect increasing numbers of people and regions (*medium confidence*)."

62. "An Open Letter on Australian Bushfires and Climate: Urgent Need for Deep Cuts in Carbon Emissions," accessed February 8, 2020, https://laureatebushfiresclimate.wordpress.com/.

63. Julia Blocher and Richard Betts, "Preparing for a future beyond 'dangerous' climate change," United Nations University (blog), November 25, 2015, https://ehs.unu.edu/blog/articles/preparing-for-a-future-beyond-dangerous-climate-change.html.

- *It gets harder and more expensive to adapt to the more extreme effects:* "Adaptation is expected to be more challenging for ecosystems, food and health systems at 2°C of global warming than for 1.5°C (*medium confidence*)." [64]

4.0° C:

This level of warming "is what scientists are nearly unanimously predicting will happen by the end of the century if no significant policy changes are undertaken."[65] And:

"If the currently planned actions are not fully implemented, a warming of 4°C could occur as early as the 2060s. Such a warming level by 2100 would not be the end point: a further warming to levels over 6°C would likely occur over the following centuries."[66]

More of the same effects, but reaching really problematic levels.

> "At the global scale, all the impacts that could plausibly be either adverse or beneficial are adverse, and impacts and risks increase with temperature change. For example, the global average chance of a major heatwave increases from 5% in 1981–2010 to 28% at 1.5 °C and 92% at 4 °C, of an agricultural drought increases from 9 to 24% at 1.5 °C and 61% at 4 °C, and of the 50-year return period river flood increases from 2 to 2.4% at 1.5 °C and 5.4% at 4 °C. The chance of a damaging hot spell for maize increases from 5 to 50% at 4 °C, whilst the chance for rice rises from 27 to 46%. There is considerable uncertainty around these central estimates, and impacts and risks vary between regions. Some impacts—for example heatwaves—increase rapidly as temperature increases, whilst others show more linear responses."[67]

Specific effects from:

- The largest warming will occur over land and range from 4°C to 10°C.
- Warming of 4°C will likely lead to a sea-level rise of 0.5 to 1 meter, and possibly more, by 2100, with several meters more to be realized in the coming centuries. Sea-level rise would likely be limited to below 2 meters only if warming were kept to well below 1.5°C. Even if global warming is limited to 2°C, global mean sea level could continue to rise, with some estimates ranging between 1.5 and 4 meters above present-day levels by the year 2300.
- a 4°C warming would significantly exacerbate existing water scarcity in many regions, particularly northern and eastern Africa, the Middle East, and South Asia, while additional countries in Africa would be newly confronted with water scarcity on a national scale due to population growth.
- Recent research suggests that large-scale loss of biodiversity is likely to occur with a temperature increase of 4° C. Climate change and high CO_2 concentration would drive the earth´s ecosystems into a state unknown in human experience.

64. IPCC, "Summary for Policymakers," in Global Warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, eds. V. Masson-Delmotte et al., 2018, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf.

65. "Impacts of a 4°C global warming," GreenFacts, accessed February 8, 2020, https://www.greenfacts.org/en/impacts-global-warming/l-2/index.htm.

66. "Impacts of a 4°C global warming."

67. Arnell, et al., "Global and regional impacts of climate change," 377–391.

- significant risk of high-temperature thresholds being crossed that could substantially undermine food security globally with a 4°C temperature increase. . . . significant effects have been observed in the United States when local daily temperatures increase to 29°C for corn and 30°C for soybeans.[68]

6.0° C:

Surprisingly few reliable projections I can find.

High-End Climate Impacts and Extremes (HELIX) offers technical reports on modeling, mostly restricted to regional effects in specific domains.[69]

This highly questionable chart is at least a provocative visual representation:

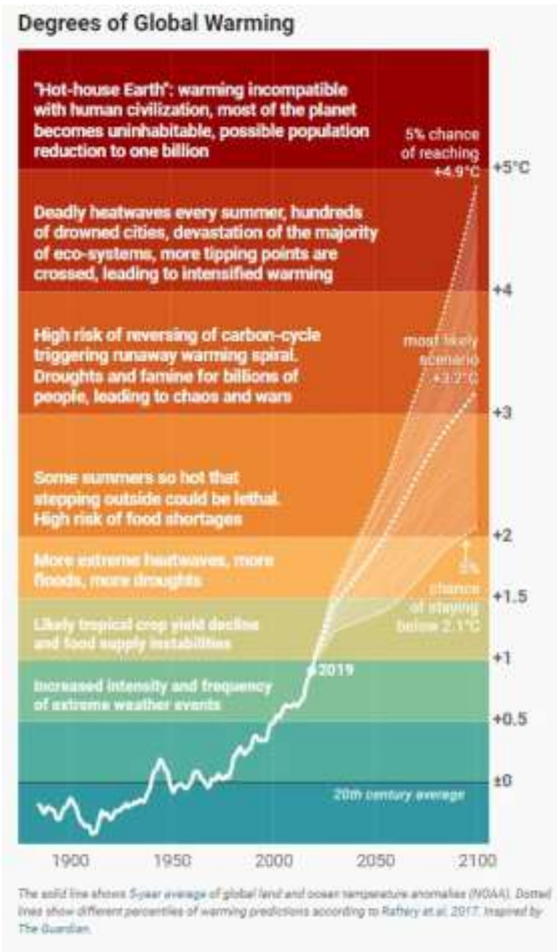
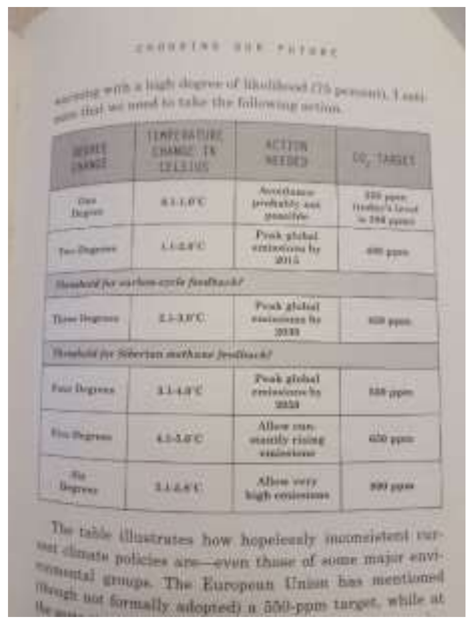


Figure2 Image from Gregor Aisch, "What Different Degrees of Global Warming Look Like," September 26, 2019, Chartable (blog), https://blog.datawrapper.de/climate-crisis-global-warming/.



[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	Peak global emissions by 2015	[illegible]
[illegible]			
Three Degrees	[illegible]	Peak global emissions by [illegible]	[illegible]
[illegible]			
[illegible]	[illegible]	Peak global [illegible]	[illegible]
[illegible]	[illegible]	Allow [illegible]	[illegible]
[illegible]	[illegible]	Allow very high emissions	[illegible]

The table illustrates how hopelessly [illegible] climate policies are—even those of some major envi[illegible] groups. The European Union has mentioned [illegible] not formally adopted) a 550-ppm target, while at [illegible]

Figure 3 Image from Lynas, *Six Degrees*, 279.

See also David Wallace-Wells, *The Uninhabitable Earth: Life After Warming* (2019) and other works by Wallace-Wells.

68. "Impacts of a 4°C global warming."
69. Please see https://helixclimate.eu/.

4. What are the most promising options for responding to climate change?

To reduce future level of greenhouse gas emissions

To mitigate systems changes that will contribute to atmospheric ghg increase

To sequester carbon already in atmosphere

To otherwise avoid the effects of climate change

Climate Stabilization Wedges strategy (est. 2000):[70]

"Keeping emissions flat for 50 years will require trimming projected carbon output by roughly 8 billion tons per year by 2060, keeping a total of 200 billion tons of carbon from entering the atmosphere."

"Each of the 15 strategies below has the potential to reduce global carbon emissions by at least 1 billion tons per year by 2060, or 1 wedge. A combination of strategies will be needed to build the eight wedges of the stabilization triangle."[71]

Efficiency

- Double fuel efficiency of 2 billion cars from 30 to 60 mpg.
- Decrease the number of car miles traveled by half.
- Use best efficiency practices in all residential and commercial buildings.
- Produce current coal-based electricity with twice todays efficiency.

Fuel Switching

- Replace 1400 coal electric plants with natural gas-powered facilities.

Carbon Capture and Storage

- Capture AND store emissions from 800 coal electric plants.
- Produce hydrogen from coal at six times today's rate AND store the captured CO_2.
- Capture carbon from 180 coal-to-synfuels plants AND store the CO_2.

Nuclear

- Add double the current global nuclear capacity to replace coal-based electricity.

Wind

- Increase wind electricity capacity by 10 times relative to today, for a total of 2 million large windmills.

Solar

- Install 100 times the current capacity of solar electricity.
- Use 40,000 square kilometers of solar panels (or 4 million windmills) to produce hydrogen for fuel cell cars.

Biomass Fuels

- Increase ethanol production 12 times by creating biomass plantations with area equal to 1/6th of world cropland.

Natural Sinks

- Eliminate tropical deforestation.
- Adopt conservation tillage in all agricultural soils worldwide

70. Princeton Environmental Institute, "Stabilization Wedges Introduction," Princeton Environmental Institute Carbon Mitigation Initiative, accessed February 9, 2020, https:// cmi. princeton. edu/resources/stabilization-wedges/introduction/.

71. Princeton Environmental Institute, "Stabilization Wedges Introduction."

Project Drawdown (est. 2014):[72]

Ranks 80 different solutions in terms of effectiveness at CO_2 emissions reduction/avoidance/sequestration. These are sorted into eight "sectors":

- Materials
- Electricity
- Food
- Women and children
- Land Use
- Buildings and cities
- Transport
- Coming attractions (promising but not-yet-established solutions)

The top 10 solutions are:

Solution	Sector
1. Refrigerant Management	Materials
2. Wind Turbines (Onshore)	Electricity Generation
3. Reduced Food Waste	Food
4. Plant-Rich Diet	Food
5. Tropical Forests	Land Use
6. Educating Girls	Women and Girls
7. Family Planning	Women and Girls
8. Solar Farms	Electricity Generation
9. Silvopasture	Food
10. Rooftop Solar	Electricity Generation

The claim is that if adopted, the recommended solutions could reverse the trend of increasing ghg emissions by 2050.

World Scientists' Warning: Six Steps (Est. January 2020)[73]

Energy. Swiftly phasing out fossil fuels is a top priority. This can be achieved through a multipronged strategy based on rapidly transitioning to low-carbon renewables such as solar and wind power, implementing massive conservation practices, and imposing carbon fees high enough to curtail the use of fossil fuels.

Short-lived pollutants. Quickly cutting emissions of methane, black carbon (soot), hydrofluorocarbons and other short-lived climate pollutants is vital. It can dramatically reduce the short-term rate of warming, which may otherwise be difficult to affect. Specific actions to address short-lived pollutants include reducing methane emissions from landfills and the energy sector (methane), promoting improved clean cookstoves (soot) and developing better refrigerant options and management (hydrofluorocarbons).

72 "Solutions," Project Drawdown, accessed February 8, 2020, https:// www. drawdown. org/solutions.

73 W. J. Ripple, C. Wolf, T. M. Newsome, P. Barnard, W. R. Moomaw, "The Climate Emergency: 2020 in Review." *Scientific American,* January 6, 2021. https://www.scientificamerican.com/article/the-climate-emergency-2020-in-review/

Nature. We must restore and protect natural ecosystems such as forests, mangroves, wetlands and grasslands, allowing these ecosystems to reach their ecological potential for sequestering carbon dioxide. The logging of the Amazon, tropical forests in Southeast Asia, and other rainforests including the proposed cutting in the Tongass National Forest of Alaska is especially devastating to the climate. Creation of new protected areas, including strategic forest carbon reserves, should be a top priority. Payment for ecosystem services programs offer an equitable way for wealthier nations to help protect natural ecosystems.

Food. A dietary shift toward eating more plant-based foods and consuming fewer animal products, especially beef, would significantly reduce emissions of methane and other greenhouse gases. It would also free up agricultural lands for growing human food and, potentially, reforestation ("Nature" step). Relevant policy actions include minimizing tillage to maximize soil carbon, cutting livestock subsidies and supporting research and development of environmentally friendly meat substitutes. Reducing food waste is also critical, given that at least one third of all food produced is wasted.

Economy. We must transition to a carbon-free economy that reflects our dependence on the biosphere. Exploitation of ecosystems for profit absolutely must be halted for long-term sustainability. While this is a broad, holistic step involving ecological economics, there are specific actions that support this transition. Examples include cutting subsidies to and divesting from the fossil fuel industry.

Population. The global human population, growing by more than 200,000 people per day, must be stabilized and gradually reduced using approaches that ensure social and economic justice such as supporting education for all girls and women, and increasing the availability of voluntary family planning services.

Net-Zero America (est. 2018)[74]

Scientific, technical, and economic analysis of various strategies to achieve net-zero emissions. Offer specific recommendations organized around five "pillars":

- Pillar 1: End-use energy productivity—efficiency and electrification
- Pillar 2: Clean electricity
- Pillar 3: Bioenergy and other zero-carbon fuels and feedstocks
- Pillar 4: CO_2 capture, transport, usage, and geologic storage
- Pillar 5: Reduced non- CO_2 emissions
- Pillar 6: Enhanced land sinks

74. E. Larson, C. Greig, J. Jenkins, E. Mayfield, A. Pascale, C. Zhang, J. Drossman, R. Williams, S. Pacala, R. Socolow, EJ Baik, R. Birdsey, R. Duke, R. Jones, B. Haley, E. Leslie, K. Paustian, and A. Swan, Net-Zero America: Potential Pathways, Infrastructure, and Impacts, interim report, Princeton University, Princeton, NJ, December 15, 2020. https://environmenthalfcentury.princeton.edu/

5. What is the role of the proposed Green New Deal in this array of possible responses?

The GND is a framework that directs U.S. policy toward addressing climate change across all areas of government influence.

It is one among a broad array of response frameworks that includes:

Pure laissez-faire capitalism: This will lead us to 6 C warming, or more, as quickly as possible. There is no reason to think that the invisible hand is good at solving complex global problems, especially those that involve a moral element that runs counter to self-interest. It did not end slavery, it did not solve pollution or the endangered species problem in the 1970's, it did not lead petroleum companies to address climate change when they became aware of it in the 1970's and earlier.

It has not addressed problems of poverty, homelessness, health care, war, or systemic racial and sexual discrimination. Defenders of this approach may object that it is not supposed to address these kinds of problems—and that's precisely my point. Like these other large-scale wicked problems, climate change is not a merely technical or economic problem in search of a "silver bullet" linear solution.

Moreover, the free market and capitalist ideology have already had a 50-year chance to address climate change, and they have failed. To endorse this approach to the exclusion of any others is to be motivated by factors other than the belief that it will effectively address climate change.

The Green New Deal would look like one of the following:

Mild Keynesean capitalism with some guidance and regulation

Planned Keynesean capitalism that relies largely on existing market mechanisms and principles of private property ownership, competition, etc. It would use regulations, penalties, taxes, and subsidies to direct people's economic behavior toward desired ends.

Beyond the GND:

A regime of **centrally-planned economic structures**, including some free markets and some regulated markets. Some version / degree of socialism.

Frameworks that involve root-level cultural change, different conceptions of value:

Zero-growth economy, circular economy

"Degrowth" economy[75]

[75] See Adams, *Green Development*.

6. Points specifically for the economic-political debate:

The measures needed to address climate change, to restrain increases to 1.5 C or 2.0 C, will be economically significant. Will they be harmful or helpful to the economy?

1. Note that "the economy" is a collection of measurements, an aggregate of phenomena that names a huge variety of discrete activities; it is not an entity in itself that merits protection at all costs. "The economy" is not an entity that has rights or intrinsic value. We would be better to focus on the effects of various climate change strategies on identifiable groups of people.
2. We can imagine climate mitigation strategies that have positive and negative effects on people. There is an opportunity and an obligation to implement positive ones.
3. Large-scale changes to our economic system have been implemented before, with positive effects: "Many argue that actions to achieve this would be economically destructive. This claim has no basis, nor is it consistent with Australia's traditional optimism and ingenuity, nor with historical experience. Similar objections were raised in the past against government policies to limit air pollution, environmental toxins and ozone-destroying chemicals, but we collectively found ways to achieve mitigation at manageable cost, and with net benefits to society that are clear in hindsight." [76]

Is it necessary to include aspects of the Green New Deal that address "non-environmental" factors such as education, income, health care, and employment?

The Economist and other conservative voices argue against this—they advocate addressing *only* the factors most directly related to ghg emissions. They instead promote several "sensible policies":

- a carbon tax
- subsidies for nuclear power
- research for carbon-capture and carbon storage technologies
- move away from coal
- more energy from natural gas and bioenergy[77]

The resolution introduced to the U.S. House of Representatives in 2019 by Rep. Alexandria Ocasio-Cortez advocates (* are *directly* connected to ghg reduction):

- *Net-zero ghg emissions by 2050
- *Efficiency upgrades to all buildings
- *Electric vehicles rather than internal combustion
- Job creation and job training
- Livable wage & universal basic income
- Clean air, clean water, and healthy food recognized and provided as human rights
- Universal health care
- Family and medical leave
- Paid vacations
- Retirement security

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76. "An Open Letter on Australian Bushfires and Climate: Urgent Need for Deep Cuts in Carbon Emissions," accessed February 8, 2020, https://laureatebushfiresclimate.wordpress.com/.
77. I.K., "The Problem with the Green New Deal," *The Economist*, February 11, 2019.

- Stronger unions
- Affordable housing
- Access to nature for recreation
- Ending oppression, inequality, racism

Development theory has long recognized that **undesirable public behaviors, such as ghg emissions, are usually the result of poverty and other choice-limiting factors** that drive people to the most convenient, and lowest-cost solutions, to meet their needs. It is thus necessary to address factors that contribute to poverty and instability. Health care, social equity, employment, education, peace, etc. make it feasible for people to move toward a low-carbon economy and to implement mitigation measures.

Jane Goodall identifies four large-scale wicked problems that are linked to climate change:

- Poverty
- Unsustainable lifestyles
- Corruption
- Human population growth[78]

Is a free-market economy structure inherently problematic as contributor to climate change? As a barrier to appropriate responses to climate change?

See also Naomi Klein, *This Changes Everything: Capitalism vs. The Climate* (2015).

My take: **The market is a powerful calculator** for solving some kinds of complex distribution problems. It has its place as a tool in appropriate circumstances. But **capitalism as an ideology and economic framework** is in a couple of respects inherently problematic.

1. It encourages **limitless growth**, which involves some degree of limitless consumption, which involves some degree of limitless consumption of finite resources (both stocks and sinks). This is doomed, as Georgescu-Roegan demonstrated in the 1970's.

   Note that the rate of growth in ghg emissions in the U.S. as of early 2019 was 3.4% in the U.S., and 2.7% globally.[79] The growth on US GDP for the same time was 2.9%, and global growth is estimated at 3.9%.
2. Conventional economics assumes the **principle of full substitutability** for any resource, including those that have no substitute (air, water, soil, climate).
3. It tolerates, and even encourages, **extreme inequalities** and the concentration of resources under the control of a very few people. This a) puts key decisions in too few, unaccountable people's hands and b) deprives many, many people of the capability to make more sustainable decisions about the consumption and waste that drive climate change. For example, 71 percent of all ghg emissions since 1988 have occurred due to 100 companies—mostly petroleum and coal companies.[80]

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78. Jane Goodall, "These 4 Issues May Not Seem Related to Climate Change. But They Are and We Need to Solve them Now," *Time*, September 12, 2019.

79. Lisa Friedman, "What Is the Green New Deal? A Climate Proposal, Explained." *New York Times*, 21 February 2019.

80. Richard Heede, "Carbon Majors: Accounting for carbon and methane emissions 1854 - 2010, Methods & Results Report," Climate Mitigation Services, April 7, 2014. http://climateaccountability.org/pdf/MRR%209.1%20Apr14R.pdf. See also: Naomi Klein, *On Fire: The (Burning) Case for a Green New Deal* (New York: Simon & Schuster, 2019), 283.

4. It encourages a degree of **technological optimism** that can verge on delusion: blind faith in new zero-emissions energy sources, global climate engineering schemes, extensive colonization of other planets.