Energy and Human Ambitions on a Finite Planet. Tom Murphy. 457 pp. eScholarship, University of California, 2021. Free PDF download, ISBN 978-0-578-86717-5, doi: 10.21221/S2978-0-578-86717-5; $25.54 (paperback from Lulu.com), ISBN 978-0-578-86696-3. (Daniel V. Schroeder, reviewer.)[1]

The best thing about this book is the way the author shows how to think like a physicist.

The worst thing about this book is that the author thinks too much like a physicist.

Let me explain.

Energy and Human Ambitions on a Finite Planet is intended as a text for a college-level general education course on the physics of energy and the environment. Other possible texts for such a course include those by Hinrichs and Kleinbach,[2] MacKay,[3] Ristinen *et al.*,[4] and Wolfson.[5]

The subject inherently involves a lot of numbers and arithmetic: calculating the energy in a pitched baseball, a barrel of oil, or a day of sunshine; making comparisons to gain intuition; going back and forth between energy and power; and converting among all the commonly used energy units. A major challenge in teaching such a course is overcoming students' fear of math, so they can grow comfortable with all those numbers.

In this book, author Tom Murphy confronts this challenge head-on. The book is packed with worked examples of short calculations, often with marginal notes pointing out ways to make the math easier, written in a playful tone that will take the edge off students' anxiety. A delightful appendix presents handy calculation tips and tricks more systematically. Hundreds of end-of-chapter problems give students a chance to develop their energy numeracy skills, often in a familiar context like human metabolism, home energy use, or buying gasoline. The emphasis is usually on quick, low-precision estimates; for instance, the book sets $g = 10\ \text{m/s}^2$ throughout.

In a few places, though, the mathematical level of the text rises above what most general education students are ready for. Much of the book's material appeared in an earlier form on the author's *Do the Math* blog,[6] and he seems to have been thinking more of his blog readers—many of whom undoubtedly hold science and engineering degrees—when he wrote the sections on Carnot efficiencies, blackbody radiation, radiative forcing of earth's climate, and nuclear physics. Readers with some basic physics background will appreciate the author's insight in these sections. General education students would be better served if the more advanced material were moved to an appendix.

Some aspects of the book's structure may pose more serious challenges for students. The first three chapters discuss certain society-wide aspects of energy, even though energy isn't defined until Chapter 5. That chapter rushes through a list of the various types of energy, plus the related concepts of work and power, with brief mentions of force, mass, acceleration, charge, current, and voltage. Here the author seems to assume that readers have already had some exposure to basic mechanical and electrical concepts. The treatment of heat and thermal energy in Chapter 6 also seems rushed. The book doesn't acknowledge the difficulty of distinguishing the technical physics meanings of terms like energy, work, heat, and power from their everyday English meanings.

The book's structural awkwardness may be a side effect of the author's main agenda: convincing the reader that humanity's future is in great peril. On the spectrum that runs from technological optimists to Malthusian pessimists,[7] Murphy lies near the Malthusian extreme. The opening chapter, on exponential growth, echoes the lectures that former AAPT President Al Bartlett delivered on this subject from 1969 until his death in 2013.[8]

The core chapters of the book focus on supporting the author's thesis that we are headed toward a crisis. Chapter 8, on fossil fuels, presents a version of Hubbert's "peak oil" argument. Chapter 9 explains the mechanism of climate change, which the author considers to be "serious" but less of a threat to civilization than fossil fuel depletion. Then comes a series of chapters covering alternative energy sources: hydroelectricity, wind, biomass, and so on. After doing the applicable math, Murphy dismisses each of these as being too limited to meet the world's current average power demand of 18 TW (primary thermal equivalent). The only exception is solar energy, which he downplays because it is intermittent, expensive, and too difficult to use for transportation.

By the end of the book, Murphy has concluded that our best course of action is to prepare for "a future defined by reduced resource availability." (Nowadays the buzzword for this attitude seems to be "degrowth," though Murphy doesn't use the term.) He advises his readers to learn to grow their own food, choose a career that doesn't depend too much on technology, take up backpacking as a way to "toughen up" for a "less cushy" lifestyle, and consider the "toll on our planet" of choosing to have children.

No single book can cover all aspects of energy and the environment. This book omits any substantive discussion of air pollution, other non-climate environmental issues, long-distance electricity transmission, carbon capture/sequestration, and the political realm of policies that incentivize some energy technologies while discouraging others. The book doesn't bother to mention some of the more outlandish energy-gathering proposals, such as space-based solar collectors or engines powered by ocean thermal gradients. Geo-engineering ideas for countering climate change are categorically dismissed without naming even one of them, because they "ring of hubris." The (im)practicality of electrified transportation is relegated to an appendix. Most surprisingly, there is little discussion of technologies for energy storage, and essentially no discussion of how a *combination* of alternative energy technologies might be used to mitigate the drawbacks that each of them has individually.

The book is written mainly for an American audience. It often presents data for the world as a whole, but rarely for any individual countries other than the U.S.

The emphases on exponential growth and on fossil fuel depletion over climate concerns give the book a somewhat dated feel. Even the factual data aren't always as up to date as one would expect: quite a few statistics from two to ten years ago are presented, sometimes as if they are still current. Fortunately, the slightly low values of U.S. oil and gas reserves and wind and solar electricity generation don't materially affect the book's narrative. More significant is that the quoted price of lithium batteries is roughly twice what they actually cost in 2020,[9] and correcting this error would weaken the book's pessimistic take on electric cars.

The very first energy data set that appears in the book is also deceptive. Figure 1.2 plots U.S. energy use from 1800 through 2000, along with a smooth curve representing an exponential fit. An accompanying note states, "Lacking comparable data for the world, we use U.S. data simply to illustrate the more broadly applicable global growth trend." But this is triply misleading. First, it is easy to find comparable data for the world;[10] second, U.S. energy use *stopped growing* around the year 2000 and has been essentially flat since then (over the entire lifetimes of many of today's college students); and third, the U.S. in this respect is *not* like the world as a whole, whose energy use is still growing steadily (though not exponentially).[11] We physicists are trained to fit data to simple mathematical models, but social science data tend to defy these models—and the simplistic narratives that go with them.

The stereotypical physicist's approach[12] becomes most dangerous in Chapter 3, on global population. After several pages of mathematical models and graphs whose applicability is far from clear, the author shifts gears and tries to describe the so-called demographic transition. This is the repeatedly observed pattern in which a society begins in a pre-industrial state with a high birth rate and low life expectancy, then industrializes and eventually transitions to a new equilibrium with a higher standard of living, longer lives, and a low birth rate.

Murphy spins this process in the most negative way he can, bemoaning the "burden" of the population surge that occurs during any demographic transition. But he overestimates the magnitude of the expected worldwide surge, using his own logistic model rather than quoting a careful prediction from professional demographers. He also presents the data in a way that obscures how far along the world's demographic transitions have already progressed,[13] and he estimates the "cost" of the demographic transition using the empirically false assumption that an average country would end the transition at the same per-capita energy consumption level as the U.S. The result is an apparent *reductio ad absurdum*: that a worldwide demographic transition cannot be completed because it would require roughly a "factor of ten" increase in energy use.

In fact, most of the world is already nearing the end of, or has already completed, the demographic transition. Half the world's people now live in countries where the fertility rate is below the replacement level of 2.1 children per woman. These countries include not just the usual suspects but also Mexico, Brazil, Turkey, Bangladesh, and Vietnam.[14] World population is on track to stabilize at around 11 billion by the end of this century.[15] Very few countries are headed for U.S. levels of per-capita energy use, and per-capita energy use is now declining in the U.S., Europe, and Japan.[16] If we assume that the world's per-capita energy use in 2100 will be the same as that of the U.K. today (less than half that of the U.S. and typical for much of Europe), we obtain an estimated total world energy demand in 2100 of a little over double—not ten times—what it is now.[17]

As this book so convincingly shows, even meeting today's world energy demand with non-fossil sources will be a monumental challenge. A further doubling of demand will double the difficulty, and to minimize climate impacts we need to phase out fossil fuels well before 2100. There is no guarantee that we can pull it off. A global economic collapse, triggered by energy shortages or climate change or something else, always remains a possibility. But the challenges are mainly in the realms of economics and politics, not physics. Our job as science educators is to help our students envision what an alternative energy future might look like, so they can (if they choose) engage in useful efforts to help bring that future about. We do tremendous harm if we mislead students into believing that physical constraints will require large parts of the world to return to a pre-industrial state of deep poverty and high child mortality.

Let me end this review on a lighter note, by commending the author for making this book available in electronic form for free, and in paperback for the cost of printing. Now that such powerful self-publishing tools are widely available, I hope more textbook authors will use these tools to reduce costs to students.

Considering that it is self-published, the production quality of this book is extraordinary. The typesetting, page layout, illustrations, and full-color design are gorgeous. The PDF version is *thoroughly* hyperlinked, both internally and to external references. The only significant flaw in the printed version is that the ink smears if you get it wet—but it's still a bargain at $25.54 plus shipping. The book has no more typographical errors than you would expect in the first printing of a commercial textbook.

One of the advantages of self-publishing is that an author can make corrections and revisions at any time. I hope we will soon see a revision of this book that addresses some of the shortcomings in its content.

Daniel V. Schroeder teaches physics at Weber State University in Ogden, Utah. He has served the American Journal of Physics in several capacities, including a five-year stint as associate editor during the Jackson Administration. His 1999 textbook An Introduction to Thermal Physics was recently reissued by Oxford University Press.

---

[1] A version of this review without the endnotes was published in Am. J. Phys. **89** (9), 897–898 (2021); `https://doi.org/10.1119/5.0062183`.

[2] Roger A. Hinrichs and Merlin Kleinbach, *Energy: Its Use and the Environment*, 5th edition (Brooks/Cole, 2013).

[3] David J. C. MacKay, *Sustainable Energy—without the hot air* (UIT, Cambridge, 2008). Reviewed by David Hafemeister, Am. J. Phys. **78** (2), 222–223 (2010); doi: 10.1119/1.3273852.

[4] Robert A. Ristinen, Jack J. Kraushaar, and Jeffrey T. Brack, *Energy and the Environment*, 3rd edition (Wiley, 2016). An earlier related book was reviewed by Delbert W. Devins, Am. J. Phys. **57** (9), 860 (1989); doi: 10.1119/1.15885.

[5] Richard Wolfson, *Energy, Environment, and Climate*, 3rd edition (Norton, 2018). An earlier edition was reviewed by Art Hobson, Am. J. Phys. **76** (12), 1174–1175 (2008); doi: 10.1119/1.2982629.

[6] Tom Murphy, *Do the Math*, `https://dothemath.ucsd.edu/`.

[7] I learned these terms from Robert L. Park, *Voodoo Science* (Oxford University Press, 2000). An excellent book about the competing views of humanity's future is Charles C. Mann, *The Wizard and the Prophet* (Knopf, New York, 2018).

[8] Albert A. Bartlett, "Arithmetic, Population and Energy." A video of one of Bartlett's lectures is posted at `https://www.youtube.com/watch?v=sI1C9DyIi_8`. For more information see `https://www.albartlett.org`.

[9] Ira Boudway, "Batteries for Electric Cars Speed Toward a Tipping Point," Bloomberg (Dec. 16, 2020), `https://www.bloomberg.com/news/articles/2020-12-16/electric-cars-are-about-to-be-as-cheap-as-gas-powered-models`.

[10] See, for instance, Max Roser *et al.*, "Global primary energy consumption by source," `https://ourworldindata.org/grapher/global-energy-substitution`. Murphy's book occasionally cites the amazingly informative Our World in Data web site, so it is puzzling that he seems unaware of much of its relevant content.

[11] Murphy's presentation of historical U.S. energy use is also misleading in a fourth way. His exponential fit, yielding an annual growth rate of 2.9%, is based on data going all the way back to the year 1650. But the pre-1850 numbers come from estimates of wood burning only by Americans of European and African descent, as they expanded across a continent that was previously the home of millions of Native Americans. What appears to be a remarkably steady exponential growth process over more than three centuries is actually, therefore, a long *geographical* expansion of one population into the territory of another, followed by the industrial expansion in more recent times. For the world as a whole, energy use never grew faster than 1% per year until the late nineteenth century (see Ref. 10).

[12] See Randall Munroe, "Physicists," `https://xkcd.com/793/`.

[13] Murphy plots what are sometimes called "crude" birth and death rates, by country, without showing any trends over time. This data will mislead many readers because it does not incorporate the population's current age distribution—an essential element for making future projections. The best nontechnical explanations of world demographics are in the videos of Hans Rosling's many presentations, posted at `https://www.gapminder.org/videos`.

[14] Another quarter of the world lives in countries like India and Indonesia where the fertility rate is barely above 2.1. In almost all countries where fertility rates are higher they are falling rapidly. See Max Roser, "Fertility Rate," `https://ourworldindata.org/fertility-rate`.

[15] Max Roser, "Future Population Growth," `https://ourworldindata.org/future-population-growth`.

[16] Max Roser *et al.*, "Energy Data Explorer," `https://ourworldindata.org/explorers/energy`.

[17] According to Ref. 16, the U.K.'s per-capita energy use in 2019 was 53% greater than that of the world as a whole. Multiplying 1.53 by a population growth ratio of 11.2/7.7 (see Ref. 15) gives a total energy growth factor of 2.23.