SOURCES, NOTES AND CALCULATIONS

Volume I: No Immediate Danger

To save space I have omitted attributions of newspaper articles not by named reporters. Thus, a certain feature datelined "Cadarache France REUTERS" is sourced simply: "*The Japan Times,* Wednesday, October 15, 2014, p. 1 (unattrib., 'Sodium: the future of nuclear power or an element of doubt?')." But if I cite the same article two or three times in widely separated areas, I repeat the full source information, for what I hope is the reader's convenience.

Epigraph: "A crime is something someone else commits."—John Steinbeck, *The Winter of Our Discontent* (New York: Penguin, 1996; orig. pub. 1961), p. 258.

0. When We Kept the Lights On

Epigraph: "We all have in us the ghosts of long-vanished things . . ."—Gene Wolfe, *Sword & Citadel: The Second Half of* The Book of the New Sun (New York: A Tom Doherty Associates Book, An Orb Edition, n.d.; *The Citadel of the Autarch,* orig. pub. 1982), p. 343.

My contractor friend: "We sure need a good Sierra snowpack this year . . ." —R.M., November 2014.

The drought in Washington State—*The New York Times,* Saturday, May 16, 2015, p. A9 (Kirk Johnson, "Emergency in Northwest Is Declared in Drought").

"The peak of production in the United States should come about 1965 . . ." —Theodore Baumeister and Lionel S. Marks, ed., *Mechanical Engineers' Handbook, Revised by a Staff of Specialists* (New York: McGraw-Hill, 1958), p. 9-5 (Eugene Ayres, "Sources of Energy"). In 1964 a solar proponent noted that "our present fossil fuels . . . are irreplaceable and they are being consumed at an increasingly rapid rate. Eventually they will become more expensive . . . " (Farrington Daniels, *Direct Use of the Sun's Energy* [New York: Ballantine, 1964], p. 253). Between 1980 and 1990, the price of crude oil, natural gas and bituminous coal actually fell by about half (in constant 1987 cents per million BTU). National Coal Association: *Facts About Coal, 1993* (Washington, D.C.: National Coal Association, 1993), p. 68. [Henceforth cited: "National Coal Association."]

"A Federal Power Commission staff study . . ."—Jim Leckie, Gil Masters, Harry Whitehouse and Lily Young, *Other Homes and Garbage: Designs for Self-Sufficient Living* (San Francisco: Sierra Club Books, 1975), p. 75.

National Coal Association assessment of coal reserves—National Coal Association, p. 8.

"In 1999 my atlas advised me that oil might last another 40 years if we were lucky."—*The Times Comprehensive Atlas of the World,* 10th ed. (London: Times Book Group Ltd., 1999), p. 46 ("The World Today: Energy"): "If rates of energy consumption remained constant then it has been estimated that proven oil reserves would last forty years, natural gas sixty years and coal three hundred years. However, because energy rates are increasing these estimates may need revision."

"Iran announced intentions to increase her gas output by 40% . . . "—*The Wall Street Journal,* Tuesday, April 28, 2015, p. C4 (Benoît Faucon, "Iran Hopes for Gas Boom").

Mr. Jonathan Lee was "as excited as a rookie . . ." + China and India were seizing "a bargain opportunity . . ."—*The New York Times,* Thursday, April 2, 2015 (national ed.), pp. B1, B4 (Stanley Reed, "Oil Glut Benefits Those Who Ferry It"). There were now 600 supertankers that could carry two million barrels of oil apiece.

Philip's views on global warming: As stated in 2014. What I heard in North Carolina, after another year of heat records, was that there did seem to be global warming, but it was not necessarily manmade, and since natural processes tend to be cyclical, it just might correct itself.

Footnote: "It's not that I don't care about global warming . . ."—Linda Tirado, *Hand to Mouth: Living in Bootstrap America* (New York: Putnam, 2014), pp. 153–54.

"For more than 40 years, Homer City has spewed sulfur dioxide . . ."—*The Charleston [West Virginia] Gazette,* May 28, 2014, pp. 1A, 9A (Dina Cappiello and Kevin Begos, "'War on Coal': Dirty power plant to clean up its act").

"Pounded Again, Coastal Town May Consider a Retreat"—*The New York Times,* Thursday, January 29, 2015, p. A13 (article by Jess Bidgood). The town is Scituate, Massachusetts, and the speaker Patricia A. Vinchesi, "the town administrator."

That "colorless gas with a faintly pungent odor . . ."—Jacqueline I. Kroschwitz, exec. ed., and Mary Howe-Grant, ed., *Encyclopedia of Chemical Technology,* 4th ed. (New York: John Wiley & Sons, 1994), vol. 5 ("Carbon and Graphite Fibers" to "Chlorocarbons and Chlorohydro-carbons-C1"), p. 35 ("carbon dioxide").

The West Virginian pastor: "Here you do see the smokestacks . . ."—Pastor Bob Blevins, whose stories will be fully cited in the coal chapter "America's Best Friend."

Bangladeshi interviewees: "no alternative" to coal extraction—Interviews in Barapukuria, May 2015. See the coal chapter "Today or Tomorrow It Will Have to Come Out."

The old West Virginian: "I'm sure it's got something to do with the situation on TV . . ."—Mr. Arvel Wyatt, interviewed in his Flat Iron Drugstore in Welch, April 2014.

"My son works in the coalfields of southern West Virginia . . ."—*Bluefield [West Virginia] Daily Telegraph,* Tuesday, April 8, 2014, p. A4 ("Opinion" section), Bobby May, Harley, VA ("Support friends of coal, not Obama"). [The comma where a semicolon should be is printed here as in the original.] The following encomium (a variation on the formula) is especially touching: *The Welch News* [McDowell County, West Virginia], Volume 90, Number 033, Friday Evening, March 28, 2014, Special Coal Edition, Section C, p. 4B ("In Tribute to our Coal Miners"), to John Presley, from his wife and three daughters: "Thank you for the many years you worked in the coal mines risking your life so we could have a better life."

"In 1971 China derived 40 percent of its energy . . ."—*The Wall Street Journal,* Saturday/Sunday, April 12–13, 2014, p. A13 ("Notable & Quotable: *From environmental writer Bjorn Lomborg's 'How Green Policies Hurt the Poor' for the Spectator (U.K.), April 5*").

The Russian woman on Saint Petersburg winters—"Masha" (tour guide), interviewed in her city in June 2015.

"As concerns the popular impression . . ."—*The Encyclopaedia Britannica,* 11th ed. (New York: Encyclopaedia Britannica Co., 1910), vol. VI (CHÂTELET to CONSTANTINE), p. 424 ("climate"). [This version henceforth cited: *"Britannica,* 11th ed."]

My experience in Mexicali, and the taxi driver's rejoinder—Last week of May 2016.

The cab driver from Algiers—Interviewed in his taxi, February 2016.

The Sierra hiker—This was my friend Ben Pax, interviewed July 2016.

The Bangladeshi businessman—Interviewed in Dhaka, June 2015.

The woman on the Amtrak platform—Interviewed in November 2014.

"When a decision affects . . . a million people . . ."—"FC": *The Unabomber Manifesto: Industrial Society and Its Future* (Berkeley, California: Jolly Roger Press, 1995), p. 37 (para. 117).

Decrease in price of crude oil (from $107 a barrel in June 2014 to under $50 a barrel in January 2015), *Time*'s announcement about big cars, decline in hybrid sales and solar stocks—*Time,* vol. 185, no. 3, February 2, 2015, pp. 34, 38–39 (various reporters, "Economy: The Cost of Cheap Gas").

"The Office's end goal . . ."—*The Welch News* [McDowell County, West Virginia], Volume 90, Number 033, Friday Evening, March 28, 2014, Special Coal Edition, p. 8B (Patrick Morrissey, Attorney General of West Virginia, "Coal Must Be a Part of the Nation's Future").

The feeble occupant of the White House—In his second term, that President finally acted strong: Shocking environmentalists, he opened up Alaskan coastal waters to oil drilling.

"There's this notion that there's something I might have done . . ."—*The New York Times,* September 8, 2016, p. A18 (cont'd from p. A1: Julie Hirschfield Davis, Mark Landler and Coral Davenport, "Obama on Climate Change: 'The Trends Are Terrifying'").

Obama "speaks as though the Earth's climate ends and begins at the shores of the United States . . ."—Randy Smith, a delegate from the 53rd district who was also a coal miner, writing in to the [Charleston, West Virginia] *Sunday Gazette-Mail*, June 15, 2014, pp. 1E, 4E (Randy Smith, "casualties of war").

Footnote: Here is another assertion of convenient powerlessness. A West Virginian politician who will occasionally make pronouncements in *Carbon Ideologies* explained [*Coal Valley News,* Wednesday, June 11, 2014, p. A4 (Nick Rahall, U.S. Congressman, "EPA wrong on economics, wrong on science")]: "The NSPS [New Source Performance Standards] rule hinges on EPA's claim that Carbon Capture and Sequestration is an available technological option, ready to be used to solve our emissions challenges. This is just hokum, and . . . undermines the public's trust in an agency that justifies its actions as being driven by science." Of course, Rahall himself proposed nothing whatsoever "to solve our emissions challenges."

Tale of the Wisconsin "agency that manages thousands of acres of state land" (the Board of Commissioners of Public Lands)—*The New York Times,* Friday, April 10, 2015, p. A12 (Julie Bosman, "Agency Bans Activism on Climate"). A bemusing bookend to the foregoing: *The Spokesman-Review* [Spokane, Washington], Saturday, April 12, 2014, p. B4 (Charles Krauthammer, "Stop spread of totalitarian impulse"): "Two months ago, a petition bearing more than 110,000 signatures was delivered to the *Washington Post* demanding a ban on any article questioning global warming . . . the left is entering a new phase of ideological agitation—no longer trying to win the debate but stopping debate altogether . . . The proper word for that attitude is totalitarian . . . Sometimes the word comes from on high, as when the president of the United States declares the science of global warming to be 'settled.' Anyone who disagrees is then branded 'anti-science.' And better still, a 'denier'—a brilliantly chosen calumny meant to impute to the climate skeptic the opprobrium normally reserved for the hatemongers and crackpots who deny the Holocaust."

The Pope's "key policy document which is expected to blame mankind for climate change"—*The Times* [U.K.], Middle East and Asia ed., Wednesday, April 29, 2015, p. 10 (Tom Kington, Vatican, "Row over papal vow on climate change").

Divestment from coal—*International New York Times,* Saturday–Sunday, June 6–7, 2015, p. 9 (John Schwartz, "Climate fears prompt giant Norway fund to drop coal"). "Norway's $890 billion government pension fund" was "the largest sovereign wealth fund in the world."

Footnote: The Missouri Farm Bureau President's complaints—*The Wall Street Journal,* Saturday/Sunday, December 5–6, 2015, p. A11 ("Opinion" section, "Cross Country" by Blake Hurst: "How Wind Farms Blow Away Rights on Real Farms").

"low level radiation is probably less 'dangerous' than the emissions from burning coal."—David E. Lilienthal, *Atomic Energy, A New Start* (New York: Harper & Row, 1980), p. 65.

"Yes, I do want to have children . . ."—Ansel Elkins to WTV, letter of October 21, 2014.

Re: performing risk-benefit analyses—One way to quantify risk is with the micromort, "the unit representing a one-in-a-million chance of dying." "An average person on an average day faces a risk of roughly one micromort from non-natural causes." Scuba diving would cost five micromorts per dive. "Breathing in Beijing" on the most polluted day would be 15 micromorts. Then there are "microlives," which express "a person's cumulative risks over a lifetime." One microlife corresponds to "30 minutes of an average young adult's lifespan." Twenty minutes' exercise each day bestows two extra microlives of lifespan. Smoking four cigarettes a day costs two microlives. Alas, when I approached David Spiegelhalter, who was the man to go to for this stuff, he informed me that it had not been worked out for radiation, carbon emissions, etcetera. Maybe it will. See *New Straits Times* [Kuala Lumpur], Wednesday, March 3, 2014 (David Roberts and Nick Riesland, "Every breath you take").

"It's cultural devastation to lose families . . ."—Daniel Phillips, interviewed on April 9, 2014. The majority of his interview begins on II:209.

"the Arctic permafrost had only begun to sizzle out methane"—Thomas F. Stocker et al. (Working Group I Technical Support Unit), *Climate Change 2013: The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (New York: Cambridge University Press / Intergovernmental Panel on Climate Change 2013). [Henceforth cited: "IPCC, 2013."] Page 531: "Methane hydrates are another form of frozen carbon, occurring in deep permafrost soils, ocean shelves," etc. "They consist of methane and water molecule clusters, which are only stable in a specific window of low temperatures and high pressures . . . Any warming of permafrost soils, ocean waters and sediments and/or changes in pressure could destabilise those hydrates, releasing their CH_4 to the ocean." And page 1116: "The conjunction of a long carbon accumulation time scale on one hand and potentially rapid permafrost thawing and carbon decomposition under warmer climatic conditions . . . on the other hand suggests potential irreversibility of permafrost carbon decomposition (leading to an increase of atmospheric CO_2 and/or CH_4 concentrations) on time scales of hundreds to thousands of years in a warming climate . . . [T]his process, induced by widespread permafrost warming and thawing, . . . might be already occurring."

Future status of the Marshall Islands—*The Japan Times,* Sunday, June 10, 2012, p. 10 (cont'd from p. 9, Christopher Johnson, "The Marshall Islands: Tropical idylls scarred like Tohoku"): "The tide-line has been creeping up . . . some researchers have estimated the Marshalls could become uninhabitable in 50 to 100 years." Cf. Seth B. Darling and Douglas L. Sisterson, *How to Change Minds About Our Changing Climate* (New York: The Experiment, 2014), p. 95: If our planet's average temperature increased by five degrees, "ice would likely disappear completely from both poles, sending sea level about 20 meters . . . higher . . . The tropics and sub-tropics would be essentially uninhabitable." Both authors were employed at the Argonne National Laboratory; Sisterson was a "senior manager . . . for the US Department of Energy's Atmospheric Radiation Measurement Climate Research Facility."

"Here I pause for one moment . . ."—David Perkins, ed., *English Romantic Writers* (New York: Harcourt, Brace & World, 1967), p. 731 ("On the Knocking at the Gates in *Macbeth*").

About the "Primer" Section

Epigraph: "Actually, this book was not of the slightest value . . ."—George R. Stewart, *Earth Abides* (Greenwich, Connecticut: Fawcett Publications / A Fawcett Crest Book, n.d. [1980?], repr. of 1949 ed.), p. 268.

books "such as an idle man cannot read . . ."—Henry David Thoreau, *A Week . . . , Walden . . . , The Maine Woods, Cape Cod* (New York: Library of America, 1985), p. 967 (*A Week on the Concord and Merrimack Rivers,* rev. ed. of 1868), p. 78.

About Tables

Epigraph: "Human eyes can perceive things . . ."—*The Complete Essays of Montaigne,* trans. Donald M. Frame (Stanford, California: Stanford University Press, 1965 repr. of 1957 ed.; orig. essays wr. 1572–88), p. 399 ("Apology for Raymond Sebond," 1575–80).

About Photographs

Epigraph: "Survey . . . the most remarkable events . . ."—Beaumont Newhall, ed., *Photography: Essays & Images* (New York: The Museum of Modern Art, 1980, p. 14 (Tiphaigne de la Roche, "Photography Predicted," 1760).

PRIMER

What Was the Work For?

Epigraph: "We are the soul . . ."—Ayn Rand, *Atlas Shrugged* (New York: New American Library / Signet, 32rd repr. [*ca.* 1975]; orig. ed. 1957), p. 579.

Internal combustion engine: "a machine for converting chemical energy . . ." —United States Naval Reserve Midshipmen's School U.S.S. "Prairie State," *Internal Combustion Engines* (Washington, D.C.: U.S. Government Printing Office, 1942, rev. June 1942), p. 51. [Henceforth cited: "USNRMS 'Prairie State.'"]

"Using electricity to generate . . . heat is extremely inefficient"—Michael Boxwell, *Solar Energy Handbook, 2012 Edition* (Ryton on Dunsmore, Warwickshire, U.K.: Greenstream Publishing, 2012; orig. ed. 2001), p. 10.

Footnote: the contractor's views on global warming—As stated in 2014.

"About 4% of the energy consumed in American homes went for clothes drying"—Information from Mara Prentiss, *Energy Revolution: The Physics and the Promise of Efficient Technology* (Cambridge, Massachusetts: Belknap Press, 2015), p. 53 (pie chart: U.S. Residential Electricity Use 2011," from U.S. Energy Administration).

Footnote: "servants might rise as early as 2:00 a.m. . . ."—Sally Mitchell, ed., *Victorian Britain, An Encyclopedia* (New York: Garland, 1988), p. 378 ("housework and domestic technology").

"Lessening man's toil . . ."—L. Jackson Newell, *The Electric Edge of "Academe": The Saga of Lucien L. Nunn and Deep Springs College* (Salt Lake City: University of Utah Press, 2015), p. 51 (letter to Lionel G. Nightingale; date lost).

"It has been calculated that about 60 per cent. . . ."—Quoted in William Digby C.I.E., *"Prosperous" British India: A Revelation from Official Records* (New Delhi: Sagar Publications, 1969, repr. from 1901 ed.), p. 420.

"Energy is a vital component of development . . ."—Asha Han, *The Power Sector in India* (New Delhi: Sterling Publishers Private Ltd., 1986), p. 10.—By this time the necessity of providing electric power was unquestioned. Consider, e.g., Government of Haryana [an Indian state not far from Delhi], Planning Department, *Fourth Five-Year Plan 1969–74* (Chd.: Government Press, 1971), p. 160 ("Power Projects"): "Out of 6,669 villages, only 1,251 villages (19 per cent) had been electrified up to the end of 1957–63. Similarly per capita consumption of electricity [which I think means percentage of people who have access to electricity] is only 37 per cent as against 44 per cent in Punjab." The foregoing explained the government's reason for building a 55-megawatt thermal plant at Faridabad.

African energy production, 1980–2011: *ProQuest Statistical Abstract of the United States 2015,* 3rd ed., issued December 2014 (Bethesda, Maryland: Bernan / Rowman & Littlefield, 2014). [This vol. henceforth cited: "U.S. Statistical Abstract, 2015."]. Page 896 (Table 1392: "World Primary Energy Production by Region and Type, 1980 to 2011"). The 1980 African figure was 17.4 Q-BTUs (quadrillion BTUs); the 2011 equivalent was 172.3—an increase by a factor of 9.9.

Cooking and cleaning times, 1965 and 1995—Patrick Canning, Ainsley Charles, Sonya Huang, Karen R. Polenske and Arnold Waters, *Energy Use in the U.S. Food System* (Washington, D.C.: United States Department of Agriculture, Economic Research Service, Economic Research Report 94, 2010), p. 16, which references "a time-use study of adults between ages 18 and 64." [Henceforth cited: "USDA Report 24."]

Laborers: "capitalists replaced them with fossil fuels"—Information from *Resources, Conservation and Recycling,* 55 (2011) [journal homepage: www.elsevier.com/locate/resconrec], pp. 362–81 (Julian M. Allwood, Michael F. Ashby, Timothy G. Gutowski and Ernst Worrell, "Material efficiency: A white paper"). [Henceforth cited: "*Resources, Conservation and Recycling,* 2011."] Page 372: "Ayres and van den Bergh (2005) discuss three mechanisms of economic growth: substitution of fossil fuels for labour to reduce costs; scale economies and learning by doing to reduce costs; substitution of information/knowledge leading to increased value to customers . . ."

"Smoke and Steel"—The phrases to which I refer are on pp. 185 and 186 of George and Willene Hendrick, ed., *Carl Sandburg: Selected Poems* (New York: Harcourt, Inc. / "A Harvest Original," 1996).

"The modern American suburbanite . . ."—Jan Jennings, *Roadside America: The Automobile in Design and Culture* (Ames: Iowa State University Press, for the Society for Commercial Archeology, n.d.).

"Stay connected and entertained . . ."—Etisalat Yellow Pages, Abu Dhabi 2016: Al Ain & Western Region, p. 25. [Henceforth cited: "Abu Dhabi yellow pages, 2016."] From the same source, p. 30: "Etisalat mobile internet plans gives you the facility to get in contact with the world through your handheld Mobile [*sic*] devices; whether you like mobile browsing, downloading images, connecting with your friends, checking your email, you can do it all with our new data plans." So now you know what that thermodynamic work was for.

Paragraph on oil tankers, trips to the sun, etc.—Information from Bill D. Berger and Kenneth E. Anderson, *Modern Petroleum: A Basic Primer of the Industry* (Tulsa, Oklahoma: PennWell Books, 1978), pp. 182–84, 203.

Footnote: Power spent by a human going upstairs—Baumeister, p. 9-28 (staff contribution, "Power Miscellany"), work done by a man raising his own weight up a stair or ladder: 81.5 ft-lb/sec, converted by WTV at 81.5 ft-lb/sec × 60 sec × 1 BTU / 778.98 ft-lbs = 6.277 BTUs. For the laptop computer's power needs, see p. 67 ("Comparative Power Requirements . . .").

Same footnote: 1 BTU is contained in one match tip—National Coal Association, p. 90. According to Berger and Anderson (p. 244), a BTU needs an entire wooden match.

Power Wastage by Group-Driven Machine Tools, ca. *1945*

All figures (except for wastage calculations, made by WTV) from Erik Oberg and F. D. Jones, *Machinery's Handbook for Machine Shop and Drafting-Room,* 13th ed., 3rd. pr. (New York: The Industrial Press, 1946), p. 1842 ("In the group drive, the motor drives a length of lineshafting . . .") and p. 1843 (unnumb. table, "Power Requirements of Group-driven Machine Tools"). In most comparative tables later on, conversions are made to British thermal units (BTUs) for consistency. That seemed undesirable here, since the numbers originally given in watts were friendlier. But for those who wish to see them in BTUs [1 watt = 0.056884 BTU per minute], here they are, respectively: Cincinnati drill presses, 20.48 and 3.98. Rockford boring mills, 92.15 and 17.07. Gridley Automatics, 86.46 and 15.34.

American energy wastage, 2012: 61%—Prentiss, p. 19 (pie chart "Fraction of Primary Source Energy Used and Wasted [U.S. 2012])."

About Waste

Epigraph: "... To condemn a thing thus, dogmatically ..."—Montaigne, p. 132 ("It is folly to measure the true and false by our own capacity," 1572–74).

Carbon monoxide emissions "occur especially in idle, low speed, and cold start conditions."—U.S. Environmental Protection Agency, *EPA 430-R-16-002: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2014* (Washington, D.C.: EPA, April 15, 2016). [Henceforth cited: "EPA, 2016." All pages cited per PDF version, not per the fiddly system of the original.] Page 119.

"The girls, with patched cotton stockings ..."—Alexander Werth, *Russia at War 1941–45* (New York: E. P. Dutton, 1964), pp. 347, 346.

Footnote: "In a workshop that's had a direct hit ..."—Ibid., p. 346.

"According to experts, 70% of the input SF_6 quantities escape."—Michael Strogies and Patrick Gniffke, eds., *Climate Change Submission under the United Nations Framework Convention on Climate Change, 2009, National Inventory Report for the German Greenhouse Gas Inventory 1990–2007* (ISSN 1862-4359) (Dessau-Roßlau, Germany: Umweltbundesamt [Federal Environment Agency], 2009). [Henceforth cited: *"Greenhouse Gas Inventory Germany, 1990–2007."*] Page 306.

Mao's backyard furnaces—Dr. Li Zhisui, *The Private Life of Chairman Mao,* trans. Tai Hung-Chao (New York: Random House, 1994), pp. 273, 277, 283, 291, 304.

Yield losses in sheet metal manufacture—*Philosophical Transactions of the Royal Society A* 2013 371, 20120496, published January 28, 2013 (Julian M. Allwood, Michael F. Ashby, Timothy G. Gutowski and Ernst Worrell, "Material efficiency: providing material services with less material production"); downloaded [by T. Gutowski] from rsta.royalsocietypublishing.org on November 4, 2014. [Henceforth cited: "Allwood et al., 2013."] Pages 5–6. There are many such wasteful manufacturing situations. For example, recycling that "occurs close to home while the materials are still in some stage of manufacture," Timothy G. Gutowski et al., in "A Global Assessment of Manufacturing: Economic Development, Energy Use, Carbon Emissions, and the Potential for Energy Efficiency and Materials Recycling, *Annual Review of Environment and Resources,* vol. 38: 81–106, 2013 [Henceforth cited: "*Annu. Rev. Environ. Resour.,* 2013," p. 94, remark: "Internal recycling actually is a form of inefficiency. That is, significant energy has been invested and carbon emitted to produce new material only to return a part of it to be reprocessed again before it can be turned into a useful product."

Absorptions of clear glass and cobalt-blue globes—Terrell Croft and Wilford I. Summers, *American Electricians' Handbook,* 14th ed. (New York: McGraw-Hill, 2002; orig. ed. 1961). [Henceforth cited: "*American Electricians' Handbook,* 2002."] Page 10.3 (Table 4: "Coefficients (Percent) of Absorption of Lighting Materials").

Food waste in Hawaii—*TGI: The Garden Island* [Kauai, Hawaii], Sunday, August 7, 2016, pp. A1, A11 (Jessica Else, "Feeding the landfill: study shows 237,000 tons of food thrown away every year"). ["During fiscal year 2015, Kauai residents and guests produced 81,500 pounds of total waste." Food was one of the top three contributors.] I calculated the resultant methane as follows: 237,000 tons is 474 million pounds. For lack of better information, I assumed that Hawaiian food waste was similar in composition to the Japanese kind. I then turned to: Ministry of the Environment, Japan, Greenhouse Gas Inventory Office of Japan (GIO), Center for Global Environmental Research (CGER) and National Institute for Environmental Studies (NIES), primary authors, *National Greenhouse Gas Inventory Report of JAPAN,* April 2015 (Tsukuba, Ibaraki, Japan, National Institute for Environmental Studies, 2015). [Henceforth cited: "*Greenhouse Gas Inventory Japan,* 2015."] In an anaerobic landfill, food waste would generate about 145 kilograms methane per ton. [Since Japan uses the metric system I assumed that these were metric tons even though they were not spelled "tonnes."] In a "semi-anaerobic" landfill, the figure was 72 kg (see p. 7-9). Each kg of methane per ton of food waste would equal: 1 kg methane / ton food waste × 2.2 lbs methane / lb methane = 2.2 lbs methane / 2,204 lbs food waste = 0.001 lbs methane per lb food waste. Plugging in 145 and 72 kg into this gave me 0.145 and 0.072. For 474 million pounds the first methane value would be 68,730,000 pounds, or (× 86; see "About Methane," II:302) 5,910,780,000 pounds of carbon dioxide equivalent; the semi-anaerobic value would be 2,935,008,000 pounds of carbon dioxide equivalent.

Footnote: Percentages of carbon in Japanese food waste and human waste—*Greenhouse Gas Inventory Japan,* 2015, p. 7-7.

"Forty years ago kerosene was refined . . ."—L. W. Ellis and Edward A. Rumely, *Power and the Plow* (Garden City, New York: Doubleday, Page & Co., 1911), p. 122.

Oil spills in Drumright—D. Karl Newsom, *Drumright!: The Glory Days of a Boom Town* (Perkins, Oklahoma: Evans Publications, Inc., 1985), p. 204.

"Of the energy generated in an engine cylinder . . ."—Ellis and Rumely, p. 17.

The tale of the Power Authority of Puerto Rico—*The New York Times,* Tuesday, February 16, 2016, pp. B1, B6 (Mary Williams Walsh, "Witness Cites Recipe for Toxic Air, and Debt, at Puerto Rico's Power Company").

Footnote: "Natural gas, the major raw material . . ."—Roy L. Donahue, Raymond W. Miller and John C. Shickluna, *Soils: An Introduction to Soils and Plant Growth,* 4th ed. (Englewood Cliffs, New Jersey: Prentice-Hall, 1977, rev. repr. of 1958 ed.), pp. 541–42.

Sulfur dioxide: "a colorless gas . . ."—H. Clark Metcalfe, John E. Williams and Joseph F. Castka, *Modern Chemistry* (New York: Holt, Rinehart and Winston, Inc., 1970), p. 589.

Transformation of SO_2 into sulfuric acid in lung tissue; and its impairment of photosynthesis—Eugene P. Odum, *Fundamentals of Ecology,* 3rd ed. (Philadelphia: W. B. Saunders Co., 1971), pp. 445, 92.

"Global warming during the 20th century was primarily initiated . . ."—*Thin Solid Films,* February 11, 2009, www.elsevier.com/locate/tsf, downloaded for WTV by Jordan Rothacker, April 2016, pp. 3188–3203 (special feature: Peter L. Ward, *Teton Tectonics,* "Sulfur dioxide initiates global climate change in four ways"), p. 3198. [Henceforth cited: "Ward."]

Power Wastage During Machining Operations at an Unspecified Toyota Factory, ca. *2000*

Information from the *Journal of Cleaner Production* [www. elsevier.com/locate /jclepro, accessed by Jordan Rothacker, December 2015], vol. 13 (2005), p. 4 (Timothy Gutowski, Cynthia Murphy, David Allen, Diana Bauer, Bert Bras, Thomas Piwonka, Paul Sheng, John Sutherland, Deborah Thurston and Egon Wolff, "Environmentally benign manufacturing: Observations from Japan, Europe and the United States"). [Henceforth cited: "*Journal of Cleaner Production*." The article with its endnotes spanned pp. 1–17.] From this same place I would like to quote an admirable slogan about factory floor sweepings: "When combined it is waste; when sorted it is a resource."

Likewise, in a certain unnamed automotive machining line, "the maximum energy resources requirement for the actual machining in terms of electricity is only 14.8% of the total . . . At lower production rates the machining contribution is even smaller."—Bhavik Bakshi, Timothy Gutowski and Dusan Sekulic, *Thermodynamics and the Destruction of Resources* (Oxford: Cambridge University Press, 2011), from PDF of chap. 6 (Timothy G. Gutowski and Dusan P. Sekulic, "Thermodynamic Analysis of Resources Used in Manufacturing Processes 1") as downloaded for WTV by Jordan Rothacker, February 2016), p. 20. Henceforth cited: "Gutowski and Sekulic."]

About Waste (continued)

"I would not characterize these energy usages as waste . . ."—E-mail to my research assistant Jordan Rothacker from Timothy G. Gutowski, Professor of Mechanical Engineering at M.I.T., Friday, February 5, 2016.

Footnote: "A number of manufacturing processes . . ."—Gutowski and Sekulic, p. 14.

"an annual reduction of 4.2% in energy input . . ." + list of ways to improve efficiency: insulation, precision testing for compressors, etc.—Kroschwitz and Howe-Grant, vol. 12 ("Fuel Resources" to "Heat Stabilizers"), pp. 441, 457–61 ("energy management").

"If I am making zero kilograms of ice . . ."—*Wired* magazine, 2.28.14, Rhett Allain, "How Much Does It Cost to Make Ice?," p. 3 of 5; downloaded for WTV by Jordan Rothacker, November 2016, from https://www.wired.com/2014/08/how-much-does-it-cost-to-make-ice/. [Henceforth cited: "Allain article, 2014."]

Yearly fuel requirements of icemaker—Since 88 watts × [0.000948067 BTU per second / 1 watt] = 0.083 BTU per second, then × 3,600 = 300.34 BTUs per hour. Multiplying this by 3 to account for ⅔ losses during power generation (see p. 152), we get 901 BTUs. Multiplying × 24 × 365 yields 7,893,135.6 BTUs per year. In the table of Calorific Efficiencies (p. 215, header. **202**), we find an HHV of 18,570 BTUs per lb of commercial fuel oil, medium grade, *ca.* 1975. Dividing 789,313.56 by 18,570, we arrive at a yearly requirement of 425.05 pounds of commercial fuel oil.

Barrel of oil equivalent—Density of diesel fuel (my standard approximation for the density of oil; see p. 583) = 7.036 lbs/gallon. Hence 425.05 lbs commercial fuel oil × 1 gal / 7.036 lbs = 60.4 gal. A barrel of petroleum = 42 gallons. Dividing 60.4 by 42 yields 1.43, which means that 1.43 barrels of oil will be required to power one icemaker for a year.

Power Wastage by Devices in Standby Mode, 2000–2010

"Unplugging a device constantly consuming standby power . . ."—Wikipedia article on "standby power," accessed February 15, 2015.

Japan—Energy Conservation Center, Japan (ECCJ), 2008 report, accessed and translated by Ms. Kawai Takako.

France—http:/standby.lbl.gov/ACEE/StandbyPaper.PDF.

Britain—Energy Review 2006, Department of Trade and Industry, U.K. http://www.bis.gov.uk/files/file31890.pdf.

California—PIER Final Project Report: "Developing and Testing Low Power Mode Measurement Methods," prepared for California Energy Commission Public Interest Energy Research Program, by Lawrence Berkeley National Laboratory. Executive summary [evidently from 2002]. Accessed by Ms. Kawai Takako. No web address provided.

About Demand

Epigraph: "Between 2000 and 2005, UK consumers on average . . ."—*Resources, Conservation and Recycling,* 2011, p. 368: Citation discouragingly continues:

"Between 1985 and 2000 the lifespan of computers purchased in US universities dropped from 10.7 to 5.5 years . . . On average 98.4% of all licensed car seats in the UK are not in use at any time . . . Even if used furniture is given away for free in the UK, the economic case for re-selling it is at best marginal . . . These examples suggest that consumers in developed countries are continuing to expand their material consumption well beyond their basic needs . . ."

"WHEN IN VEGAS . . ."—*Where Las Vegas* ("the complete guide to go"), September 2016, first [unnumbered] page after inside cover, ad for Simon Malls.

The tale of Egypt's offshore natural gas—*The New York Times,* Friday, September 2, 1016, pp. B1, B6 (Stanley Reed, "Israel Opens Up Offshore Gas Fields, and Eagerly Awaits Foreign Investment").

"Very possibly, more than half a year's entire global production . . ."—The field discovered might contain 75 trillion cubic feet (same story, p. B1). World production as of 2014 had been about 121 trillion cubic feet, according to: U.S. Energy Information Administration, "Natural Gas—Energy Explained, Your Guide to Understanding Energy" ("last updated: June 23, 2015"). "Natural gas statistics: Preliminary data for 2014, except where noted." [Henceforth cited: "USEIA, "Natural Gas, 2014."] Downloaded for WTV by Jordan Rothacker, June 2016, from http://www.eia.gov/energyexplained/index.cfm?page=natural_gas_home#tab2.

About demand—Mason Inman, *The Oracle of Oil: A Maverick Geologist's Quest for a Sustainable Future* (New York: Norton, 2016), p. 312, quoting Marion King Hubbert, 1988: "One of the most ubiquitous expressions in the language right now is growth—how to maintain our growth. If we could maintain it, it would destroy us."

What Was the Work For? (continued)

Epigraph: "A Battery of eleven Guns . . ."—Benjamin Franklin, *Writings* (New York: Library of America, 1987), p. 336 ("Course of Experiments," in *The Pennsylvania Gazette,* April 1, 1751).

Epigraph: Ad for So Truly Real® baby doll—*National Enquirer,* October 10, 2016, p. 53.

"Magic is a practical science . . ."—Jack Vance, *Tales of the Dying Earth* (New York: Orb / Tom Dougherty Associates, undated repr. of 1998 ed.), p. 582 ("Rhialto the Marvellous," 1984).

"the seemingly extravagant use of materials and energy resources by many newer manufacturing processes . . ."—Gutowski and Sekulic, pp. 37–38.

Footnote: J. G. Ballard, 1996: "Without motives our investigation would be so much easier" + "Guilt is so flexible . . ."—J. G. Ballard, *Cocaine Nights* (Washington, D.C.: Counterpoint, 1998; orig. pub. 1996), pp. 98, 113.

Re: carbon nanotubes—Gutowski and Sekulic, p. 37. The passage deserves a fuller citation here, not only for its interesting details, which inform my table on p. 59, but also for its overall point: "Carbon nanotubes are one of the most energy intensive materials humankind has produced. Yet, the cost of this energy turns out to be only a very small fraction of the price. For example, say the energy cost for making carbon nanotubes is on the order of 36GJ of electricity per kilogram or 36MJ/g [or about 15.47 billion BTUs/lb.—WTV]. This is equal to 10 kWh/g. Now at 7 cents a kilowatt hour this yields a cost of 70 cents per gram. But carbon nanotubes can sell for around $300/g. In other words, the electricity cost in this case is on the order of 0.2% of the price, and according to a recent cost study, energy costs for all manufacturing processes for nanotubes result in about 1% of the cost . . . At the same time however, since our current electricity supply comes primarily from fossil fuels, most of the environmental impacts associated with these materials (e.g. global warming, acidification, mercury emissions) are related to this use of electricity . . . Another comment, of course, is that, from an environmental perspective, electricity from fossil fuels is significantly underpriced."

The matter of single-setting steam boilers—*The New York Times,* Friday, November 20, 2015, p. A23 (Lisa W. Foderaro, "Closing a Window to Open the Door to Efficiency: Study Charges Buildings to Retrofit Radiators to Cut Emissions from Overheated Homes").

"This happened . . . in western Siberia"—In Novy Urengoy, *ca.* 2015, "the difference between the inside and the outside temperature often amounts to an unbelievable 70 degrees [Celsius]. The centrally controlled gas heating keeps the flat at a comfortable 25 degrees—and that at a fixed price. When it gets too warm, they open a window. An economic use of resources of energy is not a top priority in the gas capital"—Sophie Panzer and Christina Simmel, eds., *Gazprom City* [in German, Russian and English] (Wien: Schlebrügge Editor, 2015), p. 51.

"something more is needed to relieve the long intervals of inactivity . . ."—Samuel Johnson, *Selected Essays,* ed. David Womersley (New York: Penguin, 2003; essays orig. pub. 1739–61), p. 126 (*The Rambler,* No. 49, Tuesday, September 4, 1750).

National Coal Association: "Energy is vital . . ." + "In general, each percentage increase . . ."—National Coal Association, pp. 4, 6.

Oil expenditure of the Cape Cod lighthouse—Thoreau, *A Week . . . ,* p. 967 (*Cape Cod,* this chapter of which was written *ca.* 1865).

Henry Adams "could see that the new American . . ."—Henry Adams, *Novels, Mont Saint Michel, The Education* (New York: Library of America, 1983), p. 1174 (*The Education of Henry Adams* [1907]).

"Between 1870 and 1990, per capita energy use in America more than tripled"—Information from Kroschwitz and Howe-Grant, vol. 12 ("Fuel Resources" to

"Heat Stabilizers"), p. 2 ("fuel resources," Table 1: "U.S. Energy Consumption by Source from 1870–1990, EJ"). For the original figures and my conversions from them, see p. 72, headers **81** and **270**.

"our *absolute* energy consumption rose almost 21 times"—Information from the same place. In 1990, Americans used 85.76 exajoules; in 1870 they had used 4.1.

"Electricity is essential to economic and human development . . ."—Australian Government, Department of Industry and Science, Office of the Chief Economist, "Coal in India 2015" (n.p.: Commonwealth of Australia, June 2015, downloaded for WTV by Jordan Rothacker, February 2016), p. 31. [Henceforth cited: "Australian Government: India, 2015."]

"We saw a light in the gloomy dark . . ."—Andrey Platonov, *Soul and Other Stories,* trans. Robert and Elizabeth Chandler et al. (New York: New York Review Books, 2008), p. 263 ("The Motherland of Electricity," 1939).

"in each two days of 2009, the world burned the entire oil output of 1990"—Information from George A. Olah, Alain Goeppert and G. K. Surya Prakash, *Beyond Oil and Gas: The Methanol Economy,* 2nd rev. ed. (Weinheim, Germany: Wiley-VCH, 2009), p. 35.

"we Earthlings could have electroprocessed nearly 9.7 million pounds of titanium every minute . . ."—Based on 365.93 exajoules (which was actually the world energy consumption figure for 1991, not 1990), converted as follows: 365.93 EJ × [0.948 quads = 0.948 × 10^{18} BTUs] / 1 EJ = 346.90 × 10^{18} BTUs = 346.9 quadrillion BTUs. If energy consumption were constant over that year, then each minute we would have used [346,900,000,000,000,000,000] / [60 × 24 × 365] = 660,007,610,688,000 BTUs, which divided by 68,260 BTUs (amount of energy needed to electroprocess 1 lb of titanium in 1958) = 9,669,024,465.359 [call it 9.7 million] lbs, ignoring power plant losses.

Current used per minute by 132.5 trillion icemakers—Calculated from 0.083 BTUs per second (converted from 88 W, above, p. 40) × 60 secs/min = 5.006 BTUs, which goes 131,843,310,165,000 times into 660,007,610,688,000 BTUs.

"one out of four people in India lacked access to electricity"—Information from Australian Government: India, 2015, p. 57. The same statistic appears in *Investor's Business Daily, IBD Weekly* 33, no. 26, week of July 11, 2016, p. A6 (Allison Gatlin, "First Solar, China's Jinko, Trina, JA to Battle in Rising Indian Market," cont'd [as "Solar"] from p. A5).

"This is clearly a major barrier to economic and social progress . . ."—Australian Government: India, 2015, loc. cit.

Quadrupling of Indian power consumption—Ibid., p. 29.

India became the world's third largest energy user—Ibid., p. 27.

India: blackouts still lasted for hours or days—Information from U.S. Energy Information Administration, "India: International Energy Data and Analysis," last updated June 26, 2014, p. 18, downloaded by Jordan Rothacker, February 2016. [This source henceforth cited: "USEIA: India, 2014."] Loc. cit.: "India suffered an unprecedented electricity blackout for two days in July 2012 that affected an estimated 680 million people across the country's northern states. This outage highlights the increasing pressure on India's power system to secure more fuel supplies and infrastructure investment in each stage of power transmission."

Energy use of various American lifestyles, 1997—IEEE International Symposium on Electronics and the Environment, May 19–20, 2008, San Francisco, U.S.A. Timothy Gutowski, Amanda Taplett, Anna Allen, Amy Banzaert, Rob Cirinciore, Christopher Cleaver, Stacy Figueredo, Susan Fredholm, Betar Gallant, Alissa Jones, Jonathan Krones, Barry Kudrowitz, Cynthia Lin, Alfredo Morales, David Quinn, Megan Roberts, Robert Scaringe, Tim Studley, Sittha Sukkasi, Mika Tomczak, Jessica Vechakul and Malima Wolf, "Environmental Life Style Analysis (ELSA)," pp. 2–3. I have converted all figures from the original gigajoules, @ 1 GJ = 948,067 BTUs. The stats I selected were: Buddhist monk, 120 GJ = 113,768,040 = 113.8 million BTUs; homeless, 125 GJ = 118,508,375 = 118.5 million BTUs; five-year-old, 130 GJ = 123,248,710 = 123.3 million BTUs; coma patient, 2,500 GJ = 2,370,167,500 = 2.37 billion BTUs; senator, 3,700 GJ = 3,507,847,900 = 3.51 billion BTUs. The U.S. and world averages for 1997 were respectively given as 350 GJ = 331,823,450 [or 331.8 million] BTUs, and 64 GJ = 60,676,288 [or 60.7 million] BTUs. Re: the lifestyle of the Buddhist monk: "While 120GJ is about one third the American average in 1997 (350GJ), it is almost double the global average energy use in that year (64 GJ)."

President's Science Advisory Committee findings, 1967—Odum, p. 47. The findings were expressed in essentially the following form: American food per hectare: *3x*; Asian and African food per hectare: *x*; American mechanical energy input per hectare: 1 hp; Asian and African input per hectare: 0.1 hectare. 1 hectare = 10,000 square meters = 107,584 square feet, while 1 horsepower = 42.408 BTUs per minute. Hence in the default units of *Carbon Ideologies* 1 hp/ha = 0.003941500892 BTUs per minute per square foot.

Information on U.S. food-related energy consumption, 1993–2007—USDA Report 24, pp. i, iv, 13, 17 [job losses between 1996 and 2000], p. 18 (Table 5: "Freight industry characteristics"). ["Freight services are among the most energy-intensive industries serving the U.S. food supply chain."] Also: p. 17 (Table 3: "Energy technology change impacts on per capita energy flows for food and related items, 1997 to 2002"), p. 18 (Table 6: "Home appliance use by U.S. households"). The citation "increasingly outsourced manual food preparation . . ." comes from here.

"The rate at which the population is supplied with refrigerators . . ."—Robert V. Daniels, comp., ed., and trans., *A Documentary History of Communism in Russia: From Lenin to Gorbachev* (Hanover, New Hampshire: University of Vermont / University Press of New England, 1993), p. 303 ("Soviet Consumerism," from Alexei N. Kogygin, "Report on the Directives of the 24th CPSU Congress . . . ," April 6, 1971.

Lenin on electrification—V. I. Lenin, *Selected Works in Three Volumes,* vol. 3 (Moscow: Progress Publishers, 1977 repr. of 1975 rev.; orig. ed. 1964), pp. 270–71 (interview with Lincoln Eyre, correspondent of the American newspaper *The World,* 1920).

"the equivalent of an extra 69 pounds of coal apiece"—Calculated thus: 287,604 BTUs × [1/12,500 lbs of coal per BTU] × 3 [lbs burned in a power plant to get 1 lb's worth of energy] = 69.02496.

Footnote on reversal of ratios of GDP to electricity consumption—This addresses a point kindly made by Dr. Jacqueline Agesa, Professor of Financial and Insurance Economics at Marshall University, in her e-mail of Thursday, January 12, 2017, to Laura Michele Diener, who printed it out on my behalf: "This is important because the reader has to flip their interpretation of whether a high overall ratio indicates a country with excessive use of electric power or not."

Ratios of Per Capita Power Consumption to Per Capita Gross Domestic Product

Most information from Central Intelligence Agency, *The World Factbook, 2013* (CIA's 2012 Edition) (Washington, D.C.: Potomac Books, 2013), pp. 2–4, 6, 8, 64, 66, 374–76, 480, 482, 632, 634, 769, 771. The original total power consumption figures were: Afghanistan, 231.1 million kWh; Bangladesh, 3.94 billion kWh; world, 9.09 trillion kWh; Mexico, 181.5 billion kWh; Saudi Arabia, 194.4 billion kWh; Japan, 859.7 billion kWh; U.S., 3.741 trillion kWh. [After the library disposed of this edition, I added in United Arab Emirates figures using the online version of the *Factbook,* downloaded for WTV in February 2017 by Jordan Rothacker. The UAE's total power consumption was 70.58 billion kWh (2008 est.).] All of these were converted to BTUs @ 3,413×.

[Unrounded conversion figures, not shown in table but used in subsequent calculations: Afghanistan, 788,744,300,000 BTUs; Bangladesh, 13,447,220,000,000; world, 3.102417×10^{16} = 31,024,170,000,000,000; Mexico, 619,459,500,000,000;

Saudi Arabia, 663,487,200,000,000; Japan, 2,934,156,100,000,000; U.S., 12,768,033,000,000,000; UAE, 240,889,540,000,000.]

Insets from United Nations Development Programme [UNDP], *Human Development Report 1997* (New York: Oxford University Press, 1997), pp. 196–97 (Table 23: "Energy use." [Henceforth cited: "UNDP report, 1997."] As of 1994, "high human development" equaled 2,310 kWh per capita, "medium" (excluding China) was 1,035, and "low" (excluding India) was 147. These would have been 7,884,030 (h), 3,532,455 (m) and 501,711 (low) BTUs. To estimate amounts of coal and oil needed to produce this amount of current in a power plant I used tons of oil equivalent and tons of coal equivalent, multiplying by .907 to convert from metric to U.S. tons. Thus, for the high value:

7,884,030 BTUs required × (1 toe [1 U.S. ton of oil / 35,989,760 BTUs]) × [2,000 lbs / ton) = 438 lbs of oil required.

For medium, 196 lbs. For low, 28 lbs.

For coal I used 25,192,832 BTUs / U.S. ton. High: 626 lbs. Medium: 280 lbs. Low: 40 lbs.

For natural gas, I used [1 cu ft / 1,000 BTUs] × [0.04163 lbs / cu ft = density of methane] = 0.00004163 (or 1/24,021) lbs per BTU. High: 328 lbs. Medium: 147 lbs. Low: 21 lbs.

All these numbers were then multiplied × 3 to account for power plant inefficiency.

What Was the Work For? (continued)

Assertions on GDP of the CEO of Breitling Energy Corporation—Chris Faulkner, *The Fracking Truth: America's Energy Revolution: The Inside, Untold Story* (Bucks County, Pennsylvania: Platform Press ["the nonfiction imprint of Winans Kuenstler, LLC," 2014), p. 16. [This source cited "Chris Faulker," in order to distinguish him from R. P. Faulkner.]

Footnote: "Due to a general shift from a manufacturing-based economy . . ." —EPA, 2016, p. 137.

"The good news is that carbon emissions were essentially flat . . ."—*BP Statistical Review, 2017,* June 2017 (66th edition), downloaded for WTV by Jordan Rothacker, September 2017, p. 2.

"We all have at least one dream car . . ."—*Motor Trend,* July 2016, p. 38 ("Head to Head: 2016 Chevrolet Camaro Rs vs. 2016 Ford Mustang EcoBoost").

"CO_2 emissions have been clearly linked to economic growth"—International Energy Agency, *Coal Information 2012, with 2011 data* [henceforth cited: *"Coal Information 2012."*], page II.16.

"China, where strongly increasing electricity production is the main driver . . ." —Ibid., p. II.15. Consider also the fact that between 1990 and 2000, "the annual growth in emissions from fossil fuels averaged 2.1% between 1971 and 1990, while it averaged 1.1% between 1990 and 2000. This lower pace of growth after 1990 is . . . related to the collapse of the . . . centrally-planned economies of Central and Eastern Europe, which led to a rapid decline in output from inefficient industrial sectors and the re-structuring of these economies."

Footnote: "one car for every eight Earthlings"—Information from *Annual Review of Environment and Resources* ("online at http://environ.annualreviews.org": "This article's doi: 10.1146/annurev-environ-041112-110510"), 2013. 38: 81–106 (Timothy G. Gutowski, Julian M. Allwood, Christoph Herrmann and Sahil Sahni, "A Global Assessment of Manufacturing: Economic Development, Energy Use, Carbon Emissions, and the Potential for Energy Efficiency and Materials Recycling"), p. 98. [This document henceforth cited: "Gutowski et al., A*nnu. Rev. Environ. Resour.,* 2013."] I will reproduce more of this important passage: "The past 50 years have led to a more-than-average doubling of economic prosperity, with an increase in life expectancy from 55 to 70 years, whereas per capita power requirements and consequent emissions, having been steady for 40 years, have begun to rise in the past 10. This increase in prosperity has led to increased mobility, with per capita flights quadrupling and per capita transport emissions rising by a quarter. Personal consumption of steel, cement, and paper—three of the key materials that drive most industrial emissions—has risen absolutely steadily for paper and with a recent surge for steel and cement, largely driven by a rapid expansion of construction in China. [For details of these and other members of the "big five," see "About Manufacturing," p. 132.] In turn, this growth in material consumption has led to increased material service provision, with one car operating for every eight people on the planet, and an astounding increase of built space leading to provision of ~30 m^2 per person."

Same footnote: car ownership in Lebanon—Robert Eves et al., comp., *The Economist Pocket World in Figures* (London: The Economist Newspaper Ltd., 1998), p. 62 ("World rankings: Highest car ownership").

"As shown in Figures II.24 to II.26 . . ."—*Greenhouse Gas Inventory Mexico, 1990–2002,* in UNFCCC (United Nations Framework Convention on Climate Change), p. 66.

Footnote: "in one 24-year period, American industrial output rose 64% . . ." —Information from EPA, 2016, p. 124, where the two causes are described as "(1) more rapid growth in output from less energy-intensive industries relative to traditional manufacturing industries, and (2) energy-intensive industries such as steel are employing new methods, such as electric arc furnaces, that are less carbon intensive than the older methods."

Same footnote on total American emissions, 1990–2014—Ibid., p. 27.

Footnote: "The average per capita emissions . . ."—*Greenhouse Gas Inventory Mexico, 1990–2002,* p. 51.

Same footnote: "Four of the top ten manufacturing carbon emitters . . ." —Gutowski et al., *Annu. Rev. Environ. Resour.,* 2013, pp. 86–87. I cannot forbear quoting p. 98: "The growth in per capita demand for energy, materials, products, and services . . . is averaged over the global population and as such disguises a key question: Does this growth reflect improving prospects for the poor or an increasing gap between rich and poor? The answer to this question is that both are happening, and it is those who are actively engaged in manufacturing . . . who have the best chance to catch up. Furthermore, if this trend continues, the world will experience yet another remarkable transition, a crossover in consumption from the rich world to the poor. That is, just as [there was] . . . a crossover around 1994 between the East and the West in CO_2 emissions from manufacturing, and [there might have been] . . . a crossover in manufacturing output possibly occurring in the next decade, there is a chance that a similar crossover for consumption is not too far off . . . By 2025 developing economies could account for nearly 70% of global demand for manufacturing products . . . [I]t will be a historic event should it occur."

Comparative Energy Requirements, in multiples of 1 British Thermal Unit

"to electroprocess 1 lb of chlorine with 1952 technology would have required [3 × 5,120] BTUs of fuel, or, for instance, 0.8 lbs of medium grade fuel oil." See p. 215 in the table of Calorific Efficiencies, header **202**: Commercial fuel oil, medium grade, *ca.* 1975: 18,570 BTUs/lb. As it happens, [3 × 5,120] equals 18,570 about 0.8 ×.

I had first calculated as follows: Energy to keep warm 1 lb of water for a minute in a 40-gallon electric heater—Assuming that 1 gal H_2O = 8.34 lbs (never mind that this is at 39.1° F; it's close enough at all moderate temperatures for this reporter), 40 gal will weigh 333.6 lbs. Thus 1 lb = (1/333.6 × 40) = 0.119 gal = 0.2997% (0.002997) of the total weight. In the other table of Comparative Power Requirements (p. 69), we see that this appliance consumes 255.978 BTU/min. Therefore it would take 0.767 BTU per min to keep warm 0.2997% by weight of its water. Such was my computation (replicated and confirmed by my hired number-cruncher Mr. Matsumoto Jun). But here Gutowski politely notes (letter to WTV of August 23, 2016): "In fact, this is the only item [in this table] where we may differ. Concerning electric water heaters, I did the calculation in several different ways and they all came out a little smaller than the value you got. I did do one using the Department of Energy website with the URL listed here: http://energy.gov/eere/femp/energy-cost-calculator-electric-and-gas-water-heaters-0#output. The result is shown below, but this is a little different from your calculation; it is for using 40 gallons of hot water a day, not necessarily for a 40 gallon hot water tank . . . [PDF chart omitted.] I use the base model with an efficiency of 0.86 and an annual electric energy use of 3176 kWh. This gives, 21.7 BTU per minute, while you got 256 BTU/min. See my notes page 1. This would be 21.7/333=0.065 BTU/minute/lb." (For his part, Mr. Matsumoto obtained 29.980 BTUs/min from this calculation.) My error must have been neglecting the energy savings brought about by insulation. So I humbly defer to Gutowski (and real life), and have altered my figure accordingly.

Figures for an unspecified "semi" moving truck in 2016—Interview with Ryan, a San Francisco mover, in April 2016. This man said that his semi truck when loaded to full commercial capacity weighed 70,000 out of a potential 80,000 pounds. It then got a "lifetime" mileage of 5 to 7 miles per gallon. [Averaging this latter to 6 mpg, I calculate 1 mi per [⅙ (or 0.1667) gal for 70,000 lbs] / 70,000 = 1 mi per 0.00000238 gal (1/42,000 gal)—an almost unbelievably low figure, but never mind.] Anyhow, at 20,750 BTUs per pound of gasoline and 6.152 pounds per gallon, the calculation is: 0.1667 gal/mi × 6.152 lb/gal × 20,750 BTUs/lb = 21,279.92 BTUs to move the entire vehicle a mile, divided by 70,000 to get 0.3040 BTU per pound.

Figures for typical mid-1970s automobile and heavy rail train—John R. Meyer and José A. Gómez-Ibáñes, *Auto Transit and Cities* (A Twentieth Century Fund Report) (Cambridge, Massachusetts: Harvard University Press, 1981), p. 131 (Table 8.2, "Estimates of energy required per vehicle-mile for various urban transportation modes"). Nothing about the car is stated, so I have called it "typical" and chosen an "average" weight. According to the National Bureau of Economic Research, "Vehicle Weight and Automotive Fatalities" (www.nber.org/digest/nov11/w17170.html, accessed June 22, 2016), the 1975 average weight of an American car was 4,060 pounds.—I could not find a comparable average weight for the heavy rail train, but according to a Wikipedia entry on Amfleet (accessed June 22, 2016), the Amfleet I trains were introduced into Amtrak service in 1975. An Amfleet coach car weighed 106,000 pounds.

Figure for 1952 stock car—Baumeister and Marks, p. 11-7 (Neil MacCoull, "Automobiles," Fig. 8, graph of weight *versus* fuel consumption, Los Angeles to Sun Valley). The 21 mpg was calculated by me from a visual "guesstimate" of a graph point of approximately 0.0475 gal per mi. At 20,750 BTUs per pound of gasoline and 6.152 pounds per gallon, the calculation is: 0.0475 gal/mi × 6.152 lb/gal × 20,750 BTUs/lb = 6,063.565 BTUs to move the entire car a mile, divided by 4,000 to get 1.1516 BTUs per pound. [Gutowski checked this using slightly different conversions and got the comparable figure of 1.35 BTUs/lb.]

Figure for "Platinum" Cadillac—*Motor Trend,* August 2016, p. 61 (Angus MacKenzie, "The Practical Sports Car: It Worked for Porsche. And It Will Work for Jaguar, Too"). The Jaguar's curb weight was "3,950 to 4,100" lbs, so I took the average at 4,025. Its EPA fuel economy was 18 mpg in the city, 23 on the highway and 20 "combined." I used the last figure. Hence [1/20 gal per mi] × [6.152 lb/gal] × [20,750 BTUs/lb], all divided by 4,025 = 1.586.

Figure for "F-Pace" Jaguar—*Motor Trend,* August 2016, p. 90 (Angus MacKenzie, "The Practical Sports Car: It Worked for Porsche. And It Will Work for Jaguar, Too"). The Jaguar's curb weight was "3,950 to 4,100" lbs, so I took the average at 4,025. Its EPA fuel economy was 18 mpg in the city, 23 on the highway and 20 "combined." I used the last figure. Hence [1/20 gal per mi] × [6.152 lb/gal] × [20,750 BTUs/lb], all divided by 4,025 = 1.586.

Energy to perform 1 "delivered horsepower per hour" for 1911 tractor—Gasoline data supplied by Ellis and Rumely, 109. Period's gasoline HHV from same source. Tractor weight estimated by my ex-Minnesota-farmboy friend Paul Foster (phone interview, June 2016). 20,000 BTUs per lb of gasoline × 1.273 lbs gasoline = 25,460 BTUs for the entire tractor, divided by 2,000 lbs = 12.73 BTUs per lb, which I rounded to 13 to avoid spurious precision.

Specific cutting energy for machining 1 lb of various aluminum alloys—After Gutowski and Sekulic, p. 17, converted from 140–360 kJ/kg at 1 kJ/kg = 0.4299226 BTU/lb. Unrounded figures were 60.189 and 154.772 BTUs/lb. [Double-checking my calculations, Gutowski came up with 60.3 and 155.1 BTUs.]

Ditto, for various nickel alloys—Loc. cit., converted from 570–800 kJ/kg to 245.056–343.938 BTUs/lb.

Footnote: "The actual machining process . . ."—Loc. cit.

1975 energies to make sulfuric acid, common brick, liquid chlorine, aluminum—Han, p. 139 (Appendix I: "Energy Requirements for High Priority Primary Products"). [Source: Battelle Columbus Laboratories, 1975. Report No. PB-245759.] These data were originally given in "energy required per net ton (short ton of product in millions of BTU)." Therefore I divided each figure by 2,000 to get 1 pound.

"The values within these lines [430 to 13,000 BTUs per pound] reflect typical manufacturing energies for plastics, metals and composites, *ca.* 2010."—N. Duque Ciceri, T. G. Gutowski and M. Garetti, "A Tool to Estimate Materials and Manufacturing Energy for a Product" (unpub.?, n.d.; after 2009; PDF version sent to WTV by Gutowski in 2016), unnumbered page: "Most of the manufacturing energy figures on conventional manufacturing processes for metals, plastics and processing of many composites roughly fall within the range of 1 to 30 MJ/kg," which corresponds to 429.9226 to 12,897.678 BTUs/lb. [This document henceforth cited: "Ciceri, Gutowski and Garetti."]

Energy to make Portland cement, 1990 and 1950—Kroschwitz and Howe-Grant, vol. 5 ("Carbon and Graphite Fibers" to "Chlorocarbons and Chlorohydrocarbons-C1"), p. 591 ("cement"): "Over a 40-year span the cement industry has reduced unit energy usage by 40%, from 9.6 MJ/kg (4131 Btu/lb) in 1950 to 5.7 MJ/kg (2464 Btu/lb) in 1990." [Note: Using Mr. Matsumoto Jun's default conversion factors (slightly different from *Carbon Ideologies*'s) of 1 MJ/kg = 429.945 BTUs/lb, we obtain the close but not identical respective values of 4,127.47 and 2,450.68 BTUs/lb. They vary from the encyclopaedia's by about half of a percent.]

"Average energy required *ca.* 1958 to heat from 2,000–2,400° F 1 lb of steel in an ingot heating furnace."—Here Gutowski comments: "69 BTU/lb minimum. Assume a furnace that is 75% efficient, then [delta, or change in] E = 92 BTU/lb. Assume the furnace is electric and the electric grid is 33% efficient, then [delta] E = 276 BTU/lb.

Energy needs for ingot and batch furnaces—Baumeister and Mark, p. 7-79 (Table, "Average Net Efficiencies and Fuel Requirements of Various Furnace Types in Good Operation").

Energy needed to heat 1 lb of iron to 5,000° F—Ibid., p. 9-189 (Etherington article on atomic power).

Average energy needed to manufacture $1 worth of American products—Baumeister and Marks, p. 17-40 (Franklin J. Leerburger, "Cost of Electric Power"). In 1947, each dollar value of product cost 0.793 kWh [per a study by the Edison Electric Institute, "reported" in November 1950, "and based on the 1947 Census of Manufactures." Hence 0.793 × [1 kWh = 3,413.0 BTUs] =2,706.509. (Each kWh was an astoundingly cheap 0.94 cents. "The percent cost of purchased power to value of product was 0.74." More exactly, $1 of product value cost 0.7452 cents; so the ratio was 134.15.)

BTUs per lb of chlorine, rayon, aluminum, titanium—Baumeister and Marks, p. 17-41 (Franklin J. Leerburger, "Cost of Electric Power," Table 1, "Power Requirements for Selected Electroprocess Materials"). 1952 figures. Originally expressed in "approximate kilowatt-hours required per ton of product." Converted as per the following example: Titanium metal at [40,000 kWh/ton × 1 ton/2,000 lbs = 20 kWh per lb] × 3,413.0 BTUs/1 kWh = 68,260 BTUs/lb. (Power plant inefficiencies were not considered here; see headnotes to table.)—Here Gutowski writes: "Compare this to Fig. 4 in our Royal Society of London 2013 paper and this looks very reasonable."

Energy per lb of "ordinary" steel from pig iron in 2010—Avid Boustani, Sahil Sahni, Timothy Gutowski and Steven Graves, "Tire Remanufacturing and Energy Savings" [MITEI-1-h-2010] (Boston: Environmentally Benign Manufacturing Laboratory, Sloan School of Management, MIT, January 28, 2010). [Henceforth cited: "Boustani et al., January 28, 2010."] Page 17: "Typical energy cost of making 1 Kg of ordinary steel from pig iron is about 20–25 MJ."

Titanium electroprocessing energy: 20 kWh: "Each American 'consumer' used about this much energy per day in 1975"—Information from Leckie et al., p. 37.

Energy to complete chemical vapor deposition process—After Gutowski and Sekulic, p. 23, converted from 1 GJ/kg to get 429,922.6 BTUs/lb.

Energy to make 1 lb of carbon nanotubes—Originally was 36 GJ/kg. [See p. 15, citation re: carbon nanotubes for chapter "What Was the Work For? (continued)."] Hence final figure is 15,477,213.6 BTUs, which divided by 20,750 [the HHV/lb of gasoline] = 745.89. The density of gasoline is 6.152 lbs/gal, so our required volume = 121.24 gal.

> Cross-check: Equivalence of 15,477,213.6 BTUs to the high heating value of 123.817 gallons of gasoline—Since 1 gal of gasoline = 125,000 BTUs [HHV]. Source: www.extension.iastate.edu.agdm [downloaded by Jordan Rothacker, February 2016): Don Hofstrand, Extension Value-Added Agriculture Specialist, "Ag Decision Maker: Liquid Fuel Measurements and Conversions: File C6-87, October 2008."

Data on all "big five" (•) materials not cited above for this table from "Energy and Coal Requirements to Manufacture One Pound Each of the 'Big Five' Materials," p. 134.

About Power

Epigraph: "We stand naked and exposed . . ."—The Holy See. Encyclical Letter *Laudato Si'* of the Holy Father Francis on Care for Our Common Home. Given in Rome at Saint Peter's on 24 May, the Solemnity of Pentecost, in the year 2015, the third of my Pontificate. 82-page typescript, printed or downloaded for WTV by Father Brian Clary, May or June 2015. [Henceforth cited: "Encyclical of Pope Francis, 2015."] Page 31 (para. 105).

Epigraph: "[c]ountries of the former USSR have been encouraged . . ."—Kroschwitz and Howe-Grant, vol. 17 ("Nickel and Nickel Alloys" to "Paint"), p. 373 ("nuclear reactors (introduction)").

"Luxury is right . . ."—John O'Hara, *Stories,* ed. Charles McGrath (New York: Library of America, 2016), p. 721 ("The Farmer," 1968).

"a pound of 'average' Appalachian coal could give off 1 watt continuously for nearly 153 days"—This assumes that 1 lb coal = 12,500 BTUs, which divided by [1 w = 0.056884 BTUs per minute] = 219,745.4468 BTUs/min. Divided by [60 × 24], this becomes 152.6 days.

"An American radio from the 1950s might be rated at 60 watts"—According to H. A. Willman, *The 4-H Handbook: A Timesaver for Agricultural Leaders, County Extension Agents, Vocational Teachers, and Older Youth* (Ithaca, New York: Cornell University Press / Comstock Associates, 1952), p. 106, 1 kWh would power a radio for 15 hours. 1,000 divided by 15 = 66.666 watts.

3,413 pounds of water = 409.23 gallons—To be precise, 1 gal H_2O = 8.34 lbs at 39.1° F.

"Should you happen to have 2,650 hundred-pound sandbags on hand . . ." —Information from Daniels, pp. 239–40.

"Today, electricity is such a familiar and convenient form . . ."—Steve Parker, *Eyewitness Electricity* (New York: Dorling Kindersley Ltd., 2013 [rev.?] repr. of 1992 ed.), p. 44.

> And how much thermodynamic work would it take to *cool* a pound of water one degree? Las Vegas would be the place to ask. One day in 2016 both the Mandalay Bay and the Monte Carlo were advertising a "Minus 5 Ice Bar": *It's winter year-round in this lounge made of ice.* Outside the high was 88 degrees, a mere *+3° departure from normal.*

> > The Minus 5 Ice Bar—*Vegas 2Go* ("the in-the-know guide for visitors on the go"), September 18–October 1, 2016, p. 91.
> >
> > That day's weather and deviation from normal—*Las Vegas Review-Journal,* Thursday, September 29, 2016, p. 11A (weather section).

What 1 kWh could do in 1952—Willman, loc. cit.

"A pound of kerosene contained within it enough energy to generate 5.8 kilowatt-hours"—Since (according to *Coal Information 2012,* p. 1.14) 1 terawatt (1 trillion watts) = 0.086 mtoe [million tons of oil equivalent], then 1 TWh = 1 billion kWh = 86,000 tons of oil equivalent. Dividing kWh and toe by 1 billion and multiplying by 2,000 pounds per ton, we obtain: 1 kWh = 0.172 pounds of oil. Taking the reciprocal, we find that 1 lb of oil can generate about 5.814 kWh, which equals 19,843 BTUs. [Cross-check: 1 lb of oil at an HHV of 20,789 BTUs [see header **226** in table of Calorific Efficiencies] / 3,413.0 BTUs per kWh = 6.09 kWh.]

Per Capita Power Consumption,* ca. *1925 and* ca. *2014

Average consumption in kilowatt-hours per individual, *ca.* 1925—United States Department of Commerce, Bureau of Foreign and Domestic Commerce, *Commerce Reports Nos. 27–39, vol. 3 (Twenty-Ninth Year),* July, August, September 1926 (Washington, D.C.: Government Printing Office, 1926), p. 84 (D. S. Wegg, "Electrical Equipment").

The same, *ca.* 2014—Central Intelligence Agency, *The World Factbook, 2014–15* (Washington, D.C.: U.S. Government Printing Office, 2014). In relation to the previous order of countries:

> Japan (pp. 384, 382)—Electricity consumption, 859.7 billion kWh (2012). Population, 127,103,388 (July 2014). Hence per capita power consumption was 6,763.785 kWh/person.
>
> Germany (pp. 288, 286)—Electricity consumption, 582.5 billion kWh (2012). Population, 80,996,685 (July 2014). Hence per capita power consumption was 7,191.652 kWh.
>
> United States (pp. 793, 790)—Electricity consumption, 3.886 trillion kWh (2010). Population, 318,892,103 (July 2014). Hence per capita power consumption was 12,185.939 kWh.
>
> Norway (pp. 561, 559)—Electricity consumption, 120.9 billion kWh (2010). Population, 5,147,792 (July 2014). Hence per capita power consumption was 23,486 kWh.
>
> Canada (pp. 144,142)—Electricity consumption, 499.9 billion kWh (2010). Population, 34,834,841 (July 2014). Hence per capita power consumption was 14,350.575 kWh.
>
> Switzerland (pp. 720, 717)—Electricity consumption, 58.97 billion kWh (2012). Population, 8,061,516 (July 2014). Hence per capita power consumption was 7,315.001 kWh/person.

"Satisfying each Canadian's electric appetite"—Brown peat: 48,979,963 divided by the HHV of 10,026 yielded 4,885 lbs. Pocahontas coal: 48,979,963 / 14,550 = 3,666.3. Diesel fuel: I took the average of the two HHVs. Dividing 48,979,963 by 19,250, then dividing again by 7.036 lbs/gal [all densities taken from pp. 576–77] gave 361.5 gal. Gasoline: [48,979,963 / 20,750] / 6.152 lbs per gal] = 383.7 gal. Methane: [48,979,963 / 23,861] / 0.04163 lbs per cu ft] = 49,308 cu ft.

About Power (continued)

Footnote: "residential energy consumption," etc.—Boustani et al., p. 6.

"Between 1947 and 2008, American refrigerators grew in size by 159%"—Information from the same source, p. 17 (Table 4: "Change in refrigerator size 1947–2008").

"In general, old small refrigerators . . ."—Leckie et al., p. 38.

Manufacturing energy + use energy = embodied energy—I am indebted to Gutowski for all these concepts.

Tradeoff between 1974 and 1983 refrigerator models + "the right thing to do in 1956 and the wrong thing in 1992"—Boustani et al., loc. cit., below table. As always, unfortunately, the right choice on this topic was not something we could dope out by ourselves. Ibid., p. 21: "In years 1956, 1965, and 1974, remanufacturing an older generation refrigerator would lead to 34%, 39%, 15% savings in life cycle energy consumption, respectively. On the other hand, [the] same decision in 1983, 1992, and 2001 would cause 65%, 28%, 44% increase[s] in life cycle energy consumption, despite energy savings in [the] manufacturing phase."

The 213 million wasted BTUs, with concomitant fuel oil requirements and carbon dioxide releases—The same source (p. 52) calculated the wastage at 225,000 MJ, which we multiply × 9,48.067 BTUs per MJ to obtain 213,315,075. From the table of Calorific Efficiencies on p. 214 we see that the HHV of commercial fuel oil, heavy grade, *ca.* 1975, is 18,450 BTUs/lb. Dividing by this, then multiplying by 3 to account for the waste inherent in electric power generation, we get 34,685.378 lbs of oil. Plugging in as an approximation the density of diesel fuel at 7.036 lbs/gallon (p. 582), we get 4,929.701 gal of fuel oil. From the table "Carbon Dioxide Emissions of Common Fuels" (p. 200), we see that heavy heating oil emits 1.890 lb carbon dioxide for each 10,000 BTUs. Dividing 213,315,075 BTUs by 10,000 gives us 21,331.5075, which we multiply by 1.890 to get 40,316.549.

"Wearing our clothes, right into rags was, always best"—Sahil Sahni, Avid Boustani, Timothy Gutowski and Steven Graves, "Textile Remanufacturing and Energy Savings" (Environmentally Benign Laboratory for Manufacturing and Productivity, Sloan School of Management, MITEI-1-g-2010, January 28, 2010), p. 7: "For approximately 12 wash/iron cycles in the life time of clothes, the savings are 57% for the t-shirt and 91% for the blouse. Even if the use is extended over six fold to 75 cycles, the savings are 19% and 68% respectively. Hence, the analysis strongly concludes that reusing textiles and clothing is the energy savings strategy."

"replacing an electric motor usually saved more energy than repairing it"—Information from Sahil Sahni, Avid Boustani, Timothy Gutowski and Steven Graves, "Electric Motor Remanufacturing and Energy Savings" (Environmentally Benign Laboratory for Manufacturing and Productivity, Sloan School of Management, MITEI-1-c-2010, January 28th, 2010): "Each year approximately 2.5 times more motors are repaired compared to the new ones bought . . . A motor can be repaired, on an average, 4–6 times in its life before being permanently discarded" (p. 11). "Overall it was shown that the common notion that remanufacturing leads to energy savings was challenged an[d] it was shown that replacing with new in the case of electric motors is the energy saving strategy" (p. 29).

Retreading automobile tires: "strongly depends on the boundary conditions of the analysis"—Boustani et al., January 28, 2010, p. 72. This result is astonishing, since "more than 80% of embedded energy is retained in the casing of the tire, which is saved after the tires reach end of life. In other words, a tire is scrapped due to tread wear; the tread only takes 10 to 20% of the entire material and energy retained in a tire" (p. 8).

"Possibly the most stupendous discovery . . ."—Ellis and Rumely, p. 13.

Comparative Power Requirements and Energy Usages

"Typically, the input power for a microwave oven is 50% higher than its rated power."—Boxwell, p. 104.

Electric toothbrush, 2015—Rated at 0.9 watts, × [0.056884 BTU per minute per watt].

Freezing a pound of water [based on refrigeration ton]—Converting 1 short ton to 2,000 lb and BTUs per hour to BTUs per minute, from Kroschwitz and Howe-Grant, vol. 21 ("Recycling, Oil" to "Silicon"), p. 129 ("refrigeration").

Motion detector light, 2015—A Home Zone Security twin head LED device, model AEC-326KA2-AC14Q ES00384G, rated at 120VAC/60Hz, 30.6 watts [the latter × 0.056884 BTU/min = 1.7406504 BTUs per min].

Vibrator [40 w], sewing machine [75], radio [80], refrigerator [235; w/frostless freezer 475], hair dryer, color TV and "food freezer" [300], vacuum cleaner [540], dishwasher [1,190], window air conditioner [1,300], broiler [1,375], home electric range [11,720], all from *ca.* 1975—Leckie et al., p. 37 (Table 3.2, "Approximate Monthly KWH Consumption of Household Appliances Under Normal Usage"). That the vibrator was a plug-in is deduced from the context of the list itself, whose devices are in rated watts, and from a mid-1970s guide to lesbian sex that I just happen to possess, which refers to the necessity of power cords for these devices. All figures originally expressed in the rated watts parenthetically following them, then in estimated monthly kilowatts. "If you play a radio (80 watts) an average of 1 hour a day, then during a month's time (30 days) it would consume 30 times 80 watt-hours or about 2.4 KWH." Again, I converted using 1 watt = .056884 BTU per minute.

Metabolic requirements for sleeping and sweeping floor—Leckie et al., p. 80 (expressed as 220 and 550 BTUs/hour, respectively). On p. 37 he says: "The power equivalent of consuming 3000 food calories a day is about 150 watts—so you might say the human body is roughly equivalent to a 150-watt machine." This works out to 8.53 BTUs/min.

Operating a popular brand of laptop computer, 2014 (I will not be a corporate pimp and name the thing)—Since rating on device is 16.5 volts at 3.65 amps max, I have multiplied these to get the wattage, then multiplied by .056884 BTU per minute per watt to obtain 3.43 BTUs.

"A typical adult male at sustained labor is estimated to produce 75 to 100 watts of power"—Tom Butler and George Wurthner, eds., *Energy: Overdevelopment and the Delusion of Endless Growth* (Sausalito, California: Foundation for Deep Ecology, in conjunction with Post Carbon Institute / Watershed Media, 2012), p. 19.

Operating refrigerator, 1961—Leckie et al., p. 38, give 70 kWh/month. I calculate that 70 kWh/mo × 3,413 BTUs/kWh × (1 mo / 30 d × 1 d / 24 hr × 1 hr / 60 min) = 5.53 BTUs/min.

Ditto, 1969—Loc. cit.: 110 kWh/month. From the previous calculation, I infer that the correct figure = 5.53 BTUs/min × 110/70 = 8.69 BTUs/min.

All entries from Oberg and Jones are given in horsepower, which I have multiplied by 42.418 to obtain BTUs/min.

"Powering a 100-watt lightbulb, by definition"—A 100 watt lightbulb obviously uses 100 watts. Since 1 watt = 0.056884 BTU per minute, 100 watts = 5.6884 BTUs per minute. If this lightbulb could somehow have been powered by the solar energy received per minute per square foot just above our atmosphere and normal to the sun's rays, there would have been 1.68 BTUs to spare—enough to simultaneously operate the vibrator for a frustrating 44 seconds per minute.

Follow-up to preceding: "A burner operating at 20 MMBTU [million BTU]/hr. has a power output equivalent to approximately 60,000 light bulbs at 100 W each."—Charles E. Baukal, Jr., ed., *Industrial Burners Handbook* (New York: CRC Press, 2004), p. 114 (sec. 13.41: "Definition of Heat Released"). This works out to 5.55 BTUs (or 2.4 times the vibrator's power consumption) for 1 minute of a single 100-watt bulb.

"A moderately active human adult requires about 3 million cal[ories] every 24 hr."—Weisz, p. 487. Therefore, [(3,000 kcal per 24 hrs) / (24 × 60) = 2.0833 kcal/min] × 3.968 BTUs/kcal = 8.266 BTUs/min.

Power needed to remove metals by round-nosed lathe tool—Oberg and Jones, p. 1842.

Operating a certain electric corn popper, 1956 [the Kenmore 2½-qt model]—Sears, Roebuck and Co., fall and winter catalogue, 1956, p. 1079. [Henceforth cited: "Sears catalogue, 1956."]

Average power consumption by WTV, December 2013 and 2014—From my electric bill (given respectively as 15.3 and 12.2 kilowatt-hours per day, converted at 1 kWh = 3,413.0 BTUs and 1 day =1,440 minutes).

"American average" power consumption, 1975—Leckie et al., p. 37, calculated by WTV from their 20 kWh/day × 3,413 BTUs/kWh / (24 hr/day × 60 min/hr).

Heavy-duty blender—Rated at 750 watts, so × 0.056884 BTU/min = 42.663.

Average residential power consumption in Sacramento, California, 2016—Gmail—RE: Media Relations Questions, to Jordan Rothacker (who sent it on to WTV), from Christopher Capra, Sr., Public Information Specialist, News Media Services, at or for SMUD, Tuesday, December 6, 2016, at 6:51 p.m. [Henceforth cited: "SMUD e-mail, 2016."] Text reads: "SMUD considers 750 kWh/month as the average residential usage, for a single family residence. We do not provide an average for commercial customers as use and size of buildings vary greatly." 750 kWh / month × [1 month / 30 days] × [3,413 BTUs / (1,440 minutes = 1 day)] = 59.254 BTUs / min.

Air compressor—Rated at 10.6 amps at 110 volts (I have multiplied the amps thus instead of × 115], × 0.056884 BTU/min = 66.327.

Power (originally stated in watts per hour, and converted by WTV to BTUs/min) needed by cell phone charger, radio, laptop, LCD TV, desktop PC, 12-cubic-ft fridge, hedge trimmer, vacuum cleaner, small microwave, hair dryer, dishwasher, espresso machine and large microwave, all *ca.* 2012—Boxwell, pp. 183–84 (Appendix C, "Typical Power Requirements").

Operating 11" × 14" photographic dry mount press—This was a "Technal" model, made in Englewood, NJ, and rated at 115 volts, 1,250 watts, which latter number = 71.105 BTUs/min. I bought it used and roughly estimated its decade of manufacture based on its appearance and wear. I might be off by 20 years.

Average American household power consumption, 2010—According to Wikipedia ["standby power," accessed by a friend on February 15, 2015], "average home" consumption was 11,040 kWh/yr. At [1 kWh = 3,413.0 BTUs], this equals 37,679,520 BTUs/yr = 71.689 BTUs/min.

Operating a "Fan-forced Non-Automatic Electric Heater," 1956—Sears catalogue, 1956, p. 1078 (a Kenmore, 110–120 V, 50–60 cycle AC, 1,320 watts. "Smartly styled Harmony House Sunshine yellow enameled steel case").

Operating hypoallergenic vacuum cleaner, *ca*. 2010—This high-powered so-called "pet vacuum," meant to suck up dander, hair and other such chaff, was purchased in about 2010. Rated 12 amps. Operated at 115-volt current. Calculations analogous to those for laptop.

Per capita American food-related and overall "energy flows"—USDA Report 24, p. 11, as calculated by WTV from the following data: Our 2002 annual national energy flow was 97.9 Q-BTUs, or 340 million BTUs per capita. (The 2002 U.S. population was around 287, 941 million.) The food-related energy flow made up 12.2% of that.

American energy use per capita, 1870, 1900, 1950, 1990—Kroschwitz and Howe-Grant, vol. 12 ("Fuel Resources" to "Heat Stabilizers"), p. 2 ("fuel resources," Table 1: "U.S. Energy Consumption by Source from 1870–1990, EJ"). Here were figures I selected: 1870: 4.1 EJ [3.1 from wood and biomass, 1.1 from coal]; 1900: 10.1 EJ [2.1 for wood and biomass, 7.2 for coal, 0.2 for petroleum, 0.3 for natural gas, 0.3 from hydroelectric]; 1950: 37.1 EJ; and 1990, 85.76 EJ. To convert EJ to BTUs, multiply by 9.48 × 10 to the 14th power, or 948,000,000,000,000. Since this was a yearly figure, I divided it by ([365 × 24 × 60] = 525,600) to obtain BTUs per minute. This quotient is 1,803,652,968.03653. Thus to convert EJ to BTUs, I multiplied by 1,803,652,968:

1870	7,394,977,169
1900	18,216,894,977
1950	66,915,525,114
1990	154,681,278,539 [used as is for header 67,842,666,026]

To compute per capita energy use I needed population figures. Ari Hoogenboom, ed., and Gary B. Nash, gen. ed., *Encyclopedia of American History,* vol. VI ("The Development of the Industrial United States: 1870 to 1899") (New York: Facts on File, 2003), p. 226 ("population trends"), states that in 1870 the U.S. contained 40 million people, and in 1900, 76 million. In vol. IX ("Postwar United States: 1946 to 1968"), Allan M. Winkler, ed., and Gary B. Nash, gen. ed. (same pub. date), pp. 244–45 ("population trends") informs us that from 1940 to 1970, "aggregate population" rose from 132 to 203 million, and that from 1940 to 1950, it increased by 19 million, which implies that in 1950 it was [132 + 19] = 151 million. In 1990, the official U.S. census estimate was 251,394,000, which I have rounded to 251 million to keep it at the same level of approximation as the other population figures.

Dividing the number of BTUs per minute by the number of people in each of the given years, I arrived at the four numbers in the table.

Energy use by bulldozers, power hammers and horizontal machines for drilling, etc.—Oberg and Jones, pp. 1835–36 [unnumb. table, "Motor Power for Machine Tools and Forging Machinery"]. I am simplifying to "common bulldozers" bulldozers with any of the following motors: constant speed, compound-wound, direct current, or wound secondary or squirrel cage induction. The power hammers in this comparison have any of these same types of motors. Likewise the horizontal boring, drilling and milling machines, except that some might instead have adjustable speed DC motors.

Parsons steam turbine dynamo—Steve Parker, p. 42.

Electric water heater—Rated at 4,500 watts, × 0.056884 BTU/min = 255.978. But altered, per Prof. Gutowski, to 21.7 BTUs per minute. See p. 21, source-note to table of Comparative Energy Requirements, "Energy to keep warm 1 lb of water for a minute in a 40-gallon electric heater."

Front-loading dryers—The electric model was rated at 5,300 watts, the gas model at 22,000 BTUs per hour.

"Tumble driers are hugely energy inefficient . . ."—Boxwell, p. 105.

Light commercial sewing machine—A Singer sewing brand, purchased *ca.* 2010. Volts 120. Amps 210. [60 Hz.] 120 × 210 = 25,200 watts, × 0.056884 = 1,433.4768 BTUs per minute.

Information on Piper Cub two-seat airplane—*Plane & Pilot* [Braintree, Massachusetts], August 2017, p. 44 (Robert Goyer, "10 Thoughts on 80 Years of the [Piper] Cub"). The first Piper Cub, 1938, "featured a whopping 37 horsepower." From the "Definitions, Units and Conversions" section on p. 524, 1 hp = 42.408 BTUs/min.

Powering the 5 screens of a multiplex movie theater—From the website in.answers.yahoo.com/question/index, accessed July 2016 [data *ca.* 2009]: 5-screen multiplex at 36,000 watts. Per-minute use at = [36,000 watts × 0.056884 BTUs/min = 2,047.824 BTUs/min. [Actual use, per the website: 12 hrs × 5 days × 52 wks.]

Capacities of locomotives—Baumeister, p. 11-23 (J. F. Partridge, "Railway Engineering," Table 1, "Electric Locomotives"). Original figures were: Illinois Central, 400 hp; Virginian; 6,800 hp [both expressed as continuous]. Converted at: 1 hp = 42.418 BTUs/min.

Average U.S. electric production, week of June 17, 2015—*Coal Valley News* [West Virginia], Wednesday, June 17, 2015, p. 4B (T. L. Headley, "U.S. coal production slightly up"). The figure was 74.76 MW of electricity this week (*versus*

79.56 for the same week of the previous year). Calculation: 74.76 MWh = 74.76 × 1,000 × 3413.0 BTUs/hr = 255,155,880 BTUs / [1 week = 60 min / hr × 24 hr / day × 7 days / wk = 10,080] = 25,313.083 BTUs per minute.

U.S. energy consumed in paper manufacture and petroleum manufacture, 1988—Kroschwitz and Howe-Grant, vol. 12 ("Fuel Resources" to "Heat Stabilizers"), p. 439 ("energy management," Table 1: "Energy Usage by United States Industry in 1988"). Petroleum refining was 6.87 EJ, and paper manufacturing at 2.90 EJ, converted as usual to BTUs/min.

World energy consumption, 1950, 1990, 2050 projection—Darling and Sisterson, p. xix, expressed in terawatts [= trillions of watts], respectively 3, 12, 30 of them, which I have converted at 1 TW = 56,884,000,000 [56.9 billion] BTUs/min.

World energy consumption rate, 1991—Kroschwitz and Howe-Grant, vol. 12 ("Fuel Resources" to "Heat Stabilizers"), p. 12 (Table 13: "World Energy Consumption, 1991, EJ"). The figure given was 365.93 EJ, which I converted to 660,010,730,594 BTUs per min, as I did for the comparable numbers relevant to 1870, 1900, 1950 and 1990.

World energy consumption rate, 2015—Prentiss, p. 15: "The total energy use for the world is about 500 exajoules, which is equivalent to an average consumption rate of approximately 2×10^{13} watts." [Exa- = 10 to the 18th power.] Since 1 watt = 0.056884 BTU per minute, 2×10^{13} watts = 1,137,680,000,000 BTUs, and this divided by 2.28 = 498,982,456,140. [It is comforting to see the nearness of the BTU figure to Darling and Sisterson's [loc. cit.] for *ca.* 2014: 18 trillion watts = 1.0239 trillion BTUs per minute.

About Power (continued)

Per capita manufacturing power consumption increase as of 2010—Gutowski et al., *Annu. Rev. Environ. Resour.,* 2013, p. 100 ("Table 5: Global per capita consumption of energy, materials, products, and services in 2010 . . ."). The 2010 consumption figure was 2,449 watts per capita. All this was "total primary power." For a definition, see p. 528 in the end matter.

"People everywhere need more and more electricity . . ."—Barbara Alpert [consulting ed.: Gail Saunders-Smith, Ph.D.], *Electricity All Around* (North Mankato, Minnesota: Capstone Press / Pebble Plus Science Builders series., 2012), p. 20.

What Was the Work For? (continued)

Epigraph: Ad for "A Beloved Symbol of Christmas"—*National Enquirer,* October 10, 2016, p. 41.

Energy Required to Move an American Car One Mile, 1949 and 2010

Prentiss (p. 16) asserts that the 1949 average fuel efficiency was 13 miles per gallon and the comparable 2010 figure was 17.5 mpg. Since 1 BTU = 1/112,500 gallon of gasoline (see p. 197), then 112,500 BTUs / 1 gal gasoline × 1 gal gasoline / 13 mi = 8,653.85 BTUs per mile for 1949; the equivalent 2010 computation yielded 6,428.57 BTUs per mile. To avoid spurious precision I rounded these to the nearest whole number.—Prentiss adds (pp. 15–16 [possibly referring to 2005 rather than 2010]) that "the annual number of miles driven per vehicle has increased by more than a third since 1949; however, increases in fuel efficiency have been so large that the present U.S. fuel consumption is almost 10 percent lower than it was in 1949."

Footnote: My share of carbon dioxide emissions on the Barcelona trip—In 2015 I flew from San Francisco to Zürich on an Airbus A340-300 (Swiss International), then from Zürich to Barcelona on an Airbus A321, and finally from Barcelona to San Francisco on an Airbus A340-600 (Lufthansa for the latter two legs). These details come from my electronic ticket, as does the following: "EL CALCULO MEDIO DE EMISIONES DE CO2 DURANTE EL VUELO ES 1570.09 KG/PERSONA."

Thoreau: "We will sit on a mound and muse . . ."—Henry David Thoreau, *Collected Essays and Poems* (New York: Library of America, 2001), p. 90 ("Dark Ages," 1843).

"A curious aspect of the automobile . . ."—Walter J. Boyne, *Power Behind the Wheel: Creativity and the Evolution of the Automobile* (New York: Stewart, Tabori and Chang, 1988), p. 8.

"the way the 5.2 liter, twin-turbo V-12 storms . . ."—*Motor Trend,* July 2016, p. 21 (Angus MacKenzie, "8.16 Trend: 2017 Aston Martin DB11").

Carbon Ideologies Approached

Epigraph: "Life as we know it is not limitless . . ."—Loren Eiseley, *Collected Essays on Evolution, Nature, and the Cosmos, Volume One* (New York: Library of America, 2017), p. 349 *(The Unexpected Universe,* 1969).

"What a country it must have been . . ."—Sherwood Anderson, *Collected Stories* (New York: Library of America, 2012), pp. 683–84 ("These Mountaineers," 1930).

"Strip off the woods . . ." + "The slow-going, unthrifty farmers . . ."—John Muir, *Nature Writings* (New York: Library of America, 1997); p. 629 ("God's First Temples: How Shall We Preserve Our Forests?," 1876, and "The American Forests," 1897).

"Increasingly, there is but one way into the future . . ."—Eiseley, vol. 1, p. 267 (*The Unexpected Universe*).

"highways, gas stations and parking lots now cover more of the surface area . . ." —Wilson et al., p. 1000.

"Transportation is heavily dependent on the use of oil derivatives . . ."—Meyer and Gómez-Ibáñes, p. 124.

Footnote: Transportation as a percentage of U.S. energy consumption—Ibid., p. 124.

Carbon monoxide and nitrous oxide pollution, + sulfur and particulates—DOT, June 1979, p. II-15 (Table 2-12: "Magnitude of pollutants in rail rapid transit powered by electrical energy"). Data for carbon monoxide: coal, 0.4536 grams per car-mile; residual oil, 0.0068; natural gas, negligible. For "oxides of nitrogen": coal, 18.5976; residual oil, 17.6904; natural gas, 9.5256.

Citations from Philip Wylie—*The End of the Dream* (Lincoln: University of Nebraska Press, Beyond Armageddon series, 2013; orig. pub. 1972), pp. 91, 118, 164, 173, 186, 225, 246, 229, 235–36, 244–45, 256–57.

Footnote: "The swarming millions who now populate the planet . . ."—Eiseley, vol. 2 (*The Invisible Pyramid, The Night Country,* essays from *The Star Thrower*), pp. 366–67 (*The Star Thrower,* "The Winter of Man," 1972).

"Dense clouds of yellow dust from China were forecast to begin reaching China on Friday."—*The Japan Times,* Saturday, March 9, 2013, p. 2 (unattrib., "Fukuoka gears up for China's smog cloud"). This was "PM2.5, or hazardous particulate matter measuring below 2.5 microns," a "toxic air pollutant." There was an "average daily amount of PM2.5 forecast to reach 42 micrograms per cubic meter in city of Fukuoka, topping the national environmental standard of 35." There would be an alert "if the density looks to top the central government-set allowable level of 70 micrograms per cubic meter."

"Yellow dust linked . . ."—*The Japan Times,* Thursday, March 13, 2014, p. 2 (unattrib., "Yellow dust linked to more emergency room trips"). In Nagasaki, 12% more patients were brought to emergency rooms during high-level yellow dust days than on other days; the percentage was higher still when the yellow dust arrived "after passing over industrial districts in China's coastal areas at an altitude of less than 2 km."

"A Stanford University biologist . . ."—Donahue, Miller and Shickluna, p. 528.

The ads in *Inc.*—*Inc.: The Magazine for Growing Companies* (July 1985), pp. 16–17 (Toyota) and 23 (Compaq). Meanwhile, in the August issue (p. 25), an airline's founder (p. 28; interview with Donald Burr) explained to us all about "the competitive business strategy of People Express, which is to provide an environment for all of us to do better on the same team."

Two old names for carbon dioxide—*Britannica,* 11th ed., vol. V (CALHOUN to CHATELAINE), p. 306 ("carbon").

"The cool-moist trend of the 1960s . . ."—*The New Encyclopaedia Britannica in 30 Volumes* (Chicago: Encyclopaedia Britannica / The University of Chicago, 1976), vol. 4 (CEYLON to CONGREVE), p. 741 ("climatic change"). [This version henceforth cited: "*Britannica,* 15th ed."]

"It seems that the 10 percent increase . . ."—Ibid., p. 715 ("climate").

"Being an Earthlike-planet . . ." + (used in my fn) temperature of more than 750° F (converted from "more than 400° C" [to 752]), sulfur dioxide in Venusian atmosphere, + mention of greenhouse effect—F. W. Taylor, *The Cambridge Photographic Guide to the Planets* (Cambridge, U.K.: Cambridge University Press, 2001), pp. 50–51, 60, 66.

"Perhaps the most promising explanation . . ." + "Preliminary calculations suggest . . ." + (used in my fn) "Searing temperature" and "crushing pressure"—*Britannica,* 15th ed., vol. 19 (UTILITARIANISM to ZWINGLI), pp. 80–81 ("Venus").

Footnote: Temperature of 840° F (converted from "more than 450° C" [to 752])—Ronald Greeley and Raymond Batson, *The Compact NASA Atlas of the Solar System,* Cambridge, U.K.: Cambridge University Press, 2001; orig. noncompact ed., 1997), p. 53.

Carbon dioxide in Venusian atmosphere—*Britannica,* loc. cit.; not specifically mentioned in Taylor, but Greeley and Batson (p. 61) refer to "Venus's dense, carbon dioxide atmosphere."

Carbon dioxide "to the tune of 96.4%"—Information from David R. Lide, Ph.D., ed. in chief, *CRC Handbook of Chemistry and Physics,* 87th ed. (New York: Taylor & Francis / CRC Press, 2006), p. 14-3 ("Properties of the Solar System"). [This document henceforth cited: "*CRC Handbook,* 2006."]

"The United States accounts for roughly one half of the world's total consumption of energy and produces substantially less than it consumes."—John R. Meyer and José A. Gómez-Ibáñes, *Auto Transit and Cities* (A Twentieth Century Fund Report) (Cambridge, Massachusetts: Harvard University Press, 1981), p. 123.

"Very often the point is made . . ." + "Modern industry cannot operate without electricity . . ."—R. F. Meyer, ed., and J. C. Olson, assoc. ed., *Long-Term Energy Resources,* vol. I ("a international conference sponsored by The United Nations

Institute for Training and Research (UNITAR) and Petro-Canada, in cooperation with United Nations Development Program, Canadian International Development Agency, Petroleos de Venezuela, Hydro-Québec, Compagnie Francaise des Petroles, November 26–December 7, [1980?], Montréal . . ." (Boston: Pitman, 1981), pp. 7–8, 7 (Meyer's remarks). [This publication henceforth cited: "*Long-Term Energy Resources*."]

"If the cause of these glacial conditions . . ."—Eiseley, vol. 1, p. 312 *(The Unexpected Universe*).

Footnote: More words by Meyer—Ibid., p. lxviii (introduction).

"Energy planners must never forget . . ."—*Long-Term Energy Resources,* p. 15 (Sir Hermann Bondi, Chief Scientist, U.K. Department of Energy, "The Need for a Diversity of Energy Sources").

"Not to use oil and gas . . ."—Robert S. Livingston et al., "of Oak Ridge National Laboratory, Oak Ridge, Tennessee," *A Desirable Energy Future: A National Perspective* (Philadelphia: Franklin Institute Press, 1982), p. 8.

World primary energy output, 1981: 285 quadrillion BTUs of primary energy—U.S. Department of Energy, Energy Administration, *1981 International Energy Annual* (Washington, D.C.: U.S. Department of Energy, September 1982), p. 1, "world production of primary energy": 1973, 247 quads; and 1981, 285 quads—a 5.38% increase, which the DOE found remarkable, given the three recent politically-induced declines in production. [This document henceforth cited: "U.S. DOE, 1982."]

Conversion from quads to barrels of oil—A quad contains "roughly the energy contained in 200 million barrels of oil." (See p. 535.) So 285 Q-BTUs = 57 billion bbl oil.

HHV of a barrel of oil—42 gal × [p. 215, multiplier header **202**: 154,600 BTUs per gallon] = 6,493,200 BTUs/barrel.

Footnote: "The U.S. Department of Energy estimated a barrel of American crude at 5.8 million"—Information from U.S. DOE, 1982, p. 104 (Appendix D: "Gross Thermal Conversions by Energy Source"), using all 1980 figures.

"just enough to have manufactured 95 pounds of titanium in 1952"—[6,493,200 BTUs/barrel] / [68,260 BTUs / lb Ti; see p. 59 ["Comparative Energy Requirements," multiplier header **68,260**] = 95.1245. The immense energy requirements of titanium manufacture are indicated by the fact that if we had employed all 285 quads at this task, net production would have been "only" [57 billion / 68,260 =] 835,042.4846 pounds.

"Burning fossil fuels will increase the level of CO_2 . . ."—Livingston et al., 13.

"At present, the most serious man-made impact . . ."—The National Research Council, *Protection Against Depletion of Stratospheric Ozone by Chlorofluorocarbons* (Washington, D.C.: National Academy of Sciences, 1979), pp. 102, 111. [This source henceforth cited: "National Research Council."]

"The rapid, very voluminous release of CO_2 . . ."—Paul B. Weisz, professor of biology, Brown University, *The Science of Biology,* 3rd ed. (New York: McGraw-Hill, 1967 rev. of 1959 ed.), p. 212.

The two curves, and appended remarks—Livingston et al., pp. 40–41.

Footnote on the "medium scenario" of 700 ppm—IPCC, 2013, p. 1187. The "high scenario" imagined a grisly 700–1200 ppm.

About Data

Epigraph: "The literature review supports the oft-heard assumption . . ." —*Greenhouse Gas Inventory Germany, 1990–2007,* p. 519.

Epigraph: "I was the first one back in 2002 . . ."—*The Washington Post,* "Morning Mix" (Jacob Bogage, July 27), downloaded for WTV by Jordan Rothacker (who this time did not provide the Internet address), October 2016.

"Modeling only the gas-phase dynamics . . ."—Kroschwitz and Howe-Grant, vol. 3 ("Antibiotics" to "Batteries"), p. 743 ("atmospheric modeling").

"the 95% confidence interval . . . since 1951 is +/– 0.12° C."—*CRC Handbook,* 2006, p. 14-31 ("Global Temperature Trend, 1856–2004").

About Data Suppression

Epigraph: "We can be silent witnesses to terrible injustices . . ."—Encyclical of Pope Francis, 2015, p. 11 (para 36).

The allegations of Mr. Honma Ryu (whose book *Genpats Koukoku to Chihoushi* ["nuclear advertisements in local newspapers"] are cited repeatedly in the Nuclear Ideology section, pp. 221–27)—*Global Research,* June 5, 2016 (www.globalresearch.ca/fukiushima-and-nuclear-power . . . , downloaded for WTV by David M. Golden, October 2016): *INA Global and Asia-Pacific Journal,* June 1, 2016 (Mathieu Gaulène, "Fukushima and Nuclear Power: Does the Advertising Giant Dentsu Pull the Strings of Japan's Media?"): 4-pp. printout; all pp. used.

About Disbelief

Epigraph: Nevil Shute, *On the Beach* (New York: Bantam Books, 1970 repr. of 1957 ed.), p. 101.

"No theory can ever be *proved* to be correct . . ." + "A theory is of little value . . ." —Marion, pp. 12, 13.

"It is a strange art that can thus be practised . . ."—Robert Louis Stevenson, *The Master of Ballantrae: A Winter's Tale* (New York: Modern Library, 2002; orig. ed. 1889), p. 99.

Copernicus's iconoclasm: "has been called a last effort to 'save the appearances' "— For such assessments, see my *Uncentering the Earth: Copernicus and the Revolutions of the Heavenly Spheres* (New York: Norton / Atlas Books, 2006), pp. 203–4.

"And so the sun . . ."—Robert Maynard Hutchins, ed.-in-chief, *Great Books of the Western World,* no. 16: *Ptolemy, Copernicus, Kepler* (Chicago: Encyclopaedia Britannica, Inc., William Benton, Publisher, 1952, p. 528 (Nicolaus Copernicus, *On the Revolutions of the Heavenly Spheres* [1543], trans. Charles Glenn Wallis, 1939).

"The concept of global warming was created by and for the Chinese . . ."—Donald Trump, quoted in the *Khaleej Times,* vol. XXXVIII, no. 183, Saturday, October 15, 2006, p. 12 ("Expressions": "Zip that lip, Mr. Trump!").

"Consider It Good Fortune"

Epigraph: "We may be moving now towards a warmer phase . . ." + "If so, there will be less room for us . . ."—H. G. Wells, *The Outline of History: Being a Plain History of Life and Mankind,* rev. Raymond Postgate and G. P. Wells (Garden City, New York: Doubleday & Co., 1971 rev.; orig. ed. 1920), vol. 1, pp. 48 (epigraph) and 34 (fn).

Epigraph: ". . . and he felt reassured by the thought of New York . . ."—Rand, pp. 259–60.

Carbon dioxide values, and the line on that graph—Information from *CRC Handbook,* 2006. Each of the two figures is taken from the relevant year's "annual" column in the observatory records.

Further re: 1750 carbon dioxide values: IPCC, p. 166: "The 1750 globally averaged abundance of atmospheric CO2 based on measurements of air extracted from ice cores and from firn is 278 ± 2 ppm . . ."

When my research assistant queried NOAA regarding slight differences between their numbers and CRC's, and whether I could publish it, the following reply came from Dr. Pieter Tans at NOAA Federal (Thursday, August 18, 2016, at 4:12 p.m.): "You are very welcome to use the data. They are in the public domain. We only ask to be referenced as the source. Our values are better than in the CRC handbook. Many years ago I got a value of 0.03% from that, when MLO was showing values like 350.38 ppm, to give you an example. Maybe the handbook is more specific these days, but they get their information from us. There are a few missing months in the record—in those cases the column "interpolated" does show a value. A multiyear average seasonal cycle has been removed from the "trend" column so that it shows the steady rise. For annual averages we have a different file, also on the web, co2_annmean_mlo.txt. Our average for 1959 is the same as yours, but we round it to 315.97. Our uncertainty for the annual averages is listed as 0.12 ppm (one standard deviation, or ~65% confidence)." I print this communication for the sake of completeness. Since the CRC numbers were still very close to NOAA's, I decided to leave them, so that the relation of my experience in finding the numbers in the *CRC Handbook* would be accurate.

The United Nations "Millennium Ecosystem Assessment" (2005)—Quoted in Ward, p. 3199.

"nearly 147% higher than the planetary average over the last 800,000 years"—According to Darling and Sisterson (p. xvii), the average carbon dioxide level over this period was 230 ppm. This source claims that carbon dioxide "peaks at 250–300 ppm about every 100,000 years."

Footnote on ice cores—Information from *Scientific American,* February 1998, pp. 80–85 (Richard B. Alley and Michael L. Bender, "Greenland Ice Cores: Frozen in Time: Ice, frozen in place for tens of thousands of years, provides scientists with clues to past—and future—climate").

"preindustrial chemical equilibrium values of 280 ppm."—Dr. Pieter Tans, chief, Carbon Cycle Greenhouse Gases Group, National Oceanic and Atmospheric Administration, letter to WTV, via Jordan Rothacker, May 8, 2017. [Henceforth cited: "Tans to WTV, May 2017."]

230 parts per million—See Darling and Sisterson in source-note to future status of Marshall Islands, sources p. 6 (text p. 13). Levels in 2014—Loc. cit. As a member of the Climate Reality Project and Citizens Climate Lobby of Downington, Pennsylvania, put the case: "We pump 90 million tons of CO2 *[no subscript]* into the atmosphere every 24 hours, and it remains there for over a hundred years. It has increased CO2 levels from an 800,000 year average of 280 parts per million to today's 400 parts per million . . . From around 1850 until now we've burned 500 billion tons of carbon and raised the global average temperature .8 degrees Celsius, almost halfway to the 2-degree limit . . . so we can only burn another 565 billion tons . . . The critical issue is, globally we have 2,795 billion tons of carbon in inventory (82 percent coal, 49 percent gas, and 33 percent oil) ready to burn . . ."—*The Charleston [West Virginia] Gazette,* Monday, February 16, 2015, p. 4A ("Opinion" section, Peter Whiteford, "Climate change: Planning to fail").

Roger Revelle's predictions—Odum, p. 33.

"the oceans were 82 feet higher" (in the Pliocene)—Darling and Sisterson., p. xviii.

“In earlier years, other factors were stronger . . .”—Darling and Sisterson, p. 109.

“It could have been as early as 1951 . . . that the Earth began to absorb more heat than it sent back into space”—*The Japan Times,* Friday, January 6, 2017, p. 5 (unattrib., “Global warming didn’t pause, study shows”): A 2013 IPCC report “said the average global warming between 1951 and 2012 had been 0.12 degrees Celsius (0.22 degrees Fahrenheit) per decade.”

“it is ‘virtually certain’ . . . that the Earth has gained substantial energy from 1971 . . .”—IPCC, 2013, p. 39.

Conversion of joules to BTUs—1 BTU = 1,054.8 joules, so 274×10^{21} J × 1 BTU / 1,054.8 J = 2.599×10^{20} BTUs. Dividing this by 10^{15} [= 1 quadrillion], we obtain 260,000 quads.

“totaled merely 919 times more than the entire global energy production of 1981!”—As was stated on p. 87, this was 285 quads.

“It was as if we had burned 10 and a half billion tons of West Virginia coal in the course of those 39 years—8.52 tons each second.”—262,000 Q-BTUs / 12,500 per lb Appalachian coal / 2,000 lbs per ton = 10,480,000,000,000 tons, which divided by [39 years × 1,536,000 years to seconds] yields 173,611 tons per second.

Carbon Dioxide Emissions from Fuel Combustion, World and Selected Countries

Data sets from *CO_2 Emissions from Fuel Combustion: Highlights* (Paris: International Energy Agency, OECD/IEA, 2016); downloaded from www.iea.org for WTV by Jordan Rothacker, October 2017, p. 76 (Summary Time Series: CO_2 emissions from fuel combustion [expressed in million (metric) tonnes carbon dioxide]. [This document henceforth cited: “OECD/IEA, 2016.”]

Carbon dioxide levels in 2016—ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_mm_mlo.txt, downloaded for WTV by Jordan Rothacker on May 25, 2016. The page is headlined “NOAA ESRL DATA.” [“These data are made freely available to the public and the scientific community in the belief that their wide dissemination will lead to greater understanding and new scientific insights. The availability of these data does not constitute publication of the data. NOAA relies on the ethics and integrity of the user to insure that ESRL receives fair credit for their work.”] This value comes from the “average” column. There were also “interpolated” and “trend (season corr[ected?]” columns, which were respectively 407.42 (the same as the “average”) and 404.60. N.b.: The final (month 12 out of 12) 1959 values from this source vary slightly from the ones published in the *CRC Handbook*. The three respective columns (“average” first) were 315.58, 315.58 and 316.52. My calculation of the arithmetical average of the 12 “averages” for that year is 315.974.

Carbon dioxide levels: "43% over 1750"—Information from EPA, 2016, p. 25.

The corresponding "graph of annual global mean temperature from 1856 to 2004"—Ibid., p. 14-31 ("Global Temperature Trend, 1856–2004").

Information on increasing Tokyo temperatures, 1876–2011—*Journal of Geography* (*Chigaku Zasshu*), 122, no. 6, (2013): pp. 1010–1019 (Masumi Zaiki and Takehiko Mikami, "Climate Variations in Tokyo since the Edo Period," p. 1011 (Fig. 1: "Annual mean temperatures in JMA Tokyo for 1876–2011"), visually estimated from graph by WTV.

Predictions of the Meteorological Observatory—"Forecast of Future Temperatures in Tokyo," 2015; printed out for WTV and translated for him by Ms. Kawai Takako, January 2017. The web address is in Japanese. I have placed Kawai-san's marked-up printout among my papers at the Ohio State University.

MIT: "a world manufacturing CO_2 plot . . ."—Gutowski et al., *Annu. Rev. Environ. Resour.,* 2013, p. 87.

"We are inclined sometimes to wring our hands . . ."—Theodore Dreiser, *Sister Carrie,* restored ed., ed. John C. Berkey et al. (New York: Penguin Classics, 1994 repr. of 1981 corr. ed.; orig. ed. 1900), p. 74.

Bush and Kyoto + *The Times*'s reaction—Jean Edward Smith, *Bush* (New York: Simon & Schuster, 2016), pp. 191–92. Christine Todd Whitman, the blindsided EPA head: "The administration's insistence on playing strictly to the base in explaining the president's opposition to ratifying the Kyoto Protocol, coupled with his reversal on the regulation of carbon dioxide, was an early expression of the go-it-alone attitude that so offended our allies in the lead-up to the Iraq war" (loc. cit.).

The world's highest thermometer reading (1922)—Wendy M. Middleton, ed.-in-chief, *Reference Data for Engineers: Radio, Electronics, Computer, and Communications,* 9th ed. (Boston: Newnes, 1998, 2002), p. 49-4.

The highest California reading—U.S. Statistical Abstract, 2015, p. 261 (Table 408: "Highest and Lowest Temperatures by State Through 2013"). The highest California temperature was measured at Greenland Ranch station, 1913. The lowest (–45°) was read at Boca in 1937.

World population in 1922 and 2002—According to the Central Intelligence Agency, *The World Factbook, 2013* (CIA's 2012 Edition) (Washington, D.C.: Potomac Books, 2013), p. 1, our population had increased as follows:

1820	1 billion
1930	2 billion
1960	3 billion
1974	4 billion

1987	5 billion
1999	6 billion
2012	7 billion

The latest estimate, for July 2012, was 7,021,836,029 souls (ibid., p. 2).

Footnote: Revocation of the Libyan temperature reading due to "potentially problematical instrumentation"—*The New York Times,* Sunday, June 18, 2017, p. 9 (Salman Masood and Mike Ives, "As the Scorchers Multiply in Asia, Mercury Records Fall and Climate Concerns Rise").

"associated with a transfer of heat from the upper to the deeper ocean"—IPCC, 2013, p. 68: "Observations and models indicate that, because of the comparatively small heat capacity of the atmosphere, a decade of steady or even decreasing surface temperature can occur in a warming world. Climate model simulations suggest that these periods are associated with a transfer of heat from the upper to the deeper ocean . . ."

"Consider it good fortune that we are living in a world . . ."—Patrick J. Michaels and Robert C. Balling, Jr., *The Satanic Gases: Clearing the Air about Global Warming* (Washington, D.C.: Cato Institute, 2000), p. 188. But to keep up "plant productivity," we might need to supply more nitrogen fertilizers, whose outgassings caused global warming. For some of the ramifications, see IPCC, 2013, pp. 478, 501.

Footnote: "We can note the rise of a false or superficial ecology . . ."—Encyclical of Pope Francis, 2015, p. 17 (para. 59).

The new maple season in Maine—*The New York Times,* Monday, February 22, 2016, p. A16 (Paul Post, "Mild Winter with Sweetest of Aftertastes"). For three out of the past five years, production had been "in unprecedented quantities." As I was revising *Carbon Ideologies,* in March 2017, it looked to be another early year for mapling.

Paragraph on early effects of climate change on crops—*Encyclopedia of Agriculture and Food Systems,* vol. 2, p. 259 (J. A. Hatfield and C. L. Walthall, "Climate Change: Cropping System Changes and Adaptations"); pp. 238–40 (J. F. Hernandez Nopsa, S. Thomas-Sharma and K. A. Garrett, "Climate Change and Plant Disease").

The conclusion of Richard Tol—Chris Faulkner, p. 141. Loc. cit.: "Other scientists have concluded that the greatest benefit from climate change comes from the CO_2 itself and its beneficial effect on plants. One scientist, using three decades' worth of satellite images, had concluded that 31% of the world's vegetated areas have become greener while just 3% have become less green."

"November 1999 will go down in the record books . . ."—Michael Hunst, State Statistician, and George Howse, Deputy State Statistician, *Minnesota*

Agricultural Statistics 2000 (Saint Paul: Minnesota Agricultural Statistics Service, 2000), p. 16 ("1999 Climate Summary").

Canada: "six main glaciers 'have been shrinking . . .' "—Statistics Canada, *Canada Yearbook 2011* (Ottawa: Minister of Industry, 2011), p. 170. [Cited: "*Canada Yearbook 2011.*"]

Footnote on world and Canadian emissions, 1979–2007—Ibid., p. 171.

Definition of desertification—Central Intelligence Agency, *The World Factbook, 2013* (CIA's 2012 Edition), online version downloaded for WTV in February 2017 by Jordan Rothacker. Search field: "environment: current issues."

Datum from Turbat, + "Sixteen of the 17 hottest years . . ."—*The New York Times,* Sunday, June 18, 2017, p. 9 (Salman Masood and Mike Ives, "As the Scorchers Multiply in Asia, Mercury Records Fall and Climate Concerns Rise"). According to the same source, in 2015 there were more than 2,400 victims of fatal "heat-related illnesses."

"The contiguous U.S. experienced its warmest winter . . ."—*Time,* vol. 187, no. 10, March 21, 2016, p. 16 ("Trending" column: unattrib., "Environment"). Cf. Jos G. J. Olivier (PBL), Greet Janssens-Maenhout (EC-JRC), Marilena Muntean (EC-JRC), Jeroen A. H. W. Peters (PBL), "Trends in Global CO2 emissions: 2016 " [JRC Science for Policy Report: 103428] (The Hague: PBL Netherlands Environmental Assessment Agency, 2016 [PBL publication number: 2315]; European Commission, Joint Research Centre, Directorate Energy, Transport & Climate), downloaded for WTV by Jordan Rothacker from http://edgar.jrc.ec.europa.eu or http://www.pbl.nl/en/trends-in-global-co2-emissions, September 2017, p. 13: "As for the weather, the US National Oceanic and Atmospheric Administration (NOAA) recorded 2015 as the hottest year since records began in 1880. In addition, the 16 warmest years ever recorded are in the 1998–2015 period." [This document henceforth cited: "Olivier et al., 2016."]

The bakery girl—Interviewed in Sacramento, January 2016.

The British chemist: "Human contributions . . . are still a minor component . . ." + previous snippets on fossil fuel burning and methane—John Emsley, *Nature's Building Blocks: An A–Z Guide to the Elements* (Oxford: Oxford University Press, 2001), p. 97 ("carbon").

"Global climate change, prior to the 20th century . . ." Ward, p. 3188 (abstract).

IPCC (Fourth Assessment Report, 2007): "observations and measurements unambiguously indicate . . ."—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 52.

Table 5: "Global per capita consumption of energy . . ."—Gutowski et al., *Annu. Rev. Environ. Resour.,* 2013, p. 100.

Carbon Ideologies Defined

Epigraph: "When would this thing seem real? . . ."—C. M. Kornbluth, *Not This August* (New York: Bantam Books, 1956; orig. pub. 1955), p. 25.

Mr. Sam Hewes: "I think that we're all ideologues . . ."—Interview of July 9, 2016; see the Oklahoma oil section.

Footnote: "Lenin used to say . . ."—Aldous Huxley, *Island* (London: Vintage Classics, 2005; orig. pub. 1962), pp. 144–45. Lenin's slogan is more usually quoted: "COMMUNISM IS SOVIET POWER PLUS THE ELECTRIFICATION OF THE WHOLE COUNTRY."

About Carbon

Epigraph: "When they have discovered truth in nature . . ."—Georg Christoph Lichtenberg, *The Waste Books,* trans. R. J. Hollingdale (New York: New York Review Books Classics, 2000 repr. of 1990 ed.; orig. wr. 1765–99), p. 73 (Notebook E, 1775–76).

Abundance of carbon and cesium in the human body, by mass—*CRC Handbook,* 2006, p. 7-18 ("Chemical Composition of the Human Body"). Oxygen is 61% and carbon is 23%. Emsley (p. 93) provides very different figures (p. 93), but no overall percentage.

"No element is more essential to life than carbon . . ."—Emsley, p. 93.

Footnote: "The number of compounds that contain carbon is many times greater . . ."—Robert Thornton Morrison and Robert Neilson Boyd, *Organic Chemistry,* 2nd ed. (Boston: Allyn and Bacon, 1970 repr. of 1966 ed.; orig. ed. 1959), p. 4.

"combustion to carbon dioxide and water . . ."—Ibid., p. 37.

"Molecules with five to twenty carbon atoms . . ."—Kenneth S. Deffeyes, *Beyond Oil: The View from Hubbert's Peak* (New York: Farrar, Straus & Giroux / Hill and Wang, 2005), p. 15.

"One . . . acrylic plastic showed off 15 carbon atoms per molecule."—The stuff was polymethyl methacrylate. Kyung-Sun Lim, ed., *How Products Are Made: An Illustrated Guide to Product Manufacturing,* vol. 2 (New York: Gale Research Inc., 1996), p. 2 ("acrylic plastic").

"the solubility of carbon dioxide lessens in warmer water"—Information from Ward, p. 3189.

Abundance of carbon in Earth's crust and in the ocean: 200 ppm and 28 mg/L—*CRC Handbook,* p. 14-17 ("Abundance of Elements in the Earth's Crust and in the Sea").

Contrasting figure for C in crust of 480 ppm—Emsley, p. 96. For seawater, Emsley proposes 28 ppm, which of course is equivalent to 28 mg/L.

"Ocean temperature is . . . the primary natural control . . ."—Ibid.

"Humans burning fossil fuels and manufacturing cement . . ."—Ibid., p. 3196 ("7.8 Gt" in original).

"When pure chalk or limestone is 'burned' . . ."—*Britannica,* 11th ed., vol. V, p. 653 ("cement").

The difference between concrete and cement—according to Kroschwitz and Howe-Grant, vol. 5 ("Carbon and Graphite Fibers" to "Chlorocarbons and Chlorohydro-carbons-C," p. 584 ("cement"), "the term cement is used to designate many different kinds of substances that are used as binders or adhesives." Concrete then results when the cement is mixed with the appropriate amount of water.

Carbon dioxide from lime: "0.785 pounds or more for every pound . . . produced"—Information from *Greenhouse Gas Inventory Germany, 1990–2007,* p. 226 (Table 46: "Production and CO2 emissions in the German lime industry"). The original figures were: 5.253 million [metric] tons of CO_2 to make 6,691,134 tons of lime. [Dolomite lime was calculated separately.]

Energy to make 1 lb of lime for [Portland] cement: 3,800 BTUs—Han, p. 139 (Appendix I: "Energy Requirements for High Priority Primary Products"). [Source: Battelle Columbus Laboratories, 1975. Report No. PB-245759.] These data were originally given in "energy required per net ton (short ton of product in millions of BTU)." Therefore I divided each figure by 2,000 to get 1 pound.

Equivalences for 3,800 BTUs in white pine, fuel oil and West Virginia coal—Using my table of Calorific Efficiencies on pp. 208ff., I divided 3,800 BTUs by the HHV of each of these fuels. For example, commercial fuel oil, heavy grade, *ca.* 1975, contained 18,450 BTUs. So the quantity of oil needed was (3,800 BTUs per lb / 18,450 BTUs per lb) × 16 oz. per lb = 3.295 ounces.

Cement-smoke carbon, 1750–2011: "about 17.6 trillion pounds."—IPCC, 2013, p. 474: "Total cumulative emissions between 1750 and 2011 amount to 375 ± 30 Pg C . . . , including a contribution of 8 Pg C from the production of cement." 8 Pg = 17.6 (+/–1.3) trillion pounds = about 1/47 of 375 Pg.

Canada's total 2008 GHG emissions, and those from cement production—*Canada Yearbook 2011,* pp. 172–73 (Table 12.1, "Greenhouse gas (GHG) emissions, by source, 1990 and 2008").

Footnote: "Counting only carbon dioxide"—Canada's nitrous oxide emissions were 52,000 kilotons of carbon-equivalent (realistically rated at 310 times CO_2's global warming potential), and her methane emissions were 99,000 kilotons, rated optimistically at 21 times CO_2.

Information on Oklahoma's Portland cement, 2008 (including the substance of the accompanying fn)—Oklahoma Department of Libraries, *Oklahoma Almanac 2013–2014,* 54th ed., ed. Connie G. Armstrong (Oklahoma City: Oklahoma Department of Libraries, 2013), p. 937 ("Mining/Petroleum Overview: Non-fuel Mineral Production, 2008").

Information on American cement-making (*ca.* 2014)—EPA, 2016, pp. 208–9, 67 [or in original document, pp. 4-7, 4-8, 1-18]. By "the steelmaking trades" I mean iron, steel and coke production. [Cf. p. 4-7: "Carbon dioxide emitted from the chemical process of cement production is the second largest source of industrial CO_2 emissions in the United States."]

Cement figures for Japan, 2013—*Greenhouse Gas Inventory Japan,* 2015, p. 2-12 ND-13.

"Without consumers and decomposers to release the fixed carbon . . ."—Henry D. Foth, *Fundamentals of Soil Science,* 6th ed. (New York: John Wiley & Sons, 1978 rev. repr. of 1943 ed.), p. 126.

Cellulose as most prevalent organic compound—Neal K. Van Alfen, ed.-in-chief, *Encyclopedia of Agriculture and Food Systems,* vol. 2 (Amsterdam: Elsevier / Academic Press, 2014), p. 248 (S. E. Place, "Climate Change: Animal Systems").

Chemical formula of cellulose—Morrison and Boyd, p. 1033, where it is actually written $(C_6H_{10}O_5)n$, where n can be 1,500 or more. "It is likely that there are at least 1500 glucose units per molecule" (loc. cit.). Note, however, that the formula of glucose (p. 985) is $C_6H_{12}O_6$.

Weight of carbon in, and carbon dioxide from, 100 lbs of straw—Foth, p. 168. The CO_2 figure was actually expressed as 65% of 40 lbs.

Footnote: "Overall, throughout the time series and across all uses . . ."—EPA, 2016, p. 147.

Percentage "degradable organic carbon" of sewage sludge and diapers—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 388. This was the IPCC default for the former [in a dry state], and the "national value."

Carbon in Japanese diapers and plastic bottles—*Greenhouse Gas Inventory Japan,* 2015, p. 7-29, "estimated based on the averaged value of actual measured data for the period FY1990–FY2008 provided by four municipalities (Akita city, Kawasaki city, Kobe city and Osaka pref.) and applying it for the entire time-series."

The Rutgers study: "Every two days or so, provided that they were feeding continually, certain bacteria could generate their own dry weight of carbon dioxide."—In the original, the scientists noted that a mere 100 grams dry weight of certain bacteria could make 2 to 2.5 grams per hour of carbon dioxide.—*Soil Science,* vol. I (January–June, 1916) [Rutgers College, New Brunswick, New Jersey), p. 78 (R. S. Potter and R. S. Snyder, "Carbon and Nitrogen Changes in the Soil Variously Treated: Soil Treated with Lime, Ammonium Sulfate and Sodium Nitrate").

Both citations on American forests' carbon sequestration—www.nature.com/scientificreports, received May 10, 2015, accepted October 12, 2015, published November 12, 2015 (5, 16158 / doi: 10.1038/srep16518 [2015], downloaded for WTV by Jordan Rothacker, April 2016), David N. Wear and John W. Coulston, U.S. Department of Agriculture,"From sink to source: Regional variation in U.S. forest carbon futures," p. 1. [This source henceforth cited: "Wear and Coulston."] The units were originally expressed as Tg yr^{-1} .

Footnote: Conversion of Tg to lbs: [1,000,000,000,000] × 173 / 453.59 = 381,401,706,386.83 lbs.

"a true nonmetal in every sense."—*Britannica,* 15th ed., Macropaedia, vol. 3 (BOLIVIA to CERVANTES), p. 840 ("Carbon Group Elements and Their Compounds").

Melting points of carbon, platinum and tungsten—Baumeister and Marks, p. 4-5 (G. A. Hawkins, "Thermal Properties of Bodies and Thermodynamics").

"Essentially any organic material . . ."—Kroschwitz and Howe-Grant, vol. 4 ("Bearing Materials" to "Carbon" [1992]), p. 953 ("carbon").

Reaction of sucrose with sulfuric acid—After color photos and description in Brian Knapp, Bsc., Ph.D., *Carbon* (Danbury, Connecticut: Grolier Educational, 1997 repr. of 1996 ed.), pp. 18–19.

Chemical formula for table sugar (sucrose)—Morrison and Boyd, p. 1025. Loc. cit.: "Of all organic chemicals, it is the one produced in the largest amount in pure form."

"Carbon is widely distributed as coal . . ."—*Britannica,* 15th ed., loc. cit., p. 845.

"found native as the diamond . . ."—*Britannica,* 11th ed., vol. 5 (CALHOUN to CHATELAINE), ("carbon"), pp. 305–6.

"found . . . in the atmosphere."—Ibid.

About Agriculture

Epigraph: ". . . the energy for potatoes . . ."—Odum, p. 46 (quoting H. T. Odum).

Epigraph: "My crop of corn—Emrys Jones, ed., *The New Oxford Book of Sixteenth Century Verse* (New York: Oxford University Press, 1991), p. 393

(Chidiock Tichborne, "Tichborne's Elegy, written with his own hand in the Tower before his execution," 1586).

"Man is now unwittingly beginning to speed up decomposition . . ."—Odum, p. 33. On p. 24 he calls these "human agroindustrial activities."

Breakdown of carbon dioxide emissions in 1970—Ibid., p. 97.

Footnote: "The Work of the Plow . . ."—Ellis and Rumely, frontispiece.

"the more finely divided the soil . . ."—Ibid., p. 135.

"Pulverization changes the hard soil . . ."—Ibid., pp. 195–96. Cf. G. E. Fussell, *The Farmer's Tools: A.D. 1500–1900: A History of British Farm Tools, Implements and Machinery* (London: Andrew Melrose, 1952), p. 37: "All seed bed preparation is a matter of soil comminution." Oh, and we'd better not neglect Roy Bainer, R. A. Kepner and E. K. Barger, *Principles of Farm Machinery* (New York: John Wiley & Sons, Inc., Ferguson Foundation Agricultural Engineering ser., 1955), pp. 139–40: Tillage serves to keep weeds down, to pulverize the soil for seed and rootbeds and to insert "surface residues."

"soil is the interface between the living and the dead . . ."—Foth, p. 15.

"plants need to 'breathe in' oxygen through their roots"—Information from R. P. Faulkner, *Garden Manures and Fertilizers, Embodying Special Recommendations for Fruit, Vegetables and Flowers* (London: W. H. & L. Collingridge Ltd., 1949), p. 25 (hence tillage). [Cited: "R. P. Faulker," to distinguish him from the frack lord Chris Faulkner.] "Roots . . . play a not inconsiderable part in decomposing soil particles" (loc. cit.). Claude Culpin, *Farm Machinery,* 5th ed. (London: Crosby Lockwood & Son, Ltd., 1957 rev. of 1938 ed.), p. 102: "Oxygen is certainly required in the soil for the germination of seeds, the respiration of plant root systems and the activity of certain beneficial root bacteria."

Carbon in the soil: 0.08 to 38.0%—The American Society of Agronomy and the Soil Science Society of America, *SSSA Special Publication Number 11, Chemical Mobility and Reactivity in Soil Systems* (Madison, Wisconsin: SSSA and ASA, 1983; original symposium in Atlanta, Georgia, 1981), p. 154 (ch. 11: Dennis R. Keeney, "Principles of Microbial Processes of Chemical Degradation, Assimilation, and Accumulation"). [This article henceforth cited: "Keeney, 1981."]—Cf. p. 155: "We can assume that ca. 2.5% of the soil C is biomass. At steady-state (no fresh C residues), the microbial biomass of a mineral soil with 2% C, 2% as biomass, 25% of the biomass as bacteria, and 10% C fresh weight of the bacteria, a standing crop bacterial biomass of about 1400 [kilograms per hectare], and fungal biomass of about 4200 [kilograms per hectrte] can be calculated."

"The least stable, hence most energy-rich, carbon combinations . . ."—Weisz, p. 462.

"The first stage in the formation of plant tissue . . ."—R. P. Faulkner, p. 13.

"Mature plant residues . . ."—Foth, p. 168. The C/N ratio in them usually = 50 (loc. cit.).

Footnote: "The same goes for dead animals."—Information from the same, p. 142: "Organic matter is about 58% carbon by weight."

Decomposition process of composting—Foth, p. 170.

Characteristics of carbon-retaining soils—Arvin R. Mosier, J. Keith Sayers and John R. Freney, ed., *Agriculture and the Nitrogen Cycle: Assessing the Impacts of Fertilizer Use on Food Production and the Environment* (Washington, D.C.: Island Press, SCOPE ser., no. 65, 2004), p. 98: "Microbial community composition and metabolic status determine the balance between C released through respiration and C assimilation into biomass during decomposition . . ." + "fungal-dominated decomposer communities" sequester more carbon, + "decomposers in soils with greater diversity of plant species . . . or larger abundance of C relative to N . . . have reduced energy requirements for maintenance and therefore convert a greater proportion of metabolized C to biomass."

"Soil organic carbon has been called 'the largest terrestrial C sink'"—EPA, 2016, p. 384.

"Or roots might drink it in"—Arthur Wallace and Richard E. Terry, *Handbook of Soil Conditioners: Substances That Enhance the Physical Properties of Soil* (New York: Marcel Dekker, Inc., 1998), p. 274: "Besides proper root action stimulated by improved aeration and consequent availability of oxygen in soil air, metabolism of soil bacteria and fungi also starts. Both these processes augment the CO_2 supply in the root zone of soil."

"Most consider that microbial life in soils . . ."—Keeney, 1981, p. 153.

"cultivation 'reduces the mean residence time' of carbon"—Neal K [no period] Van Alfen, ed.-in-chief, *Encyclopedia of Agriculture and Food Systems,* vol. 2 (Amsterdam: Elsevier / Academic Press, 2014), p. 224 (M [no period] van Noordwijk, Jalan Cifor, Bogor, Indonesia, "Climate Change: Agricultural Mitigation").

"Sometimes our doings sent half the mineralized carbon straight up into the sky!"—Information from EPA, 2016, p. 395.

"Our crops . . . were beneficiaries of the energy . . ."—Butler and Wurthner, p. 44.

"All the chemical and biological processes are going on so much faster . . ."—R. P. Faulkner, pp. 40–41. The nutrients required: Salts of nitrogen, sulfur, phosphorus, potassium, iron, magnesium and boron (pp. 16, 20, 31).

“Conservative estimates indicate that about 30% . . .”—Kroschwitz and Howe-Grant, vol. 10 (“Explosives and Propellants” to “Flame Retardants for Textiles”), p. 503 (“fertilizers”).

Footnote on C and N in Bangladeshi soils—Japanese Society of Soil Science and Plant Nutrition [Tokyo], *Soil Science and Plant Nutrition,* vol. 43 (March 1997–December 1997), pp. 863, 871, 873 (Md. Mohsin Ali et al., “Soil Degradation during the Period 1967–1995 in Bangladesh: I. Carbon and Nitrogen”). Carbon declined by 16.2 tons per hectare and nitrogen by 1.38 tons per hectare. The author notes (p. 876) that both elements are “associated with organic matter decomposition.”

Ammonium sulfate “supplies nitrogen” as ammonia for conversion to nitrate—R. P. Faulkner, pp. 31, 50.

“most likely to be deficient in the soil”—Willman, p. 33.

Footnote: Sources of P and K fertilizers—Kroschwitz and Howe-Grant, vol. 10 (“Explosives and Propellants” to “Flame Retardants for Textiles”), pp. 454, 475–78 (“fertilizers”).

Same footnote: “Volumewise, it is the production of N, P, and K fertilizers . . .” —Same entry, p. 436 (“fertilizers”).

Same footnote: Carbon emissions of phosphates [based on the usual “production from natural phosphate rock”]—Information from EPA, 2016, p. 254.

Same footnote: Finnish emissions, 2012—EU greenhouse report, 2014, p. 426 (Table 4.32 2B5: Other: “EU-15 CO_2 emissions—emission trends between 1990 and 2012 and MS contribution”). Page 432: “The total amount of CO_2 released from phosphoric acid plant has been calculated multiplying the use of apatite and calcite with CO_2 content of defined yearly average of daily samples.” My calculation from Gg to lbs.

Same footnote—Production of potassium chloride (“the world’s most commonly used potash”): Potash-bearing ores (there were four of them, including sylvinite) were mined not unlike coal, using either longwall or room-and-pillar methods [q.v., p. 560], then crushed, then slurried into a brine from which the clay must be separated out, after which the chloride was drawn out with high-grade beef tallow, then de-brined, centrifuged and dried. (In a very few places it was possible to evaporate potash from brine pools.) Information from Kroschwitz and Howe-Grant, vol. 19 (“Pigments” to “Powders, Handling”), pp. 1058–69 (“potassium compounds”).

“Of all plant nutrients, an application of nitrogen . . .”—A. Philip Draycott and Donald R. Christenson, *Nutrients for Sugar Beet Production: Soil-Plant Relationships* (Wallingford, Oxon, U.K.: CABI Publishing, 2003), p. 11.

Uses of ammonium sulfate in Thailand—Report prepared for the Government of Thailand by the Food and Agriculture Organization of the United Nations, acting as executing agency for the United Nations Development Programme, *Soil Fertility Research: Thailand: Use of Fertilizers on Eight Upland Crops* (Rome: UNDP, 1973), pp. 229 (for maize, ammonium phosphate as a basal dressing, ammonium sulfate as a top dressing, and a nitrogen top dressing when it rains) and 230 (for peanut, double superphosphate and potassium chloride, and ammonium sulfate as needed to facilitate nodulation and early growth).

Effects of ammonium sulfate on carbon dioxide production (including fn on "previous drying")—*Soil Science,* vol. I (January–June 1916) [Rutgers College, New Brunswick, New Jersey), pp. 79, 88, 89 (Table IV: "Composition of Carbon Dioxide Evolved from Organic Decompositions"): R. S. Potter and R. S. Snyder, "Carbon and Nitrogen Changes in the Soil Variously Treated: Soil Treated with Lime, Ammonium Sulfate and Sodium Nitrate."

Ammonium sulfate: "Began with the coal we had already roasted in coking ovens"—Kroschwitz and Howe-Grant, vol. 10, p. 327 ("feedstocks (coal chemicals)"), which puts the matter thus: 0.3% of coal put into coking ovens ends up as ammonia, "usually converted to ammonium sulfate and sold as a fertilizer."

Sodium nitrate: "assimilated by plants at once"—R. P. Faulkner, p. 50.

Ammonium nitrate: "highly regarded because of the rapid agronomic response"—Kroschwitz and Howe-Grant, same vol., p. 447 ("fertilizers").

The "pipelines of chilled anhydrous ammonia," their N content and their routes—Same entry, pp. 442–43.

1991: 85 million metric tons per year—Same entry, p. 439: "In the year ending June 30, 1991, 77.0 million metric tons of fertilizer N was used worldwide," which × 1.1023 = 84.7881 million U.S. tons.

"Shall we estimate their carbon dioxide pollution at, say, 119 million tons?"—Since the two nitrate-based fertilizers whose carbon dioxide outputs we are given above seem to give off about 1.4 times the fertilizer's weight in greenhouse gas, I multiplied 77.0 million × 1.4 to get 107.8 million metric tons, which × 1.1023 = 119.0484 million U.S. tons.

"at least half the fertilizers we deployed got *wasted*"—Ibid., p. 440: "On the average, no more than one-half of the applied fertilizer is used by crops."

Relative emissions of tea, "other crops" and paddy rice—*Greenhouse Gas Inventory Japan,* 2015, p. 5-32 (Table 5-40: "N_2O emission factor for synthetic fertilizer to agricultural soil"): Paddy rice gave off 0.31% [kg-N_2O-N/kg-N]; tea, 2.9%; and "other crops," 0.62%. "Emission factor of Japan is lower than . . .

default value in the *2006 IPCC Guidelines* . . . [because] the volcanic ash soil that is widely distributed in Japan releases little N_2O emissions."

"Nutrient demand is on the rise worldwide . . ."—Richard T. Meister, ed.-at-large, et al., *MeisterPro Crop Protection Handbook* (Willoughby, Ohio), 2008, vol. 94, p. C1 ("Fertilizer Outlook").

"Rice has always been the most important grain crop . . ."—Jan G. de Geus, *Fertilizer Guide for the Tropics and Subtropics,* 2nd ed. (Zürich: Centre d'Etude de l'Azote, 1973 rev. of 1967 ed.), p. 36.

Khmer Rouge: "When there is rice, there is everything"—See my *Rising Up and Rising Down* (chapter: "The Skulls on the Shelves.").

My Japanese interpreter: "We can survive, of course . . ."—Ms. Kawai Takako, phone interview of August 25, 2016.

Ricefield images of Saigyo and Yosa Buson—Hiroaki Sato and Burton Watson, *From the Country of Eight Islands: An Anthology of Japanese Poetry* (New York: Columbia University Press, 1986), pp. 175, 341.

"Nourishing themselves on pure hydrogen . . . they break down organic matter . . . eventually emit much of its carbon as methane"—Cf. Keeney, 1981, p. 160: "It is now well accepted that much of the CH_4 is produced from the reduction of CO_2 by H_2 . . . The CH_4-forming bacteria use H_2 for energy."

Amount of methane given off each year by ricefields: "Maybe 40 billion pounds' worth, or, as it might be, 200 billion . . ."—Japanese Society of Soil Science and Plant Nutrition [Tokyo], *Soil Science and Plant Nutrition,* vol. 43 (March 1997–December 1997), pp. 387ff. (Netera Subadiyasa, Nyoman Arya and Makoto Kimua, "Methane Emissions from Paddy Fields in Bali Island, Indonesia"), p. 387: "It has been reported that 20 to 100 Tg y^{-1} of CH_4 is emitted from paddy fields." One Tg [teragram] = 1 trillion grams = 1 billion kilograms. [Cf. *Encyclopedia of Agriculture and Food Systems,* vol. 2, p. 224 (van Noordwijk): "Net methane emissions" in a ricefield are something on the order of 10 milligrams per meter per hour.

Japanese 2013 methane emissions from rice (50%)—*Greenhouse Gas Inventory Japan,* 2015, p. 2-6 (sec. 2.3.1). Cf. p. 5-24: "CH_4 emissions from Rice Cultivation in FY2013 are 18,077 [metric] kt-CO_2 eq., comprising 1.3% of total emissions (excluding LULUCF). The value represents an increase by 4.5% from FY1990." Total methane emissions were 723.1 kilotons. (There are many local variables in ricefield methane *versus* nitrous emissions. For instance, consider this note from pp. 5-45 and -46: "For paddy cultivation in organic soils, it is known that N_2O emission in paddy field is lower than the one in upland field. In Japan, Nagata (2006) . . . observed N_2O emissions for paddy of organic soil in Hokkaido, but the observations included emissions from applied nitrogen. Therefore, country-specific emission factor is determined to be 0.30 [kg-N_2O-N/ha/year] by deducting country-specific emission factor of fertilizers indicated in Akiyama (2006).")

Fresh straw: "effect on rice yield has been greater than that of compost"—International Rice Research Institute, *Nitrogen and Rice* [a symposium], (Los Baños, Laguna, Philippines, 1979), p. 442 (Wang Keun Oh, "effect of incorporation of organic materials on paddy soils"). P. 446: "The beneficent effect of rice straw . . . is largely attributed to the storage of plant nutrients in soil during the early stage of plant growth probably through increased microbial activity and the release of the nutrients in the later stage of growth." That microbial activity presumably makes the methane.

Percentage increases in methane emissions for the two kinds of Indonesian soil—Information derived from the same article, pp. 387ff. This study considered two types of volcanic soil: Alfisol and Inceptisol. For the Alfisol plots, mean methane emission rates on fields without rice straw were 1.37 to 2.13 mg CH_4-C m^{-2} h^{-1} [in other words, 0.0137 to 0.0213 milligrams of methane and other carbon emission, the latter being presumably carbon dioxide, per square meter of paddy field per hour], and on fields with rice straw, 2.14 to 3.362 mg CH_4-C m^{-2} h^{-1}. For the Incepitsol plots, the comparable figures were 2.32 to 3.32 and 4.18 to 6.35 mg CH_4-C m^{-2} h^{-1}. Averaging each pair of figures, I got 1.75 and 2.751 for the Alfisols and 2.82 and 5.265 for the Inceptisols. Thus for the Alfisols the average emission increase with rice straw was 47.3%; for the Inceptisols, 86.7%. Over the growing season, up to 8.8 grams of methane might issue from each square meter of paddy. [Conversion to 1/554th of a pound per square foot—8.8 g / 453.59 = 0.0194007 lbs; 1 sq meter = 10.758 sq ft, so I divided 0.0194007 by 10.758. In the antiquated units of *Carbon Ideologies,* that did not sound like very much: 1/554th of a pound per square foot. But there were many square feet.] [Total amounts emitted during the growth period were, with and without rice straw respectively [the authors now put the numbers in that order], 3.9 to 6.8 and 2.6 to 3.3 g CH_4-C-h^{-1} for Alfisol and 6.9 to 10.7 and 4.2 to 5.8 for Inceptisol. I calculated averages for the Alfisol of 5.35 with and 2.95 without, a ratio of 1.813, and for the Inceptisol 8.8 with and 5 without, a ratio of 1.76. It was the Inceptisol 8.8 grams to which the text refers.]

Emissions in Sumatran study—Loc. cit. The soil was Ultisol, and the figures for paddies treated with rice straw were 67.8 to 105.3 grams per square meter.

"The amount of emissions may have been markedly underestimated"—Ibid., p. 392.

Footnote: "Enteric fermentation is the second largest anthropogenic source . . ." —EPA, 2016, p. 37.

"Each cow belched up . . . two liters of methane per minute"—Information from Edward O. Wilson, Thomas Eisner, Winslow R. Briggs, Richard Dickerson, Robert L. Metzenberg, Richard D. O'Brien, Millard Susman and William E. Boggs, *Life on Earth* (Stamford, Connecticut: Sinauer Associates, 1974; 2nd pr. of 1973 ed.), p. 403. In case you were wondering, the authors go out of their way to assure us that the cow emitted this gas mostly through belching, not flatulence.

"25% of all carbon-equivalent emissions from milk were enteric methane"—Information from *Encyclopedia of Agriculture and Food Systems,* vol. 2, p. 248 (S. E. Place, "Climate Change: Animal Systems").

"volatilizing nitrogen fertilizers"—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 6-82: "Indirect nitrous oxide (N_2O) emissions from managed soils: . . . The indirect N_2O emissions include, N_2O emissions from volatilization of N as NH_3 and NOx and deposition of these gases and their products NH_4+ and NO_3– onto soils and the surface of lakes and other waters, and N_2O emissions from leaching and runoff in regions where leaching and runoff occurs." In 2013 this category generated 35.9 kt-CO_2 eq.

Footnote: "Nitrous oxide emissions from household wastewater . . ."—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 396.

"Food production caused 80% of all NO_2 pollution"—IPCC, 2013, p. 510.

Nitrogen fertilizers: "winter wheat, cauliflower and above all Brussels sprouts"—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 354 (Table 106: "Recommended quantities of fertiliser").

"1% of the nitrogen . . . became nitrous oxide"—Ibid., p. 353, where the emission factor for NO_2 is given as (0.01 kg kg^{-1} N), or 0.01 kg emitted per kg of N present in the soil.

Japanese NO_2 emissions—*Greenhouse Gas Inventory Japan,* p. 2-7. All Japanese figures date from 2013. Total nitrous releases were [22.7 million [metric] tons × [1.1023 for standard U.S. tons] = 25.02221] million tons of carbon dioxide equivalent—1.6% of the total. Much to her credit, Japan had decreased her emissions of this gas by 29.7% since 1990. (In earnest inventories, statisticians now estimated the per capita excretion volume of farm animals, and the excretions' nitrogen content. A Japanese hen deposited 0.136 kilograms a day, with a urine nitrogen content of 1.54 grams [ibid., p. 5-515 (Table 5-19: "Amount of feces and urine excreted (Ex) and nitrogen content amount by type of livestock(Nex)"]).)

American "agricultural soil management": 78.9% of N_20 for 2014—EPA, 2016, p. ES-20: "Agricultural soil management activities such as fertilizer application and other cropping practices were the largest source . . ."

Manure: "it is essential for it to be half rotted before it is dug in"—R. P. Faulkner, p. 43. According to the same source (loc. cit.), "average farmyard manure" is comprised of the following: moisture, 72.6%; organic matter, 27.4%; nitrogen, 0.77%; phosphoric acid, 0.39%; potash, 0.6%.

"leaving it to half-rot above ground generates more nitrous oxide."—Information from *Encyclopedia of Agriculture and Food Systems,* vol. 2, p. 246 ("S. E. Place" entry).

Canadian "manure management," 2008—*Canada Yearbook 2011,* pp. 172–73 (Table 12.1, "Greenhouse gas (GHG) emissions, by source, 1990 and 2008"). In 2008, Canadian agriculture logged 37,000 carbon-dioxide-equivalent kilotons of nitrous oxide from "agriculture," of which 4,700 kilotons [= 10,340,000 lbs] derived from "manure management." Total 2008 agriculture CEQ emissions were a grossly understated 25,000 KT of methane [closer to 102 KT at methane's 20-year GWP calculation] and 37,000 KT of nitrous oxide.

"methane emissions from manure management increased by 64.7 percent . . ." —EPA, 2016, p. 37. *Greenhouse Gas Inventory Japan,* 2015, p. 5-10: "CH_4 and N_2O emissions from manure management in FY2013 are 2,411 kt-CO_2 eq. and 4,543 kt-CO_2 eq., comprising 0.2% and 0.3% of total emissions (excluding LULUCF), respectively. The value represents a reduction by 28.1% for CH_4 and an increase by 6.9% for N_2O from FY1990."

"United Nations News Centre—Rearing cattle produces more greenhouse gases than driving cars, UN report warns," downoaded for WTV by Jordan Rothacker on 6/23/2017 from http://www.un.org/apps/news/story.asp?NewsID=20772#.WU1zuhPyvR0.

Deforestation as "one of the largest anthropogenic sources of emissions to the atmosphere globally"—EPA, 2016, p. 409. Cf. IPCC, 2013, p. 167: "The main contributors to increasing atmospheric CO_2 abundance are fossil fuel combustion and land use change." Calculating LULUCF involves many complex local factors. Consider this summary, from *Greenhouse Gas Inventory Japan,* 2015, p. 6-9: "All forests in Japan are managed forests, and they consist of intensively managed forests, semi-natural forests, bamboo, and forests with less standing trees. Japan's forest land area in FY2013 was about 25.2 million ha—about 66.6% of the total national land area. The net removal by this category in FY2013 was 68,162 kt-CO_2 (excluding 4.32 kt-CO_2 eq. of CH_4 and N_2O emissions resulting from biomass burning, 0.83 kt-CO_2 eq. of N_2O emission resulting from N fertilization in forest land, and 161 kt-CO_2 eq. of N2O emission from nitrogen mineralization resulting from change of land use or management of mineral soils). This represents a decrease of 13.8% below the FY1990 value [which was –79,073], and a decrease of 11.9% below the FY2012 value. This declining trend in removals in recent years is considered due to the maturity of Japanese forests."

"We grazed and grubbed 38% of the ice-free land acreage of our planet"—Information from IPCC, 2013, p. 475: "Since 1750, anthropogenic land use changes have resulted into about 50 million km^2 being used for cropland and pasture, corresponding to about 38% of the total ice-free land area . . . , in contrast to an estimated cropland and pasture area of 7.5 to 9 million km^2 about 1750." So 5.55 to 6.66 × was how much we had multiplied our holdings.

"As a result of land-use changes . . ."—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 378. The original figure was 11,881.4 Gg [= 13,096,867.22 U.S. tons].

3.1 million tons "were released from wetlands . . ."—Ibid., p. 376 (original figure: 2,823.1 Gg).

15.5 million tons from grasslands—Ibid., p. 375 (14,102.58 Gg).

"LAND USE, LAND USE CHANGES AND FORESTRY": 13.24%—Ibid., p. 361 (my summation of items 5.A through E).

Footnote on German nitrous oxide releases—Ibid., p. 353: "N_2O releases as a result of conversion of grassland, settlement land, wetlands, other lands and forest land to cropland are calculated to amount to 2.14 Gg N_2O, or 445.37 Gg CO_2 equivalents."

"In 2014, half the territory of the European Union happened to be farmed"—Information from the same source, p. 528.

"This sugarcane field in Rhodesia is being burned . . ."—Roy L. Donahue, Raymond W. Miller and John C. Shickluna, *Soils: An Introduction to Soils and Plant Growth,* 4th ed. (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1977 rev. repr. of 1958 ed.), p. 150.

Footnote on Nigerian pollutants—Federal Ministry of Environment, Nigeria, FUEL QUALITY PROGRESS IN NIGERIA FOR NIGERIA NATIONAL AIR QUALITY MANAGEMENT PROGRAM, 18/5/2015 (2015_Ecowas_FuelQualityProgress_Emmanuel(1).pdf, downloaded for WTV by Jordan Rothacker, October 2016), p. 6.

"the smoke contained carbon dioxide, nitrous oxide and methane"—*Greenhouse Gas Inventory Japan,* 2015, p. 5-50: "CH_4 and N_2O emissions from Field Burning of Agricultural Residues in FY2013 are 69 [metric] kt-CO_2 eq. and 21 kt-CO_2 eq., comprising 0.005% and 0.002% of total emissions (excluding LULUCF), respectively."

The Three Most Dangerous Greenhouse Gases as of 2011

Percentage source data—IPCC, 2013, p. 169.

"The massive increase in the number of ruminants . . ."—Ibid., p. 52.

2011 GWP for methane—Ibid., p. 731 (Appendix 8.A: "Lifetimes, Radiative Efficiencies and Metric Values"; Table 8.A.1: "Radiative efficiencies (REs), lifetimes/adjustment times, AGWP and GWP values for 20 and 100 years, and AGTP and GTP values for 20, 50 and 100 years").

Footnote: The three main Japanese methane sources + fugitive emissions from fuel (2013)—*Greenhouse Gas Inventory Japan,* 2015, p. 2-6.

Footnote: The four main U.S. methane sources (2014)—EPA, 2016., pp. ES-13, -14 and -17.

"N_2O has overtaken CFC-12 . . ."—IPCC, 2013, p. 54.

"natural sources . . . might have equaled or outweighed the anthropogenic ones"—Ibid., p. 468: "Anthropogenic N_2O emissions increased steadily over the last two decades and were 6.9 (2.7 to 11.1) TgN (N_2O) [per year] in 2006 . . . Natural . . . emissions derived from soils, oceans and a small atmospheric source are together 5.4 to 19.6 TgN . . ."

GWP for nitrous oxide—Ibid., p. 731.

"M" percentage data—*Greenhouse Gas Inventory Mexico, 1990–2002,* p. 36.

"EU" percentage data—EU greenhouse report, 2014, p. x, including Tables ES.4 ("Overview of EU-28 GHG emissions and removals from 1990 to 2012 in CO_2 equivalents (million tonnes)" and E.S.5, which does the same for the EU-15. I have calculated as follows (parenthetical percentages are my responsibility), and then combined the two sets of figures in my table. EU-28: CO_2, 82%; methane, 403 MT (8.8%); nitrous oxide, 341 (7.5%). EU-15: CO_2, 83%; methane, 296 MT (8%); nitrous oxide, 264 (7.3%).

"J" percentage data—*Greenhouse Gas Inventory Japan,* 2015, p. E.S.3 (Table 1, "Trends in GHGs emission and removals in Japan"). Calculated from: CO_2, 81,245.8 MT carbon-dioxide-equivalents; methane, 36.0; nitrous oxide, 22.5; HFCs, 31.9.

"U" percentage data—EPA, 2016, p. ES-8 (Figure ES-4: "2014 U.S. Greenhouse Gas Emissions by Gas (Percentages based on MMT CO_2 Eq.")

About Agriculture (continued)

Global net carbon dioxide releases from land use change, 2002–11—IPCC, 2013, p. 12: "Annual net CO_2 emissions from anthropogenic land use change were 0.9 [0.1 to 1.7] GtC [per year] on average during 2002 to 2011 (medium *confidence*)."

"about 0.9 metric gigatons, or 'only' ¾ of the entire 2011 carbon dioxide . . . emissions of Japan"—*Greenhouse Gas Inventory Japan,* 2015, p. E.S. 3 (Table 1, "Trends in GHGs emission and removals in Japan"): Japan's 2011 total carbon dioxide figure, including LULUCF, was 1,191.3 million metric tons. Hence the calculation went: 1,000,000,000 [× 0.9] / 1,000,000 × [1,191.3] = 900,000,000 / 1,191,300,000 = 0.75547.

"Tons of coal and carloads of water . . ."—Ellis and Rumely, p. 5.

"influential men from the largest oil corporation . . ."—Ibid., p. 8.

"the whole agricultural industry now depends so much upon electrical energy . . ."—Willman, p. 104.

"No progress is possible without an increase in agricultural production . . ." —Asha Han, *The Power Sector in India* (New Delhi: Sterling Publishers Private Ltd., 1986), p. 17.

Footnote: 1975 energies to make ammonia and phosphorus—Ibid., p. 139 (Appendix I: "Energy Requirements for High Priority Primary Products"). [Source: Battelle Columbus Laboratories, 1975. Report No. PB-245759.] These data were originally given in "energy required per net ton (short ton of product in millions of BTU)." Therefore I divided each figure by 2,000 to get 1 pound. Adding the two energy requirements and dividing by the West Virginian Coal Association's average HHV of 12,500 yields 1.992.

"typical computed load" for dairy barn—*American Electricians' Handbook,* 2002, p. 9.332 (Table 493: "Typical Computed Loads and Probable Maximum Demands"). Computed by dividing [15 kW = [3,413.04 × 15] = 51,195.6 BTUs/hr] by the HHVs of coal (West Virginia average), diesel (average of 18,500 and 20,000) and "North American" natural gas, as given in the table of Calorific Efficiencies. This came out to 4.1 pounds of West Virginia coal, or 2.7 pounds of diesel fuel, or 2.1 pounds of natural gas. Each figure was then multiplied by three, to account for thermodynamic losses of power plants. [Note: Mr. Ben Coleman, the chemistry graduate student who fact checked parts of this book, came up with a dairy barn load of 51,182 BTUs per hour, using 1 kWh = 3,412.14 BTUs.]

Ditto, for "farm residence"—Loc. cit.

"lighting in the poultry house . . ."—Ibid., p. 9.335-6. In the just-cited Table 493 these authors propose that an 8,000-square-foot "poultry laying house" might have a maximum demand of 15.2 kW and a typical load of 11.7.

"irrigation, fertilizer application and pest control were ever more often accomplished mechanically."—Information condensed from Odum, p. 45.

“Crops highly selected for industrialized agriculture . . .”—Odum, p. 47.

“80 percent of an Iowa corn farmer’s costs . . .”—Kenneth S. Deffeyes, *Beyond Oil: The View from Hubbert’s Peak* (New York: Farrar, Straus & Giroux / Hill and Wang, 2005), p. 6.

Estimate for 2008: “19–29% of global anthropogenic . . . emissions . . .” —*Encyclopedia of Agriculture and Food Systems,* vol. 2, p. 223 (van Noordwijk).

About Industrial Chemicals

Epigraph: “Let us suppose that last night . . .”—Berger and Anderson, pp. 235–36.

“two statistics from 2014” on proportion of unburned fossil fuels: France—EU greenhouse report, 2014, p. 354: “According to the survey approximately 14% of the consumption of petroleum products is used for non-energy use, mainly as primary material.”

Netherlands—Ibid., p. 359. Original reads: 49% “of the gross national consumption of petroleum products.”

“A single $15 barrel of crude . . .”—Berger and Anderson, p. 229.

“we could refine propylene . . . out of crude oil”—Kroschwitz and Howe-Grant, vol. 10 (“Explosives and Propellants” to “Flame Retardants for Textiles”), pp. x, 351 (“feedstocks (petrochemicals)”).

Origins of detergents, antifreeze and rubbing alcohol—Berger and Anderson, p. 237.

Manufacture of polyethylene and Teflon—Information from Knapp, pp. 32–33.

“familiar to most of us . . .” + the formula for polyvinyl chloride—Morrison and Boyd, p. 260.

Carbon dioxide from synthetic ammonia production, hydrogen production, substitute natural gas production [fermentation and limestone calcination]—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 35. And here are some ammonia production figures from *Greenhouse Gas Inventory Japan,* 2015, p. 3-12 (Table 3-7, “Allocated CO_2 emissions from fuel used for non-energy purpose such as feedstock”): Indigenous natural gas, 14.0 tons of carbon dioxide per terajoule; and imported steam coal, 24.4 [t-C/TJ].

“When . . . we synthesized ammonia for our fertilizers . . .”—Same source, vol. 10, p. 442 (“fertilizers”): “Over 95% of all commercial nitrogen fertilizer in the 1990s is derived from synthetic ammonia”—which, by the way, is made by squeezing hot nitrogen and hydrogen together in the presence of an iron catalyst.

Carbon dioxide: "3,630 pounds of it for every ton of nitrogen"—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 243: "Due to a lack of plant-specific data, an emission factor of 1,500 kg CO_2 /t NH_3—the figure proposed as the IPCC default factor—is still being used. Conversion with the aforementioned stoichiometric factor produces an emission factor of 1,815 kg CO_2 / t N; this is the factor used in calculations," which I converted to 3,993 pounds per metric ton, then multiplied by 0.909 to get 3,630 pounds per U.S. ton.

Ammonia: "half a percent of Germany's greenhouse emissions for 2007"—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 242.

Germany used heavy fuel oil as a feedstock—EU greenhouse report, 2014, p. 404. German, Austrian, U.K. production methods, loc. cit.

In India (*circa* 1979), the petroleum route had been cheapest—*Chemtech IV: Fourth Volume of Manual of Chemical Technology: Synthetic Organic Products* (Madras: Chemical Engineering Education Development Centre, Indian Institute of Technology, 1979), ch. 2 (S. L. Venkiteswaran, Amar Dye Chem. Ltd., Bombay, "Petrochemicals"). [This source henceforth cited: "*Chemtech IV*" + chapter.] Original reads (p. 2.13): "Hydrogen for ammonia synthesis can perhaps be derived from coal or electrolysis at a much higher cost" than from petroleum.

American use of petroleum coke—EPA, 2016, p. 4-21. Details: "There are five principal process steps in synthetic ammonia production from natural gas feedstock. The primary reforming step converts methane . . . to CO_2, carbon monoxide . . . and H_2 in the presence of a catalyst." And then (same page): "To produce synthetic ammonia from petroleum coke, the petroleum coke is gasified and converted to CO_2 and H_2. These gases are separated, and the H2 is used as a feedstock to the ammonia production process, where it is reacted with N_2 to form ammonia."

Footnote: "the easiest route" [for manufacture of ammonia from nitrogen]—Kroschwitz and Howe-Grant, vol. 10 ("Explosives and Propellants" to "Flame Retardants for Textiles"), p. 335 ("feedstocks (coal chemicals)").

Nitric acid: "0.94% of Germany's nitrous oxide"—*Greenhouse Gas Inventory Germany; 1990–2007,* p. 244.

Greek *versus* British emission factors for making same—EU greenhouse report, 2014, p. 410: "The implied emission factors per tonne of nitric acid produced vary for 2012 between 0.0002 t N_2O/t of nitric acid produced for the UK and 0.0070 t N_2O/t of nitric acid produced for Greece." This is 0.0002 *versus* 0.0070 U.S. tons per U.S. ton, or 0.4 *versus* 14 pounds per ton.

Nitric acid: U.S. "27 times worse"—EPA, 2016, p. 4-29: "For 2009 [the latest year available]: Weighted N_2O emission factor—5.45 kg N_2O/metric ton

HNO_3." Converting to [U.S.] tons N_2O per tons nitric acid, I got 0.00545—27.25 times higher than the U.K. factor.

Facts on carbon dioxide in soft drinks (in text and accompanying fn)—Kroschwitz and Howe-Grant, vol. 5, p. 25 ("carbonated beverages"); and vol. 19 ("Pigments to Powders, Handling"), p. 619.

Same footnote: The petrochemistry of soft drink bottles—Ibid., vol. 19, loc. cit. (PET was supposedly good to keep carbonated beverages in) and p. 612 ("polyesters, thermoplastic"): PET (= polyethylene terephthalate, p. 625) originated in petroleum refining: "fractional crystallization from the C-8 aromatic fraction (including ethylbenzene)." The highest melting of the three isomeric dimethylbenzenes, which is p-Xylene, was air oxidized "in acetic acid under moderate pressure" to get terephthalic acid, or TA; this was the feedstock for PET and PBT. "PET polymer is safe and poses no threat to animals or humans" (same entry, p. 626).

"The economics of scale provided the great advantage . . ."—*Chemtech IV,* p. 2.6 (ch. 2: "Petrochemicals").

The Parable of Adipic Acid

Epigraph: "But I can't believe that any group . . ."—C. M. Kornbluth, *The Syndic* (New York: Berkeley Medallion, 1965; orig. pub. 1953), p. 31.

Nylon as "protein-like"—John R. Lewis, *First-Year College Chemistry,* 8th ed. (New York: Barnes and Noble, College Outline ser., 1965 rev. of 1932 ed.), p. 196: "Polyamide resinoids (protein-like amids").

The nylon 6,6 in pantyhose—Neil Schlager, ed., *How Products Are Made: An Illustrated Guide to Product Manufacturing,* vol. 1 (New York: Gale Research Inc., 1994), p. 317 ("pantyhose").

Footnote: "Long linear molecules . . ."—Morrison and Boyd, p. 911.

Its other name, number of atoms of C, O and H per molecule (counted out by looking at the chemical formula) and physical properties—Ibid., pp. 906–7. Kroschwitz and Howe-Grant, however (vol. 1, "A" to "Alkaloids,") p. 466, ("adipic acid"), calls it "colorless"—which may mean white. And this is also the citation for the acid's sour taste. [Melting point of 303.8° F. Converted by WTV from original of 151° Celsius.]

Adipic acid's useful products: synthetic lubricants and urethane foams, tanginess in foods, etc.—EPA, 2016, pp. 4-30–31.

"commercial importance" since the 1940s—Kroschwitz and Howe-Grant, p. 471.

Corrosiveness of aqueous solution—Ibid., p. 467.

Amount in American jellies etc.—Ibid., p. 486.

"one of the purest materials produced on a large scale"—Ibid., p. 483. Knapp, p. 37: "Synthetic fibers such as nylon and polyester are cheap to manufacture and so are used for most modern clothing."

"the best route to cyclopentane"—Kroschwitz and Howe-Grant, op. cit., pp. 912–13.

Visual description of the "pallid syrup," etc.—after photos in Knapp, pp. 38–39.

"the nylon rope trick"—Mr. Ben Coleman of Marshall University inserts here [fact-checking comments, March 2017]: "This 'trick' was actually how Nylon was discovered."

"Polyamide produced at the interface. . ."—Procedure described in detail in Kroschwitz and Howe-Grant, pp. 469–70.

"Each pound of nylon cost 'only' 18,700 BTUs . . ."—Manufacturing energy from Boustani et al., January 28, 2010, p. 17: 43.49 MJ per kg. At 1 MJ/kg = 429.9226 BTUs/lb, nylon's figure becomes 18,697.33 BTUs/lb.

"10 and a half pounds of carbon dioxide"—The table "Carbon Dioxide Emissions of Common Fuels" (p. 199) shows that heavy heating oil emits 1.890 lbs of carbon dioxide for each 10,000 BTUs. Dividing 18,697.33 by 10,000 and then multiplying by 3 to account for power plant wastage ratios, and finally multiplying by 1.890, we get 10.6 lbs carbon dioxide emitted.

The Cordtex brassiere and the rayon velvet outfit—Sears catalogue, 1956, pp. 302, 4.

"All current economic systems are predicated on growth . . ."—*Resources, Conservation and Recycling,* 2011, p. 375.

The 200,000-pound hopper cars + "The continued buildup of capacity . . ." —Kroschwitz and Howe-Grant, p. 482.

The 130,000-ton plant—Loc. cit. Originally expressed as 120,000 metric tons, which would be 132,276 U.S. tons.

The South Korean facility—Ibid., p. 483.

Adipic acid's manufacture from cyclohexane, cyclohexene, etc.—Ibid., p. 471.

Adipic acid in automobile exhaust—Ibid., p. 485.

Details of adipic acid production—Ibid., pp. 472–81. The process was not especially clean. After steamstripping of KA there were "non-volatile by-products." "Both the metals and acid content may be high enough to dictate that this stream be classified as a hazardous waste. It is usually burned and the energy used to generate steam."

"'considerable' nitrous oxide"—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 247: "4.2.3 Chemical industry: Adipic acid production (2.B.3)." [And you will enjoy this tidbit from *Greenhouse Gas Inventory Japan,* 2015, p. 4-23: "Caprolactam is a monomer for nylon-6 which transforms into Nylon 6 by ring-opening polymerization. Nylon 6 is used as fibers for carpets etc, or resin material. N2O is emitted from ammonia oxidation during the manufacturing process."]

Adipic acid's share of German greenhouse gases, 2007 (0.55%)—Loc. cit.

1990 share of same (1.49%)—*Greenhouse Gas Inventory Germany, 1990–2007,* loc. cit.

"about 1993, German chemists had invented two new ways of decomposing almost all the nitrous into oxygen and nitrogen"—One method was catalytic, and the other purely thermal.

"In one country, . . . one kind of greenhouse pollution had been reduced"—Japan was another: "There is a sharp decline in emissions from . . . industrial processes . . . from FY1998 to 1999, as N_2O abatement equipment came on stream in the adipic acid production plant in March 1999." Indeed, our story bulged with heroes! Adipic acid's nitrous emissions in the European Union fell 99% between 1990 and 2012, at which point they comprised a mere 0.01% of the entire EU greenhouse budget. Furthermore, "the main reason for large N_2O emission cuts was reduction measures in the adipic acid production."—Even the Americans, the world's number one producer of adipic acid (30% of all stocks, most of which went for nylon 6,6), managed between 1990 and 2014 to increase production by 36% while reducing emissions by 64%! (One factor was *pollution control measures;* the other, I am sad to say, was merely *plant idling in the late 2000s;* my countrywomen's armoires must have been stuffed with pantyhose). [Carbon-equivalent nitrous oxide emissions were 5.87% of the U.S. total in 2014. Adipic acid emissions were 1.34% of those, or 0.0786% of the total.]

Source to above note: Adipic acid in Japan: *Greenhouse Gas Inventory Japan,* 2015, p. 2-7. Loc. cit.: "Nitrous oxide emissions in FY2013 were 22.7 million tonnes (in CO_2 eq., including LULUCF), accounting for 1.6% of total GHGs emissions. They decreased by 29.7% since FY1990 and by 0.1% compared to the previous year. Their decrease since FY1990 is mainly a result of a 85.6% decrease in emissions from industrial processes and product use (e.g. adipic acid production in the chemical industry)."

Same note: EU adipic acid emissions—Information from EU greenhouse report, 2014, pp. 420 ("4.2.2.3 2B3 Adipic Acid Production"), p. 117.

Same note: U.S. figures on adipic acid production and emissions, 1990–2014, with reasons why—U.S. EPA, 2016, p. 4-30.

Same note: Carbon-equivalent nitrous oxide emissions, 2014—5.4 MMT CO_2 Eq., from p. 4-31, Table 4-29: "N2O Emissions from Adipic Acid Production (MMT CO_2 Eq. and kt N_2O)," divided into 6,870.5 (p. ES-4: "In 2014, total U.S. greenhouse gas emissions were 6,870.5 MMT or million metric tons CO_2 Eq.") to obtain 0.078956%, and into 403.5 (total nitrous oxide MMT CO_2-equiv on p. ES-6) to obtain 1.3383%.

"To date, a counter-trend has been achieved . . ."—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 105.

About Manufacturing

Epigraph: "Iron thoughts sail out at evening on iron ships . . ."—*The Selected Poems of Malcolm Lowry,* 17th pr. (San Francisco: City Lights Books, The Pocket Poets Ser., no. 17, 2016 galley of 2017 repr.; orig. pub. 1962), unnumbered typescript page ("Iron Cities," which I have dated "bef. 1958" since Lowry died in 1957).

"The titanium dioxide in my toothpaste and the glass in my windows both cost considerable carbon dioxide to make"—Information from EPA, 2016, p. 237 ("the principal use of TiO_2 is as a pigment in white paint, lacquers, and varnishes; it is also used as a pigment in the manufacture of plastics, paper, and other products . . . Emissions of CO_2 from titanium dioxide production in 2014 were estimated to be 1.8 MMT CO_2 Eq. . . . which represents an increase of 47 percent since 1990") and 215 ("glass production is an energy and raw-material intensive process that results in the generation of CO_2 from both the energy consumed in making glass and the glass process itself").

"our 'global energy inputs' went slightly more to titanium than to glass"—From my visual estimation of the bar graph in Gutowski et al., *Philosophical Transactions of the Royal Society A: Mathematical, Physical & Engineering Sciences,* 2013 371, 20120003, published online January 28, 2013 (Timothy G. Gutowski, Sahil Sahni, Julian M. Allwood, Michael F. Ashby and Ernst Worrell, "The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand"), downloaded from rsta.royalsocietypub lishing.org on January 28, 2013 [by Gutowski]. Information is from p. 3 (Figure 1: "Annual primary energy used for the production of 29 materials worldwide, cumulative scale on the right. PE, polyethylene; PVC, polyvinyl chloride; PP, polypropylene; PS, polystyrene; PET, polyethylene terephthalate; ABS, acrylonitrile butadiene styrene; PA, polyamides"). Re: primary energy, the authors explain (loc.

cit.): "The energy intensity (or embodied energy) is defined as the energy required to produce a material from its raw form, per unit mass of material produced. The energy is usually measured as the low heating value of the primary fuels used plus any other primary energy contributions. These energy requirements are dominated by two main steps: (i) harvesting and (ii) refining. For metals from minerals, this would involve the mining, crushing, washing and separation of the ore from the surrounding material (called gangue), and the chemical-reduction process that produces the refined material from its ore (called smelting in metal processing)."

"A molten ton of glass cost you somewhere between 120 and 208 pounds of carbon dioxide"—The Germans for their part manufactured both "flat glass" (possibly window glass) and "domestic glass." I in my ignorance cannot define either of those, but to make a molten ton of the former released 208 pounds of carbon dioxide; the latter cost you only 120 pounds. See *Greenhouse Gas Inventory Germany, 1990–2007,* p. 237 (Table 53: "CO_2-emission factors for various glass types [calculated in comparison with figures from the CORINAIR manual]"), converted from the original figures of 208 and 120 kg/metric ton (the ratios are obviously the same in pounds per U.S. ton).

Information on glass firing temperatures and on the use of lime—David Whitehouse, Executive Director, comp., The Corning Museum of Glass, *Glass: A Pocket Dictionary of Terms Used to Describe Glass and Glassmaking,* rev. ed. (Corning, New York: 2006; orig. ed. 1993), pp. 26–27, 36, 52) (entries on "crizzling," "firing," "lime").

"Our annual energy expenditure on glassmaking was the merest 30th of that used to produce steel"—From my visual estimation of the bar graph in Gutowski et al., loc. cit.

"Nothing in the previous practical advances . . ." + "To-day in the electric furnace . . ."—Wells, vol. 2, p. 801. These separated sentences come in reverse order in the original.

"the iron and steel industry . . . is the second important CO_2-emissions source . . ."—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 122. That sector achieved 4.53% of their global warming for 2007—like nitric and adipic acids, not much, you might say . . . although the category euphoniously called "3.1.4.6 Manufacturing industries and construction—Other" comprised a good 7.89% of the national total (ibid., p. 255; cf. p. 142. Peculiarly enough, on p. 136 what appears to be this same category now makes up only half a percent ["Manufacturing industries and construction: iron and steel"]; 2007 value: 0.57%.)

"summing up steel, aluminum and various chemical manufactures all together accounted for less than 10% of all Germany's greenhouse gases"—Ibid., pp. 242 (ammonia, 0.51% of total emissions in 2007), 244 (nitric acid, 0.94%); 247 (adipic acid, 0.55%); 250 ("other production processes," 1.01%); 255 (iron and steel, 4.53%); 263 (aluminum, 0.07%); 265 (SF_6 in Al and Mg production, 0.23%); 273 (production of HCFC-22, 0.02%, and production of halocarbons and SF_6: fugitive emissions, 1.07%). Total =8.93%.

"Manufacturing is now . . . 200 times larger . . ."—Gutowski et al., *Annu. Rev. Environ. Resour.,* 2013, p. 84.

"You may not have all that you should not have."—Euripides, vol. 1 [LCL 12], ed. and trans. David Kovacs (Cambridge, Massachusetts: Harvard University Press / Loeb Classical Library, 2001 corr. repr. of 1994 ed.), p. 161 ("Alcestis," 438 B.C.).

Cement: "Making it released 8% of worldwide CO_2 pollution in 2015."—Information from Olivier et al., 2016, pp. 64–65: "CO_2 emissions are generated by carbonate oxidation in the cement clinker production process, the main constituent of cement and the largest of non-combustion sources of CO_2 from industrial manufacturing, contributing to about 4.0% of the total global emissions in 2015. Fuel combustion emissions of CO_2 related to cement production are of approximately the same level . . ."

"most energy is used in industry to make a few key materials . . ."—Gutowski et al., op. cit., p. 101.

Energy and Coal Requirements to Manufacture One Pound Each of the "Big Five" Materials

Data on manufacturing energy, BAT and manufacturing energy reduction from recycling from Gutowski et al., *Annu. Rev. Environ. Resour.,* 2013, p. 93 (Table 2: "The estimated global average direct energy intensity of materials production [in megajoules/kilogram (MJ/kg)] and the estimated reductions from best available technology (BAT) as percent of primary"), converted by WTV to BTUs/lb @ 1 MJ/kg = 429.9226 BTUs/lb. For the amount of coal required in each case I used the West Virginia Coal Association's average HHV of 12,500 BTUs/lb (see the table of Calorific Efficiencies). Plugging in this figure, I divided each material's manufacturing energy in BTUs/lb by 12,500, then multiplied the result by 3 to account for power generation losses.

"Most of the paper we produce is thrown away . . ."—Encyclical of Pope Francis, 2015, p. 7 (para. 22).

"'default half-life' for paper"—*Greenhouse Gas Inventory Japan,* 2015, p. 6-74. On p. 7-13 the decomposition half-life of paper is given as seven years.

Re: titanium dioxide—EPA, 2016, p. 4-36: "In 2014, U.S. TiO_2 production totaled 1,310,000 metric tons . . . [or] 1.8 MMT CO_2 Eq. (1,755 kt CO_2), which represents an increase of 47 percent since 1990 . . ."

"In terms of climate change, . . . the most important metal is iron . . ."—Gutowski et al., *Annu. Rev. Environ. Resour.*, 2013, p. 94.

"Nitrous oxide was another greenhouse gas associated with steelmaking"—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 136, 3.1.4.1: "Manufacturing industries and construction—iron and steel (1.A.2.a)": German iron and steel manufacturing emitted 1% of that country's nitrous oxide in 1990, 0.57% in 2007.

"The top seven CO_2-producing manufacturing nations . . ."—Ibid., p. 89.

Re: American steel production—EPA, 2016, p. 4-58, notes: "Emissions of CO_2 and CH_4 from iron and steel production in 2014 were 53.4 MMT CO_2 Eq. (53,417 kt) and 0.0094 MMT CO_2 Eq. (0.4 kt), respectively . . . totaling approximately 53.4 MMT CO_2 Eq. Emissions decreased in 2014 and have decreased overall since 1990 due to restructuring of the industry, technological improvements, and increased scrap steel utilization."

Footnote on Japanese iron and steel emissions, 2013—*Greenhouse Gas Inventory Japan,* 2015, p. 3-37 (3.2.6. "CO_2 Emissions from Manufacturing Industries and Construction (1.A.2.:CO_2)").

"Plastics . . . are produced by the conversion of natural products . . ."—American Chemistry Council, "How Plastics Are Made," downloaded for WTV by Jordan Rothacker in September 2016 from https://plastics.americanchemistry.com/How-Plastics-Are-Made/10/3/2016, p. 1 of 9. [This document henceforth cited: "American Chemistry Council, 2016."]

Footnote: Embodied energy from aluminum "today"—Gutowski to WTV, August 23, 2016. Since 1 MJ = 948.067 BTUs, then 200 MJ/kg = [189,613.4 BTUs/2.2 lbs] = 86,188 BTUs/lb.

Association of sulfur hexafluoride with aluminum manufacture—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 104.

"the largest source of PFC emissions in Germany."—Ibid., p. 297: "Production of primary aluminium continues to be the largest source of PFC emissions in Germany, in spite of the considerable reductions that have been achieved since 1990. Thanks to extensive modernisation measures in German aluminium foundries, and to decommissioning of production capacities, absolute emissions from this sector fell by 87% between 1995 and 2006. As to the future development of PFC emissions, stagnation at a low level can be expected."

Re: Steel and aluminum—Gutowski et al., *Phil. Trans. R. Soc. A,* 2013 371, 20120003, p. 5: "The pig iron data show an almost one order of magnitude reduction in the energy intensity over a time period of about 200 years. The aluminium data show an equally impressive reduction over about a century . . . While there is still room for improvement, new improvements will be constrained by thermodynamics."

About Manufacturing (continued)

"The 'big five' released 56% of the world's industrial carbon dioxide" + "20% of all energy and process related CO_2 emissions"—*Resources, Conservation and Recycling,* 2011, p. 365.

My view in the Corniche of Sharjah—After a visit to United Arab Emirates in October 2016. Sharjah is the city (and emirate) just east of Dubai.

"We cry out for a little romance . . ."—Henry James, *Essays on Literature, American Writers, English Writers* (New York: Library of America, 1984), p. 862 (review of Benjamin Disraeli's *Lothair, Atlantic Monthly,* August 1870).

"'Best available technology' could have reduced the energy needed . . ."—Gutowski et al., *Annu. Rev. Environ. Resour.,* 2013, same table.

BAT information on cement—Loc. cit.; also, Gutowski et al., *Phil. Trans. R. Soc. A,* 2013 371, 20120003, p. 8: "There is no known route to efficiently recycle cement."

Same footnote: Reducing proportion of clinker in cement—Olivier et al., 2016, loc. cit.: "CO_2 emissions are generated by carbonate oxidation in the cement clinker production process, the main constituent of cement and the largest of noncombustion sources of CO_2 from industrial manufacturing . . . [A]verage clinker fractions in global cement production have decreased between 60% and 80%, compared to nearly 95% for Portland cement[, which] has resulted in about 20% decrease in CO_2 emissions per tonne of cement produced, compared to the 1980s."

Annual per capita cement production and increase—Gutowski et al., *Annu. Rev. Environ. Resour.,* 2013, p. 100 (Table 5), 2010 figures, converted by WTV from 480 kg. Another figure for per capita annual cement production was 880 pounds of cement (Allwood et al., 2013, p. 3).

"Whenever we made it, we emitted carbon dioxide . . . and four other greenhouse gases"—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 263: "In Germany, aluminium is produced at four foundries, in electrolytic furnaces with pre-burnt anodes. The principal emission sources are the waste gases from the electrolytic furnaces and fugitive emissions via the hall roofs. The principal climate-relevant pollutants emitted are CO, CO_2, SO_2, CF_4 and C_2F_6."

Aluminum: 2,374 pounds per ton—Ibid., pp. 263–64: "An SO_2 emission factor of 10.4 kg/t Al can be calculated. The CO_2-emission factor is calculated on the basis of the specific carbon content of petrol coke, 857 kg per t . . . By multiplying the average anode consumption by the mean carbon content and carrying out stoichiometric conversion to CO_2, one obtains a CO_2– emission factor of 1,367 kg/t aluminium. Theoretically, [this] must be reduced by the proportion resulting from a CO component of 180 kg/t Al . . . The CO_2 factor listed below does not take this into account," but I have: 1,367 − 180 = 1,187 kg/t = 2,611.4 lb/[metric] ton = 2,374 pounds per U.S. ton.

Weight of aluminum *versus* steel, + corrosion resistance of Al and some typical applications—Edwin H. Gaylord, Jr., Charles N. Gaylord and James E. Stallmeyer, *Structural Engineering Handbook,* 4th ed. (New York: McGraw-Hill, 1997), pp. 11-1–11-4.

Aluminum in bicycles—EPA, 2016, p. 271: "The production of primary aluminum—in addition to consuming large quantities of electricity—results in process-related emissions of carbon dioxide (CO_2) and two perfluorocarbons (PFCs): perfluoromethane (CF_4) and perfluoroethane (C_2F_6)."

The New Jumbo Carrier Cake Cover and the automatic playing card shuffler—Sears catalogue, 1956, pp. 1092, 744. Back in the 1860s, Napoleon one-upped everybody with his aluminum knives and forks (Emsley, p. 23).

Aluminum in 1956: "4 pounds of it (which must have burned 30 pounds of coal)"—From the table of Comparative Energy Requirements on p. 59 one sees that the 1950s manufacture of aluminum did not burn much more energy than in the early 21st century. My calculation: 30,717 BTUs/lb × 41 lbs × 3 [power plant inefficiency] ÷ 12,500 [default HHV of coal] = 29.488 lbs of coal.

Entry for Widest Steel Industries LLC—Abu Dhabi yellow pages, 2016, p. 239.

Calculation of energy needs of same: This company's production was either [at the low end of energy usage] 10,000 MT of steel, 10,000 MT of aluminum [at the high end], or 10,000 MT of mixed aluminum and steel, in which case the energy usage would be in between those two extremes. 10,000 metric MT = [10,000 × 1,000,000 × 1.023 short tons per metric tonne × 2,000 lbs/ton] = 22,046,000,000,000, or 22.046 trillion, U.S. pounds. This will be the total capacity in pounds of Widest Steel Industries. Plucking from the table of "Big Five" Materials and multiplying by 3 to account for power plant inefficiencies, I get [10,7448 × 3] or 32,244 BTUs/lb for steel and [39,983 × 3] or 119,949 BTUs/lb for aluminum. Multiplying each of these by WSI's total pound capacity, I find that 7.109×10^{17} [= 711 quadrillion] BTUs will be needed to make the steel, and 2.64×10^{18} [= 2.64 quintillion] BTUs for the aluminum. In the UAE the default energy source is oil. Let me plug in [from the table of Calorific Efficiencies, p. 215] my default value for heavy heating oil of 18,450 BTUs/lb. Dividing each of the two energy requirements by that number I obtain for the steel 38,528,521,626,016 [= 38.53 trillion] pounds of heavy heating oil, and for the aluminum 143,327,677,723,577 [= 143.33 trillion] pounds. Using a density of 7.036 lbs/gal [again see p. 582] as an approximation, we get for the two metals respective requirements of 5.48 and 20.37 trillion gallons.

Footnote: Manufacturing energy reduction from recycling—Gutowski et al., *Annu. Rev. Environ. Resour.,* 2013, same table. Remarks on plastic: Ibid., p. 95. Another comment in the same source (p. 93) deserves quotation: "Although it is generally true that there is more improvement potential in the developing countries compared with the industrialized countries, the situation is reversed for aluminum smelting and pulp and paper production . . . Potentially larger efficiency gains can be had by increasing recycling. The gains look very significant for steel, aluminum, and paper. The low value for plastics is a result of our not including the fuel value of the material, which is substantial. For example, if the fuel value for the plastics is estimated as 40 MJ/kg and this is charged to primary production, then the maximum potential reduction from recapturing this material could be portrayed as 80%."

Energy savings in substituting aluminum for other metals—Information from Gutowski et al., *Phil. Trans. R. Soc. A* 2013 371, 20120003, p. 9. "This is true for buildings where heating, cooling or lighting dominate, and for vehicles where fuel use dominates."

Steel manufacturing and recycling, 1980–2006—Gutowski et al., *Annu. Rev. Environ. Resour.,* 2013, p. 96.

Per capita annual steel production: 440 pounds—Allwood et al., 2013, p. 3.

Footnote: "UK steel consumption is currently around 530 kg steel per person . . ."—Ibid., p. 9.

"without which such inexpressible confusion must ensue"—Gordon S. Wood, ed., *The American Revolution: Writings from the Pamphlet Debate 1764–1772* (New York: Library of America, 2015), p. 431 (John Dickinson, "Letters from a Farmer in Pennsylvania, to the Inhabitants of the British Colonies," 1768; Letter IV).

Per capita paper production—Gutowski et al., *Annu. Rev. Environ. Resour.,* 2013, p. 100 (Table 5), 2010 figures, converted by WTV from 58 kg. The increase was 1.1% per year.

"Under all six scenarios . . ."—Gutowski et al., *Annu. Rev. Environ. Resour.,* 2013, p. 100.

About Transportation

Epigraph: "Transportation is the major culprit . . ."—*European Journal of Scientific Research* 34, no. 4 (2009), pp. 550–60 (F. I. Abam, Department of Mechanical Engineering, Cross River University of Technology, Calabar, Nigeria, and

G. O. Unachukwu, National Centre for Energy Research and Development, University of Nigeria, Nsukka, Nigeria, "Vehicular Emissions and Air Quality Standards in Nigeria"), p. 551.

Epigraph: "Even the most vibrant experiences become slightly faded over time . . ."—*Travel + Leisure* (New York), August 2016, p. 88 (Thessaly LaForce, "Beyond: Urban Study: Artist's Colony").

Epigraph: "We choose to go to the moon because it is profitable!"—*National Geographic*, August 2017, p. 37 (Sam Howe Verhovek, "Shoot for the moon").

Description of a Japanese express train ride—After a trip in January 2017.

The Three Most Dangerous Sectors of Human Activity

"EU" percentages—EU greenhouse report, 2014, p. xi. Percentages for EU-28 countries stated in note on Table ES.6. (Total 2012 emissions for EU-28: 4,603 metric MT excluding LULUCF. Not all data is recapitulated here, so the reader must go to the original to verify my calculations.) From Table ES.7 [EU-15 emissions]. I took the numbers and converted them into the percentages in parentheses: energy, 2,893 metric MT of carbon-dioxide-equiv. emissions (79.9%); agriculture, 373 (10.31%); industrial, 243 (6.71%). Then I converted each pair of percentages into a range for my table. For example, for energy: 79% for EU-28, 79.9% for EU-15. Range in table on p. 144, rounded to nearest digit: 79–80%.

"M" percentages—*Greenhouse Gas Inventory Mexico, 1990–2002,* p. 36: Since the total with LULUCF was 643, 183 Gg and LULUCF was 89,854 Gg, then total without LULUCF was 553,329 Gg. Dividing the actual figures for the emissions subcategories into this new total, I obtained: energy, 70.39%, waste, 11.85%; industrial processes, 9.41%; and agriculture, 8.33%.

"Emissions from solid waste disposal . . ."—Ibid., p. 52.

"J" percentages—*Greenhouse Gas Inventory Japan,* 2015, p. E.S.4. Cf. p. 4-3: "The emissions of CO_2, CH_4, and N_2O from this sector have decreased by 34.6% compared to 1990. The emissions of HFCs, PFCs, SF_6, and NF_3 from this sector have increased by 9.1% compared to 1990."

"U" percentages—EPA, 2016, p. ES-17 (Table ES-4: "Recent Trends in U.S. Greenhouse Gas Emissions and Sinks by Chapter/IPCC Sector (MMT CO_2 Eq.)"). Numbers converted into the percentages in parentheses: energy, 2014: 5,746.2 MT (83.6%); industrial products and product use, 379.2 (5.5%): agriculture, 573.6 (8.5%); total emissions 6,870.5 (100%). On p. ES-23 we read (evidently some rounding was going on): "Activities related to agriculture accounted for 9 percent of U.S. emissions."

Industry: Global per capita CO_2 emissions and increases—Gutowski et al., *Annu. Rev. Environ. Resour.,* 2013, p. 100 (Table 5), converted by WTV from 0.90 metric tons.

Footnote: Japanese cement-making—*Greenhouse Gas Inventory Japan,* 2015, p. 2-13.

About Transportation (continued)

"the five monitored air pollutants . . ."—*European Journal of Scientific Research* 34, no. 4 (2009), pp. 550–60 (F. I. Abam, Department of Mechanical Engineering, Cross River University of Technology, Calabar, Nigeria, and G. O. Unachukwu, National Centre for Energy Research and Development, University of Nigeria, Nsukka, Nigeria, "Vehicular Emissions and Air Quality Standards in Nigeria"), p. 550. Ibid., p. 552: "Studies conducted in Kaduna and Abuja cities show higher values of CO2 concentration in heavily congested areas: 1840 ppm for Sambo Kaduna, 1780 ppm for Stadium round-about, Kaduna, and 1530 ppm for A.Y.A., Abuja, 1160 ppm for Asokoro Abuja, Akpan and Ndoke (199). Similar work by Jimo and Ndoke (2000) at Minna, a city in Nigeria, shows the maximum value of 5,000 ppm for CO2 in congested areas, which was still lower than WHO stipulated maximum value of 20,000 ppm." [No subscript in original.]

Mexican transportation emissions, 2002—*Greenhouse Gas Inventory Mexico, 1990–2002.* On p. 36, "transport" was given as 18% of national emissions. But this seems to have included LULUCF. Page 43: "In 2002, the total GHG emissions in the transport sector . . . in units of CO2 equivalent, were 114,385 Gg. The contribution by type was: automobile . . . 91%; air . . . 6%; sea . . . 2% and rail . . . 1%." So .91 × 114,385 = 104,090.35. This divided into total emissions without LULUCF [553,329 Gg] = 18.81%.

German transportation emissions, 2007—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 161.

Japan's transportation emissions, 2013—*Greenhouse Gas Inventory Japan,* 2015, p. 3-42. (The category also included "other transportation (1.A.3.e)".) From 1990 to 2013, Japan's increase was a modest 8.74%. Ibid., p. 2-4 (Table 2-2: "Trends in CO2 emissions and removals in each sector"): 1990 transportation emissions were 178,442 thousand metric tons carbon dioxide; the corresponding 2013 figure was 194,039. Calculation: x % of [178,442 = 194,039 – 178,442] = 15,597, so x% = [15,597 / 178,442] × 100 = 8.74%.

Canada's transportation emissions, 2011—*Canada Yearbook 2011,* p. 156.

America's emissions, 2014—EPA, 2016, p. ES-11-12: "The largest sources of transportation CO_2 emissions in 2014 were passenger cars (42.4 percent), medium- and heavy-duty trucks (23.1 percent), light-duty trucks, which include sport utility vehicles, pickup trucks, and minivans (17.8 percent) [total thus far = 83.3%], commercial aircraft (6.6 percent), pipelines (2.7 percent), rail (2.6 percent), and ships and boats (1.6 percent)." Cf. p. ES-23: "Transportation activities, in aggregate, accounted for the second largest portion (26 percent)" of U.S. greenhouse gas emissions in 2014.

Footnote on previous entry: "Methane and nitrous oxide emissions increase this figure by only a quarter of a percent"—Ibid., p. 3-22 (Table 3-13: "CH_4 Emissions from Mobile Combustion (MMT CO2 Eq.)"), 2014 figure: 2.0. Page 323 (Table 3-14: "N_2O Emissions from Mobile Combustion (MMT CO_2 Eq.)"). 2014 figure: 16.3. On p. ES-4 we read that 2014, total U.S. GHG emissions were 6,870.5 MMT CO_2 Eq. Dividing [2 + 16.3] into 6,870.5 gives 0.266%.

North America; 41.8% of refinery output for gasoline, compared to the rest of the world—U.S. Department of Energy, Energy Administration, *1981 International Energy Annual* (Washington, D.C.: U.S. Department of Energy, September 1982). Remainder of original sentence reads: Motor gasoline "did not exceed 19 percent of refinery yield in any other region of the world."

"In terms of the overall trend . . ."—EPA, 2016, pp. ES-11-12. A case in point: Sahil Sahni, Avid Boustani, Timothy Gutowski and Steven Graves, "Engine Remanufacturing and Energy Savings" [MITEI-1-d-2010] (Boston: Environmentally Benign Laboratory, Laboratory for Manufacturing and Productivity, Sloan School of Management [MIT], January 28, 2010), p. 3: "The United States Transportation sector consumed 28.5% of the total 101.5 quadrillion BTUs of energy consumed in the US in 2007. This fraction has been consistently rising at more than 1% over the last couple of decades. It is also true that the United States on-road transportation energy use is dominated by [p]assenger [c]ars . . . The total energy used by on-road transportation (by cars, trucks, motorcycles and buses) in 2007 is 22,393 trillion BTUs." [This document henceforth cited: "Sahni et al., January 28, 2010."]—But Kroschwitz and Howe-Grant, vol. 12 ("Fuel Resources" to "Heat Stabilizers"), p. 342 ("gasoline and other motor fuels"), tell a slightly different story. In 1992, American consumers "burned 422 $\times 10^9$ L[iters] of gasoline," "the average family car" got driven 15,000 km/yr, which "has not changed much since 1948." Did the demand increase after 1992? Or did increasing demand simply mean increasing absolute, not per capita demand?

"nearly 307,000 people will travel to the destination . . ."—*Simply 55+* ("Southern Nevada's Premier Magazine for Active 55+"), September/October 2016, p. 40 (Oscar B. Goodman, "2016 Presidential Debate").

The downward trend in German emissions, and *Tanktourismus*—*Greenhouse Gas Inventory Germany, 1990–2007,* pp. 162–64. German 2000–2007 emissions decline converted from 27.3 million metric tons. [Regarding the decrease, here is a lesson in context (p. 161): In 1990, "road transport" accounted for 11.91% of all emissions. In 2007, it accounted for 14.13%—simply because Germany's total emissions were declining faster than the ones in this category.] The specific amounts are in Table 28: "Emissions from road transports."

Carbon dioxide percentage decrease, 1990–2007—Calculated by WTV from Table 28 (150,358.33 minus 144,114.20).

Footnote: "Significant to astonishing decreases"—*Greenhouse Gas Inventory Germany,* 1990–2007. For instance: Methane fell by 77%, sulfur dioxide by 98.8% (my computations from the absolute numbers).

"The second largest key source . . ."—EU greenhouse report, 2014, p. 220.

"The Member States Germany . . ."—Ibid., p. 221.

German 2012 emission in Gg—Ibid., p. 222 (Table 3.51: "1A3b Road Transport: Member States' contributions to CO2 emissions"). Germany's gasoline emissions had decreased and her diesel emissions increased (pp. 222–24).

Maximum-Range Carbon Dioxide Emissions of Selected Aircraft

Initial data from: Paul Jackson, MRAeS, ed.-in-chief, *Jane's All the World's Aircraft [no. 94]: 2003–2004* (Surrey, U.K.: Jane's Information Group Inc., 2003), pp. 1 (AT-63 Pampa: total fuel capacity, 2,017 liters = 533 U.S. gallons, 444 Imperial gallons); 125–27 (Dassault Rafale: 2,300 L = 608 U.S. gal); 575 (Boeing 777, 195,283 L = 51,590 gal). [Since this source is cited only here, please note that all other citations to "Jackson" refer to A. Jackson, *Modern Steelmaking for Steelmakers.*]

Carbon dioxide emissions of jet fuel—Per *Plane & Pilot,* August 2017, p. 10 ("Plane Facts"), the "most commonly used aviation gasoline for turbine engines" is kerosene-based unleaded JET A-1, whose emission coefficient is 18.4 lbs carbon dioxide per combusted gal. As my table notes, "airplane fuel's 'total global warming impact is significantly higher [than its volume of use would suggest,] due to vapor trails and the other effects of burning fuel at altitude.'" Therefore I wish to insert here, for whatever it may be worth, a higher emissions coefficient of 24.5 lbs/gal, which I calculated as follows: Per table beginning on p. 199 ["Carbon Dioxide Emissions of Common Fuels"], aircraft fuel emits 1.701 pounds of CO_2 for each 10,000 BTUs. Per the table of Calorific Efficiencies beginning on p. 208, aviation gasoline, mid-20th-century formulation, was 21,400 BTUs / lb. Per 9A on p. 581, the density of aviation fuel is 775–840 g/liter. The arithmetical average of that pair is 807.5 g/L. Since 1 U.S. gal = 3.78 L, the appropriate density for aircraft fuel would be 6.73 lb /gal. So the HHV of 1 gal. would be 144,022

BTUs. Therefore: [1.701 lbs dioxide / 10,000 BTUs] × [144,022 BTUs / gal] = 24.498 lbs carbon dioxide emitted per gallon of aviation fuel.

"Total global warming impact . . ."—Mike Berners-Lee and Duncan Clark, *The Burning Question: We Can't Burn Half the World's Coal and Gas. So How Do We Quit?* (Berkeley, California:Greystone Books, 2013), p. 150.

About Transportation (continued)

Global per capita CO_2 from transportation—Gutowski et al., *Annu. Rev. Environ. Resour.,* 2013, p. 100 (Table 5), converted by WTV from 820 kg.

About Power Plants

Epigraph: "The larger the amount of power . . ."—*Britannica,* 11th ed., vol. XXII (POLL to REEVES), p. 238 (entry on "power transmission").

Epigraph: "Steam is really just a medium of exchange . . ."—Kroschwitz and Howe-Grant, vol. 12 ("Fuel Resources" to "Heat Stabilizers"), p. 443 ("energy management").

Operation of fossil fuel and nuclear plants—John A. Camara, PE, *Electrical Engineering Reference Manual for the Electrical and Computer PE Exam,* 6th ed. (Belmont, California: Professional Publications, Inc., 2002; pub. date of orig. ed. not given), pp. 33-1, 33-3. Re: atomic power, a tome by Alan M. Herbst and George W. Hopley, *Nuclear Energy Now: Why the Time Has Come for the World's Most Misunderstood Energy Source* (New York: John Wiley & Sons, 2007), puts the matter prettily: "A commercial nuclear reactor, essentially a large and very complex tea kettle, boils water to produce steam through a controlled reaction of fissionable material. This steam spins turbines to create electricity" (p. 127).

2,400 to 3,500 psi: "equivalent to pressures from a mile to a mile and a half under the ocean"—According to the *CRC Handbook,* 2006, 1 psi = 0.00689457 mPa (p. 1-35 ["Conversion Factors for Pressure Units"]). Hence the two respective psi figures become respectively 16.547 and 24.131 mPa. On p. 14-14 ("Ocean Pressure as a Function of Depth and Latitude"), there is a chart of "excess pressure over the ambient atmospheric pressure at the surface." At zero degrees of latitude, a depth of 1,500 meters = 24.131 mPa, and 2,500 m = 25.2895 mPa. Dividing each side of each equation by the lefthand quantity, in order to get the left side down to unity, we find that in both cases, 1 meter is about 0.0101 mPa. Since 1 m = 3.28 ft, 1 foot of depth = 0.003079 mPa. Employing this conversion factor (e.g., dividing 16.547 mPa by 0.003079 mPa per foot), it appears that 2,400 psi corresponds to 5,374 ft, and 3,500 psi to 7,837.2 ft.

"Efficiency improves when the source temperature is raised."—Camara, p. 33-1.

Answers of the "Public Information Specialist"—SMUD e-mail, December 2016.

"No process is possible . . ."—Mark W. Zemansky, Ph.D., *Heat and Thermodynamics: An Intermediate Textbook,* 5th ed. (New York: McGraw-Hill, 1968), p. 178. Cf. 172–73: "Since heat is always rejected during the condensation of water, Q_C [the heat lost during condensation] cannot be made equal to zero, and therefore the input Q_H [the heat absorbed by the water in the boiler] cannot be converted completely into work."

Innate Energies versus *Actual Electric Power Generated*

Data for innate energies—"7/13/2016 How much coal, natural gas, or petroleum is used to generate a kilowatthour of electricity?—FAQ—U.S. Energy Information Administration (EIA)," downloaded for WTV by Jordan Rothacker, July 2016, from https://www.eia.gov/tools/faqs/faq.cfm?id=667&t=8. [Henceforth cited: "EIA, 7/13/2016"]. From this e-document: "Fuel heat contents (for fuels received by electric power industry in 2014). Coal = 19,420,000 Btu per short ton (2,000 pounds). Note: Heat contents of coal vary widely by types of coal. Natural gas = 1,029,000 Btu per 1,000 cubic feet (Mcf). Petroleum = 5,867,946 Btu per Barrel (42 gallons). Note: Heat contents vary by type of petroleum product." Righthand values from the table of Calorific Efficiencies.

Data for actual electric power generated—EIA, 7/13/2016: To generate 1 kWh [which presumably implies the standard ⅔ power plant wastage], requires the following: 1.04 lbs coal, or 0.01011 Mcf [= thousand cubic feet] natural gas, or 0.07 gal petroleum. My calculations: This means 1 lb coal generates 0.96 kWh = [multiplying by 3,413] 3,281.730 BTUs. By comparable arithmetic: 1 lb natural gas generates 8,109.213 BTUs, and 1 lb petroleum [calculated per density of diesel] generates 6,929.668 BTUs.

About Power Plants (continued)

"To manufacture a 2010-model desktop computer we had to burn up to 660 pounds of coal in a power plant"—Ciceri, Gutowski and Garetti, unnumbered page: "In the case of a desktop (CPU tower) . . . the total electronics manufacturing results in about 2900 MJ/unit, for which 2780 MJ goes into the wafer manufacturing/chip packaging." The two numbers correspond respectively to 2,749,394.3 and 2,635,626.26 BTUs, or 2.7 million and 2.6 million BTUs. Dividing by the West Virginia Coal Association's HHV of 12,500, then multiplying by 3 to account for power plant wastage, we obtain 659.876 and 635.55 lbs of coal.

"Of the electric power thus generated, 95% went to make the silicon chip . . ."—Loc. cit.: "About 95% of the energy content is needed in this phase."

"a refrigerator, required somewhere between 1,000 and 1,400 pounds . . ."—Loc. cit.: The refrigerator required somewhere between 4,517 and 6,306 MJ to fabricate. This was 4,282,419 to 5,948,511 BTUs, or, following the same logic as for the computer, 1,032 to 1,440 lbs of coal. From the table of Calorific Efficiencies on p. 214 we see that the HHV of commercial fuel oil, heavy grade, *ca.* 1975, is 18,450 BTUs/lb. Then, by analogous logic to the above, a power plant would need to burn 699 to 975.6 lbs of the stuff to power the manufacture of a refrigerator.

"more than 80% of that refrigerator's substance was steel and plastic"—Avid Boustani, Sahil Sahni, Timothy Gutowski and Steven Graves, "Appliance Remanufacturing and Energy Savings" (Environmentally Benign Manufacturing Laboratory, Sloan School of Management, MITI-1-a-2010, January 28, 2010). [Henceforth cited: "Boustani et al."]. Page 14: "Bill of materials" for "a 1997 model refrigerator" includes: steel, 47.55 kg; and plastic, 23.48 kg (and other materials).

Comparative Power Efficiencies

BTUs per kWh for steam-electric, diesel-electric and gas-turbine plants—Baumeister and Marks, pp. 17-45, -46, -47 (Franklin J. Leerburger, "Cost of Electric Power").

Alleged inefficiency of Japanese nuclear reactor—Takashi Hirose, *Fukushima Meltdown: The World's First Earthquake-Tsunami Nuclear Disaster,* trans. Izumi Kaori et al. [this ed. copyright in name of Douglas Lummis, one of the translators] ("Printed in the USA": no publisher, 2011; orig. Japanese ed. pub. by Asahi Shinso, 2011), pp. 149–51. Cf. OECD, 1974, 159: Reactors show "a low thermodynamic efficiency (about 33 per cent) and a consequently large volume of low grade heat discharge."

"The overall efficiency of [American] electric power plants consisting of coal-fired boilers and steam turbines has plateaued at about 39% . . ."—Kroschwitz and Howe-Grant, vol. 6 ("Chlorocarbons and Chlorohydrocarbons—C_2" to "Combustion Technology" [pub. 1993]), p. 484 ("combustion technology"). For entry at 3.09 ×, input BTUs = 3,413/0.39 = 8,751.

"'Best' 'fossil fuel' power plant," *ca.* 1976—*Britannica,* 15th ed., vol. 18 (TAYLOR to UTAH), p. 773 ("turbine").

Efficiencies of natural gas power plants, 2002 and 2012—Prentiss, p. 20.

Efficiency of combined-cycle thermal energy generator, and data in accompanying footnote—Organisation for Economic Co-operation and Development, Paris, *Energy Prospects to 1985: An Assessment of Long Term Energy Developments and Related Policies (A Report by the Secretary-General),* vol. 1 (Paris:

OECD, 1974), p. 59 (Annex 4-A: "Energy Conservation in Electricity Conversion"). [This source henceforth cited: "OECD, 1974."]

"Ultra-supercritical and advanced ultra-supercritical plants"—In 2015 an Australian government report claimed that "Ultra-supercritical and Advanced ultra-supercritical plants operate at efficiencies between 45–50 per cent. The capital cost of these plants is high because they must use advanced materials (with high nickel content) in the boiler. They use less coal and emit less CO2 than supercritical plants." Source: Australian Government: India, 2015, p. 41. Ibid., p. 95: "Ultra-supercritical (USC) plants operate at even higher temperatures and pressures than other plants, achieving efficiencies around 45 per cent. USC plants are built using advanced materials, require higher quality, low ash coals, and have higher capital costs (up to 40–50 per cent more than a subcritical plant) and longer build times. However, operating costs are typically lower because of reduced coal consumption. The overall power costs of USC is greater relative to other coal-fired technologies, unless coal prices are high, or a carbon price exists. However, the benefits of using USC plants are evident when comparing a USC plant operating at 48 per cent efficiency to a subcritical plant operating at 32 per cent efficiency . . . The poorest quality subcritical power plants can emit more than 1 tonne of CO2 per megawatt hour, compared with 700 kilograms for USC plants."

Tepco Kawasaki thermal plant, 2016—In 2016 the Tokyo Electric Power Company released an "outline" of their Kawasaki thermal plant, whose efficiency was by my standards laudable. Units 1 and 2 ran at 59%. Unit 3 offered a still higher efficiency, thanks to its exhaust heat recovery system, although "currently, rated output has been reduced from 710MW to 685MW and generation efficiency from approx. 61% to approx. 59% when comparing with the original design. This is due to emergency construction work based on another company's defective steam turbine." Source: "Outline of Kawasaki Thermal Power Station," downloaded in January 2017 for WTV by Jordan Rothacker from www.tepco.co.jp/en/press/corp-com/release/betu16_e/images/160629e0201.pdf June 29, 2016—Attachment. "Outline of Kawasaki Thermal Power Station. 1. Outline of power station. (1) Address: Chidori-cho 5-1, Kawasaki-ku, Kawasaki-shi." I would like to thank the antinuclear activist Mr. Yamasaki Hisataka for making me aware of this plant, thanks to his e-mail of January 14, 2017. [Relevant text reads: "Currently, Tepco's highest efficiency power plant is the Kawasaki thermal plant at 62%. This is the efficiency of power generation only, so if they can utilize the waste heat they may be able to achieve 80% or more."]

Footnote: "even cheerier figures, *ca.* 1974"—OECD, 1974, p. 79 (Table 4-1: "Sectoral percentages of total primary energy consumption on OECD 192 regional energy balances"). "Currently, about two-thirds of the energy used to provide electricity . . ."—Ibid., p. 59 (Annex 4-A: Energy Conservation in Electricity Conversion").

About Power Plants (continued)

Efficiencies of up to 80% + "Systems typically produce electricity . . ."—Ross & Associates Environmental Consulting, Ltd., *U.S.-Mexico Border Region Greenhouse Gas Inventories and Policy,* review draft (3/1/09), prepared for U.S. EPA (official date March 2009), pp. 20–21. [Henceforth cited: "Ross & Associates, 2009."]

Power and Climate

Epigraph: "There was nothing he could do to help her . . ."—Tom Godwin, *The Cold Equations and Other Stories,* ed. and comp. Eric Flint (Riverdale, New York: Baen Publishing Enterprises, 2003), pp. 419, 426 ("The Cold Equations").

Canadian emissions, 2008—*Canada Yearbook 2011,* pp. 172–73 (Table 12.1, "Greenhouse gas (GHG) emissions, by source, 1990 and 2008"), converted (@ × 1.1023) from 547,000 [to 602,958.1] and 118,000 [to 130,071.4] metric kilotons. The percentage of the first into the second was calculated using these more exact figures.

Footnote: American contribution: "the single largest source of CO_2 emissions in the United States . . ."—EPA, 2016, p. 122.

Contributions of manufacturing and transportation—*Canada Yearbook 2011,* p. 156: 31% of 2009 energy consumption was in transportation. Mining, manufacturing, forestry and construction took 29%. For details see p. 166 (Table 11.8: "Energy fuel consumption, by manufacturing industry, 2004 to 2009").

Power Generation's Share of Greenhouse Gas Emissions for Selected Countries

EU data—EU greenhouse report, 2014, p. 135.

U.S.A.—ES-23. Also, p. ES-2 (Table ES-2: "Recent Trends in U.S. Greenhouse Gas Emissions and Sinks (MMT CO2 Eq.)"). Carbon dioxide from electricity generation: *2,039.3* out of 5,556.0 *MMT of CO2.* This = 36.7%. Then on p. 2-13 we are told: "The main driver of emissions in the Energy sector is CO2 from fossil fuel combustion. Electricity generation is the largest emitter of CO2, and electricity generators consumed 34 percent of U.S. energy from fossil fuels and emitted 39 percent of the CO2 from fossil fuel combustion in 2014."

Germany—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 122.

Japan—*Greenhouse Gas Inventory Japan,* 2015, p. 3-13, Annex 4-13 (Table A 4-2: "Energy balance simplified table (General Energy Statistics, FY1995)"). Electricity was 194,155 TJ. Heat production was 1,063,574 TJ. I divided electricity into the sum of these two, then multiplied the resulting decimal fraction by 40.3%. Got 6.22%.

Power and Climate (continued)

U.S. winter peak load capacity, 1980–2013—U.S Statistical Abstract, 2015, p. 625 (Table 965: "Electric Power Industry—Capability, Peak Load, and Capacity Margin: 1980 to 2013"). I converted 921,966,000 kWh × 3,413 to get 3,146,669,958,000 = 3.147 trillion BTUs [= 0.003147 Q-BTU = 1/318 of a quad].

"Burning 674,286,420 pounds of pure carbon . . ."—Calculated from [3.146 trillion BTUs] × 3 × 1 lb pure carbon / 14,000 BTUs.

Emissions of pure carbon—I estimated them as comparable to those of bituminous coal [p. 201: 2.466 lbs CO_2 per lb]. Multiplying this × 224,762,140 gave 554,263,437.24, which I conservatively rounded down to 550 million.

Primary Greenhouse Gas and Precursor Emissions from American Power Generation

Data from: Energy Information Administration, "Electricity—Energy Explained, Your Guide to Understanding Energy" (7/18/2016), downloaded for WTV by Jordan Rothacker, August 2016, from http://www.eia.gov/energyexplained/index.cfm?page=electricity_home#tab2.

About Solar Energy

Epigraph: "Look at the bright side always . . ."—Perkins, p. 424 (Coleridge, *Anima Poetae*, first pub. 1895).

Remarks of Dr. Canek Fuentes-Hernandez, throughout this chapter—From his detailed letter of criticism on an earlier version of "About Solar Energy"; this letter, dated May 23, 2017, was copied to disk for WTV by Jordan Rothacker. Henceforth cited: "Dr. Canek Fuentes-Hernandez to WTV, May 2017."

Solar Energy En Route to Earth's Surface

"Solar Energy Lost En Route to Reaching Earth's Surface"—Calculated by WTV from the following statements in Baumeister and Marks, p. 9-230 ("Power from Solar Energy"): "The heat received from the sun on 1 sq ft of surface normal to the sun's rays above the atmosphere of the earth amounts to 442.4 BTU per hr." [The same source, p. 12-114 (Hoyt C. Hottel, "Solar Energy for Heating"), gives the mean solar constant = "incidence on surface external to earth's atmosphere, normal to solar beam and at mean solar distance" = 442 BTU/square ft/hr or 10,660 per day. This likewise works out to 7.37 BTU/sq ft/min.] Insolation on a horizontal square foot in the continental U.S. is (or then was) 1,800–2500 BTUs/ft in summer, 500–1,100 BTUs per day in winter.

Footnote on declining insolation—*Encyclopedia of Agriculture and Food Systems,* vol. 2, p. 257 (J. A. Hatfield and C. L. Walthall, "Climate Change: Cropping System Changes and Adaptations").

Same footnote on increasing insolation—IPCC, 2013, p. 184: "Downward thermal radiation observations started to become available during the early 1990s at a limited number of globally distributed terrestrial sites. From these records, Wild et al. (2008) determined an overall increase of 2.6 W [per square meter] per decade over the 1990s, in line with model projections," while other scientists calculated somewhat lower values. Since 1 watt per square meter = 1.634 BTUs per square foot, 2.6 W/ sq m = 4.2484 BTUs/sq ft.

Baumeister and Marks note (p. 9-5 [Eugene Ayres, "Sources of Energy"]) that the Earth receives about 10^{18} horsepower-hours per year but 30% of it (= 3×10^{17} hp-hr) gets reflected back into space.

"The total solar energy reaching the earth . . ."—Farrington Daniels, *Direct Use of the Sun's Energy* (New York: Ballantine Books, 1964), p. 253.

"One estimate for this total solar energy is 9.9 quadrillion [9,897,816,000,000,000] BTUs per minute, or 174,000 terawatts"—I had previously had 5,460,864,000,000,000 BTUs per minute, or 96,000 terawatts (original in TW only, converted by WTV), based on Darling and Sisterson, pp. 174–75. But Dr. Fuentes-Hernandez wrote me: "Each hour the earth receives, at the edge of its atmosphere, around 174,000 terawatts (not sure what assumptions were made on the source quoting 96 0000 terawatts, but the value I give you is the one you will find in most of the scientific literature and government agencies such as DOE, NREL and NASA) (or an irradiance of around 1366 W/m2, prior to any atmospheric losses)." So I have followed his figure (and once again converted to BTUs).

"The sun delivers energy . . ."—Prentiss, p. 32.

Further note: re: 7.37 BTU/min-ft^2—According to the *Britannica,* 15th ed., vol. 6 (EARTH to EVERGLADES), p. 857 ("energy sources"), "solar radiation outside the earth's atmosphere is 1.4 kilowatts per square metre."1.4 kW/m^2 × 1 m^2/[3.28 × 3.28 feet] = 1.4 kW/10.7584 ft^2 = 0.13013 kW/ft^2 = 0.13013 × [57.87 BTU/min] / ft^2= 7.53 BTU/min-ft^2, which is close but not identical to the 7.37. In his letter to me, Dr. Canek Fuentes-Hernandez speaks of "an irradiance of around 1366 W/m2, prior to any atmospheric losses," which I convert to the very similar 7.21 BTUs/min-ft^2 (a mere 2.05% less than 7.37).

"At most, 67 per cent . . ."—Odum, p. 40 (citing Gates, 1965). Cf. Marion, p. 266: "The Earth receives radiant energy from the Sun at the rate of 1.95 cal/min on an area of 1 cm^2 oriented perpendicular to the direction of the Sun."

"77% actually strikes the ground"—Dr. Canek Fuentes-Hernandez to WTV: "On its way to the earth's surface, around 23% is absorbed by the atmosphere leading to a total energy resource of around 121 000 terawatts each hour (around 1000 W/m2 or 1 GW/km2), prior to any absorption or reflection by earth's surface (Note that these losses are also shared by any other biological process that use the sun, i.e. all biomass). Give or take a few terawatts, this represents about the same energy the entire world consumed during year 2014 (see key world facts 2014 and round total energy consumption to around 10 000 mtoe [million tons of oil equivalent] ~ 116 300 terawatts/hour)."

June and December values for Stillwater, Oklahoma—Jim Leckie, Gil Masters, Harry Whitehouse and Lily Young, *Other Homes and Garbage: Designs for Self-Sufficient Living* (San Francisco: Sierra Club Books, 1975), p. 88 (Table 4-6, "Daily Averages of Solar Energy Received on a Horizontal Surface").

General amount of insolation striking planet's landmass—The *Britannica* goes on (loc. cit.): "Expressed in terms of Q units ($Q = 10^{18}$ BTU) the amount of solar radiation striking the earth's atmosphere in one year is 5,000 Q. More than half of this reaches the surface of the earth, with 900 Q per year being absorbed over land and the remainder over water." Since 900 / 5,000 = 0.18, I have made this figure 18%.

About Solar Energy (continued)

Blackbody: "an ideal substance capable of absorbing all the thermal radiation falling on it"—Zemansky, p. 98.—"The fraction of all the radiation (i.e., over all wavelengths) from the direction . . . that is absorbed by a surface is called the directional absorptance."—John A. Duffie and William A. Beckman, *Solar Energy Thermal Processes* (New York: John Wiley & Sons, 1974), p. 86.

"It must also be able to emit all the radiation it absorbs."—Ibid., p. 62: "A blackbody is also a[n] . . . emitter of thermal radiation. In fact, the definition of a blackbody could have been made in terms of a body that emits the maximum possible radiation."—"The directional emittance is defined as the ratio of the emitted total intensity . . . to the blackbody intensity" (ibid., p. 86).

"we're going to have to wait a few more years . . ."—Leckie et al., p. 33.

"millions of Americans now get their electricity . . ."—*The New York Times,* Saturday, July 1, 2017, p. B1 (Diane Cardwell, "Battle Over Solar Trade").

"Over 2000 years, the cumulative amount of heat retained in the Earth system . . . is about 8 times larger than if we count only the first 100 years"—Dr. Pieter Tans to WTV, May 2017.

Absorbance and emittance of carbon black and zinc oxide paints—Ibid., p. 97 (Table 5.5.1, "Radiation Properties"). "A large thickness of carbon black can absorb about 99% of all incident thermal radiation."—Ibid., p. 62.

A remark on carbon black pigment—Of course manufacturing it (by burning carbon black oil) generates methane and carbon dioxide.

Copper's relative thermal conductivity—Duffie and Beckman, pp. 372–73 (Miscellaneous Information), thermal conductivity in W/m deg C. The conductivities in question were: copper, 385; ice at –1° C, 2.26; rigid foam polyurethane, 0.024.

"aluminum is perhaps the best and cheapest material . . ."—Daniels, p. 61. [Aluminum, says this source, has a reflectivity of 60–70%.] According to Jim Leckie, Gil Masters, Harry Whitehouse and Lily Young, *Other Homes and Garbage: Designs for Self-Sufficient Living* (San Francisco: Sierra Club Books, 1975), p. 98 (Table 4.8, "Thermal Conductivity (k) of Miscellaneous Substances at Room Temperature"), aluminum is only about 48% as conductive as silver and 69% as conductive as gold. But Daniels is also considering price and durability.

Information on the solar house in Denver—Duffie and Beckman, 278 (Table 12.3.1, "Energy Balance of Denver Solar House Winter 1959 to 1960: all values in million Btu . . .").

Comparison to coal's thermal efficiency: 226.86 mBTUs / 12,500 BTUs per lb = 18,148.8 lbs W.V. coal. For the 12,500-BTU inherent energy, see the table of Calorific Efficiencies.

The less than 2% efficiency was calculated thus: The average continental U.S. winter value was 7.3%. So 24.56% of this would be 1.79. Perhaps this is one reason why Daniels believed (p. 259) that "like fossil fuels its [solar energy's] practical availability is limited to specific localities. Beyond the limit of a few hundred miles with electric transmission lines, it must be converted into chemicals that can be stored and transported."

The solar energy conversions of various crop plants—Odum, p. 45 (Table 3-4: "Relationships Between Solar Radiation and Gross and Net Production . . .").

"The sun stores up power enough in an acre of plants . . ."—Ellis and Rumely, p. 114.

Discussion of Perch Lake—*Atmosphere-Ocean* 23, no 3 (1985), pp. 238–53 (E. Robertson and P. J. Barry, "The water and energy balances of Perch Lake

(1969–1980)"). DOI: 10.1080/07055900.1985.9649227. Taylor & Francis Group. Published online: November 15, 2010. © Canadian Meteorological and Océanographic Society. [Henceforth cited: "Robertson and Barry, 1985."]

Dimensions of Perch Lake—Given (p. 238) as 0.45 sq km in area, which equals about 4,840 square feet, and 2 m deep, which is 6.56 feet. The location of the lake is given in the same place.

"Perch Lake used to receive not quite 150,000 BTUs . . . per square foot."—"From 1 May to 31 October nearly 1700 MJ m^{-2} of heat enter the lake" (p. 243). My figure was computed as follows: [1,700 MJ] × [1,000 kilojoule per megajoule] × [1 BTU / 1.0548 kJ] = 1,611,679.9393 BTUs per square meter = 148,812.227 BTUs per square foot.

"80% provides latent heat of evaporation . . ."—Loc. cit.

Comparison of 148,812.227 BTUs to the HHVs of pure carbon and rocket fuel—By simple division, using the HHVs on pp. 213 and 217. ["On average, the highest net radiative energy input rate occurs in the last period of May." Loc. cit.]

Fourier: "The radiation of the sun in which this planet is incessantly plunged . . ."—Robert Maynard Hutchins, ed.-in-chief, *Great Books of the Western World,* vol. 45: Lavoisier, Fourier, Faraday. Chicago: Encyclopaedia Britannica, Inc., 1975 repr. of 1952 ed.), p. 170 (Jean Baptiste Joseph Fourier, *Analytical Theory of Heat,* 1822, trans. Alexander Freeman). This appears to be a republication of the first part of Fourier's prize-winning "memoir" of 1807; hence the latter date in my text.

"Farrington Daniels . . . had hoped for 10% efficiency"—Op. cit., p. 177.

"Today's best [solar] cells convert into electricity . . ."—Irwin Stambler, *Automobile Engines of Today and Tomorrow* (New York: Grosset & Dunlap, 1972), p. 132.

Achievement of Okamato, and aspiration of the racily acronymed TIT—*MIT Technology Review* 118, no. 1 (January–February 2015), p. 28 (Peter Fairley, "Can Japan Recapture Its Solar Power?"), pp. 33–34.

"the efficiency of solar power generation is increasing rapidly . . ."—E-mail reply from Mr. Yamasaki Hisataka to Ms. Kawai Takako, printed out in Japanese on January 14, 2017, and orally translated by her for WTV. Since the translation was quick and rough, she asked me to improve the English, which I have done. The original Japanese printout will be deposited in my archive at the Ohio State University. [This document henceforth cited: "Yamasaki Hisataka e-mail, January 14, 2017."]

"Japan is an island country . . ."—Interview at Tokyo Electric Power Company (Tepco) headquarters, 1-3 Uchisaiwai-cho 1-chome Chiyoda-ku, in the Shimbashi district of Tokyo, Monday, October 20, 2014. The interviewees were Mr. Sakakibara Kohji, group leader; Mr. Togawa Satoshi, deputy manager, International Public Relations Group, Corporate Communications Department; and Mr. Hitosugi Yoshimi, section manager, Corporate Communications Department. The speaker I am citing here was Mr. Sakakibara.

Concerning Mr. Travis Fisher—*The New York Times,* Sunday, July 9, 2017, p. 13 (Hiroko Tabuchi, "After Rapid Growth, Rooftop Solar Programs Dim Under Pressure from Utility Lobbyists").

About Greenhouse Gases

Epigraph: "The greatest things in the world . . ."—Lichtenberg, p. 4 (Notebook A, 1765–70).

Comparative Carbon Dioxide Emissions of Power Plants

Information from *The Charleston [West Virginia] Gazette,* Tuesday, December 2, 2014, p. 9A (Karl Ritter and Margie Mason, AP, "Climate funds for coal highlight lack of UN rules"). An "old coal power plant" was stated as emitting 20% more carbon dioxide than the Cirebon one, so I totted up 865.5 (the average of 856 and 875) + 173.1 (which is 20% of 865) = 1,038.6, rounding it to 1,000.

"Combustion of natural gas emits about half the CO_2 that coal generates at equivalent heat output."—Kroschwitz and Howe-Grant, vol. 13 ("Helium Group" to "Hypnotics"), p. 744 ("hydrocarbons": "survey").

About Greenhouse Gases (continued)

"because the pipeline gathering systems needed for such gas tend[ed] to be prohibitively expensive."—Kroschwitz and Howe-Grant, vol. 13, p. 816.

"It was natural gas's most common component"—Kroschwitz and Howe-Grant, vol. 13, p. 814 ("hydrocarbons": "C_1–C_6"), lists methane proportions in various parts of the world from 65.8% in Klifside, Texas, to 95.0% in Salt Lake.

"The flaring of about 1 billion cubic feet per day of natural gas . . ."—Chris Faulkner, p. 145.

"Purposeful venting or flaring of natural gas . . ."—Loc. cit.

"Concentrations of CO_2, CH_4, and N_2O . . ."—IPCC, 2013, p. 11.

Germany's CO_2 emissions in 2007—*Greenhouse Gas Inventory Germany, 1990–2007,* pp. 44–45.

Japan's CO_2 emissions in 2013—*Greenhouse Gas Inventory Japan,* 2015, pp. 2-1 through 2-2: "Carbon dioxide emissions in FY2013 were 1,311 million tonnes (excluding LULUCF), accounting for 93.1% of total GHGs emissions." LULUCF = "Land-use, Land-use Change, and Forestry."

CO_2 "warmed the Earth by half a BTU per square foot."—According to IPCC 2013, p. 13, "Emissions of CO_2 alone have caused an RF of 1.68 [1.33 to 2.03] W m^{-2}." This equals 1.68 W × [0.056884 BTUs per minute / W] per [1 sq m / 10.758 sq ft] = [1.68 × 0.056884 / 10.758] BTUs per min per sq ft = 0.008883 BTUs per min per sq ft = 1.06596 BTUs per 2 hours per sq ft.

"By 2100, [RF] might be 3 or 5 times worse than it was in 2011."—That is, 5 or more than 8 watts per sq m. Ibid., p. 701.

"Carefully observe the impulses of nature . . ."—Thomas À Kempis, *The Imitation of Christ,* trans. Leo Shirley-Price (New York: Penguin Classics, 1952; orig. wr. "probably during the years immediately preceding and following his ordination" in 1413 [p. 22]), p. 168 (ch. 54).

Uncertainty ranges of GWPs—IPCC, p. 711.

All remarks of Dr. Pieter Tans in this chapter—Tans to WTV, May 2017.

The clause "(ever more rapidly)" in the preceding—Information from IPCC, 2013, p. 13: "The total anthropogenic RF for 2011 relative to 1750 is 2.29 [1.13 to 3.33] W[att] [per square meter], and it has increased more rapidly since 1970 than during prior decades. The total anthropogenic RF best estimate for 2011 is 43% higher than that reported . . . for the year 2005. This is caused by a combination of continued growth in most greenhouse gas concentrations and improved estimates of RF by aerosols indicating a weaker net cooling effect (negative RF)."

Footnote: GWPs and C-O / C-F bonds—Information from *Environmental Science and Technology* 40, no. 7 (2006), pp. 2242–46 (Cora J. Young, Michael D. Hurley, Timothy J. Wallington and Scott A. Mabury, "Atmospheric Lifetime and Global Warming Potential of a Perfluoropolyether"), p. 2242. [Henceforth cited: "Young et al."]

Lovecraft's "Cool Air"—Written in 1926; set in 1923.

Presence of CFC-12 in "the vast majority" of refrigerators in the world "by the last decade of the 20th century" (to be precise, 1990) + (in fn) the fact that those refrigerators would work for "20 years or more"—Kroschwitz and Howe-Grant, vol. 12, p. 135 ("refrigeration").

Footnote on the Genetrons + information on the bright green flame (revealed by "passing them through a copper gauze kept hot by the essentially colorless flame of burning methyl alcohol")—Baumeister and Marks, p. 18-5 (Harold M. Hendrickson, "Mechanical Refrigeration").

"The Freons are colourless, odourless . . ."—*Britannica,* 15th ed., Micropaedia, vol. IV, p. 314 ("Freon").

"an almost perfect industrial chemical"—Frank N. Magill, ed., *Magill's Survey of Science,* vol. 1 (Pasadena, California: Salem Press, Applied Science ser., 1993), p. 418 ("Chlorofluorocarbons"). They further, opined Magill (p. 422), did "an enormous boon to life on earth in their ability to cool, insulate, clean, and perform myriad other tasks."

"as gases in the chlorofluorocarbon (CFC) group . . ."—Neil Schlager, ed., *How Products Are Made: An Illustrated Guide to Product Manufacturing,* vol. 1 (Washington, D.C.: Gale Research Inc., 1994), pp. 358–59 ("Refrigerator"). Re: replacements for freon, the same source continued (p. 359): "Thus far, the most promising among them is HCFC-22, which, although still a chlorofluorocarbon, contains an additional hydrogen atom that reduces the molecule's ozone-depletion capacity by 95 percent."

"which in turn can destroy 10,000 ozone atoms apiece"—Information from Kroschwitz and Howe-Grant, vol. 6, p. 510 ("fluorine compounds, organic—(aliphatic)"): "One chlorine atom destroys 10,000 ozone molecules before getting trapped as inorganic HCl," or hydrochloric acid.

"at the 1976 emissions rate, CFCs would make global warming 10% worse"—Information from National Research Council, *Protection Against Depletion of Stratospheric Ozone by Chlorofluorocarbons* (Washington, D.C.: National Academy of Sciences, 1979), p. 111: An increase of CFM [= chlorofluoromethanes, the most ozone-depleting CFCs] can perturb the climate directly by enhancing . . . atmospheric opacity . . . and thereby contribut[ing] to the greenhouse effect . . . [and] can also perturb the climate indirectly by altering the ozone amount or distribution, which will then affect the radiation balance." Page 118: "If the CFM emission is continued at its 1976 level, we will have about 10 percent less time to deal with the CO_2 problem than we will have without the CFMs." Page 127: "The surface warming from such CFC release is expected to be about 10 percent of the warming that is predicted to result from increased atmospheric CO_2 (mainly from continued increase in the burning of fossil fuels)." I have quoted at such length to hammer home the now disputed point that in 1979, human-induced global warming was already scientifically accepted.

Hydrochlorofluorocarbons "have zero O[zone] D[epletion] P[otentials]s . . ." —Ibid., p. 511. Meanwhile [loc. cit.], perfluorocarbons have "very large GWPs."

My attempt to reach the seven refrigerator companies—I quote the intermediary, the determined Mr. Jordan Rothacker:

Queries for *Carbon Ideologies* with Their Responses:

Refrigerator:

3-7-16	I e-mailed Frigidaire on its website the letter below (re-sent 5-27-16).
" "	GE by e-mail (vm on 5-27-16)
" "	Kenmore by e-mail to Zeno Group (media firm) (vm 5-27-16)
" "	LG by e-mail (and at online form) (vm 5-27-16)
" "	Samsung by e-mail (e-mail again to two other addresses, 5-27-16)
" "	Thermador by e-mail to Finn Partners (media firm) (got her on the phone, she said no, client wouldn't want to participate, 5-27-16)
" "	Whirlpool by e-mail at Ketchum (media firm?) (left vm and re-sent e-mail on 5-27-16)

HCFC-22: "less than five percent of the damage to the ozone layer that CFC 12 does"—Magill, p. 422. The same source says (loc. cit.) that using it in cars would require stronger batteries and a redesign of the air conditioners. "General Motors Corporation estimated that it would cost $600 million to refit its assembly lines for HCFC 22."

Comparative One-Century Global Warming Potentials

List of original Kyoto Protocol gases—*Greenhouse Gas Inventory Japan,* 2015, p. iii.

"Precursors"—Information from EPA, 2016, p. 1-5.

"The use of ammonia . . ."—Kroschwitz and Howe-Grant, vol. 21 ("Recycling, Oil" to "Silicon"), p. 128 ("refrigeration"), p. 139.

"might actually exert a cooling effect . . ."—Information from IPCC, 2013, p. 56.

Carbon dioxide emissions "during the production of synthetic ammonia, primarily through the use of natural gas, petroleum coke, or naphtha as a feedstock"—EPA, 2016, p. 222.

Water vapor—Information from IPCC, 2013, pp. 666–67.

Carbon monoxide—GWP from the same source, p. 740 (Table 8.A.4). U.S. exhaust emission reductions, 1969 (or "pre-control," which occurred in 1970) through 1980—Kroschwitz and Howe-Grant, vol. 12, p. 370 ("gasoline and other motor fuels," Table 7, "Federal Light-Duty Exhaust Emission Standards").

CO figures: 1969: 56 g/km; 1980: 4.4. The reduction was 12.74. [More impressive was the reduction in "hydrocarbons," from 9.4 to 0.25, a factor of 37.6.] German aviation kerosene [which they spell "kerosine"] data: *Greenhouse Gas Inventory Germany, 1990–2007,* p. 159: Average emission factor for "all flight phases (LTO and cruising flight), 1992–2015": 9.2 grams CO per combusted kg [= 1 pound CO given off for every 108.69 pounds of fuel burned].

Carbon monoxide: Cigarette emissions—information from *Greenhouse Gas Inventory Japan,* 2015, p. 3-58.

HCFC-123: Kroschwitz and Howe-Grant, vol. 6, p. 512 (Table 9: "Physical Property Comparisons . . .").

Nitrogen oxide GWP—IPCC, 2013, p. 739 (Table 8.A.3: "GWP and GTP for NOX from surface sources for time horizons of 20 and 100 years from the literature. All values are on a per kilogram of nitrogen basis.") GWP was 159 +/– 79, direct and indirect aerosol effects included.

Nitrogen oxides—Kroschwitz and Howe-Grant, vol. 6, p. 739 (Table 8.A.3) and p. 684 (FAQ 8.2).

Footnote on nitrogen oxides: "Profound changes have occurred . . ."—Michael Strogies, Patrick Gniffke, eds., for the Federal Environment Agency, Germany (Umweltbundesamt), *National Inventory Report for the German Greenhouse Gas Inventory 1990–2007: Submission under the United Nations Framework Convention on Climate Change 2009 (ISSN 1862-4359).* "This publication is only available as download under http://www.umweltbundesamt.de:(-Dessau-Roßlau, Germany: Umweltbundesamt, 2009). [Henceforth cited: *"Greenhouse Gas Inventory Germany, 1990–2007."*] Pages 156, 158.

Same footnote: "Nitric Oxide could not only increase your ability to get an erection . . ."—Advertisement for Vesele in *National Enquirer,* October 10, 2016, p. 55.

GWPs for nitrous oxide, CFC-11 (the "other source" rating it at 3,400), perfluorocarbons, sulfur hexafluoride—Michael Allaby, *Encyclopaedia of Weather and Climate*, vol. 1 (New York: Facts on File, Inc., 2002), vol. 1, p. 250 (global warming). For nitrous oxide I reduced the lower bound from 298 times carbon dioxide's to 296 x, since the latter figure is given in the *Encyclopedia of Agriculture and Food Systems,* vol. 2, p. 223 (M. van Noordwijk, Jalan Cifor, Bogor, Indonesia, "Climate Change: Agricultural Mitigation"). I later reduced it further, to 264, based on the table in IPCC, 2013, p. 731.

Nitrous oxide: "Generated by the action of microbes . . ."—*Greenhouse Gas Inventory Japan,* 2015, p. 5-46. "Increasing mainly as a result of agricultural intensification . . ."—IPCC, p. 510. "Released during the production of nitric acid (for fertilizers) and adipic acid (for nylon)."—Information from EPA, 206, p. 228. P. 231: "Adipic acid is a white crystalline solid used in the manufacture of synthetic fibers, plastics, coatings, urethane foams, elastomers, and synthetic lubricants."

American nitrous oxide emissions on "freeways and surface arterials," 1979—D. B. Sanders and T. A. Reynen, with assistance from K. Bhatt and FHWA/UMTA staff, Report No. UMTA-IT-06-0049-79-1: *Characteristics of Urban Transportation Systems—A Handbook for Transportation Planners* (Washington, D.C.: U.S. Department of Transportation, June 1979), p. IV-13 (Table 4-7 (B): "Composite Pollutant Emission Factors (1982 [*sic*]), Freeways and Surface Arterials (1)"). [This handbook henceforth cited: "DOT, June 1979."] Strangely enough, at 15 mph, autos emitted 4.28 g/mi and trucks 7.70.

"The increase, at least since the early 1950s . . ." + average rate of rise—IPCC, 2013, p. 168.

Nitrous oxide lifetime: 131 years—Ibid., p. 1473.

Nitrous oxide: "approximately 300 times more powerful than CO_2"—EPA, 2016, p. ES-14. "10% of global emissions derived from anesthetic use"—Information from *Greenhouse Gas Inventory Germany, 1990–2007,* p. 313. ("It is the oldest narcotic in use, and it is among those with the fewest side-effects."—Loc. cit.)

HFC-152a: Kroschwitz and Howe-Grant, vol. 6, p. 514 ("fluorine compounds, organic—(aliphatic)").

HCFC-22: A refrigerant but also a "feedstock for . . . synthetic polymers"—EPA, 2016, p. 248. "ozone depleting substance substitute emissions . . ."—Ibid., p. 31.

Footnote: "Because HCFC-22 depletes stratospheric ozone . . ."—Ibid., p. 248.

HCFC-22: "the main driver of the increase in *all* HCFC emissions"—Information from IPCC, 2013, p. 679.

HFC-134a: HFCs "were emitted from manufacturing . . ."—*Greenhouse Gas Inventory Japan,* 2015, p. 472. "In Germany it was wisely replaced by isobutane."—Information from *Greenhouse Gas Inventory Germany, 1990–2007,* p. 279 (the switch occurred "shortly after" 1994). HFC-134a "caused the most global warming of any HFC"—Information from IPCC, 2013, p. 679. Atmospheric concentrations + "The largest emissions occur . . ."—IPCC, 2013, p. 167.

HCFC-142b: Kroschwitz and Howe-Grant, vol. 6 ("Chlorocarbons and Chlorohydrocarbons—C_2" to "Combustion Technology"), p. 477 ("fluorine compounds, organic—introduction").

Footnote on HFC-134a: "Inhaled HFCs are not broken down . . ."—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 294.

CFC-11: Kroschwitz and Howe-Grant, vol. 6, pp. 508, 511 ("fluorine compounds, organic—(aliphatic)"); vol. 21 ("Recycling, Oil" to "Silicon"), p. 135 ("refrigeration"). "Extremely desirable for use with centrifugal compressors." —*Britannica,* 15th ed., vol. 15, p. 564 ("refrigeration equipment").

CFC-113: Kroschwitz and Howe-Grant, vol. 6, pp. 508, 511 ("fluorine compounds, organic—(aliphatic)").

PFC-14—IPCC, 2013, p. 733.

CFC-12: "facing the problem of replacing methyl chloride . . ."—Kroschwitz and Howe-Grant, vol. 6 ("Chlorocarbons and Chlorohydrocarbons—C_2" to "Combustion Technology"), p. 467 ("fluorine compounds, organic—introduction"); pp. 507, 511 ("fluorine compounds, organic—(aliphatic)"). "Traditionally used . . ."—Ibid., vol. 21, pp. 137, 140, 146 (another industrial refrigerant being HCFC-22). Sometimes called Freon—Referred as such in Magill, vol. 1, p. 421, the source for the information on 1990s automobile air conditioners; called "Freon" with a capital "f" in Metcalfe, Williams and Castka, p. 490, where CFC-12's odorlessness is mentioned. "Replaced by HFC-134a (whose 100-year GWP was a mere 1,430)"—Information from EPA-420-F-14-040a, p. 3. The 14-year lifetime and the range for the GWP of 1,590 to 3,800 come from the IPCC report.

CFC-12: "At one time . . . the third largest contributor to global warming"—IPCC, 2013, p. 53.

Perfluorocyclobutane and HFC-23—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 73 (Table 4: "Global Warming Potential (GWP) of greenhouse gases").

Information on PFPMIE—Young et al., pp. 2242, 2244–45. The original used round numbers—for instance, 9,000 × the GWP of carbon dioxide, instead of my 8,970 for the same figure, calculated from the article's [1.95 × the 100-year GWP of CFC-11 @ 4,600]. Since I had not rounded elsewhere in the table, I clung to my spurious precision.

HFC-23: "For process-related reasons . . ."—Ibid., p. 273. Origins of emissions, atmospheric lifetime + upper bound of GWP—IPCC, 2013, p. 168.

CFC-13: Kroschwitz and Howe-Grant, loc. cit.

Nitrogen trifluoride—IPCC, 2013, p. 733. Japanese emissions, 1990–2013—*Greenhouse Gas Inventory Japan,* 2015, p. 2-2. Emissions in 2013 were 1.4 million metric tons carbon dioxide equivalent. Ibid., p. 2-11: "Their increase since

CY1990 is mainly a result of an increase in fugitives from fl[u]orocarbon production."

GWPs of nitrogen trifluoride and carbon tetrachloride—IPCC, 2013, p. 733. I suspect that the IPCC report, being most recent, is more accurate than the figures in Kroschwitz and Howe-Grant, which are decades older. But I have quoted both of them in the table's range, to convey confusion and despair.

Nitrogen trifluoride: "A byproduct of fluorocarbon production and semiconductor manufacture"—Information from EPA, 2016, p. 31.

Sulfur hexafluoride: "Allows for more compact substations . . ."—EPA 2016, p. 304. "blown over molten magnesium metal . . ."—Ibid., p. 276. "The most potent greenhouse gas the . . . (IPCC) has evaluated."—Ibid., p. 202. "Used as a tracer gas . . ." + "currently the only viable way to measure emissions of methane from ruminant livestock . . ."—EU greenhouse report, 2014, p. 484, which continues: "A small charge of SF_6 is stored in a permeation tube, which is then introduced to the rumen of the animal. The gas emissions are vacuum sampled from eructation via a tube near the animal's muzzle connected to an evacuated flask. The total CH_4 emissions are inferred from the differential concentrations of SF_6 and CH_4." Use in Japanese AWACS radar—*Greenhouse Gas Inventory Japan,* 2015, p. 4-90. "common in switching systems [which have a minimum 40-year working life]"—Information from *Greenhouse Gas Inventory Germany, 1990–2007,* p. 298.

Sulfur hexafluoride in Germany + accompanying fn: "since 1975, SF_6 has been used to enhance . . ."—Ibid., pp. 301–3. Its use in auto tires "for reasons of image," in sports shoes and in solar collectors is mentioned in the same source, pp. 104, 303.

American sulfur hexafluoride emissions, 2012—U.S. Statistical Abstract, 2015, p. 254 (Table 393: "Emissions of Greenhouse Gases by Type and Source: 1990 to 2012"). Source: EPA, April 2014.

A typically helpful note from (what we shall soon introduce as) the *regulated community,* re: SF_6, emissions: "No information can be provided regarding quantities for the emissions sources 'shoes,' 'AWACS' and 'welding,' since the relevant data are confidential" (ibid., p. 278).

Information on all other compounds comes from I[ntergovernmental] P[anel on] C[limate] C[hange] Fourth Assessment Report: Climate Change 2007, https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html, downloaded for WTV by Jordan Rothacker, April 2016. "Climate Change 2007: Working Group I: The Physical Science Basis," sec. 2.10.2, "Direct Global Warming Potentials." [Henceforth cited: "IPCC report, 2007."]

About Greenhouse Gases (continued)

Carbon tetrachloride: "an excellent feedstock for Freon"—Information from Metcalfe, Williams and Castka, p. 362.

Footnote on gases limited by the Kyoto Protocol—*Greenhouse Gas Inventory Japan,* 2015, p. iii.

Footnote on atmospheric lifetime—Young et al., p. 2243.

"There have . . . been two dozen times during the past 46,000 years . . ."—Ward, p. 3188.

"The structure of a molecule affects both its lifetime . . ."—Young et al., p. 2245.

"The probability of landslides . . ."—Oleg Voitsekhovych, A. Jakubik, IAEA experts, consultants. "UMREG-2014. 23-24 09 2014. Freiberg. Germany. Preliminary Hazards Analyses at the Uranium Production Legacy Sites Minkush and Mailuu Suu Kyrgyzstan. Based on IAEA experts missions [*sic*] carried out during 2013 in the frame of CGULS [= Coordination Group for Uranium Legacy Sites] radiological survey assistance to the MS." (Freiberg: IAEA, 2014.) "These studies were carried out in the frame of KIG-7002 project and also supported by the CGULS project funded by EC (2012–2015) . . . Mailuu Suu (field mission 9-13 09 2013)." Page 20. [This document henceforth cited: "Voitsekhovych and Jakubik, 2014."]

"Erosion of riverbanks . . ."—Ibid., p. 23.

"the site of TSF No 15 . . ."—Ibid., p. 27.

"Strategic Action Plan for Complex Remediation . . ." + "No national strategy . . ."—Ibid., p. 28. Full name of the Plan: ". . . and Minkush."

"Atmospheric concentrations of HFCs . . ." to end of paragraph—All information about these various compounds from IPCC, 2013, pp. 13, 169.

Footnote: Effects of specific halocarbons on global warming—Ibid., p. 54.

Same footnote: "the Freons were actually getting more dilute . . ."—Ibid, p. 170.

"Between 1990 and 2012, HFC emissions in the EU-15 nations more than doubled."—EU greenhouse report, 2014, p. 102 (Table 1.24: "Data basis of actual HFCs, PFCs and SF6 emissions in CO2 equivalents (Gg)"): EU-15 HFCs: 1990, 27,832; 2012, 71,540—an increase of 2.57.

Sulfur hexafluoride emissions: "at least twice the reported values"—IPCC, 2013, p. 169.

HCFCs and CFCs *ca.* 2013—IPCC, 2013, p. 679: "The CFCs and HCFCs contribute approximately 11% [to global warming] . . . Although emissions have been drastically reduced for CFCs, their long lifetimes mean that reductions take substantial time to affect their concentrations. The RF [radiative forcing] from CFCs has declined since 2005 (mainly due to a reduction in the concentrations of CFC-11 and CFC-12), whereas the RF from HCFCs is still rising (mainly due to HCFC-22)."

Japan's hydrofluorocarbons emissions, 1990–2013—*Greenhouse Gas Inventory Japan,* 2015, p. 2-8. (Here is a different story: "In 2013, emissions from this category were 33,034 kt-CO_2 eq., and represented 2.3% of Japan's total GHG emissions (excluding LULUCF). The emissions had increased by 7.26 times since 1990" (p. 4-67). Evidently the HFCs and CFCs were being considered here only as "product uses as substitutes for ODS (2.F.)." They were also used in silicon chip manufacture, etc. Page 4-70 is of mournful interest: From 2002 onward, "amount of refrigerant" and "fugitive refrigerant ratio from operation" increased because devices became larger with the increase of commercial packaged AC devices. The "fugitive refrigerant ratio" during use was 2–17% (depending on the machine). Air conditioners got their own story on p. 4-75.

"Each question branches out into more and more questions . . ."—Béla Zombory-Moldován, *The Burning of the World: A Memoir of 1914,* trans. Peter Zombory-Moldovan (New York: New York Review Books, 2014; orig. ms. wr. bef. 1968), p. 11.

Footnote on HFC-134a: "The time series show a significant emissions increase . . ."—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 285.

Same footnote: Concentrations of that gas, 1990–2011—IPCC, 2013, p. 1402 (Table AII.1.1a: "Historical abundances of the Kyoto greenhouse gases").

Same footnote: "Global warming is a major environmental concern . . ."—*2012 ASHRAE Handbook: Heating, Ventilating, and Air-Conditioning SYSTEMS AND EQUIPMENT,* inch-pound edition (Atlanta: ASHRAE, 2012), p. 43.9 ("Liquid Chilling Systems").

Same footnote: American HFC emissions, 1990–2014—EPA, 2016, p. ES-8.

"The most important energy-related gas is CO_2 . . . "—EU greenhouse report, 2014, p. 127.

Footnote: "other relevant products . . ."—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 295.

Comparative Responsibilities for Greenhouse Gas Emissions

Information from *Encyclopedia of Agriculture and Food Systems,* vol. 2, p. 295 (J. Chen et al., "Climate Change, Society, and Agriculture: An Economic and Policy Perspective").

About Fuels

Epigraph: "Fuel—petrol and benzine! . . ."—Fyodor Vasilievich Gladkov, *Cement,* trans. A. S. Arthur and C. Ashleigh (Evanston, Illinois: Northwestern University Press, 1994; orig. Russian ed. not listed; *ca.* 1920?), p. 115.

My opening remarks about a fuel being an energy-rich substance that gives off energy-poor combustion products is much indebted to Metcalfe, Williams and Castka, p. 394.

"Bonhams' modern and contemporary African art auction . . ."—*Financial Times,* Europe edition, Saturday, March 28–Sunday, March 29, 2015, FT Special Report, p. 1 (Maya Jaggi, "Continent's economic revival boosts prices: Africa's artists are enjoying a rising market").

Footnote: "The prices on which consumers base their decisions . . ."—OECD, 1974, p. 64.

Same footnote: "It has also been shown that the greater the peat consumption . . ." —*Long-Term Energy Resources,* p. 639 (André Chamberland, Institut de recherche de l'Hydro-Québec, "Peat Gasification for Diesel Generating Stations").

Per capita global fuel combustion figures for 2010—Gutowski et al., *Annu. Rev. Environ. Resour.,* 2013, p. 100 (Table 5), converted by WTV from 4.35 metric tons.

EU fuel combustion emissions in 2012—EU greenhouse report, 2014, p. xi (Tables ES.6 and ES.7).

Japan: "fuel combustion" caused 95.4% of her CO_2 emissions in 2013—Information from *Greenhouse Gas Inventory Japan,* 2015, p. 2-3. On p. 3-1 we read that "in FY2013, emissions from fuel combustion were 1,258,202 kt-CO_2 eq., which accounted for 89.4% of Japan's total GHG emissions (excluding LULUCF) . . . The major contributing factors for the rise in emissions from 1990 are the increase of fossil fuel consumptions [*sic*] accompanied by the rise in electricity consumption and in traffic demand of passenger cars."

"The primary greenhouse gas emitted by human activities . . ."—EPA, 2016, p. 30.—Energy Information Administration, *Annual Energy Review 2000* (Washington, D.C.: Energy Information Administration, August 2001), p. xxxiii: "In the United States, fossil fuel combustion is responsible for 98 percent of all emissions from carbon dioxide . . . Total carbon dioxide emissions reached 5.6 billion metric tons . . . in 1999, 13 percent higher than the 1990 level."

"Affordable, reliable, and plentiful energy . . ."—"POLICY TIPS: POLICY ANALYSIS FROM THE HEARTLAND INSTITUTE, August, 2016: Five Elements of a Pro-Energy, Pro-Environment, Pro-Jobs Plan" (downloaded for

WTV by Jordan Rothacker, October 2016; no specific web address, but we are invited to e-mail the Heartland Institute at think@heartland.org). [Henceforth cited: "Heartland Institute FAQ, August, 2016."]

Comparison of packaging waste and tires—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 144 (Table 22: "Inputs of secondary fuels in the cement industry: emission factors and their biogenic components").

1 kg emissions per 1 TJ of combusted fuel = 2.2046 lbs emissions per 948,067,700 combusted BTUs = 1 / 430,040,687.65 lbs/BTU. Therefore, at 56,854 kg/TJ = 56,854 / 430,040,687.65 = 1 / 7,563.948 lbs/TJ, making for 1 lb per each 7,563.948 BTUs. By the same logic, 97,319 kg/TJ = 1 lb per 4,418.867 BTUs. The ratio between those two products equals 1:1.7117.

"Nuclear power is essential . . ."—*The New York Times,* Sunday, January 1, 2017, "Sunday Review" section, p. SR8 (Letters: "Nuclear Power, Debated": Michael Mallary, Sterling, Mass.).

"contains more heat energy . . ."—Andrew Norman, John "Drew" Corinchock and Robert Scharff, *Diesel Technology: Fundamentals, Service, Repair* (Tinley Park, Illinois: The Goodheart-Willcox Company, Inc., 1998).

Footnote: "As a fuel for internal combustion engines, diesel . . ."—Kroschwitz and Howe-Grant, vol. 12.

Average Fuel Consumption in Moving One American Electric Light Rail Car One Mile

Data from DOT, June 1979, p. II-14 (Table 2-11: Electric Light Rail Transit Energy Consumption), "default value energy consumption per car mile." All converted from: coal, 3.18 lbs; diesel fuel, 0.29 gal; gasoline, 0.32 gal; natural gas, 37.20 cu ft; manufactured gas, 74.40 cu ft.

For how I made the conversions, see the "Definitions, Units and Conversions" section, section 9A ("Weights and Densities of Fuels"). In this table alone, for gasoline I took the average of [5.935 and 6.152] lbs per gal given in Baumeister, thinking that this mid-20th-century source was closer in time to 1979 than any current figure. Elsewhere in the book I have relied on my period's 6.152 lb/gal.

About Fuels (continued)

"Alcohol *versus* kerosene made a comparable conundrum"—According to Ellis and Rumely, p. 113, alcohol held 10,200 to 12,900 BTUs per pound, while there were 20,000 in gasoline or kerosene. But although 1.8 times as much alcohol as gasoline was needed to produce the same amount of power (evidently in a tractor engine), the thermal efficiency of alcohol was superior.

BTUs per kilowatt-hour—EIA, 7/13/2016: "Power plant heat rates (for steam electric generators in 2014) Coal = 10,080 Btu/kWh[;] Natural gas = 10,408 Btu/kWh[;] Petroleum = 10,156 Btu/kWh."

Worldwide energy produced and electricity generated, 1980 and 2011—U.S. Statistical Abstract, 2015, p. 896 (Table 1391: "Net Electricity Generation by Energy Source and Country: 2011"); and same page (Table 1392: "World Primary Energy Production by Region and Type, 1980 to 2011"). Source: U.S. Energy Information Administration.

"enough to electroprocess 457 million tons of titanium"—Calculated from 187.3 quadrillion BTUs / 68,260 BTUs per lb of electroprocessed titanium (see p. 61), then dividing by 3 to get 457,320,050.7.

"Fossil fuels possess almost ideal properties for humans."—Rolf Peter Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution,* trans. Michael P. Osman (Cambridge, U.K.: White Horse Press, 2001 trans. of 1982 German ed.), p. 204.

"The higher the heating value of a motor fuel, the greater its fuel economy."—For instance, see Kroschwitz and Howe-Grant, vol. 12, p. 369 ("gasoline and other motor fuels," Fig. 5, which shows [pp. 368–69] that "the fuel economy in modern vehicles responds linearly and with a slope of almost unity to changes in the energy content of the fuel."

"Energy-sector employment is one of the few bright spots . . ."—*Time,* vol. 185, no. 3, February 2, 2015, p. 34 (various reporters, "Economy: The Cost of Cheap Gas").

Footnote on impossibilities—Ibid., p. 1172.

Table A: 0.4 metric tons [MT] coal yields 1 barrel of oil—Information from James E. Duffy and Howard Bud Smith, *Auto Fuel Systems* (South Holland, Illinois: The Goodheart-Willcox Company, Inc., 1987), p. 83: 1 MT coal yields 2.5 barrels of "synthetic oil suitable for refinement in gasoline." Hence 1.1023 tons / 2.5 barrels = 0.44902 tons per barrel.

Pound conversion of same: [0.44902 × 2,000] = 881.84.

4 to 5 MT tons of tar sand yields 1 barrel of oil—Duffy and Smith, p. 83.

Pound conversion of same—[4.5 ave. mt × 1.023 U.S. t × 2,000 lbs/t] = 9,920.7 lbs.

Pound conversion of 1 barrel of oil—42 gal × 7.036 lbs/gal [= density of fuel oil] = 295.512 lbs.

1 barrel of oil yields [less than] ½ barrel of gasoline—Duffy and Smith, p. 65: 1 barrel of oil = 46.2% gasoline, or [0.462 × 42] = 19.404 gal, which × 6.152 lbs/gal l [= density of gasoline] = 119.373 lbs.

Footnote: "In energy content, it takes about 6,000 cubic feet of natural gas . . ." —Deffeyes, p. 59. Multiplying this number by [0.0283166 cubic meters / cu ft] yields 169.8996 cu m. (Moreover, "6 mcf = 1 barrel of oil on a BTU basis" comes verbatim from Mr. Sam Hewes [interview of July 9, 2016; see the Oklahoma oil section].) Cf. Butler and Wurthner, p. 103: "Global natural gas production equals 3,139 billion cubic meters annually, which is the energetic equivalent of 21 billion barrels of oil . . . ," which implies that 1 barrel of oil is about 149.476 or 150 cubic meters of gas.

N.B. Re the sometimes quoted "1 BTU = 1/1,000 cubic foot of natural gas"—David A. Waples, *The Natural Gas Industry in Appalachia: A History from the First Discovery to the Tapping of the Marcellus Shale,* 2nd ed. (Jefferson, North Carolina: McFarland & Company, 2012), p. 296, states that 1 cubic foot = "A unit of measurement for volume of gas approximately equal to one hundred BTUs." But see p. 564, "Definitions, Units, and Conversions."

Pound conversion of same—[6,000 cu ft × 0.04163 lbs/cu ft (= density of methane)] = 249.78 lbs.

Various fuels "from the standpoint of *innate energies*" in table C: As calculated from the table of Calorific Efficiencies (pp. 212, 214, 215, 217), dividing the HHV of oil (Mexican crude = 18,755) by that of gasoline (automotive, mid-20th-cent. = 20,750, to get 0.9), by that of coal (bituminous West Virginia average = 12,500, to get 1.5), by that of oil sands (= tar sands; bitumen alone = 17,768, to get 1.055), by that of natural gas (USEA value = 24,328, to get 0.77).

Equivalents in table D: 1 short ton of coal to crude, gasoline, etc. [+ information on 1 BTU, 1 MBTU, 1 Q-BTU]—National Coal Association, p. 90, citing Energy Information Administration. The same source also gives the following slightly different equivalents (pp. 10–11): "In general, U.S. coal deposits have an average heat content of 22 million Btu per ton. This is equal to the energy obtained by burning 22,000 cubic feet of natural gas, 160 gallons of distillate fuel oil, or one cord of seasoned firewood."

Table F: 1 BTU ~ energy of 1 match tip—National Coal Association, p. 90.

1 BTU ~ 1/112,500 gallon of gasoline—USDA Report 24, p. 20: 2.7 million BTUs is "roughly the equivalent of an additional 24 gallons of gasoline," in which case gasoline *ca.* 2010 was 112,500 BTUs per gallon.

1 BTU ~ 1/12,500 pound of coal—Calculated from West Virginia Coal Association's oft-stated average HHV of 1 lb of coal = 12,500 BTUs.

1 ton of coal equivalent = 0.7 ton of oil equivalent = 27,776,000 BTUs—*Coal Information 2012,* p. I.17 (BTU calculation by WTV, from 1 kcal = 3.968 BTUs).

Same table—Starting from the just cited sentence "in general, U.S. coal deposits have an average heat content of 22 million Btu per ton," I divided by sides by 22 million and multiplied by 2,000 lbs to obtain: 1 BTU = 1/10,999.99 . . . lb of coal.

"Who is enslaved by physical needs . . ."—Ayn Rand, *Atlas Shrugged* (New York: New American Library / Signet, n.d. [*ca.* 1975]; orig. ed. 1957), p. 976.

Table G—U.S. energy expenditure in 2007, and percentage from fossil fuels—USDA Report 24, p. 3. Apparently one-fourth of our energy was imported, 80% of that being "crude oil and petroleum products."

Pound-equivalents in this first chart—Calculated by WTV using the densities of natural gas [as methane], of oil [as diesel] and gasoline, on p. 582, and converting from cubic meters to cubic feet per p. 589.

Equivalents: Coal or tar sands to oil to gasoline—Information from James E. Duffy and Howard Bud Smith, *Auto Fuel Systems* (South Holland, Illinois: Goodheart-Willcox Company, Inc., 1987), pp. 65, 83.

Equivalents: 1 barrel of oil = 150 cubic meters of natural gas—Butler and Wurthner, p. 103: "Global natural gas production equals 3,139 billion cubic meters annually, which is the energetic equivalent of 21 billion barrels of oil . . .," which implies that so 1 barrel of oil is about 149.47 or 150 cubic meters of gas.

Equivalents: 1 ton of coal equivalent = 0.7 ton of oil equivalent = 27,776,000 BTUs—*Coal Information 2012,* p. I.17 (BTU calculation by WTV, from 1 kcal = 3.968 BTUs).

Equivalents: 6 mcf = 1 barrel of "oil on a BTU basis"—Verbatim from Mr. Sam Hewes [interview of July 9, 2016; see the Oklahoma oil section].

Footnote: "in energy content, it takes about 6,000 cubic feet of natural gas . . ."—Deffeyes, p. 59.

"In a white-washed kitchen in the glen . . ."—Peig Sayers, *An Old Woman's Reflections: The Life of a Blasket Island Storyteller,* trans. Séamus Ennis (New York: Oxford University Press, undated pbk. repr. of 1962 ed.), p. vii (introduction by W. R. Rodgers).

Peat HHV of 8,600 BTUs per pound—U.S. Geological Survey, Energy Program *Chemical Analyses in the World Coal Quality Inventory, Version 1.* Compiled by Susan J. Tewalt, Harvey E. Belkin, John R. SanFilipo, Matthew D. Merrill, Curtis A. Palmer, Peter D. Warwick, Alexander W. Karlsen, Robert B. Finkelman, and Andy J. Park. Presumed date: 2006 [but possibly 2007]. Microsoft Excel file downloaded by Jordan Rothacker, April 2016. [Henceforth cited: "WoCQI, 2006."] Row converted by WTV from 1995 MJ/kg to 8,577 BTUs/lb, which I rounded to

8,600 to avoid spurious precision based on this one sample. For the two immediately following peat HHVs in the same paragraph, see p. 210, headers **72** and **83**.

“Most kinds burn with a red smoky flame . . .”—*Britannica,* 11th ed., vol. XI (FRANCISCANS to GIBSON), p. 274 (“fuel”).

Peat “had already released clouds of carbon dioxide, methane and nitrous oxide during its drying”—EPA, 2016, 428: “On-site emissions from managed peatlands occur as the land is cleared of vegetation . . . CO_2 is emitted from the oxidation of the peat . . . Peatlands located on highly fertile soils contain . . . organic nitrogen in inactive form. Draining land in preparation for peat extraction allows bacteria to convert the nitrogen into nitrates which leach to the surface where they are reduced to N_2O, and contributes to the activity of methanogens, which produce CH_4, and methanotrophs which oxidize CH_4 into CO_2.”

Footnote: “Globally, peatlands store more than half of total soil carbon” + their carbon emissions (100 times and more those on mineral soils) + “Peatland emissions derive from the use of fire . . .”—*Encyclopedia of Agriculture and Food Systems,* vol. 2, p. 224 (M. van Noordwijk’s entry).

Same footnote: “Practically all cultivated soils in the world are very much in need of nitrogen . . .”—De Geus, p. 21.

“a significant source of energy for Russia, Finland, and Ireland”—Kroschwitz and Howe-Grant, vol. 12 (“Fuel Resources” to “Heat Stabilizers”), p. 15 (“fuel resources”).

“Often neglected in earlier years . . .”—*Long-Term Energy Resources,* p. xlix (introduction).

Lignite: “Some was calorifically inferior to peat.”—*Britannica,* loc. cit.

Carbon Dioxide Emissions of Common Fuels, in multiples of natural gas’s

Source: *Greenhouse Gas Inventory Germany, 1990–2007,* pp. 450–55 (Table 134: “Aggregation and allocation of basic emission factors for CO_2, as of 1990—energy”), values from 2007 column.

The units: [pounds of CO_2 released for each 10,000 BTUs released by the combusted fuel]—These were originally expressed in the typical metric units of most of the world’s greenhouse gas inventories: metric tons of CO_2 per terajoule [TJ] of energy. In American units, this ratio would be 1 pound of emissions per 430,955 BTUs. Since [in the case of hard coal] 94 lbs per 430,955 BTUs = a visually wearisome 0.00021812 lb per BTU, I multiplied everything by 10,000 to get 2.1812 lbs per 10,000 BTUs. This energy level (the 10,000 BTUs) corresponds to the central part of the table of Calorific Efficiencies on p. 208.

Footnote: "The amount of C emitted from the combustion of fossil fuels . . ." —EPA, 2016, p. 3–28.

Peat: "Higher than the I[mplied] E[mission] F[actor] of hard coal"—EU greenhouse report, 2014, p. 150.

Carbon Dioxide Emissions of Common Fuels, in multiples of lignite's

Original data from Environment—U.S. Energy Information Administration (EIA). Release Date: February 2, 2016, "Carbon Dioxide Emissions Coefficients" (PDF downloaded from https://www.eia.gov/environment/emissions/co2_vol_mass.cfm for WTV by Jordan Rothacker, June 2016). All figures converted by WTV from original units to pounds of carbon dioxide emitted by burning a pound of the stated fuel. The densities I used for these calculations appear in the statistical end matter (pp. 581–83). For gasoline I arbitrarily used the heavier value of 6.152 lbs/gal.

The 4.8-fold difference between a lignite and an anthracite—The lignite is the stuff burned by the brickmaker R.C. in the Bangladeshi chapter (II:273). Its stated HHV is 2,450 BTUs/lb (converted by me from joules per kg). Its rival is Virginia anthracite coal at a HHV of 11,850 (p. 211, "Comparative Calorific Efficiencies . . .").

10LL and JET A-1 figures—*Plane & Pilot*, August 2017, p. 10 ("Plane Facts"). "Most commonly used aviation gasoline for piston engines" is blue 100LL [which has tetraethyl lead "to allow increased engine compression without detonation"]. Density of all grades of avgas at 15° C is 6.01 lbs/U.S. gal. Given emission coefficient is 18.4 lbs carbon dioxide per combusted gal, which divides out to 3.06 lbs carbon dioxide per lb. "Most commonly used aviation gasoline for turbine engines" is straw-colored, kerosene-based unleaded JET A-1, whose density at 15° C is 6.71 lbs/U.S. gal and whose emission coefficient is 21.1 lbs carbon dioxide per combusted U.S. gal, which converts to 3.14 lbs per combusted lb.

Cross-check for gasoline entry—EPA fact sheet EPA-420-F-14-040a, May 2014, "Questions and Answers: Greenhouse Gas Emissions from a Typical Passenger Vehicle," p. 2, explains: "Most vehicles on the road in the U.S. today are gasoline vehicles, and they average about 21.6 miles per gallon. Every gallon of gasoline creates about 8,887 grams of CO_2 when burned." This equals 19.59647 pounds of carbon dioxide, which is awfully close to the EIA figure.

Combined emissions of 2016 American aviation gas and kerosene-based jet fuel, if it were all combusted—According to *Plane & Pilot,* August 2017, p. 10 ("Plane Facts"), there were 4,080,000 barrels aviation gas produced in the United States in 2016. Since 1 barrel = 42 gal, that would be 171,360,000 gal, which, at the given emissions coefficient of 18.4 lbs of carbon dioxide per combusted U.S. gal, would give off 3,153,024,000 lbs of carbon dioxide. Meanwhile (loc. cit.), there were 576,317,000 barrels of kerosene-based jet fuel produced in the United States in 2016. That substance's emissions coefficient was again 18.4 lbs of carbon dioxide per combusted gal, which works out to 510,732,125,500 lbs carbon dioxide if it all got burned. Hence total carbon dioxide emissions would be 3,153,024,000 + 510,732,125,500 = 513,885,148,500 lbs.

About Fuels (continued)

"From well to wheels, burning a gallon of gasoline . . ."—*The New York Times,* Thursday, March 10, 2016, p. A23 (op-ed: Daniel F. Becker and James Gerstenzang, "Stalling on Fuel Efficiency").

Footnote on emissions of three cars—See (II:418–19, in the "About Internal Combustion Engines" section) the table "Carbon Dioxide Emissions of Three New-Model American Cars, 2016."

Footnote: "When oil prices plummeted . . ."—The Putnam Fund for Growth and Income, semiannual report, April 30, 2015, p. 8 (Robert D. Ewing, "Interview with your fund's portfolio manager").

"The kettle's cover teeters and rings . . ."—Kahedmul Islam, comp. and trans., *On the Side of the Enemy: Short Stories in Translation* (Dhaka, Bangladesh: Bengal Lights Books, 2014), p. 72 (Syed Shamsul Huq, "A Life Like a Story"). For another beautiful description of fire, see pp. 170 and 172 of N. Scott Momaday, *House Made of Dawn* (New York: Harper Perennial Modern Classics, 2010; orig. ed. 1968).

Footnote: "And if your phone dies . . ."—*The New York Times,* Wednesday, June 28, 2017, p. D4 (Kim Severson, "Campsite Cooking Sheds Its Rough Edges").

"How much would those enchantments have warmed our atmosphere?"—See *Greenhouse Gas Inventory Germany, 1990–2007,* p. 176 (Table 33: "Sectoral emission factors for combustion systems in the residential and commercial/institutional sectors for reference year 2005"), residential use: unprocessed wood. For each terajoule this stuff provided, it emitted 100 kg methane, and 1.5 kg of nitrous oxide. Since 1 TJ = 948.1 MBTU, then we have: 100 kg methane / 948.1 MBTU = [2.2 × 100] lb / 948.1 MBTU = 0.00000232 lb methane per BTU = 1 lb methane per 4,309,546 BTUs. Selecting from the table of Calorific Efficiencies (p. 210) the 1958 average HHV of dry, resin-free American wood = 8,300 BTUs/lb, we get (4,309,546 / 8,300) = 519.2 lbs burned wood per pound of emitted methane. By a similar procedure, we get 76,152.6 lbs wood per lb nitrous oxide.

"each wood-pound we threw in the fire gave off 1.2 pounds of carbon dioxide"—Since the "range of sample wood-energies from 4,082 to 5,340 BTUs" averages

4,711 BTUs/lb, and the previous text table estimates 2.599 lbs carbon dioxide per 10,000 BTUs, then (because 4,711 goes into 10,000 2.12269 times) we must divide 2.599 by 2.12269 to get carbon dioxide emissions in pounds given off per combusted pound: 1.224.

Let me also mention that mid-19th-century German folktale of the count who tested a dreamy foundling's worth by telling him to chop all the wood in his courtyard within a month. Such was the boy's magical success that the count had him "trained as a knight." Franz Xaver von Schönwerth, *The Turnip Princess and Other Newly Discovered Fairy Tales,* comp. Erika Eichenseer, trans. Maria Tatar (New York: Penguin, 2015; orig. tales collected *ca.* 1850s), pp. 112–15 ("Woodpecker").

Citations from "Daughters of the Vicar"—D. H. Lawrence, *The Complete Short Stories,* vol. 1 (Hammondsworth, Middlesex, England: Penguin Books Ltd., 1977 repr. of 1961 Viking ed.), pp. 136, 161, 179, 180.

"Coal is our most abundant energy resource"—National Coal Association, p. 6.

"fossil fuels made up about 83% of our 'overall global energy supply'"—Darling and Sisterson, p. xix. But on p. 171 these authors claim that nuclear made up 6%, and renewables the remaining 10%, so that by my math fossil fuels would have made up more like 84%.

Criticisms of Common Fuels

Coal: "Compared to oil and gas, coal produces the highest amount. . ."—Olah, Goeppert and Prakash, p. 34. James Hansen—Butler and Wurthner, p. 61.

Natural gas "Conventional natural gas . . ."—Ibid., p. 82.

Natural gas: "Natural gas systems . . ."—EPA, 2016.

Oil: "An evil Power . . ."—Upton Sinclair, *Oil!* (Berkeley: University of California Press, 1996 repr. of 1926 ed.), p. 527.

Oil—Antonia Juhasz, *The Tyranny of Oil: The World's Most Powerful Industry—And What We Must Do to Stop It* (New York: HarperCollins / William Morrow, 2008), p. 2.

Nuclear power—Coalition for Direct Action at Seabrook, *It Won't Be Built! Seabrook May 24, 1980 Occupation / Blockade Handbook,* p. 4.

About Fuels (continued)

World carbon dioxide emissions, 1971–2009 + fn: "However, this is 455 million tons less . . ."—*Coal Information 2012,* p. II.15 ("million tons" was "Mt" in the original).

"In areas which are heavily forested the direct burning of wood . . ."—Han, p. 38.

"some of us had to burn two-thirds of a ton of coal to make one ton of steel"—Information from *The Welch News* [McDowell County, West Virginia], volume 90, number 033, Friday Evening, March 28, 2014, Special Coal Edition, p. 3D (Jason Bostic, "Coal and Steel").

Gasoline: "pound for pound, 'produces more total energy than dynamite.'"—Ibid., p. 83.

Comparative Calorific Efficiencies, in Multiples of the Thermal Energy of Blast Furnace Gas

The "three lower and possibly more realistic 'working values'": 107 (generic "coal"), 226 ("petroleum") and 264 ("natural gas")—"7/13/2016 How much coal, natural gas, or petroleum is used to generate a kilowatt-hour of electricity?—FAQ—U.S. Energy Information Administration (EIA)," downloaded for WTV by Jordan Rothacker, July 2016, from https://www.eia.gov/tools/faqs/faq.cfm?id=667&t=8. "Last updated: February 29, 2016." According to this source [henceforth cited "U.S. EIA, July 2016"]: "Amount of fuel used to generate 1 kWh: Coal = 0.00052 short tons or 1.04 pounds. Natural gas = 0.01011 Mcf (an Mcf equals 1,000 cubic feet). Petroleum = 0.00173 barrels (or 0.07 gallons)." In short, to generate 1 kWh [which presumably implies the standard ⅔ power plant wastage], requires the following: 1.04 lbs coal, or 0.01011 Mcf [= thousand cubic feet] natural gas, or 0.07 gal petroleum. This means 1 lb coal generates 0.96 kWh = [multiplying by 3,413] 3,281.730 BTUs. By comparable arithmetic: 1 lb natural gas [calculated per density of methane @ 0.04163 lbs/cu ft] generates 8,109.213 BTUs, and 1 lb petroleum [calculated per density of diesel @ 7.036 lbs/gallon] generates 6,929.668 BTUs. Multiplying each of these calorific efficiencies by 3 to get something comparable to the LHV, we get: Coal, 9,845.19 BTUs/lb; petroleum, 20,789.004; natural gas, 24,327.639.

Efficiency of blast furnace gas, Pittsburgh natural gas, refinery oil gas—Baumeister and Marks, p. 7-32 (Table 24, "Characteristics of Typical Gaseous Fuels"). "Blast furnace gas has a very low calorific value . . ."—A. Jackson, *Modern Steelmaking for Steelmakers,* rev. ed. (London: George Newnes Ltd., 1967; orig. ed. 1960), p. 72.

Efficiency of blast furnace gas: 105 BTUs per cubic foot—Jackson, p. 71.

1974 value for efficiency of lignite—OECD, 1974, vol. 2, p. 4.

Energy in a pound of TNT—From Electropaedia website, accessed June 22, 2016: 1 ton TNT = 4.184 GJ. Therefore 1 lb TNT = 1/2,000 (3,966,712 BTUs) = 1,983.356 BTUs.

The other figure for TNT—J . L. Maienschein, "Estimating Equivalency of Explosives Through a Thermochemical Approach" (UCRL-JC-147683), U.S. Department of Energy, Lawrence Livermore National Laboratory, July 8, 2002. Submitted to 12th International Conference Symposium, San Diego, California, August 11–16, 2002. [Henceforth cited: "Maienschein, 2002."] Page 6: TNT's density is 1.654 g/cc. Its total energy of combustion is 7.403 kJ per cc. To convert each kJ/cc to BTUs/lb I used: 1 kJ/cc × 1 cc/ D g [where D = density in g/cc] × 453.5 g/lb × 1 BTU/1.0548 kilojoules = [429.9393/D] BTUs/lb. Hence TNT's total energy of detonation is 1,924.3294 BTUs/lb. On this same page, TNT's heat of combustion is given as 3474 cal/g. To convert each cal/g to BTUs/lb I used: 1 cal/g × 1 kcal/1,000 cal × 453.5 g/lb × 1 BTU/0.252 kcal = 1.9776 BTUs/lb. Therefore, TNT's heat of combustion is 6,251.822 BTUs/lb.

The "assertion in a physics textbook"—Jerry B. Marion, *Physics and the Physical Universe* (New York: John Wiley & Sons, 1971), p. 261: "The explosion of 1 ton of TNT releases approximately 4.1 × 10^{16} ergs." Therefore, [1 ton /2,000 lbs] × 4.1 × 10^{16} ergs = 0.00205 × 10^{16} ergs = 2.05 × 10^{13} ergs × [1 IT cal / 4.187 × 10^{7} ergs] cal × [1 BTU / 251.996 IT cal] = 1,942.93 BTUs.

"TNT is carbon-rich . . ."—Maienschein, 2002, p. 3.

PBXN-109—Ibid., p. 7. I used the same conversions as for TNT [HHV = 1,983 or 1,924], using the following original figures: density, 1.662 g/cc; total energy of detonation, 11.818 kJ per cc, heat of combustion, 4,310 cal/g. [This source gives it a TNT equivalent of 1.59. When I divide its total energy of combustion by TNT's I obtain 1.36.]

Carbon monoxide—According to Metcalfe, Williams and Castka, this gas's heat of combustion = 67.64 kcal per mole, which equals = 67.64 kcal per ([12.011 g = atomic weight of C] + [15.999 g = atomic weight of O] = 28.01 g). Hence the height of combustion of CO = 2.4149 kcal/g. Multiplying by 1,798.7961584, we obtain 4,343.83 BTUs per pound.

Wood efficiencies—Selected from Baumeister and Marks, p. 7-19 (Table 12, "Approximate Weights and Heat Values per Cord of Fuel Woods"). "The standard cord is 8 ft long, 4 ft high, and 4 ft wide, or 128 cu. feet as piled, but the actual solid wood content is only about . . . 90 cu. ft for wood of average size." Barkley and Rice's table gives BTUs per cord. Since they provide each wood's weight in pounds per cord, I have divided each wood's BTU figure by that wood's cord-weight to express the efficiency in BTUs per pound. For example, 1 cord of white pine greenwood at 3,240 lbs per cord yields 17.3 million BTUs per cord. Thus 1 lb of this wood produces 17,300,000/3,240 = 5,340 BTUs per lb. The figures for willow charcoal and tanbark come from Table 11 on the same page, in which HHV is already expressed in BTU/lb.

Wood gives off "the highest amount of carbon emissions per unit of energy produced . . ."—Chris Faulkner, p. 3.

Efficiencies of threshed straw, corn, city garbage—Ibid., pp. 7-20–7-21.

"Harvested wood," Japan—*Greenhouse Gas Inventory Japan,* 2015, p. 3-29 ("Table 3-17: Theoretical exhaust gas and air volumes, and higher heating values for different fuels"). Original value was 14,367 kJ/kg. [1 kJ/kg = 0.4299226 BTUs/lb.]

"Typical" HHV of air-dried peat—Ibid., p. 7-18 (J. F. Barkley and W. E. Rice, "Peat, Wood and Miscellaneous Solid Fuels").

Peat "seldom contains more than 60 percent carbon"—Magill, p. 434 ("coal gasification").

Coal efficiencies—Selected from Baumeister and Marks, pp. 7-3–7-6 (Table 1, "Analyses of Mine Samples and Average Analyses of Delivery Samples of Anthracite," Table 2, "Analyses of Mine Samples and Analyses of Delivery Samples from Bituminous, Subbituminous, and Lignitic Coal Regions of the United States"). I have chosen the highest and lowest values, then selected others which seemed especially informative.

"Alcohol," 1911—Ellis and Rumely, p. 113.

General approximate efficiencies for lignite and subbituminous coal—William L. Leffler, *Petroleum Refining in Nontechnical Language,* 4th ed. (Tulsa, Oklahoma: PennWell Corp., 2008; orig. pub. 1979), p. 214.

Efficiency of Barapukuria lignite coal—Information from laminated brochure: "Barapukuria Coal Mining Company Limited (a company of Petrobangla)," n.d. (after 1998; collected 2015).

1974 value for efficiency of "hard coal"—OECD, 1974, vol. 2, p. 4.

Efficiency of coke—Lom and Williams, p. 58 (Table 4.1, "Typical Properties of Solid Fuels.")

Japanese charcoal—*Greenhouse Gas Inventory Japan,* 2015, p. 3-29 (Table 3-17: "Theoretical exhaust gas and air volumes, and higher heating values for different fuels"). Original value: 30,500 kJ/kg. Charcoal's composition: graphite crystals—Knapp, p. 22.

The "general approximate value for the energy in a pound of coal"—Figure from Baumeister and Marks, p. 9-184 (C. H. Etheridge, "Atomic Power"). The steelmaker's figure for the same comes from Jackson, p. 71. "Each pound of coal supplies enough electricity to light 10 light bulbs (100 watt) for about an hour."—National Coal Association, p. 58. *However, that works out to only*

[3,413], because this would be 10 bulbs × [60 minutes per hour] × [5.6884 BTUs per minute per 100-watt bulb] = 3,413.04 BTUs per hour.

"Combustion of a pound of pure carbon"—Ibid., p. 9-189 (Etheridge).[I have added the descriptor "pure," assuming that this must be what is meant and what distinguishes this yield from the yield of a pound of coal, which contains impurities.] This figure seems plausible, because [according to Metcalfe, Williams and Castka, p. 394), the heat of combustion of carbon = 94.05 kcal per mole. The atomic weight of that element is 12.011 grams. Hence C gives off [94.05 kcal/ 12.011 g] = 7.829 kcal/g. Since 1 kcal/g = 1,798.7961584 BTUs/lb, carbon gives off 14,083.65 BTUs/lb.

Efficiency of pitch—Jackson, p. 71.

Chemical energy of fats—Metcalfe, Williams and Castka, p. 376, converted from 9 kcal/g as follows: 1 kJ/kg = 0.4299226 BTU/lb, and 1 calorie = 4.184 joules, so 1 kcal = 4,184 joules = 4.184 kJ. Since 1 kcal/g × [4.184 kJ/kcal] = [4.184 kJ/g × 1,000 g /kg] = [4,184 kJ/kg] × 0.4299226 kj/kg per BTU/lb] = 1,798.7961584 BTUs/lb, then multiplying this number by 9 to get 16,189.165 yields the equivalent.

Footnote: "Without the light-driven conversion . . . of water . . ."—Wilson et al., p. 385.

Efficiency of oil sands (bitumen only)—L. Douglas Smoot and Philip J. Smith, *Coal Combustion and Gasification* (New York: Plenum Press, 1985), pp. 34–35 (Table 2.1). HHVs are expressed in kJ/kg, so in all cases I have divided by 2.33. The original figure for the oil sands was 41,400 kJ/kg. Note: This table gives the following relevant HHVs (type of material never stated): wood, 8,927 BTUs/lb, which is higher than any specific wood efficiencies in Baumeister and Marks; peat, 8,498, which approximates my listed 8,462 for salt marsh water-free peat, Kittery, Maine; and Wyoming subbituminous coal, 11,888, which fits in plausibly with other coal HHVs and which I have inserted into the chart.

Peat efficiencies—Selected from Baumeister and Marks, p. 7-18 (Table 10, "Analyses and High Heat Values of Air-dried Peat").

Efficiency of methanol—Olah, Goeppert and Prakash, p. 186, where methanol's energy content is given at 5429 kcal kg^{-1} [= 5,429 kcal/kg]. Multiplying by [1 kcal/kg = 1.7987961584 BTUs/lb], we obtain 9,765.664 BTUs/lb.

Efficiencies of methyl alcohol, ethyl alcohol, coal tar—Baumeister and Marks, p. 7-30.

Efficiencies of gasified anthracite, coke and West Virginia bituminous coal—Ibid., p. 7-55 (Table 1, "Typical Process Transformers").

Average HHV of dry, resin-free wood, and of resin—Loc. cit.

Japanese "indigenous natural gas"—*Greenhouse Gas Inventory Japan,* 2015, p. 3-12, converted from 40.2 MJ/kg @ 1 MJ/kg = 429.9226 BTUs/lb.

Efficiencies of heavy, medium and light commercial fuel oils—Lom and Williams, p. 78 (Table 4.12, "Typical Properties of Commercial Fuel Oils").

Efficiencies of different specific gravities of petroleum oil—Baumeister and Marks, p. 7-23 (Table 16: "Heat Values of Petroleum Oils").

Footnote on toe variations in kcal—OECD, 1974, vol. 2, p. 3, converted as follows: [1 metric ton / 1.10 short ton] × [10,000,000 kcal/metric ton] × [1 short ton / 2,000 lbs] × [1 BTU / 0.252 kcal] = 18,037.5 BTUs/lb.

Efficiencies of Mexican crude, California crude, kerosene and gasoline—Baumeister and Marks, p. 7-21 (R. M. Gooding, "Petroleum and other Liquid Fuels," Table 14, "Analyses and High Heating Values of Crude Petroleum . . ."); also (for gasoline and kerosene), pp. 7-24, 7-26, and (for gasoline only), p. 9-124 (Table 10, "Properties of Constituents of Internal-combustion-engine Fuels").

Per-cubic-foot efficiency in diesel in comparison to gasoline—Duffy and Smith, p. 76.

"diesel-powered vehicles typically get 30–35% more miles per gallon . . ."—www.fueleconomy.gov [downloaded June 2016 by Jordan Rothacker], U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, U.S. Environmental Protection Agency, "Model Year 2014 Fuel Economy Guide," updated March 11, 2016 (Laurel, Maryland: U.S. Government Printing Office, Laurel Publications Distribution Center c/o Fuel Economy Guide). PDF p. 33. [Henceforth cited: "2014 Fuel Economy Guide."]

Efficiency of light naphtha—Lom and Williams, p. 67 (Table 4-7, "Typical Properties of Refinery Products (LPG to Gas Oil).")

Efficiencies of butane and propane—Baumeister and Marks, p. 7-33 (Table 25, "Average Properties of Commercial Propane and Butane"). The second efficiency figure for each gas comes from Lom and Williams, p. 67 (Table 4-7, "Typical Properties of Refinery Products (LPG to Gas Oil)."

Efficiencies of aviation gasoline, methane and pure hydrogen—Baumeister and Marks, p. 9-124 (Table 10). Aviation fuel: "Its total global warming impact . . ." —Berners-Lee and Clark, p. 150.

Efficiency of natural gas from Groningen, Holland—W. L. Lom and A. F. Williams*, Substitute Natural Gas Manufacture and Properties* (New York: John Wiley & Sons / Halstead Press, 1976), p. 28 (Table 2-3, "Some Properties of Various Natural Gases").

Efficiencies of liquefied petroleum gas and liquefied natural gas—http://greet.es.anl.gov/, accessed by Jordan Rothacker, June 2016: "GREET, The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model, GREET 1.8d.1, developed by Argonne National Laboratory, Argonne, IL, released August 26, 2010." [Henceforth cited: "GREET, 2010."]

Efficiencies of dry Soviet and dry American natural gas, 1980—U.S. DOE, 1982, p. 104 (Appendix D: "Gross Thermal Conversions by Energy Source").

Methane: "The single largest source of methane . . ."—Berners-Lee and Clark, p. 158. "Reacts readily with oxygen to release heat" + energy release expressed in kJ and kcal/g—Kroschwitz and Howe-Grant, vol. 12, p. 332. The other source, which gives an HHV of 18,056.75, is Emsley, p. 187 ("hydrogen"), converted from 42 kJ/g [= 42,000 kJ/kg × 0.4299226 = 18,056.75 BTUs/lb]. "Methane, the almost ideal fuel."—*Long-Term Energy Resources,* p. 5 (Joseph Barnea, "Long-Term Energy Resources and the Energy Outlook"). "The single largest source of methane . . ."—Berners-Lee and Clark, p. 158.

Footnote on "Khuff" natural gas—Organization of Arab Petroleum Exporting Countries, *Proceedings of the Symposium on the Ideal Utilization of Natural Gas in the Arab World (Algiers 29/6–1/7, 1980)* (Kuwait, 1980), p. 16. [This document henceforth cited: "OAPEC, 1980."] Converted to BTUs/cu ft as per next fn.

Efficiency of "North American natural gas"—OECD, 1974, vol. 2, p. 5. Converted from 1,015 BTUs/cu ft [× 1 lb / 24.02 cu ft for methane].

Efficiency of rocket fuel: LOX + liquid hydrogen—Baumeister and Marks, p. 7-50 (Table 29, "Characteristics of Rocket Fuels"). The author notes: "Their relatively low density requires large volumes for storage." The other source, which gives an HHV for hydrogen of 44,711.95, is Emsley, p. 187 ("hydrogen"), converted from 104 kJ/g [= 104,000 kJ/1,000 g = 104,000 kJ/kg × 0.4299226 = BTUs/lb = 44,711.95 BTUs per lb].

Caveat on hydrogen: "While liquid hydrogen is highly energetic. . ."—Dr. Richard P. Hallion, ed., *NASA's Contributions to Aeronautics,* vol. 1 (Washington, D.C.: National Aeronautics and Space Administration, 2010), p. 813 (Caitlin Harrington, "Leaner and Greener: Fuel Efficiency Takes Flight"). [This volume henceforth cited: "NASA, 2010."]

U-235, "thermal energy actually generated"—Information from Kroschwitz and Howe-Grant, vol. 24 ("Thioglycolic Acid" to "Vinyl Polymers"), p. 660: "The thermal energy generated by fission of 1 g of U-235 is equivalent to that released by burning 2200 L of crude oil or 2.7 [metric] t of coal." For coal: Since 2.7 t × 2,204.6 lb / t = 5,952.42 lbs coal, for which I assume the West Virginia Coal Association's HHV of 12,500 BTUs/lb, the total thermal energy will be

74,405,250 BTUs. For oil: Density of diesel fuel: 7.036 lbs/gallon, and 1 liter = 0.264 U.S. gal. Hence 2200 L × 0.264 gal / L × 7.036 lb / gal = 4,080.65 lb. For HHV I use Mexican crude's: 18,755 BTUS / lb. Then the total thermal energy will be 76,642,472.5 BTUs. The average of the two total thermal energies = 75,523,861 BTUs, which is what I plugged in.

U-235 "in theory"—Emsley, p. 479. His figure is 1 kg of U-235 @ 20 trillion J. Since 1 J = 0.000948067 BTUs, this gives us 18,961,340,000/kg = 8,618,790,909.09/lbs.

Pu-239—Emsley, p. 327: "One gram of plutonium used in a conventional nuclear reactor has the potential to release as much energy as a [metric] tonne of oil." This works out to 1/453.5 lb per 2,204.6 lbs, a ratio = to 1/999,786.099. The latter number is more than 99% of a million. As a shorthand for "oil" I used (per the table of Calorific Efficiencies beginning on p. 208) the average HHV for diesel of 19,250 BTUs/lb. Therefore, plutonium's efficiency would be 19.25 trillion (19,250,000,000) BTUs.

HHV of reactor fuel (theoretical and actual)—Ibid., p. 9-184 (Etherington entry on atomic power). His figure for U-235 of 3.5×10^{10} BTU per pound appears on p. 9-197.

Energy of Hiroshima atom bomb: 3.45×10^{10} BTUs per pound—According to Marion, pp. 260–61, the fission of 1 kg of U-235 releases 8×10^{20} ergs—"approximately the size of the original atomic bomb of 1945." Since 1 erg $= 9.4805 \times 10^{-11}$ BTUs, this converts into [8×10^{20} ergs / 1 kg] × [1 kg / 2.2 lbs] × [9.4805×10^{-11} BTUs / 1 erg] = 75,844,000,000 BTUs = 20 kilotons TNT. Dividing by 2.2 to find BTUs per pound, we get 34,474,545,454.5455, or 3.45×10^{11} BTUs per pound.

Efficiency of completely fissioning of 1 lb uranium-235—Baumeister and Marks, p. 9-188 (Etherington article on atomic power; figure given in mev), state that 1 atomic fission of U-235 = 200 million electron volts. Hence [200 mev = 200,000,000 ev = 2×10^8 ev] × 1.52×10^{-22} BTU per ev = 3.04×10^{-14} BTUs per atomic fission. To find the fissioning energy for 1 lb, I calculated as follows:

1 mole of U-235 atoms = 6.023×10^{23} atoms

1 mole U-235 is about 238 grams

Therefore, [3.04×10^{-14} BTUs per atom] × [6.023×10^{23} atoms per 1 mole] × [1 mole per 238 g] × [453.5 g per 1 lb] = 3.49×10^{23} BTUs per pound.

NUCLEAR

Nuclear Ideology

"Wool, a very complex molecule . . ."—Philip Baker et al., "Radioisotopes in Industry," "Understanding the Atom" ser. (Oak Ridge, Tenn.: United States Atomic Energy Commission, Division of Technical Information, 1965), p. 30.

"The relatively low share of greenhouse gas emissions . . ."—EU greenhouse report, 2014, p. 133.

"Will free us from the fear . . ." + "May help to save the coal-mines . . ."—Hans Thirring, *Energy for Man: Windmills to Nuclear Power* (Bloomington: Indiana University Press, 1958), pp. 367, 391.

"NUCLEAR POWER . . . could have a long-run stabilizing effect . . ."—OECD, 1974, p. 150.

"Ultimately, if the technical problems of solving nuclear fusion are solved . . ." —*Britannica,* 15th ed., Macropaedia, vol. 6, p. 858 ("energy").

"Redesign of the internal combustion engine . . ."—Odum, p. 92.

"Almost exhausted oil boy"—Honma Ryu, *Genpats Koukoku to Chihoushi* ["nuclear advertisements in local newspapers"] (Tokyo: Aki Shobo, 2014), p. 361 (ad from October 26, 1985; translated by Mrs. Keiko Golden). [Henceforth cited: "Honma."]

"At school and at the university . . ."—Alexievich, p. 164.

"A pound of enriched uranium, which is smaller than the size of a baseball . . ." —Herbst and Hopley, p. 129. Loc. cit.: "The fission of one U-235 nucleus will release 50 million times more energy than the combustion of a single carbon atom, approximately 200 million electron volts."

"A thimbleful of nuclear reactor fuel . . ."—John Tabak, Ph.D., *Nuclear Energy* (New York: Facts on File, Inc., 2009), p. 33.

"On average, an installed nuclear kilowatt . . ."—Mycle Schneider, Antony Froggatt et al., *The World Nuclear Status Report 2015* ("a Mycle Schneider consulting project") (Paris, London: Heinrich Böll Stiftung / The Green Political Foundation, July 2015), p. 17.

"The densest (in watts per square meter) . . ." + "Potential applications . . ." + "Japan's 2011 Fukushima nuclear disaster . . ."—*The Wall Street Journal,* Tuesday, April 28, 2015, p. C4, p. A17 ("Opinion" section, Eric McFarland, "Rethinking the U.S. Surrender on Nuclear Power"). "Mr. McFarland is a professor and director of the Dow Centre for Sustainable Engineering Innovation at the University of Queensland, Australia."

"Besides making nuclear power available . . ."—Farrington Daniels and Robert A. Alberty, *Physical Chemistry, Third Edition* (New York: John Wiley & Sons, 1966), p. 698.

"Studies have shown that radioisotopes such as plutonium-210 . . ."—Stambler, p. 143.

"[A] socialist transition worthy of the name . . ." + "While the trauma caused by this accident [at Fukushima] was great . . ."—Michael Joseph Roberto, Gregory Meyerson, James Essex and Jeff Noonan, "Moment of Transition: Structural Crisis and the Case for a Democratic Socialist Party" (84-pp. typescript; *Cultural Logic,* ISSN 1097-3087; copyright 2010), pp. 5, 31. [Henceforth cited: "Roberto et al."]

"We therefore conclude that the limit to population . . ."—S. Fred Singer, ed., *Is There an Optimum Level of Population?* (New York: McGraw-Hill, 1971), p. 41 (Alvin M. Weinberg and R. Philip Hammond, "Limits to the Use of Energy").

"I would be afraid to say this in Japan . . ."—Mrs. K.G., interviewed November 2014.

Footnote: "China already has the world's fastest-growing nuclear energy program . . ."—*The Japan Times,* Saturday, January 16, 2016, p. 4 (unattrib. ["Washington, AP"], "China's hard choice over nuclear waste: Continued reprocessing called risky, costly").

"Unlike oil, nuclear fuel is available . . ." + "Does not emit CO_2 . . ." + "The cost of electricity is comparatively low . . ."—Interview with Tepco PR people [Mr. Sakakibara Kohji, group leader; Mr. Togawa Satoshi, deputy manager, International Public Relations Group, Corporate Communications Department; Mr. Hitosugi Yoshimi, section manager, Corporate Communications Department; and a woman who did not identify herself], at Tepco HQ in Tokyo, Monday, October 20, 2014.

"For each 1,000 megawatts of installed capacity . . ."—*The New York Times,* Sunday, January 1, 2017, "Sunday Review" section, p. SR8 (Letters: "Nuclear Power, Debated": Tyson Smith, Mill Valley, California).

"Nuclear power started at Fukushima . . ."—Honma, p. 35 (ad from January 1, 1971; translated by Mrs. Keiko Golden).

"When we were young . . ."—Mr. Endo Kazuhiro, interviewed February 2014. See the "Harmful Rumors" chapter.

"It is a pity, the current situation . . ."—Honma, p. 47 (ads from January 11 and February 8, 1976; translated by Mrs. Keiko Golden).

“Plutonium thermal is needed . . .”—Ibid., p. 137 (ad from September 8, 2008; translated by Mrs. Keiko Golden).

“To Save the Planet . . .”—*The New York Times,* December 22, 2016, p. A27 (op-ed).

“With nature power . . .”—Ibid., p. 361 (ad from January 31, 2009; translated by Mrs. Keiko Golden).

“I don’t want to forget the warmth . . .”—Ibid., p. 344 (ad from October 26, 1993; translated by Mrs. Keiko Golden).

“From now on, I will turn my face . . .”—Ibid., p. 356 (ad from June 14, 1997; translated by Mrs. Keiko Golden).

“Our goal is the nuclear power plant that walks with neighbors”—Ibid., p. 353 (ad from January 29, 2010; translated by Mrs. Keiko Golden).

“Yotaro is wetting radiation”—Ibid., p. 356 (ad from June 13, 1993; translated by Mrs. Keiko Golden).

“We tried to think about life . . .”—Ibid., p. 345 (ad from March 30, 2009; translated by Mrs. Keiko Golden).

Nuclear power is the energy source of life. The town where there is energy . . .” —Ibid., n.p.

“Nuclear power makes money.”—Ibid., p. 275 (*Mainichi Newspaper,* February 5, 1983; translated by Mrs. Keiko Golden).

“America’s nuclear energy plants empower us” + “a critical source . . .” + “the only energy source that runs 24/7. . .” + “if we want to keep America working . . .” —*The New York Times,* Tuesday, November 18, 2014, p. A9 (a long-running advertisement from “Nuclear Matters”).

I sadly deleted the following slogan from my hoard of tautological twaddle: “Funs jump out from energy land.” *Tepco, 1994.* [Ibid., p. 241 (ad from July 17, 1994; translated by Mrs. Keiko Golden)]. I had delightedly interpreted this to mean that any nuclear power zone was an “energy land” filled with “funs.” Alas, when I clarified the matter with Keiko, it turned out that “Energy Land” [so capitalized] was simply an amusement park for small children.

“The radiation exposures in the highly publicized incidents . . .” + “The Rasmussen estimate . . .”—Bernard L. Cohen, *Before It’s Too Late: A Scientist’s Case for Nuclear Energy* (New York: Plenum Press, 1983), pp. 65, 14–15. Cohen further asserts (p. 12): “Only one-half of one percent of human cancers are caused by the 40 trillion particles of radiation that hit us over a lifetime . . .”

"Nuclear power is safer than oil."—Ibid., p. 36 (editorial from March 27, 1971; translated by Mrs. Keiko Golden).

"Watching the safety of [the] nuclear power plant with my big eyes"—Ibid., p. 36 (ad from October 25, 1986; translated by Mrs. Keiko Golden).

George Monbiot—Roberto et al., p. 33 (continuation of fn 68, quoting George Monbiot).

"Safety is our greeting word . . ."—Honma, p. 349 (ad from October 26, 2009; translated by Mrs. Keiko Golden).

"Over the years, the safety record . . ."—Olah, Goeppert and Prakash, p. 140.

"Danger [will] never be a reality . . ."—Honma, p. 349 (ad from April 18, 1976; translated by Mrs. Keiko Golden).

"Reactors are designed to be inherently safe . . ."—Kroschwitz and Howe-Grant, vol. 17, p. 373 ("nuclear reactors (introduction)").

"If there is [an] unexpected accident . . ."—Honma, p. 256 (ad from July 26–28; 1996, translated by Mrs. Keiko Golden).

"Nuclear power plants actually have caused fewer fatalities per unit of energy . . ."—*The New York Times,* Thursday, March 31, 2016, p. A7 (Wang Shang, Ma Qian an Deng Yushan, Xinhua advertisement: "Nuclear Power: An Effective Alternative for Global Climate Battle").

About Uranium

Epigraph: "Have you ever heard of the element uranium?"—Tyrone Mineo, ed. Therese Shea, *Uranium* (New York: Gareth Stevens Publishing / Rare and Precious Metals ser., 2014), p. 4.

Blackness of first specimen—Information from Kroschwitz and Howe-Grant, vol. 24 ("Thioglycolic Acid" to "Vinyl Polymers"), p. 638 ("uranium and uranium compounds").

"The silvery luster of freshly cleaned uranium metal . . ."—Ibid., p. 653.

Colors of uranium compounds—Ibid., pp. 667, 661, 665, 664.

Uranium in the crust: 2 ppm—Emsley, p. 480.

Information on the effect of U-irradiations on core heat, on U's general abundance and on its presence in crops and cropland soils—Op. cit., pp. 476–77, 480.

"A general cellular poison . . ."—Kroschwitz and Howe-Grant, same entry, p. 684.

"Everyone is exposed to a small amount of radiation . . ."—Mineo, p. 16.

Comparative radioactives of "natural uranium" and radium-226—Kroschwitz and Howe-Grant, p. 639. Originally expressed: 2,800 kg "natural uranium" is as radioactive as 1 g radium-226.

The literal heat of radium-226—*Britannica,* 11th ed., vol. XXII (POLL to REEVES), p. 802 ("radiation"). Originally expressed as 100 gram calories per gram per hour of "radium" or "a radium compound," which I hereby call equivalent to radium-226, since that is the longest-lived isotope, deriving from "the decay of the most abundant uranium isotope" (Emsley, p. 353). Since 1 BTU = 251.98 calories, then 1 gram emits 0.397 BTUs per hour; therefore 1 lb emits 179.97 BTUs per hour. Anyhow, our best minds found a way to make uranium as hot as was needed. The U-235 that killed 200,000 people at Hiroshima warmed the epicenter to 5,400° F. (Rhodes, pp. 734—"five-year deaths related to the bombing"—and 714).

Plutonium: "feels hot, like a live rabbit"—Testimony of Leona Marshall, quoted in Richard Rhodes, *The Making of the Atom Bomb* (New York: Simon & Schuster Paperbacks, 25th anniversary ed., 2012; orig. pub. 1986), p. 660.

Footnote: Extraction of one pound of radium—Information from Emsley, p. 352. Originally given as 150 to 350 milligrams Ra per metric ton of U ore, which equals 150 to 350 times [1/1,000] × [1/453.5] lb per 2,204.6 lbs = 1 lb Ra for every 6,665,240.68 to 2,856,531.72 lbs of U ore. Thus it takes between 2.85 and 6.65 million pounds of uranium ore to get 1 pound of radium. [In his cross-check, Mr. Ben Coleman, for the high figure only, comes up with 6,666,666.67 lbs.]

Footnote: Austrian use in ceramics—Emsley, p. 478.

Same footnote: Uses of sodium uranate, uranyl sulfide and uranyl nitrate—*Britannica,* 11th ed., vol. XXVII (TONALITE to VESUVIUS), p. 788 ("uranium").

Same footnote: Uranium toning—William Crawford, *The Keepers of Light: A History and Working Guide to Early Photographic Processes* (Dobbs Ferry, New York: Morgan & Morgan, 1979), p. 172.

Same footnote: Uranium prints—By Kris Haggblom, in Malin Fabbri, ed., *Alternative Photography, Art & Artists, Edition 1* (Stockholm: Malin Fabbri, AlternativePhotography.com, 2006), pp. 89–90.

"relatively high levels of uranium as impurities"—Ibid., p. 480.

Footnote: Abundance of U in seawater—Loc. cit. Original absolute figure was 5 billion metric tons [× 2,204.6 =11,023,000,000,000].

U's two "isotopes of significance"—There are actually 19 (Kroschwitz and Howe-Grant, p. 639). Of these, one more occurs naturally: U-234.

"U-238 inhibits the fission of U-235"—Or, as Rhodes puts the matter in more detail (p. 287), U-235, could fission continually but "the more abundant U-238 captured most of the neutrons." Not caring to pause and explain neutrons right here, I simplified.

Mining, milling, oxidizing, leaching—Kroschwitz and Howe-Grant, same entry, pp. 641, 647, 649–50. I have simplified a great deal in this summary.

Half-lives of U-235 and U-238—See p. 540, Table 2. Due to its rarity, I have omitted discussion of U-234.

Isotopic abundance of U-238—Kroschwitz and Howe-Grant, same entry, p. 642.

Advertisement for the Geiger counter from Sears, Roebuck—1956 catalogue, p. 680.

Radon-222: "highly unstable and highly dangerous . . ."—Emsley, p. 354. This was actually said about radon in general, presumably applying to all 31 isotopic cases. On p. 357 we learn that the longest-lived isotope, radon-222, is emitted by uranium.

Ra-222's 4-day half-life + "placed in large piles . . ."—Kroschwitz and Howe-Grant, vol. 17 ("Nickel and Nickel Alloys" to "Paint"), p. 467 ("waste management").

2012 EU-15 greenhouse emissions from ammonia production—EU greenhouse report, 2014, p. 402.

The solvent method of getting U from phosphates—Emsley, p. 479.

The manufacture of magnesia—All information from Kroschwitz and Howe-Grant, vol. 15 ("Lasers" to "Mass Spectrometry"), pp. 703–7 ("magnesium compounds"): Rare in nature, magnesia (MgO) did, however, appear in the mineral periclas (or periclase). One commercial version was calcined dolomite. A certain firm in Ohio calcined dolomitic limestone at high temperatures (in other words, considerable energy inputs) to make that stuff. Dead Seas Periclase Ltd. took concentrated magnesium chloride brine from, yes, the Dead Sea, and "sprayed" it "into a reactor at about 1700° C," which must have required significant energy, I should say, after which more was done to the stuff. There were several types of magnesia, and several manufacturing processes associated with them: hard-burned, "readily soluble only in concentrated acids," which was lovely for ceramics, animal feed supplements, leather tanning, wastewater treatment and fertilizer; dead-burned, which "reacts very slowly with strong acids" and was used in cement kilns for metal refining; and pure-fused, whose use I never learned but which was "produced at extremely high . . . temperatures using graphite electrodes in an electric-arc furnace." So I think it fair to say that magnesia-making required a fair amount of energy. Only the seawater production process did not sound bad (except for the part where "spent seawater is disposed to the sea)."

The photo of yellowcake + "METAL MANIA! . . ."—Mineo, pp. 9, 6.

Refining—Kroschwitz and Howe-Grant, vol. 24, p. 651.

Uranium dioxide: "brown to copper-coloured"—*Britannica,* loc. cit.

"It takes a lot of energy . . ."—Mineo, p. 11.

UF_6: "an extremely corrosive . . . solid . . ."—Kroschwitz and Howe-Grant, vol. 24, p. 664.

The membrane of silvered zinc—Emsley, p. 478 ("silver-zinc" in original). For more information on the original diffusion at Oak Ridge, see Rhodes, p. 492.

4,000 diffusion cells to attain 99% U-235—Daniels and Alberty, pp. 700–701. Diffuse rate varies inversely with the square root of the molecular weight. The ratio between the rates of U-238 hexafluoride and U-235-hexafuxoride is a mere 1.0043 (loc. cit.).

Enrichment requirements for reactors and weapons + "Gaseous diffusion units are enormous . . ." + information on centrifugal separation—Kroschwitz and Howe-Grant, pp. 657–58.

Reactor-grade enrichment (here rated at %): "More than a thousand separation stages . . ."—Kroschwitz and Howe-Grant, vol. 17, p. 404 ("isotope separation").

Details on the coal-fired power plant at Oak Ridge—Rhodes, pp. 494, 553.

Conversion from 800 million BTUs to 96 tons of coal—Dividing 812,246,400 [= 238,000 kW × 56.88 BTUs per min per kW × 60 min per hr] by coal's average 12,500 BTUs/lb HHV, then dividing by 2,000 lbs/[U.S.] ton, then multiplying by three to compensate for a fossil fuel power plant's ⅔ wastage (see "About Power Plants, p. 150) yields 97.

"the other nuclear fuels": Uranium metal, sulfates, etc.—List from Kroschwitz and Howe-Grant, vol. 17, p. 429 ("reactor types").

Note on uranium tetrafluoride—EU greenhouse report, 2014, p. 433.

Conversion of U-238 into Pu-239—Equation in Emsley, p. 325.

Footnote on electromagnetic separation—Kroschwitz and Howe-Grant, vol. 24, p. 659.

Same footnote: "laser radiation of precise energy . . ."—Emsley, p. 478.

Conversion of U-238 into Pu-239—Information from Marion, p. 595.

Use of Pu-238 on Apollo 14—Ibid., p. 327.

"A single recycle of plutonium . . ." + "Plutonium from reprocessed fuel . . ." + information on DPU for MOX ("The plutonium, as an oxide, is then mixed with depleted uranium left over from an enrichment plant to form fresh mixed oxide fuel (MOX, which is UO2+PuO2). MOX fuel, consisting of about 7–11% plutonium mixed with depleted uranium, is equivalent to uranium oxide fuel enriched to about 4.5% U-235, assuming that the plutonium has about two-thirds fissile isotopes. If weapons plutonium is used (>90% Pu-239), only about 5% plutonium is needed in the mix.")—World Nuclear Association, 2016, "MOX, Mixed Oxide Fuel—World Nuclear Association," downloaded on February 7, 2017, by Jordan Rothacker for WTV from http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/fuel-recycling/mixed-oxide-fuel-mox.aspx. [Henceforth cited: "World Nuclear Association, 2016."]

Footnote on the MOX accident in Ibaraki—*The Japan Times,* Friday, June 9, 2017, pp. 1–2 (unattrib., "Plutonium exposures fox experts: Authorities probing whether safety failures behind release"). I converted the Sv/yr figures to microSv/hr as follows: (a) [1.2 Sv/ yr] × [1 yr /365 d] × [1 d / 24 hr] × [1,000,000 microSv / 1 Sv] = 136.986 micros / hr [comparable to Okuma's "more than 100" micros after the accident]; and (b): [12 Sv/ 50 yr] × [1 yr /365 d] × [1 d / 24 hr] × [1,000,000 microSv / 1 Sv] = 27 micros / hr [comparable to some gratings and drains I measured in Okuma and Tomioka].

"The problem of the disposition of 500,000 [metric] tons"—Kroschwitz and Howe-Grant, vol. 24, pp. 659–70.

"During the early nuclear testing times in Nevada . . ."—The anti-fracking Sharon Carlisle's expansions and corrections of my rough transcript of her interview in Loveland, Colorado, July 5, 2015. For the bulk of the interview, see the fracking chapter.

Efficiency of Pu-239—See note on Sources, p. 113. Dividing the calculated efficiency of 19.25 trillion BTUs per lb by the capacity of the Oak Ridge coal-fired plant, one finds that 1 lb of Pu-239 could power it for 2.785 years.

Calorific Efficiencies of Coal, Oil, Natural Gas, Uranium-235 and Plutonium-239

Estimate of uranium burned in a 1-million-kWh Japanese reactor—Hirose, p. 26: "About 2 kg of uranium will be burned if a reactor with a daily capacity of

1 million KW is operated for one day." I presume he means kWh—in which case, 2 kg = 4.4 lb for 24 million kWh, meaning that 1 lb generates 5,454,545 kWh = × 3,413 = 18,616,363,636.3636 BTUs, or, better yet for our inexact purposes, 18,600,000,000 (8.6 billion) BTUs. [In this place he also says: "One reactor alone each day burns uranium equivalent to three or four Hiroshima bombings." One can see where his heart lies.]

About Uranium (continued)

Footnote: Length of fuel rods at Fukushima—David Lochbaum, Edwin Lyman, Susan Q. Stranahan and the Union of Concerned Scientists, *Fukushima: The Story of a Nuclear Disaster* (New York: New Press, 2014), p. 5.

Characteristics of zirconium—Emsley, pp. 508, 510.

"Nuclear power cost about the same as coal"—Information from Kroschwitz and Howe-Grant, vol. 17, p. 374 ("nuclear reactors (introduction)").

"The used or spent fuel contains a large inventory . . ."—Ibid., p. 467 ("waste management").

The three methods of waste disposal—Ibid., p. 468.

The typical to-do list—Ibid., p.495, "nuclear reactors (safety)."

"low level nuclear waste" "must be kept apart from residential settlement for up to 400 years"—*The Japan Times,* March 23, 2014, p. 1 (unattrib., "Nuclear waste buildup relentless"). At that time, over 496,000 cubic meters of "low level radioactive waste" would require interment if all Japanese reactors were decommissioned. "Japan's mountain of nuclear waste will only continue to grow."

Cs-137 and Sr-90 "provide most of the radioactivity . . ."—Kroschwitz and Howe-Grant, same entry, p. 469 ("waste management").

Characteristics of DPU shells—Kroschwitz and Howe-Grant, vol. 24, p. 660. Emsley (p. 478) calls DPU "one of the densest of metals." He mentions its use as ballast on p. 479. Metcalfe, Williams and Castka (p. 659, "Properties of Common Elements") give the specific gravities (water standard) of U at 19.05, tungsten at 19.3, gold at 19.32 and platinum at 21.45.

"And D[P]U has the added advantage . . ."—Theodore Gray, *The Elements: A Visual Exploration of Every Known Atom in the Universe* (New York: Black Dog & Levanthal Publishers, 2009), p. 211. Although Gray's "DU" is a more intuitively understandable abbreviation than "DPU," the latter appears in my bible, Kroschwitz and Howe-Grant.

About Nuclear Reactors

Epigraph: “The true romance which the world exists to realize . . .”—Emerson, p. 492 (“Experience”).

HHV of a gram of pure carbon: 14,000 BTU / 1 lb × 1 lb /453.59 g = 30.865 BTUs per gram.

Self-heating values of Pu-239 and -238 + failure of plutonium heating system—Kroschwitz and Howe-Grant, vol. 19 (“Pigments” to “Powders, Handling”), pp. 408, 417 (“plutonium and plutonium compounds”).

Footnote: Conversion from 7 W[atts]/kg—Multiplied by [1 kg / 2.2046 lbs] × [0.056884 BTU per minute / 1 watt], this becomes 0.1806 BTU per minute per pound.

Same footnote: “Twelve and a half pounds would be needed to give as much power as the plug-in vibrator on p. 68.” Calculated from 2.28 / 0.1806 BTUs per min = 12.625 BTUs per min.

“In the . . . Voyager space probes they produced electricity for more than half a century.”—The two Voyager space probes left Earth in 1977. They were still communicating with the home planet in 2017, according to *National Geographic,* August 2017, p. 23 (Timothy Ferris, “Fantastic Voyage: Deep in Space: Two Intrepid Travelers Turn 40”). Loc. cit.: “Their weakening radio signals . . . are expected to fall silent around 2030, when the Voyagers’ plutonium-powered electrical generators finally falter.” This would be a 53-year working life.

U-238 “can become plutonium-239 . . .”—World Nuclear Association, 2016.

Boron—Kroschwitz and Howe-Grant., vol. 17, p. 391 (“water chemistry of light-water reactors”): “Used to compensate for fuel consumption and to control reactor power.”

Paragraph beginning “And so the control rods retracted . . .”—All information from the same source, vol. 17, pp. 369, 372 (“nuclear reactors (introduction)”).

Nuclear power as a percentage of worldwide 2011 electricity generation—Calculated from U.S. Statistical Abstract, 2015, p. 896 (Table 1391: “Net Electricity Generation by Energy Source and Country: 2011”). [Data source: U.S. EIA, 2014.] The worldwide total was 21,080.9 billion kWh. Nuclear’s was 2,517.7 billion kWh. I calculated the percentage; I also converted from kWh to BTUs by multiplying × 3,413.

Description of PWRs and BWRs—Kroschwitz and Howe-Grant, vol. 17, p. 370 (“nuclear reactors (introduction)”), pp. 391–92 (“water chemistry of lightwater reactors”), pp. 457–58.

Japanese distribution of PWRs and BWRS—Hirose, p. 25.

"Two practice problems in a physics textbook"—Marion, p. 267; problems 7.51 and 7.53.

Josephine Cochran's dishwasher—Ethlie Ann Vare and Greg Ptacek, *Patently Female: From AZT to TV Dinners, Stories of Women Inventors and Their Breakthrough Ideas* (New York: John Wiley & Sons, 2000), pp. 38, 39.

"In contrast to power plants . . ." + emissions from "normal operations"—Kroschwitz and Howe-Grant, vol. 17, p. 373 (same entry).

Footnote: Takashi Hirose on nuclear power's contribution to global warming—Op. cit., p. 150.

Same footnote: "*thermal pollution* will become an increasingly serious problem . . ."—Odum, p. 466 (italics in original). Note that these two sources differ on thermal pollution rates. Hirose (who might have in mind different "average size" than Odum) asserts a rate of 100,000,000 kW = 5,688,400,000 BTUs/minute. Odum proposes that a 3,000 MW "average size" nuclear station "produces waste heat at the rate of more than 20×10^9 BTU per hour," which works out to a very different 333,333,333,333 BTUs/min.

Footnote: Half-lives of Xe and Kr radioisotopes—Emsley, pp. 489, 214.

Reactor contamination products (in general)—Kroschwitz and Howe-Grant, vol. 17, pp. 467 ("waste management"), 499 (nuclear reactors (safety)").

"the lifespan of each part is around 30 years at maximum."—Hirose, p. 25.

Radiocontaminants specific to BWRs *versus* PWR—Ibid., pp. 395, 401.

The reactors at Fukushima—Lochbaum et al., pp. 5, 15; Hirose, pp. 23–29, 48–51, 124, 126–27.

"one gram of plutonium used in a nuclear reactor . . ."—Emsley, p. 327.

"Nuclear power plants need electrical power 24 hours per day . . ."—United States Nuclear Regulatory Commission, "NRC: Mitigation Strategies" [2-pp. PDF] (downloaded for WTV by Jordan Rothacker in September or October 2016 from http://www.nrc.gov/reactors/operating/ops-experience/japan-dashboard/mitigation-strategies.html]. [This document henceforth cited: "NRC: Mitigation Strategies, 2016."]

Tale of the diesel generators at Daiichi—Hirose, p. 34.

"A loss of coolant is conceivable . . ."—*Britannica,* 15th ed., vol. 13 (NEWMAN to PEISISTRATUS), p. 321 ("nuclear reactor").

1. Lower Than for Real Estate Agents

"For the Fukushima disaster . . ."—*The Wall Street Journal,* Saturday/Sunday, April 12–13, 2014, p. C3 (Craig Nelson, "A Radiation Reality Check: From bananas to bricks, radioactivity is everywhere—but it's nothing to be afraid of"). Also from this article: "The United Nations spent 25 years investigating the Chernobyl disaster and determined that 57 people died during the accident itself (including 28 emergency workers), while 18 children living nearby died in the following years of thyroid cancer from drinking the milk of tainted cows." Nelson then quoted the physicist Bernard Cohen, who predicted that after half a century Chernobyl would have caused 16,000 fatal cancers. "To give this number perspective, around 16,000 Americans die every year from the pollution of coal-burning power plants."

Comparative Measured Radiation Levels in Multiples of the Lowest Sacramento Reading

Footnote: "The natural background from all sources in most parts of the world . . ."—*CRC Handbook,* 2006, p. 16-46 ("Protection Against Ionizing Radiation").

Footnote: "It is an odd quantitative choice . . ."—Crownover to WTV, June 2017.

Re: my darkroom coating counter: "On a per-minute basis, the cumulative per capita fallout dose in the Northern Hemisphere from 1945 through 1999 was 1/27 of this amount."—Roy E. Gephart, *Hanford: A Conversation About Nuclear Waste and Cleanup* (Columbus, Ohio: Battelle Press, 2003), p. 4.28: The "cumulative radiation dose for a person" in the Northern Hemisphere is "between . . . 1945 and 1999 was 108 millirems." Since 10 micros = 1 mrem, I multiplied by 10 and then divided by [54 years × 365 days × 24 hours] to get the hourly dose of 0.00228 micros per hour.

1 milli per year: Recommended ceiling, per ICRP—Information from Hirose, p. 59.

1 milli per year as TBI from natural sources at sea level "in most parts of the world" + 0.28 millis per every 500 meters—Harry Foreman, ed., *Nuclear Power and the Public* (Minneapolis: University of Minnesota Press, 1970), p. 77 (Merril Eisenbud, "Standards of Radiation Protection and Their Implications for the Public's Health"); see also p. 79.

Footnote: "The ICRP recommended . . . limit . . . radiation . . . [1990] is 20 mSv/yr . . ."—*CRC Handbook,* 2006, p. 16-46 ("Protection Against Ionizing Radiation").

Footnote on decontamination target for Iwaki households: The "long-term goal in the Fukushima cleanup . . ."—*The Japan Times,* Sunday, March 10, 2013, p. 7 (Winifred Bird, sidebar: "Giving the children of Fukushima a place to play is not easy"); *The Japan Times,* Monday, July 21, 2014, p. 3 (unattrib., "Fukushima file: New radiation measurement method spreads confusion").

2 mSv per year, "assuming that an individual spends eight hours outdoors . . ." —*The Japan Times,* Monday, July 21, 2014, p. 3 (unattrib., "Fukushima file: New radiation measurement method spreads confusion").

2.4 millis per year—Assertion of Mr. Kida Shoichi, a decontamination specialist in the Nuclear Hazard Countermeasure Division, Iwaki, as interviewed in text.

Footnote: "Discussion of Taylor's [B]ooks . . ."—Crownover to WTV, June 2017.

"An average radiation background dose for a human being" (3 mSv per year) —James A. Mahaffey, Ph.D., *Nuclear Power: Radiation* [so written on title page, but on copyright page only "Radiation"] (New York: Facts on File, 2012), p. 30: "An average radiation background dose for a human being is 300 millirems per year. A dosage of 500 millirems in five hours is considered lethal . . ."

"The average resident of the United States is routinely exposed to about 300 millirem . . . every year from the soil beneath their [*sic*] feet and the sun shining overhead," and the sentence complacently finishes: "—without concern." —Gephart, p. 4.9. Cf. *CRC Handbook,* 2006, p. 16-46 ("Protection Against Ionizing Radiation"): "The U.S. average is about 3.6 mSv/yr but can range up to 50 mSv/yr in some areas."

Average American yearly dose, mid-1990s—Kroschwitz and Howe-Grant, vol. 17, p. 497 "nuclear reactors (safety)"). Converted by WTV from U.S. average of 0.0036 Sv/yr (the "3" digit from natural sources, the rest from humans).

5 milliSv per year—Converted from 500 millirads per year.

"For an individual steadily receiving 500 millirads per year . . ."—Gofman and Tamplin, pp. 288–89.

"A read of 5 millisieverts is one of the thresholds . . ."—*The Japan Times,* Tuesday, March 8, 2016, p. 1 (unattrib., "32,000 at Fukushima No. 1 got high radiation dose").

More than 15 milliSv per year: Bikini—*The Japan Times,* Sunday, June 10, 2012, p. 10 (cont'd from p. 9, Christopher Johnson, "The Marshall Islands: Tropical idylls scarred like Tohoku"), quoting International Atomic Energy assessment.

Footnote: "Readings in airplanes . . ."—Crownover to WTV, June 2017.

Definition of green zone: "decontaminate with priority"—Conveyed orally by Mr. Yoshikawa Aki en route to Namie, October 26, 2015.

"A passenger in a plane flying at 12,000 meters . . ."—*CRC Handbook,* 2006, p. 16-46 ("Protection Against Ionizing Radiation"). This altitude = 39,360 ft.

100 milliSv per year—International Committee on Radiological Protection assessment. *The Japan Times,* Saturday, March 8, 2014, p. 3 (Reiji Yoshida, "Radiation check clears most food items"). "This was the average dose received by the 'liquidators' who entombed the reactor at Chernobyl."—Information from Herbst and Hopley, p. 144. This source continues: About 20,000 "liquidators" got 250 mSv and "a few received 500 mSv."

> 13 micros an hour (hot spots in Aiikuen Orphanage)—*The Japan Times,* Sunday, March 10, 2013, p. 7 (Winifred Bird, sidebar: "Giving the children of Fukushima a place to play is not easy").

120 millis per year (the Brazilian village)—Foreman, p. 79, quoting the figure of 12 rads. Since 1 rad [at least per old definition] = 1 rem = 10 millis, 12 rads = 120 millis. This is insanely high, and I wonder whether Foreman slipped a decimal point. Cf. bracketed note on Guarapari based on Nanao Kamada, M.D., *One Day in Hiroshima: An Oral History,* trans. Richard C. Parker et al. (Shift Project / International Physicians for the Prevention of Nuclear War, 2007), p. 74, where we read that this place's dose is (so far as I can tell from a data-poor chart) a mere 10 mSv/yr. [This source henceforth cited: "Kamada." The first-person voice in this oral history is an old lady in a nursing home, whose name is not revealed.]

Footnote: "It is possible that an unnamed Brazilian village . . ."—Crownover to WTV, June 2017.

"Radiation dosimeters were given to selected individuals . . ."—Jacob Kastner, "The Natural Radiation Environment," "Understanding the Atom" ser. (Oak Ridge, Tenn.: United States Atomic Energy Commission Division of Technical Information, 1968), p. 21.

Exposure in outer space; mission to Mars—Mahaffey, pp. 25–26: "The background radiation on the ground is about 240 millirems (2.4mSv) per year, with about 30 millirems (0.3 mSv) due to cosmic rays. In interplanetary space, the exposure would be 40 to 90 rems (400 to 900 mSv) per year . . . A 30-month mission to Mars could result in a 114 rem (1.14 Sv) exposure."

Japanese chest X-ray—Kamada, p. 73.

0.3 rem per week—Baumeister and Marks, p. 9-191 (C. H. Etherington, "Atomic Power").

"The shielding for dental X-rays . . ."—Crownover to WTV, June 2017.

100 milliSv per week—*The Japan Times,* Friday, August 1, 2014, p. 3 (unattrib., "Nuclear watchdog may raise radiation exposure limit for emergencies").

Full-body CT [computerized tomography] scan: 10 millis an hour—Kamada, p. 75.

Footnote: "If the dosimeter was placed . . ."—Crownover to WTV, June 2017.

"First responders" should content themselves with 50 millisieverts per incident—Information from Jill Meryl Levy, *The First Responder's Guide to Radiation Incidents* (Campbell, California: Firebelle Productions, 2006), p. 153. For consistency with the units of this essay, I have converted from her figure of 5 rems: 5 rem = 50 mSv × 1 Sv/1,000 mSv = 0.05 sievert.

25 mSv in 10 minutes by the crewmen of Reactor No. 1—Lochbaum et al., p. 31.

"A total dose of 50 rem of gamma radiation . . ."—Baumeister and Marks, p. 9-191 (C. H. Etherington, "Atomic Power").

Footnote to 50 milliSv per hour: We are told that the first responders at Chernobyl took in "up to 20,000 millisieverts . . ."—Herbst and Hopley, p. 143.

1.3 Sv per hour: The girl at Hiroshima—Kamada, p. 28: "A university professor told me that I had been exposed to an estimated 1,300 millisievert . . . , including both gamma and neutron rays." This was "about the same amount as when you have an X-ray on your stomach for 130 times in a row . . ."

2–3 Sv per hour: "Permanent female sterility is possible"—Mahaffey, p. 39.

3–4 Sv per hour—Loc. cit.

6 Sv per hour—Bruce Clayton, Ph.D., *Fallout Survival: A Guide to Radiological Defense* (Boulder, Colorado: Paladin Press, 1984), p. 28. This author asserts the following (which he expresses in Roentgens [so capped], converted by WTV at 1 Sv = 100 R): 0.5 Sv, no visible effects; 0.75–1 Sv, possible nausea on day of exposure; 2 Sv, radiation sickness symptoms for up to half of all exposed persons, but only 5–10% will require medical treatment and none of them will die from this; 4.5 Sv "serious radiation sickness in most members of the group," with a 50% death rate in 2–4 weeks; 6 Sv, serious radiation sickness, leading to the deaths of nearly all exposed persons in 1–3 weeks.

16.793 Sv per hour—Information from Svetlana Alexievich, ed., *Voices from Chernobyl: The Oral History of a Nuclear Disaster,* trans. Keith Gessen (New York: Picador, 2005; orig. Russian pub. 1997), p. 134, converted from statement "the activity reached 1,800 roentgens per hour" as follows: 1,800 × (1 R × [1 rem / 1.07185 R] × [1,000 mrem / 1 rem] × [10 microSv / 1 mrem] = 9,329.663

microSv) = 16.793 Sv/hr. [We are also told (loc. cit.) that the colonel received 600 Bq—which might correspond to "merely" 6 mSv.]

10–50 Sv per hour—Mahaffey, p. 40.

10.3 Sv per hour—*The Japan Times,* Wednesday, September 3, 2014, p. 3 (Hideki Takahashi and Hisashi Ota, "Workers tried to save reactor 1 through venting"). Converted from 10,300 millisieverts per hour.

When the Wind Blows from the South

Footnote: The paperweight of Rick Anderson—Roberto et al., pp. 29–30 (fn 64).

Radiation incident guide: "alpha and beta emitters are the most hazardous . . ."—Jill Meryl Levy, *The First Responder's Guide to Radiation Incidents* (Campbell, California: Firebelle Productions, 2006), p. 120.

"the development of the nuclear reactor, which promises to be a very important power source . . ."—Daniels and Alberty, p. 695.

"a lethal whole-body single dose . . ."—Ibid., p. 719. "According to AEC regulations, no worker should be exposed to more than 5 roentgens per year" (loc. cit.).

Footnote: A sievert defined as a "unit of equivalent dose . . ."—*CRC Handbook,* 2006, pp. I-39–I-40 ("CONVERSION FACTORS FOR IONIZING RADIATION"); p. 16-46 ("Protection Against Ionizing Radiation").

25 to 50 roentgens may cause "blood-cell destruction"—Donald E. Tilley and Walter Thumm, *Physics for College Students with Applications to the Life Sciences* (Menlo Park, California: Cummings Publishing Co., 1974), p. 34.

The hardboiled American dosimetrist: "We would pull the amount of air you would breathe in a month . . ."—Source ML, interviewed April 19, 2011. His identity and contact information were made available to fact checkers at Byliner, this chapter's original publisher. He worked in the nuclear industry and did not wish to have his name published here.

"the incident guide remained at peace"—Information from Levy, pp. 153, 46–48, 93–96. In her text the normal background exposure is expressed in mR (milliroentgens). For our purposes, a rem (roentgen equivalent man, a measure of biological damage) equals a roentgen. See the tables and definitions at the end of this book.

"Denver received triple this amount"—Confirmed by Source ML.

At 5,000 rems "all patients will die within forty-eight hours"—Levy, loc. cit.

Dr. Jean Pouliot and Josephine Chen—They helped me in early March 2011.

“In the quarter-hour we spent in that room, God regaled us with 0.6 heavenly millirems!” + accompanying fn—Since 1 millirem = 10 micros, this corresponded to 6 micros in 15 minutes or 24 micros an hour. For Tomioka and Okuma readings, see the chapter “The Red Zones.”

“Well, for a member of the general public you’ve got guts . . .”—Source ML.

“On March 11, 2011, a nine-magnitude temblor . . .”—Information from *The Japan Times,* Monday, March 28, 2011, p. 1 (“Big quakes ‘don’t set off distant temblors’”).

Casualty figures from the earthquake-tsunami—*The Daily Yomiuri,* no. 21,742 (Tuesday, April 5, 2011, edition T), p. 1.

Footnote on final death figure from the tsunami—Richard Lloyd Parry, *Ghosts of the Tsunami: Death and Life in Japan’s Disaster Zone* (New York: Farrar, Straus & Giroux / MCD, 2017; uncorrected proof), p. xi.

Events at Plant No. 1, March 11–20, 2011—Some of the details were not known, or at least released to the public, at the time. My brief summary of what happened follows Lochbaum et al., chaps. 1–4, 6. This book presents the history of American nuclear regulation as a series of chicaneries. A typical passage (p. 206): In a 1982 press conference, Representative Edward Markey of Massachusetts announced, as the Union of Concerned Scientists phrases it, that “the NRC was suppressing the results of a study that estimated the consequences for human health and the environment of severe accidents for every nuclear plant in the United States.”

At the Tepco interview of Monday, October 20, 2014, Mr. Hitosugi told the story thus: “First of all, why it happened. You should know that in 2011 March we had a huge earthquake, and after 40 minutes, a large tsunami hit. And due to that, the energy source was lost. During the investigation, it was found that right after the big tremor, the reactor stopped safely. After that, no pressure change was detected, which means that no major pipes were ruptured. No safety functions were lost due to the earthquake. But on the other hand, after the reactor was stopped, we needed to keep cooling it. So we had to keep adding water. That kind of safety function needs an energy source, and that was drained. In the case of Fukushima there is a power line from outside, and also an emergency line within the premises, and these two are needed in any emergency. In the case of Daiichi, except that one emergency power line, all other sources went dead. And this was not sufficient to take all the reactors off line. (In Niigata we have a power plant, and based on our experience in the Fukushima accident, we made some improvements there in Niigata to the emergency power source in case of a tsunami.)

"The fuel keeps emitting heat after operation. Both No. 1 and No. 2 need to keep cooling. But after awhile, reaction heat comes down. Then you can take out the fuel and put in a dedicated cask. Less than a hundred degrees [Celsius] is a cold shutdown. This was achieved around March 20."

Footnote: Descriptions of Reactors 1–5—Ibid., p. 15. According to an anti-nuclear source: "A typical 1,000 megawatt electric . . . Pressurized Water Reactor will release nearly 800 curies of tritium per year . . ." A comparable boiling water reactor "will release 120 curies of tritium per year."—Beyond Nuclear, 6930 Carroll Avenue, Suite 400, Takoma Park, MD 20912, "Warning: Uncontrolled Radioactive Releases: Buried below is a tangle of corroded pipes uninspected for decades now leaking radioactive water" [61-pp. typescript], March 2015, rev. from April 2010, p. 10. [Henceforth cited: "Beyond Nuclear."]—Regarding the Westinghouse design I would like to quote David E. Lilienthal, *Atomic Energy: A New Start* (New York: Harper & Row, 1980), pp. 114–15: "In recent years I have asked myself often, do we Americans have the *moral* right to promote and sell a complicated, immature, and fundamentally unsafe nuclear system to the rest of the world . . . ? I am convinced that we do not have that right. We *do* have the obligation to develop a nuclear system that is far safer, much less complex, for them and for ourselves."—Mr. Lilienthal was the first chairman of the Atomic Energy Commission.

Footnote: Hirose: "An electric power company that lost control . . ."—Op. cit., p. 29.

Measurements at the American naval base at Yokosuka (1.5 mrems)—Ibid., p. 78.

"By the twenty-sixth . . . water in Reactor 2 was emitting at least a sievert per hour . . ."—*The Japan Times,* Sunday, March 27, 2011, p. 2 (map: "Maximum radiation levels in eastern Japan: Data from 5 p.m. Friday to 5 p.m. Saturday").

"At this rate, a person would receive that 5-rem dose in about three minutes"—Five rems (or 5,000 millirems) divided by 1 sievert per hour (which is 100,000 mrems per hour) = 0.05 hours.

"Plant officials and government regulators say they don't know"—*The Japan Times,* Sunday, March 27, 2011, p. 2 ("Radioactive water stymies crews").

". . . not known as of Saturday afternoon"—*The Japan Times,* Sunday, April 3, 2011, p. 1 (Masami Ito and Minoru Matsutani, "Sea contamination traced to cracked storage pit connected to reactor: Tepco dumps concrete to plug radiation leak at No. 2").

Peter Bradford: "I'm getting increasingly concerned . . ."—Phone interview by author, March 28, 2011.

Footnote: "Another element released by uranium fission is iodine-131 . . ."—Emsley, p. 480.

Unnamed Meteorological Agency official: "If the government releases two different sets of data . . ."—*The Daily Yomiuri,* no. 21,742 (Tuesday, April 5, 2011, edition T), p. 1.

Peter Bradford: "I don't think we're any less vulnerable than the Japanese."—*The Sunday News & Observer* [Raleigh, N.C.], April 6, 2014, final ed., p. 12A (Matthew L. Wald, *The New York Times,* "Dozens of nuclear reactors can't prove quake resistant"): "Owners of at least two dozen nuclear reactors across the United States, including the operator of Indian Point in Buchanan, N.Y., have told the Nuclear Regulatory Commission that they cannot show that their reactors would withstand the most severe earthquakes that revised estimates say they might face, according to industry experts."

"Nothing in the world is permanent or lasting . . ."—*The Teachings of Buddha,* 1029th rev. ed. (Tokyo: Bukkyo Dendo Kyokai [Society for the Promotion of Buddhism], 2000), p. 198 (Defilements, 6).

Footnote: Japanese power consumption, 2010 and 2011—U.S. Statistical Abstract, 2015, p. 898 (Table 1395: "Energy Consumption by Country, 2010 and 2011"). Data source: U.S. EIA, 2014.

Japanese grid: 290 gigawatts, to which Fukushima Daiichi contributed 1.6% (calculated by WTV from 4.7 gigawatts)—*MIT Technology Review* 118, no. 1 (January/February 2015), p. 28 (Peter Fairley, "Can Japan Recapture Its Solar Power?"), Okamato and hope of Tokyo Institute of Technology—p. 30.

"dangerous forms of energy generation might become accepted as necessary. So it proved, in the time when I was alive"—In place of the last sentence, the original published version, which was directed less to the future than to the present, read: "Practically speaking, any individual Japanese (or American) is powerless to prevent the construction of nuclear plants, regardless of his attitude about them. But while you read this story, please consider how many more times you desire the Fukushima reactor disaster to occur. Should you come down on my side, consider relocating upwind."

"In 2010 . . . nuclear power did work all over the world, to the tune of 2,600 terawatt-hours, or 8.873 quadrillion BTUs—the equivalent of burning a billion metric tons of coal . . ."—According to *Coal Information 2012,* p. II.27: "In 2010, nuclear produced 2 600 TWh globally, roughly equivalent to 1 billion tonnes of coal." Since 1 TWh = 0.086 mtoe, then 2,600 TWH = 223.6 mtoe. Multiplying this × [1 mtce / 0.7 mtoe], we get 319.42857 mtce. Since 1 tce = 27,776,000 BTUs, we multiply 319.42857 mtce × [1 million × 27,776,000 BTUs] / [1 mtce] to get

8,872,448,000,000,000 BTUs. (Or one could multiply 2,600 TW × [3,413,000,000,000 BTUs / TW] instead to get 8,873,800,000,000,000 BTUs, which agrees with the first to 99.985%.) So much for the first figure. Now, since 1 tce = 27,776,000 BTUs, then 1 billion tce = 1 billion × 27,776,000 BTUs = 27,776,000,000,000,000 (2.7776 × 10 to the 16th power). The first figure is not quite ⅓ of the second. And indeed, according to *Coal Information 2012,* "the primary energy equivalent of nuclear electricity is calculated from the gross generation by assuming a 33% efficiency, i.e. 1 TWh = (0.086 ÷ 0.33) Mtoe" (p. I.17).

Carbon Dioxide Emissions from Fossil Fuels: Japan, U.S. and World

Data taken from U.S. Statistical Abstract, 2015, p. 900 (Table 1399: "Carbon Dioxide Emissions from Consumption of Fossil Fuels by Country: 1980 to 2011"). Multipliers and percentages by WTV.

When the Wind Blows from the South (continued)

Description of the image by Yamahata Yosuke—After *Yamahata Yosuke,* gen. ed. Shinichi Otsuka (Tokyo: Iwanami Shoten, Nihon no Shashinka 6 [Japanese Photographers ser., vol. 6], 1998), plate 12.

Amount of "tsunami sediment" placed in landfills 2011–13 + its appearance in greenhouse inventory for 2015—*Greenhouse Gas Inventory Japan,* 2015, pp. 7-10, 7-4 (re: solid waste disposal). This report (the latest one available to me when I was finishing *Carbon Ideologies*) reflected greenhouse emissions of 2013 and 2014. In 2013 the sediment's methane emissions were 3,464 kt-CO_2 eq., or 0.2% of total greenhouse releases (p. 7-5). But the cleanup was ongoing in 2015 and 2016. Tsunami sediment was only about 4.5% carbon—about a tenth of the percentage for food waste (ibid., p. 7-7). "Calculated by multiplying the fraction of organic matter in tsunami sediment by the fraction of carbon contents in the organic matter; assuming the fraction of organic matter in tsunami sediment finally disposed of is 10%, and 45.2% of fraction of carbon content for wood is substituted for tsunami sediment by expert judgment" (note to Table 7-4: "Carbon content of waste disposed of in managed landfill sites (dry base)").

Footnote accompanying the preceding—Information from p. 7-13 ("the half-life for wood is used for the half-life of tsunami sediment as a substitute by expert judgment"), p. 7-9 (Table 7-6: "Emission factors by type of biodegradable waste and by treatment").

"The bell of the Gion Temple tolls . . ."—*The Tale of the Heike,* trans. Hiroshi Kitagawa and Bruce T. Tsuchida (Tokyo: University of Tokyo Press, 1977 pbk repr. of 1975 ed.; author unknown, provenance 13th cent.), vol. 1, p. 5.

Footnote: *The Japan Times's* assertion that "in terms of soil contamination" the accident was in fact only ⅛ as severe as Chernobyl's—Thursday, March 15, 2012, p. 1 (Jun Hongo, "Fukushima soil fallout far short of Chernobyl"). The highest strontium-90 levels, 5700 becquerels/sq m, were detected 5 km from Fukushima, but 30 km from Chernobyl.

"According to the newspaper, the actual level" in Koriyama "was closer to 44 times Tokyo's"—*The Yomiuri Shimbun,* April 9, 2011, p. 1. The Koriyama figure at 6:00 p.m. (taken the previous day, obviously), was 1.98 microsieverts per hour, which works out to 47.52 microsieverts per day, or 4.75 millirems per day—11 times higher than my reading. I cannot in good conscience match any of my recorded values against any corresponding newspaper value, because on none of my three Koriyama-related days did I spend a straight 24 hours in that city. The dosimeter's minimum turnover of 0.1 is so high in relation to the thankfully moderate daily radiation doses I encountered that there remains a huge margin of error. My attempts to calculate some provisional constant for each place visited (except Tokyo: 1/10 mrem per day × 1/24 day per hour = 1/240 mrem per hour) were accordingly frustrated. For instance, my approximate figure for Sendai of 0.012 millirems per hour, based on time averaging from April 6 to 7, is surely depressed by time spent at the hot springs up in the mountains. The calculation of 0.1127 mrem per hour for Kesennuma and Oshima, based on 17 hours on April 8, cannot be verified on the morning of the 9th, since radiation there cannot really be differentiated from radiation between there and Ohira, and Ohira and Koriyama. Had the situation been productive of more precision, our radiation exposure would have been, let's say, an order of magnitude higher. And, by the way, it is worth reiterating that the dosimeter measured only gamma rays. In the chapter "Harmful Rumors," the high beta readings indicated by the Tepco employees at Tomioka are usefully ominous reminders of the kinds of radiation which I could not measure.

"'Source ML' . . . opined that as much as half of this [Koriyama's measured gamma levels] might be pre-disaster 'natural' background radiation"—Source ML, who thought my 0.4 millirems per day "a very reasonable assumption." He said that as much as 0.2 millirems might be normal background for that area. He did not say that he knew this to be a fact, and I would imagine, giving his nuclear reactor background, that he might tend toward optimistic characterizations in this regard.

Footnote: 5 rems in 3 years as 0.19 millirems per hour—[5 rem / 3 yr] × [1 yr / 365 d] × [1,000 mrem / 1 rem] = 4.57 mrem / d, or 0.19 mrem / hr.

Footnote: Alternate (full) names of Okuma and Futaba—Hirose, p. 23.

Footnote: "A different (one-time) statistic gave Iitate's dose as 9.13 microsieverts per hour . . ."—See *The Japan Times,* Sunday, March 27, 2011, p. 2 (map:

"Maximum radiation levels in eastern Japan: Data from 5 p.m. Friday to 5 p.m. Saturday").

"Big Palette held the inhabitants of eight towns and villages"—Information from Mr. Sato Yoshimi (see in text below), who listed them.

"One man": "There's nothing to do there. We just have three meals which we're supplied . . ."—This was Mr. Sato again.

Footnote: Sorrel as "the thing that absorbed the most radiation" at Chernobyl—Alexievich, p. 103 (testimony of Katya P.).

Situation of Tamura after 2011—According to *The Japan Times,* Wednesday, April 2, 2014, p. 2 (unattrib., "Living in no-go zone allowed for first time"), the evacuation order was lifted in April 2012 for "part of the city of Tamura," day-time entry only. "The Miyakoji district is the first to have the advisory removed in the 11 municipalities near the Tokyo Electric Power Co. complex." On Monday, March 24, 2014 ("Radiation-hit village may OK overnight stays," p. 2), the same periodical reported that as of April 1, Tamura would be the first area in 20-km zone to have the evacuation order rescinded.

"The Nuclear and Industrial Safety Agency classified the reactor accident as a Level Seven"—In the interpreter's original translation, which she later corrected, this entity was the Ministry of Energy.

"One agency said 370,000 terabecquerels had been released so far. Another said 630,000 terabecquerels."—*Chugoku Shimbun,* April 11, 2011, front page.

Footnote: 220,000 killed at Hiroshima and Nagasaki—Mahaffey, p. 42.

Hiroshima: "twice Tokyo's background"—The footnote states that I found the same levels in Hiroshima (and Kyoto) once again in 2017. My new dosimeter measured in microsieverts instead of millirems. 1 millirem = 10 microsieverts. Instead of the 0.2 daily mrem I was getting in 2011, I accrued an equivalent 2 daily microSv.

Same footnote: Ed Lyman—Phone interview of January 25, 2017.

"American dosimetrist later remarked that this reading was probably within the pre-atomic norm for that area"—This person was Source ML.

Harmful Rumors

Preparing the much-abridged version of this chapter published in 2015, my editor at Harper's Magazine *advised me that readers tend to skip over numbers, and in her much-cut version of the "Harmful Rumors" chapter removed nearly all readings and measurements, as was certainly her right. My own view is that since we cannot* *sense radiation except through instruments, the numbers here are essential to an accurate comprehension of what I encountered at Fukushima. For those who prefer a merely atmospheric or empathetic comprehension, it may suffice to look over the table of Comparative Measured Radiation Levels (p. 244). After all, what bears most relevance is not the number itself, but the meaning of the number. While reading, you can easily make the comparison yourself. When you come across any measurement in microsieverts per hour, simply divide it by 0.06 to find how many times greater it is than the reference radiation level in my studio in Sacramento, California.*

"two out of the nine evacuated towns had formally reopened . . ."—*The Japan Times,* Monday, March 11, 2013, p. 1 (Mizuho Aoki, "Slow pace of decontamination choking Fukushima: Fitful rebuilding effort keeps residents away"). The two towns were Hirono and Kawauchi.

Footnote: "There had been hydrogen explosions in the concrete building . . ."—Hirose, p. 34.

Footnote on anti-nuclear protesters—Personal communication from Ms. Kawai Takako, July 2017.

Tepco's discovery of "high levels of strontium and other radioactive substances . . ."—*The Japan Times,* Monday, July 11, 2013, p. 2 (unattrib., "Toxic No. 1 water found in well by sea").

Elaboration of preceding citation: "The concentration of these poisons was a hundred times greater than the legal maximum." The concentration was 3,000 Bq per liter.—Loc. cit.

Footnote: A "reactor site may have anywhere from two to 20 miles of . . . pipes . . ."—Beyond Nuclear, p. 7.

Cesium-134 and cesium-137: "both about 90 times the levels found Friday."—*The Japan Times,* Wednesday, July 10, 2013 (unattrib., "Radiation surge mystifies Tepco: "Cesium soars in water under No. 1 plant"). "Groundwater in an observation well" registered 9,000 Bq per liter of cesium-134 and 18,000 becquerels of cesium-137. The legal maximum was 60 Bq per liter for cesium-134 and 90 Bq for cesium-137. "The water collected Monday also contained 890,000 becquerels of substances that include strontium, which emits beta radiation, compared with 900,000 becquerels found in groundwater sampled from the well Friday."

"the company had not been aware that water from the river would be used for agricultural purposes . . ."—*The Japan Times,* Saturday, July 13, 2013, p. 1 ("Local officials say agency kept them in dark: Radioactive water was dumped into farm-use river").

"Tepco now admits radioactive water entering the sea at Fukushima No. 1 . . ." —*The Japan Times,* Tuesday, July 23, 2013, p. 1 (unattrib., "Tepco now admits radioactive water entering the sea at Fukushima No. 1 . . ."). "Fueling fears that marine life is being poisoned" is from the body of the article.

Footnote on tritium—Information from *Britannica,* 15th ed., Micropaedia, vol. X, p. 132 ("tritium"). "The necessary ingredient of a boosted fission bomb."—Rhodes, p. 465. "manufactured at the Savannah River Plant . . ."—Kroschwitz and Howe-Grant, vol. 17, p. 449 ("reactor types"). "Easily permeates most kinds of materials . . ."—Beyond Nuclear, pp. 9, 10. "The good news about tritium" comes from the same report, p. 13: "could contaminate the entire global hydrological cycle"—Odum, p. 466.

Tritium at twice the permitted levels and climbing—*The Japan Times,* Wednesday, June 26, 2013, p. 1 (Reiji Yoshida, "Tritium samples in sea near No. 1 soar"). On June 21, 2013, seawater sampled east of No. 1's turbine building showed 1,100 becquerels per liter, double what it had been 10 days before and the highest so far. The "legally permitted level of tritium" was 60,000 becquerels per liter. At that time Tepco was "still analyzing the water for strontium-90."

NRA's recategorization of the leak as a Level Three, "a serious accident"—*The Japan Times,* Thursday, August 22, 2013, p. 1 (Reiji Yoshida, "Rating would be most serious action since 3/11: NRA looks to raise leak severity level").

"about 100 times more than what Tepco has been allowing to enter the sea each year . . ."—*The Japan Times,* Friday, August 23, 2013, p. 1 (Kazuaki Nagata, "Rate of radioactive flow to Pacific alarming: Fukushima No. 1 leaks estimated at 30 trillion becquerels since May 2011"). The water escaping from under the turbine buildings contained 10 trillion becquerels of strontium [evidently strontium-90] and 20 trillion becquerels of cesium-137.

"the size of the release is roughly in line with the allowed range of 22 trillion becquerels a year"—*The Japan Times,* Sunday, August 4, 2014, p. 1 (unattrib., "Huge leak of tritium feared in Fukushima").

"Of course, a reactor running out of control . . ."—Hirose, pp. 39–40.

Korea bans the importation of fish from eight Japanese prefectures—*The Japan Times,* Saturday, September 7, 2013, p. 1 (staff report, "Seoul bans fish imports from eight prefectures"). The prefectures were Fukushima, Aomori, Ibaraki, Gunma, Miyaga, Iwate, Tochiga and Chiba, no matter how low the radiation level of the catch might be.

February 14, 2014: More than doubling of cesium concentration in one sampling well since last July—*The Japan Times,* Friday, February 14, 2014, p. 1 (unattrib., "Groundwater cesium reaches record level"). Tepco has now found "a record

54,000 becquerels of radioactive cesium per liter in groundwater collected from an observation well east of the reactor number 2 turbine." This "far exceeded the previous record of 22,000 . . . from a separate observation well in July 2013."

The cesium concentration doubles again in a day—*The Japan Times,* Saturday, February 15, 2014, p. 2 (unattrib., "Highest cesium yet in groundwater"). The reading was now 130,000 becquerels per liter, as taken from an observation well east of No 1.

Strontium levels: Five and a half times worse than previously stated—*The Japan Times,* Saturday, February 8, 2014, p. 1 (unattrib., "No. 1 well radiation worse than thought: Tepco: Strontium spikes in groundwater"). A groundwater sample from No. 1 taken in July turned out to have "a record high 5 million becquerels per liter of radioactive strontium-90." Tepco "initially said it had detected 900,000 becquerels per liter" in that sample on July 5, but in October it had confessed to certain "problems."

"'Three hundred tons' of radioactive water now entered the ocean every day"—Information from *The Japan Times,* Thursday, August 8, 2013, p. 1 (unattrib., "Tepco needs public cash to dig deep wall: Radioactive flow to sea 300 tons daily; Suga says utility can't halt it").

The ocean's cesium vagaries—*The Japan Times,* Thursday, May 23, 2013, p. 1 (Mizuho Aoki, "Cesium levels in water, plankton baffle scientists").

Number of nuclear refugees: 150,000—*The Japan Times,* Sunday, September 1, 2013, p. 8 (Jeff Kingston, "Tepco's follies, reactor restarts and awkward plutonium stockpiles").

A Ph.D.: "The products of the fission reaction continue to generate thermal energy . . ."—Tabak, p. 36.

"The safety of [pressurized water reactors] . . ."—Ibid., p. 71.

"the prospect that several independent systems would simultaneously fail . . ."—Ibid., p. 100.

"a maximum of *one* millisievert per year for ordinary citizens is the general standard determined by the International Commission of Radiological Protection"—Information from Hirose, p. 59. Mr. Kida Shoichi, interviewed below, used the same figure. The decontamination contractor I interviewed also told me that his maximum annual dose was 1 milli.

"The workers will be allowed to undergo annual ultrasonic thyroid examinations free of charge"—*The Japan Times,* Saturday, July 20, 2013, p. 1 (unattrib., "Tepco admits exposure topped 100 millisieverts: 1973 at No. 1 face thyroid cancer risk").

"The total cost of the disaster now approached 100 billion yen"—Information from *The Japan Times,* Sunday, September 1, 2013, p. 8 (Jeff Kingston, "Tepco's follies, reactor restarts and awkward plutonium stockpiles").

Footnote re "no immediate danger": "The stock phrases used by both Edano and the TV. . ."—Hirose, p. 45.

"Tepco plans to isolate the area by injecting liquid glass . . ."—*The Japan Times,* Saturday, August 10, 2013, p. 1 (unattrib., "Tepco starts pumping groundwater: But longterm solution will take two years at least").

The electric-powered wall of ice around No. 1 that "would only cost 30 or 40 billion yen"—Information from *The Japan Times,* Thursday, August 8, 2013, p. 1 (unattrib., "Tepco needs public cash to dig deep wall: Radioactive flow to sea 300 tons daily; Suga says utility can't halt it").

Edwin Lyman of the Union of Concerned Scientists—Interviewed by phone, March 13, 2013. Although he was a Ph.D., he preferred not to be called "doctor" so that the medical profession wouldn't feel crabby.

"There is simply no doubt that the Great Tokai Earthquake will come in the near future . . ."—Hirose, p. 112. He goes on to claim (p. 159) that if another earthquake-tsunami causes another hydrogen explosion in the so-called "reprocessing center for spent fuel," it will be "equivalent to the simultaneous explosion of some 100 nuclear reactors. It would be the end of the Japanese Archipelago, or rather, the end of the world." Let's hope that's merely a harmful rumor.

Encyclopaedia entry: Iwaki is a "city in southeastern Fukushima Prefecture . . ."—*Japan, An Illustrated Encyclopedia* (Tokyo: Kodansha Ltd., 1993), p. 640.

"Ten years ago, so I was told, Iwaki had been by area the largest urban entity in Japan"—Information from my first Iwaki taxi driver.

"the tidal wave had killed more than 300 Iwakians"—*The Japan Times,* August 6, p. 3 (Chico Harlan, *The Washington Post,* "Openings of Iwaki beaches offer semblance of normalcy . . .").

Iwaki "in larger type than the row of villages to the north"—*Japan, An Illustrated Encyclopedia,* pp. 1794–95 (map of Tohoku).

Voluntary evacuation notice for Shidamyo and Ogi—Public Relations Division & Project Team, Department of Administrative Management, Iwaki City, Iwaki Centre for Creation of the Future, *One Year from the Great East Japan Earthquake: Documentary Record of Iwaki City Issued on the 11th March 2012* [49-pp. booklet] (Iwaki City: Iwaki City, 2012), p. 5. [Henceforth cited: *Documentary Record of Iwaki City.*]

"Openings of Iwaki beaches offer semblance of normalcy"—*The Japan Times,* August 6, p. 3 (Chico Harlan, *The Washington Post,* "Openings of Iwaki beaches offer semblance of normalcy . . ."). I never could find anyone who was willing to wade in the ocean with me. Well, of course it was February. By the way, all my taxi drivers believed that only one beach was open.

Maximum radiation levels in Iwaki: 23.72 microSv/hr—*Documentary Record of Iwaki City,* p. 20.

Maximum radiation levels in Iwaki: "about 380 times Tokyo's average background exposure"—This assumes 1.5 microsieverts per 24 hours in Tokyo. In fact, my dosimeter reported 2 microsieverts per day only about two-fifths of the time, but to keep the calculation simple, and honor the undoubtedly significant standard of error, I simply split the difference between 1 and 2 microsieverts as if each one of these numbers appeared with equal frequency. Had Iwaki's radiation level remained at this level, it would have been 208 times greater than the accepted safe dose of 1 millisievert per year (23.72 × 24 × 365 = 207.7872 millisieverts). American "first responders" are recommended to make 250 millisieverts their maximum dose for the saving of human lives (Levy, loc. cit.), although of course receiving 250 millisieverts in a single episode is far worse than getting 208 millisieverts in the course of a year.

"Radiation levels rapidly dropped to a mild 0.2 microsieverts per hour"—Information from *Documentary Record of Iwaki City,* pp. 5, 20.

"Even after one week from the earthquake, harmful rumours . . ."—Ibid., p. 11.

"harmful rumours due to the accidents at nuclear power stations . . ."—Ibid., p. 27.

The man in the hallway of the Fishermen's Union, re: a nuclear cruise: "You cannot. The Coast Guard is very strict here. It's prohibited"—After awhile, he added: "Try the Iwaki Fishermen's Union, since they're more distant from the Coast Guard."—That place was not easy to find, but eventually a taxi brought me there, north through Iwaki to Yotsukura, about which *The Japan Times* [Saturday, August 31, 2013, p. 3 (Koji Ueda)] featured an article headlined "Fukushima fishermen can't catch a break: One more blow comes in form of toxic water reaching sea." We were 45 kilometers south of No. 1. The Iwaki Fishermen's Union's ruined shell, a casualty of the tsunami, presided over a few small fishing boats, with here and there a laborer or fisherman on the ugly beach. Had this been Mexico or even the United States, one of these men would have been willing to dicker with me. They said to ask the fellow in the yellow boots where the Fishermen's Union was. He explained that its temporary office was near Onahama, so we drove back there, and met the extremely executive Ms. Aoki, who wished to know my exact purpose, which I revealed. She was not surprised. Television crews went near No. 1 all the time. It would cost a minimum of

100,000 yen for a five-ton boat, and possibly more, since the fuel alone would be 40,000. It didn't matter how long or how short my cruise might be. As she smilingly explained, "Taking a photograph on land is free, but as soon as you go on the water it will cost you." Moreover, I would need to get permission from the Coast Guard, who doubtless would require various other expenditures, abasements and authentications. So I gave that up.

"By early 2016 there would be nine million" black bags—Masae Yuasa, "Social situation of the populations affected by Fukushima Nuclear Power Plant Accident" (unnumbered). Evidently posted in late February or early March 2016. www.chernobyl/congress.org/fileadmin/user_upload/T30F5/F8_yuasa_final.pdf, downloaded for WTV by Teresa McFarland on March 15, 2016. Sec. "Life with radiation." [This source henceforth cited: "Masae Yuasa."]

"12 kilometers south of No. 1"—Information from Hirose, p. 125.

Tomioka's pre-accident population: 16,000—Hirose, p. 125, gives the number 16,000, while Mr. Endo Kazuhiro, the head of the Tomioka residents' association at Takaku, told me it had been "slightly under 10,000." Mr. Endo may have believed in too small a figure, because in the "footnote on Tomioka's barricades and zones," cited almost immediately below, I quote *The Japan Times* as mentioning a downtown population of 10,000 and a southern district population of 1,500. Perhaps Mr. Endo did not consider the latter to be part of his hometown.

Footnote on Mr. Matsumura Naoto and the paralyzed person's caregiver—*The Japan Times,* Friday, April 6, 2012, p. 3. At that time his cumulative dosage was supposedly a mere 2.5 millis.

Footnote on Tomioka's barricades and zones—*The Japan Times,* Tuesday, March 26, 2013, p. 2 (unattrib., "Evacuation zone revised in Fukushima's Tomioka"). I enjoyed the tone of the article; it was almost as if something wonderful had happened: "The town of Tomioka shed its exclusion zone designation Monday, allowing it to be realigned with three evacuation sectors delineated by estimated annual radiation dosage." Toward the end the reporter wrote: "The central government . . . expects to lift the evacuation advisory for the most heavily tainted zone in Tomioka in 2017, and for the other two zones in 2016. It believes the town will not be fully habitable until at least 2017." Writing in 2015, I find that last projection stunningly optimistic.

Mr. Takamitsu Endo's wish to be with his parents—They lived "south of Sukogawa," which lies "an hour or two northwest by car."

Fukushima Prefecture Dental Association's search "for cesium or other isotopes" in children's extracted teeth—*The Japan Times,* Monday, January 20, 2014 (unattrib., "Fukushima kids' teeth to be checked for strontium-90").

Strontium "appeared to offer the highest promise" to poison Germans—Richard Rhodes, *The Making of the Atom Bomb* (New York: Simon & Schuster Paperbacks, 25th anniversary ed., 2012; orig. pub. 1986), p. 511.

"RELATIVE STRONTIUM-90 CONCENTRATIONS IN PERCH LAKE (CANADA)*,* 1963"—Data from Odum, p. 460 (selected from Fig. 17-5, "SR-90 IN PERCH LAKE FOOD WEB," after Ophel, 1963).

Footnote: "Perch Lake is situated near the southern edge . . ."—Robertson and Barry, 1985, p. 238.

The Ministry of Health's good news about cesium in vegetables—*The Japan Times,* Tuesday, September 25, 2012, p. 3 (Mizuho Aoki, "Cesium contamination in food appears to be on wane"). Still unsafe were mushrooms, "mountain vegetables," wild game, freshwater fish and bottom fish.

"Doses of up to 15 millisieverts of cesium-134 . . ."—*The Japan Times,* Sunday, June 2, 2013, p. 1 (unattrib., "U.N. experts see no increased risk of cancer for residents near No. 1 plant").

The Iwaki doctors who declined to be interviewed—I also met with a prominent local journalist in hopes that he could introduce me to a talkative physician. I remember his suit and tie, not to mention his glazed weary look. He was rather unimpressed with the interpreter and me. "Since you are strangers," he said coolly, "of course I cannot recommend you." He kept looking at his watch.

"back to Hisanohama by the other ruined Fishermen's Union"—In fact this was part of the same trip to the Fishermen's Union, whose failure I have relegated to a note above.

"Fukushima's 150,000 nuclear refugees"—*The Japan Times,* Sunday, September 1, 2013, p. 8 (Jeff Kingston, "Tepco's follies, reactor restarts and awkward plutonium stockpiles"): "Almost 2 1/2 years after the three reactor meltdowns at Fukushima, Tepco is still groping in the dark while 150,000 people remain displaced from their homes . . ."

"Michiko": "We left after midnight of the tsunami day, March eleventh"—She actually said the thirteenth, which I have silently corrected.

"Leaving her alone behind her wall of ice, we drove back to Iwaki"—Here in fact this second driver took me to Ms. Aoki at the temporary offices of the Fishermen's Union, an almost fruitless interview which was therefore mentioned only in passing, in an earlier note on the subject of that organization. The interviews with Ms. Kuwahara and Mr. Kida, which appear here immediately below, actually took place two days later, as did the interview with the farmer, Mr. X—all of these with the aid of the third driver, who has not yet been introduced here, and who first drove me to Kawauchi and Tomioka. I have reported these interviews out of order, for narrative reasons.

Evacuees in Takaku: "Some of them worked for Tepco"—This information is courtesy of Mr. Endo Kazuhiro, whose interview appears below.

Interview with Ms. Kuwahara Akiyo—With graceful self-deprecation she said: "Because the leader is absent I'll give you my card if you would accept it."

"The year previous to the accident, Futaba's air dose had averaged 0.043 micros an hour"—Citizens' Study Group on Internal Exposure of Radiation website, accessed and translated for WTV by Ms. Kawai Takako, January 2017, from www.radiationexposuresociety.com/archives/3757, 4th table [labeled "D" in Kawai-san's annotated printout, and translated "Monthly air dose rate from April 2010 to March 2011 (till the previous day of the Great East Japan Earth Quake and Tsunami)." Rows 16–19 refer to Futaba. The air doses vary from 39 to 45 Gy/hr, converted by WTV to microSv by, as Kawai-san reminds us, "removing three zeroes." [This source henceforth cited: "Citizens' Study Group on Internal Exposure of Radiation website, January 2017." The marked up copy, with translations, will be deposited in my archive at the Ohio State University.]

The study on "losses from soil to river sediments" from cesium fallout—Referenced in William L. Graf, *Plutonium and the Rio Grande: Environmental Change and Contamination in the Nuclear Age* (New York: Oxford University Press, 1994), p. 114.

Columbia River Basin plutonium eroded in 20 years (0.263%)—Ibid., p. 113.

Footnote: Decontaminating No. 1 "will take nearly a half-century"—*The Japan Times,* Friday, June 14, 2013, p. 3 (Yuri Kageyama, "Fukushima No. 1 faces labor crunch as better jobs attract").

Mr. Kida's multicolored information sheets: graphic display of radiation, November 2011–December 2012—Iwaki City Nuclear Disaster Countermeasures Section, 12-pp. typescript with color illustrations: "Decontamination work in Iwaki City, Nov. 19, 2013," pp. 6–7. Based on the given scale, this area was about 26 km from end to end (NNW by SSE).

"The city's report": Removal of schoolyard topsoil if it measured more than 0.3 microsieverts per hour—*Documentary Record of Iwaki City*, p. 21.

Mr. Kida: "Ten kinds of fish are prohibited"—However, 40 fish were listed on a sheet he gave me dated "List of restrictions on shipment of sea produce (December 17, 2013)" [http://www.pref.fukushimajp/suisan/fish-index-htm, accessed

February 2014]. The first few of these included greenling, cynoglossus, sand eel, stone flounder and surf fish. Perhaps these were prohibited for export instead of for domestic consumption.

"some catches measured 200 or 300" Bq/kilo—For vegetables the maximum permissible level was 100 Bq per kilo, and for water 10. For infants it was 50 Bq for fish and vegetables, and again 10 for water.

Mr. Kida's "very long printout" of fish testing results from March 2011 until February 2014—"Emergency Monitoring of Sea Produce in Fukushima: Results from Mar. 30, 2011 to February 20, 2014. No. of samples: Sea products, 16,112. River/lake products, 1408. Inland-farmed produce 498." The units are in becquerels per kilogram, and the two contaminants measured are iodine-131 and "cesium-134 & -137 total."

Radioactive iodine dose below "the critical 50-millisievert level . . ."—*The Japan Times,* Sunday, June 2, 2013, p. 1 (unattrib., "U.N. experts see no increased risk of cancer for residents near No. 1 plant"). "The results differ markedly from those in a report published by the World Health Organization in February that warned of a higher cancer risk for residents and nuclear plant workers around . . . No. 1 than . . . for Japan's entire population."

Mr. Yamasaki's autobiography—"Originally I was anti–nuclear weapons. I was born in Toyoma Prefecture in 1959 and there were many nuclear tests, on the Japan Sea side: U.S., USSR and China. That radiation affected us children. We were told not to go out every time the test occurred. Fear of the radiation I didn't really feel at that time, but I came to know about Hiroshima, Nagasaki, Bikini Atoll, and I became angry. So I was anti–nuclear war in 1980s. The connection with nuclear power generation is after Chernobyl."

Footnote: Mr. Kawama Tatsuhiko—Interviewed in Iwaki, February 2014.

"They also said that the poor souls who were trying to ice away No. 1 were getting 40 millis a year"—About 110 microsieverts a day. Of course since my informants were not currently themselves plant workers (although one of them, as you will see, had worked at No. 1 after the accident), I will label this figure "plausible and informed hearsay."

"In the yard, the bag of waste that the nearest worker was filling emitted 0.3 microsieverts per hour. Another bag was 0.26. The target for decontamination was 0.22"—Respectively 7.20, 6.24 and 5.28 microsieverts per day. "The tolerance is plus or minus 0.01," Mr. Kanari remarked. Re: the 0.22 microsievert hourly target, perhaps when Mr. Kida stated the goal as 0.23 microSv/hr, he meant to convey that this was the minimum radiation level that would require decontamination.

"I had Mr. Kanari test a potted houseplant: 0.14 micros; the construction boss's boot, 0.11; a dirt berm behind the house, 0.33; a rain channel in the sloping concrete driveway, a surprisingly low 0.16; then the drainpipe: 0.49"—That is, 3.36, 2.64, 7.92, 3.84 and 11.76 microsieverts per day.

"Here were two black bags side by side, at 0.35 and 0.38 microsieverts; and there was the next door neighbor's drainpipe at 0.17"—Respectively, 8.40, 9.12 and 4.08 microsieverts per day.

The field of vegetables: 0.13 away from the dirt, 0.18 close to the dirt—3.12 and 4.32 microsieverts per day.

Ohisa readings: 0.17 about 2 meters from DO NOT ENTER sign; 0.19 almost on bag of contaminated waste—4.08 and 4.56 microsieverts per day.

The bamboo grove measured by Mr. Kanari: "They replied that no one should stay here more than half a month"—This was based on the annual maximum dose of 1 milli. I assume that for their recommendation to be correct, the grove would have had to be emitting 1 millisievert every two weeks, which works out to 2.76 microsieverts per hour, or almost seven times the actual radiation level.

Footnote: "decontaminating a forest (by removing fallen leaves)"—Ministry of the Environment, Japan, pamphlet: "Japan's Decontamination Efforts and its Effects" (undated, collected in Fukushima City in October 2014), p. 16.

"Radiation sickness . . . may begin to appear after a dose of 0.7 sieverts . . ."—Levy, pp. 93–96. The range for initial onset of symptoms is 0.7 to 1.0 sieverts.

"which you would get from a thousand chest X-rays"—A chest X-ray is 0.7 millisievert. Tabak, p. 93.

International Commission on Radiological Protection: "The resulting whole-body activity at the end of the period is significantly different . . ."—International Commission on Radiological Protection, *Annals of the ICRP* 39, no. 3 (2009), Publication 111: "Application of the Commission's Recommendations to the Protection of People Living in Long-term Contaminated Areas after a Nuclear Accident or a Radiation Emergency," p. 20. The example is of an episodic intake of 1,000 Bq of Cs-137 *versus* "a daily intake of respectively 1 and 10 Bq of Cs-137 over 1000 days." Since the conversion to millisieverts, with which you are hopefully now familiar, from becquerels, is so complex an affair, I have substituted my own example. Glasstone and Dolan, pp. 577–78, offer an even more extreme one: A dose of more than 600 rems [= 6 sieverts] could cause death "within a few weeks" but if that same dose is spread over 20 years there might be "no observable effect." That works out to 300 millisieverts per year, or 300 times the annual recommended maximum dose for ordinary citizens.

"All responsible bodies involved in considering radiation hazards have agreed to use the linear theory . . . "—John W. Gofman and Arthur R. Tamplin, *Poisoned Power: The Case Against Nuclear Power Plants* (Emmaus, Pennsylvania: Rodale Press Inc., 1971), p. 297.

"A dose of 2x mSv [= millisieverts] of radiation . . ."—Tabak, pp. 98, 93.

"and by 'response' he means nothing pleasant"—Response is "usually interpreted as cancer rate" (Tabak, p. 184).

"Naraha, former population 7,500 . . ."—Hirose, p. 125.

Tomioka measurements by Mr. Kanari—3.5 microsieverts per hour = 84 micros/day; 7.5 micros/hr = 180 micros/day; 3.72 micros/hr = 89.28 micros/day.

"some 480 of the 1,061 houses . . . "—*The Japan Times,* Friday, June 28, 2013, p. 3 (unattrib., "Fallout decontamination effort falling short").

"Since the [environment] ministry hasn't explicitly promised . . . "—Ibid.

Prime Minister Abe on Kawauchi: "a front-runner in rebuilding" + projection by the headmaster of Kawauchi's elementary school—*The Japan Times,* Monday, March 11, 2013, p. 1 (Mizuho Aoki, "Slow pace of decontamination choking Fukushima: Fitful rebuilding effort keeps residents away"). According to the same source, the original population of "nearly 3,000" is now 420; 65% was over 65 years old; before this age group had made up 34%.

"the place now pondered permitting its residents to sleep there overnight"—Information from *The Japan Times,* Monday, March 24, 2014, p. 2 ("Radiation-hit village may OK overnight stays"). The new policy would go into effect for a three-month trial period "starting April 26." In due course, the same periodical reported (Monday, April 28, 2014, p. 2 [unattrib.]: "Kawauchi residents get overnight stays: Evacuation order may be lifted for second tainted Fukushima area.") But due to "radiation fears," only 40 residents from 18 households applied to return. (Kawauchi had 134 households which contained in total 276 residents.) Anyhow, the newspaper must have been telling only part of the story, for as late as Tuesday, August 19, 2014, p. 1 (unattrib., "Kawauchi evacuation order may be lifted on Oct. 1"), it explained that the government was "considering lifting its evacuation advisory for the eastern part of Kawauchi," which was more heavily contaminated.

Kawauchi: "a steady resident would take in only half a milli per year"—"Official reading for Kawauchi, 10:00 a.m., 24 February 2014." Re: half a milli, an anti-nuclear flier I picked up at an Iwaki protest (described in the next section of this essay) claims: "According to the decision by the Japanese Government the areas with radiation level [*sic*] of 20 mSv/y or more are designated as 'Evacuation Zones' . . . In Belarus and Ukraine, however, 0.5 mSv/y is the criterion for

Evacuation Zone . . ." (International Labor Solidarity Committee of Doro-Chiba (National Railway Motive Power Union of Chiba), *Doro-Chibe Quake Report,* December 12, 2103, issue 60, p. 3).—According to *The Japan Times,* Sunday, April 20, 2014, p. 2 (unattrib., "Late report on radiation irks Tamura"), in one zone of Kawauchi, "an individual engaged in farming" could get 3 to 3.5 millis per year.

Kawauchi: Testimony of Mr. M. Y.—I will leave his identity in a file entitled "Confidential Sources," to be placed among my papers (restricted access) at the Ohio State University.

Footnote: Remarks of Mr. Togawa at Tepco—Interview of Monday, October 20, 2014.

Mr. Endo's estimate of the dose he got on his previous trip to Tomioka: four microsieverts, time unit unknown—I have not seen the dosimeter that Tomioka residents are issued, but I presume they measure not, like my pancake frisker, in real-time micros per hour, but, like mine, in accrued dose—which is what a dosimeter should do. In my 3⅔ hours in Okuma later that year (and Okuma was more radioactive than Tomioka), I accrued 9.1 micros, since much of that time was spent in a vehicle. Since Mr. Endo was in Tomioka for about five hours, and again most likely in his car or in his house, this total dose seems low but not impossible, given what my dosimeter said on my trip to his house—but likewise all too plausible for an hourly dose, which if it were steady would work out to 35.04 millisieverts a year—which looks not out of place if you inspect the Readings and Recommended Doses table.

Footnote on graffiti and broken car windows—*The Japan Times,* Monday, September 1, 2014, p. 3 (cont'd from p. 1, Mari Saito and Antoni Slodkowski, "Iwaki pressured by local resentment as outsiders pile in").

"Which plutonium isotope had escaped from No. 3 in 2011? . . ."—See Hirose, pp. 49–51.

Footnote: Highest level of Pu-238—*The Japan Times,* Thursday, August 23, 2012, p. 1 (unattrib., "Plutonium traces detected at 10 locations in Fukushima"). According to this source, no plutonium was detected any farther than 45 km from No. 1.

Tomioka's "visible damage rapidly lessening now that we were out of the tsunami's reach," having proceeded westward—At Takaku Mr. Endo had explained: "One kilometer from the ocean, that area was damaged by the tsunami. Closer to the beach, each house is gone. Other houses were damaged by the earthquake."

Footnote: "Carbon pools in bamboo in forest land . . ."—*Greenhouse Gas Inventory Japan,* 2015, p. 6-9.

"So what if my 10 half-lives calculation was faulty?"—Before I departed on my Tomioka idylls, the anti-nuclear activist Mr. Yamasaki projected for my benefit a very detailed, quantitative and convincingly scientific-looking graph of fallout concentrations in Tokyo over the last half-century. The maximum concentration of American, Soviet and Chinese nuclear testing fallout was detected in 1963, at about 600 becquerels per square meter. By 2014, contamination due to this source measured only 0.01 to 0.001 millibecquerel per square meter. Here we see an astoundingly rapid playing out of decrease to less than a thousandth of original levels: only 50 years to fall by a factor of 600,000! It certainly appears to discredit my theory of 10 half-lives. Perhaps the particles got washed into the sewers; who am I to say? At any rate, in 1986, Chernobyl fallout reached a level comparable to that of 1963, then quickly fell again. But after the Fukushima accident occurred, fallout in Tokyo grew between 100 and 1,000 times higher than 1963. (By the way, it should be noted that the measuring station was in Koenji, Tokyo, until 1980, then moved to Sukuba, which is outside Tokyo. Mr. Yamasaki said that this would affect the results only insignificantly.) This sounds frightening, and perhaps it should be. All I knew, with my lonely ignorance and my $500 dosimeter (whose make, at least, is reliable), is that the Tokyo radiation levels that the interpreter had measured over three years were only about one-third of those in Ed Lyman's apartment. No doubt the hundred- or thousand-fold increase in post-Fukushima radioactivity was still in absolute terms a low value—but this does not explain the rapid reductions after 1963 and after Chernobyl. I presume that a great deal of cesium took up residence in clay soils (see pp. 444, 468), some entered plants and some settled in lakes and streams.

U.S. Army: After the first 48 hours "the extent of radioactivity will be reduced a hundredfold, enabling you to leave the shelter . . . "—Headquarters, Department of the Army, *FM-21-76, Department of the Army Field Manual: Survival Evasion and Escape* (Washington, D.C.: n.p., 1969; repr. by Dorset Press, n.d.), p. 65 (sec. 2-23: "Radioactive Areas").

Remarks of Ed Lyman: "how uniform are the hot spots?" + proposal of compensation to residents who refused to accept 1/1,000 level of post-accident radioactivity + "Assuming that it's beta decay from cesium-137 . . ."—Phone interview, March 24, 2014. In a followup phone interview of January 31, 2015, he said: "Since cesium-134 has such a shorter half-life, the radiation has reduced by half. As for cesium-137, there's natural decay, erosion and deposition of clean soil. But then there's the issue of the kind of reservoirs on the hillsides and forests that'll keep getting washed down. For a long time, you're going to get very variable hot spots. They do have limited success in decontaminating structures. If people move back, they'll have to be vigilant." He then reiterated: "The consensus is that *there's no safe level of radiation.* The accepted level is the international standard:

one milli per year. We think if there's an accident, the standard should be the same."

Dr. Lyman's conversion of Cs-137 cpms to millirems to microsieverts: Divide by 100—As noted in a footnote in the text, "when I returned to Fukushima with that pancake frisker, which measured in both cpms and microsieverts per hour, my data did not verify this conversion." For instance, in the abandoned commercial district of Tomioka my device read 553 cpms and 0.031 micros per minute, which is to say 1.86 micros per hour, not 5 micros per hour. Generally speaking, on 1-minute timed counts with this "pancake frisker," which was calibrated for Cs-137, I found that cpms divided by 18,000 yielded the approximate value in microsieverts per minute. Hence to get micros per hour I divided cpms by 300. [See "Definitions, Units and Conversions."] In the Tomioka example, this division (553 / 300) gives an acceptable close 1.84 micros an hour.

"Tomioka might be more unhealthy than I had supposed."—Based on the dosimeter's gamma readings, never mind how superficial they were, I had calculated a mean annual dose of 21.90 millisieverts, or about 60 times Iwaki's levels—not far off from the factor of 72 that I had proposed to Mr. Kida. In a year the sidewalk would give off another 438 millisieverts of beta radiation. Since I lacked any measurement of beta levels in Iwaki, no comparison between the beta levels of the two cities could be made, but given the all too evident fact that this particular form of harmfulness remained invisible to the little toy that the interpreter and I were carrying, Tomioka might be considerably more dangerous than I had supposed.

A photo of a beta burn on the neck one month after exposure—Samuel Glasstone and Philip J. Dolan, comp. and ed., *The Effects of Nuclear Weapons,* 3rd ed. (Washington D.C.: United States Department of Defense and the Energy Research and Development Administration, 1977), p. 595.

"Criticality accidents are extremely unlikely . . . "—Tabak, p. 99.

"The likelihood of an accident leading to a breach . . ."—John G. Collier and Geoffrey F. Hewitt, *Introduction to Nuclear Power* (Washington, D.C.: Hemisphere Publishing Corp. / Harper & Row, 1987), p. 164.

"in six months I got 6.62 millisieverts, working 20 days a month"—Assuming an 8-hour workday, with significant transit time to and from J Village through contaminated areas in possibly contaminated vehicles, let us postulate 9 hours per day of significant radiation exposure. Thus: 9 × 20 × 6 = 1,080 hours of exposure every six months. 6,620 micros in 1,080 hours is a very plausible 6.13 micros an hour. In this man's year and a half of work he would have accrued at this rate 19.86 millis. Were he to be subjected to this exposure for a solid year, he would have won the prize: 53.70 millis.

Footnote: My college physics textbook's remarks on the radiation susceptibility of pine trees—Tilley and Thumm, p. 202. According to Alexievich (pp. 135–36), pines and evergreens near Chernobyl "turned red, then orange."

Same footnote: Red pines at Hiroshima—The Committee for the Compilation of Materials on Damage Caused by the Atomic Bombs in Hiroshima and Nagasaki, *Hiroshima and Nagasaki: The Physical, Medical, and Social Effects of the Atomic Bombings,* trans. Eisei Ishakawa and David L. Swain (New York: Basic Books, Inc., 1981), p. 84. [Henceforth cited: "CCMDCABHN, 1981."] This source says that cedars also turned reddish due to radiation damage.

Same footnote: "apparent increases in growth mutations of fir trees"—*The Japan Times,* Saturday, March 5, 2016, p. 2 (unattrib., "DNA damage found in Fukushima forests: Greenpeace says mutations are just beginning to be seen five years on").

Legal limit: 20 millis a year—*The Japan Times,* Thursday, March 27, 2014, p. 1 (Yuri Kageyama, "Life at Fukushima No. 1 gets manga treatment").

"He claimed to have measured 1.6 to 3.8 microsieverts in any one of those black bags—'6 microsieverts if you stand beside it'"—Assuming these to be hourly figures, their yearly equivalents would be respectively 14.02, 33.29 and 52.56 millisieverts.

Footnote: Subcontractor buried alive at No. 1—*The Japan Times,* March 30, 2014, p. 2 ("Fukushima No. 1 plant worker dies after getting buried alive").

Resumption of sale of Iwaki seafood at Tsukiji—*The Japan Times,* Saturday, May 18, 2014, p. 2 (unattrib., "Seafood from Iwaki makes return to Tsukiji").

Information in water intake sample—*The Japan Times,* Sunday, May 18, 2014, p. 2 (unattrib., "Fukushima radiation at all-time high"). "At one sampling point in the port, between the water intakes for reactors 2 and 3, 1,900 Bq per liter of tritium was detected Monday, up from a previous high of 1,400 Bq measured on April 14." In the case of the Sr-90 in the intakes for Reactors No. 1 and 2, the previous high value was 540 Bq/L. Officials at Tepco said the cause was "unknown."

Footnote:—*The Japan Times,* Saturday, October 1, 2016 (Kazuaki Nagata, "Tepco admits ice wall efficacy still not known: Six months on, utility unable to rate its efforts in Fukushima"). The official whom I quoted was Mr. Masuda Naohiro, "who heads Tepco's decommissioning project."

The Red Zones

Footnote: "But restarting reactors remains crucial . . ."—*The Japan Times,* Sunday, September 1, 2013, p. 8 (Jeff Kingston, "Tepco's follies, reactor restarts and awkward plutonium stockpiles").

Footnote: "Those little bastards blame our generation . . . "—O'Hara, p. 303 ("You Can Always Tell Newark," first pub. 1961).

My San Francisco reading as 2.5 × Shinjuku's one day before the accident—*The Japan Times,* Wednesday, March 12, 2014, p. 2 (Jacob Adelman, "Tokyo radiation less than the level in Paris"). The reading was 0.0339 microSv/hr, on March 6, 2014, "about the same as the day before" the nuclear accident.

The pancake frisker: "He looked up the calibration test for my serial number"—My frisker "measured 3,000 counts in a 10-microsievert field" when "The correct figure was 3,200 counts." Other calibration data for my specimen:

Reference	Measured
80 micros	77.11
20	20.14
8	7.96
2	2.04

There is not enough data here for me to guess whether my frisker significantly underreported radiation in the red zones.

"the red zones more than overshadowed every other place I went in those days"—That is, between 2014 and 2017.

Details on the 1944 nuclear pile—Rhodes, pp. 603–4, 557.

"There were about 10 or so . . ."—*The Japan Times,* Wednesday, September 24, 2014, p. 3 (Hideki Takahashi and Shinya Kokubun, "Lives on the Line," Part 4 of 6: "Helplessness as reactor 2 lost cooling: On verge of meltdown, operators feared evacuation of Tokyo possible").

Amount of plutonium in Nagasaki bomb (9 kg.), number of reactors (9) and duration of plutonium production (1944–87)—*The Japan Times,* Tuesday, August 20, 2013, p. 2 (Shigeru Sato and Yuji Okada, "Hanford offers Tepco lesson in cleaning up Fukushima").

"It is a thing of beauty to behold . . ." + "We removed our glasses . . ."—Samuel Hynes et al., ed. and comp., *Reporting World War II, Part Two: American Journalism 1944–1946* (New York: Library of America, 1995), pp. 763, 770

(William L. Laurence, "'A Giant Pillar of Purple Fire': Nagasaki, August 9, 1945: Atomic Bombing of Nagasaki Told by Flight Member").

"environmental conditions more favorable than most power-plant . . . sites . . ."—Charles H. Fox, "Radioactive Wastes," "Understanding the Atom" ser. (Oak Ridge, Tenn.: United States Atomic Energy Commission, Division of Technical Information, 1969 rev. of 1966 ed.), pp. 20–21.

Plutonium as less poisonous than arsenic, less hazardous than Cs-137 and Sr-90—Graf, p. 28.

Footnote: "Its most stable compound is plutonium dioxide."—Information from Graf, p. 27.

Same footnote: plutonium dioxide as "an attractive reactor fuel"—Kroschwitz and Howe-Grant, vol. 19 ("Pigments" to "Powders, Handling"), p. 430 ("plutonium and plutonium compounds").

"Hanford became the primary source for plutonium . . ."—Graf, p. 21.

Details on the Hanford N Reactor and its purpose, + information on Chernobyl reactor in accompanying footnote—Kroschwitz and Howe-Grant, vol. 17, pp. 437–38 ("reactor types"). Graphite reactors can actually use unenriched uranium (p. 435).

"When you're doing oil field, it's not the fracking . . ."—See the John Mahoney interview beginning on II:377.

"the most serious long-term threat to the Columbia River . . ."—Rich Landers, *Paddle Routes of the Inland Northwest* (Seattle: The Mountaineers, 1998), p. 181.

"It's among the most toxic nuclear waste sites . . ."—*The Japan Times,* Sato and Okada article.

"found to be leaking 1000 gallons . . ."—Landers, loc. cit.

"some 1,500 sq. km. of scrubland"—*The Japan Times,* Sato and Okada article.

Extent of Hanford: 1,518 square kilometers + 212 million liters of radioactive waste "cached in aging underground tanks"—*The Japan Times,* Monday, June 3, 2013, p. 1 (Shannon Dininny, AP, "Leaks complicate cleanup of U.S. nuclear facility"). This source said that cleanup had cost American taxpayers $36 billion so far and would cost $115 billion more. When I was alive, there were always cost overruns in such projects.

"concrete cocooning"—*The Japan Times,* Sato and Okada article.

"sediments always contain the largest quantities of heavy metals . . . "—Graf, p. 9. The book goes on to say that at Oak Ridge and Los Alamos, "the soil and surface sediments contain more than 99 percent of the plutonium."

"inhalation of plutonium-spiced sediments . . . . probably the most important from the standpoint of human contamination"—Ibid., p. 28.

"My detector was rated . . . at an efficiency of 11% for plutonium-239"—Or, to be more precise, at a 4 pi surface plane efficiency of 11% for plutonium-239.

Footnote on Pu-238 and her sisters—World Nuclear Association, 2016.

Description of Hanford Reach—After a visit in August 2015.

Ringold fish hatchery "had received the highest fallout dose from Hanford"—Information from Gephart, p. 4.19. "The 27-year cumulative dose to an adult that [*sic*] received the highest possible dose . . . between 1945 and 1972 ranged from 6 to 1000 millirems" (loc. cit.).

Most of Hanford's fallout from I-131—Ibid., p. 4.18.

"the Department of Energy's side of the river . . ."—U.S. Fish & Wildlife Service, undated download from www.doi.gov (printed for WTV by Tom Colligan, April 2015): "Hanford Reach National Monument / Washington," unnumbered p. 1.

"the leg from Priest Rapids Dam to Ringold Springs . . ."—Landers, p. 177.

Footnote: "Although 90% of the uranium available for mining . . ."—Information from Kroschwitz and Howe-Grant, vol. 24 ("Thioglycolic Acid" to "Vinyl Polymers"), p. 641 ("uranium and uranium compounds").

The high readings from granite in the table "Lowest and Highest Measured One-Minute Average Radioactivities in Selected Safe Cities"—To underscore the matter here is my partial log of readings for the four days whose frisks included the Anichkov Most; such instances I have boldfaced. As you see, in this relatively "hot" city the measurements of that granite bridge were consistently high—higher than most other levels—and Petersburg's highest *timed average* was a granite windowsill:

Date	Time	Location	cpms	microSv/ hr
6.15	**21.05**	**W on granite of Anichkov Most [Bridge]**	**180**	**0.60**
	21.07	**W on Nevskii Prospekt, going 2 blocks east of previous (air dose)**	**109**	**0.36**
	21.08–26	**MAX, continuing walk in same direction**	**178**	**0.586**

Date	Time	Location	cpms	microSv/hr
6.19	11.26	air dose, anteroom of Dostoyevsky museum (site of his last flat)	52	0.18
	13.51	gravel in courtyard of Fontanka house where Akhmatova lived	148	0.48
	13.53?	air dose in same	79	0.24
	13.57?	W Liteny, heading south toward Nevskii	83	0.30
	13.59?	continuing same	99	0.30
	14.01?	continuing same	94	0.24
	14.03–13?	**MAX on Nevskii and across Anichkov Most (on bridge, reading went straight from 150 to 480)**	**480**	**1.579**
	14.16?	air dose in fancy cafe Kutsov Eliseevi on the Nevskii	41	0.12
	14.23	granite windowsill outside previous	283	0.96
	14.25?	painted drainpipe on same windowsill	164	0.54
	14.40?	table in Czech restaurant Karlovy Pivo on Nevskii	60	0.18
	15.30	**W on Nevskii going east; headwind from Anichkov Most**	**137**	**0.48**
	15.31–34	**MAX, continuing on same walk**	**160**	**0.527**
	15.40?	**sidewalk close to Anichkov Most**	**113**	**0.36**
	15.43?	continuing away from previous	76	0.24

As you see, my MAX readings were indicative but not exactly the last word. And the MAX reading of 1.184 micros an hour there in the river breeze at Hanford did not even match the 1.579 micros per hour of a Russian tourist bridge. The day after my return from Hanford I laid down the frisker on a brick sidewalk on Seventh and Yamhill in Portland, and in the first few seconds of a six-minute MAX reading the display chittered up to and stayed at 300 counts per minute, 0.987 micros per hour. Caveat emptor.

Footnote on swallows: “Countless” numbers on the White Bluffs—Landers, p. 183.

Relative densities of plutonium dioxide and quartz—Graf, p. 13.

"Heavy metal concentrations are usually highest in the finest stream sediments"—Graf, p. 13.

"plutonium content of suspended sediment . . ."—Ibid., p. 231.

"The grand mean concentration for plutonium-238 in river water . . ."—Ibid., p. 131. And ibid., p. 133: "One picocurie per gram of plutonium in sediment represents much less than one part per billion of the metal in natural materials and could not be detected by ordinary physical or chemical methods."

Footnote on the 2017 Hanford accident—*The Washington Post,* May 9, 2017 [e-version, so no p. no.; accessed by WTV on July 20, 2017), "Post Nation" section, Lindsey Bever and Steven Mufson ("Tunnel collapses at Hanford nuclear waste site in Washington state"). 1 rem = 10 millisieverts = 1.07185 roentgens. Since "in excess of five roentgens an hour" is not very precise, we might as well just speak roundly of an "excess of 50 millis an hour," which would be 438,000 millis a year, or 438 sieverts [= 438 million micros].

Anyway, there must have been some plutonium left at Hanford, since *in the Rio Grande system,* and so presumably in the Columbia, *more than 99 percent of the sediment eroded from the landscape will remain in the river system for more than 20 years and . . . more than 99 percent of the fallout also will remain in that system,* although another researcher thinks that *the figure is probably 98 percent* (ibid., p. 113). In the Columbia, only 0.263 percent of the plutonium would have eroded in 20 years. If I had done the math correctly, then after 71 years not even one full percent would have washed away yet. Let us suppose, as seems probable, that even though the pancake frisker could not detect any plutonium at Hanford, there was some. One source (Gephart, p. 4.18) estimates that of Hanford's fallout only 1 to 2% derived from Pu-239. The I-131, which made up most of the radiocontamination, was of course long since decayed away. The city of Spokane was 5 times more radioactive than Hanford, due to granitic rock (p. 4.23).

Concentration of radioactivity in plankton—Hirose, pp. 72–74.

"Concentrations of Radioactive Phosphorus at Hanford Nuclear Site, 1954–58"—Information from Odum, pp. 459–60.

"Other Concentration Factors at Hanford, 1954–58"—Ibid., p. 460.

First footnote to table: "That is, 0.003 parts per million."—One unnamed but mathematically-inclined skimmer of this manuscript wrote: "In the first FN, '0.003 parts per million' by my analysis/calculation would require the number in the main text to be 0.000003, that is, one more zero right of decimal. Interestingly, that number would then require a 'CONCENTRATION FACTOR' of

2,000,000, not '200,000,' and you'll find a '2,000,000' in the second FN!" Alas, Odum's "number in the main text" is 0.00003 [4 zeros right of decimal point], not 0.000003.

Failure of Tepco's freezing project in April 2014; problems with debris removal at Reactor No. 3; plans for Reactor No. 1 in 2015 and 2017—*The Japan Times,* Wednesday, September 24, 2014, p. 1 (unattrib., "Tepco to start removing blast debris by late 2015: Utility vow not to let radioactive material escape reactor 1 building").

"Tepco's ice wall runs into glitch"—*The Japan Times,* Thursday, June 19, 2014, p. 1 (unattrib.). The coolant was piped-in aqueous solution of calcium chloride at −30° Celsius.

400 tons per day of groundwater seepage; Tepco's request to dump filtered toxic water—*The Japan Times,* Tuesday, August 12, 2014, p. 1 (unattrib., "Tepco asks to build toxic-water dumping facility at Fukushima No. 1").

"Ice wall at No. 1 plant fails"—*The Japan Times,* Thursday, August 21, 2014, p. 1 (unattrib., "Ice wall at No. 1 plant fails: Tepco").

Footnote: "Tepco admits ice wall efficacy still not known"—*The Japan Times,* Saturday, October 1, 2016 (Kazuaki Nagata).

Results of next sampling, and measured rainfall of Typhoon Phanfone—*The Japan Times,* Thursday, October 16, 2014, p. 2 (unattrib., "Radioactivity spikes in No. 1 water well: Tepco").

Tritium concentration after Typhoon Phanfone—*The Japan Times,* Monday, October 13, 2014, p. 1 (unattrib., "Tritium shot up tenfold in No.1 groundwater after typhoon").

"We do sampling of the ocean water . . ."—Tepco interview of October 20, 2014. Mr. Hitosugi went on: "Inside the power plant, there are lots of efforts being made. One is, you put water to cool the fuel, and that becomes contaminated water. To remediate that, there is a system to recycle that water. At the same time, several hundred cubic meters of groundwater per day is coming in. That portion is accumulating, and so for that we use tanks. That contaminated water, we are trying to reduce it using the recycling system. Also, several hundred tons of groundwater per day get mixed with leaked water, becoming new contaminated water, and we are trying not to let this go out into the ocean. More specifically, we have made a steel wall in the oceanside, more than 10 meters deep [the interpreter expressed this as: "more than 10 + several meters deep"]. Also we improved the soil; we used soluble glass to make the soil harder. And finally, we made a wall to the land side, so that the contaminated water will accumulate in the plant and stay there. That water is pumped out and cleaned."

"But what about the wall of ice?" I asked. "Are you progressing with that?"

"It's right under construction. The purpose of this to prevent that water from coming in. We hope to freeze the site by 2015."

In 2016 they had made progress, and were still hoping.

Size of past and prospective tsunamis at No. 1, and amount of cesium in danger of being released—*The Japan Times,* Sunday, October 4, 2014, p. 3 (unattrib., "Fukushima No. 1 could next see 26-meter tsunami, Tepco warns").

News about No. 4's fuel rods + headline "No. 1 fuel rod removal . . . "—*The Japan Times,* Friday, August 22, 2014, p. 2 (unattrib., "No. 1 fuel rod removal to finish ahead of time, Tepco chief says").

Approval of nuclear restart in Kagoshima Prefecture—*The Japan Times,* Thursday, September 11, 2014, p. 1 (Kentaro Hamada and Osamu Tsukimori, "Nuclear plant OK'd for restarts: Kyushu facility first to meet NRA's tougher safety rules"). The utility was Kyushu Electric, not Tepco.

Swallows with white spots and peculiarly-sized butterflies (these last were actually pale blue grass butterflies)—*The Japan Times,* Saturday, August 16, 2014, p. 1 (unattrib., "Japan, U.S. warn of species mutations in Fukushima"). Timothy Mosseau and Anders Moller, who researched Chernobyl and Fukushima, reported "gnarly distortions of tree growth and numerous abnormalities in insects, birds and other animals"—in other words, "genetic mutations induced by exposure to the radiation."—*The Japan Times,* Sunday, March 10, 2013, p. 8 (Counterpoint: Roger Pulvers, "Tohoku has been truly rent asunder for untold generations yet to be born"). All I saw was one peculiar insect in Iitate.

"Comparative Average Radiation Levels," fn on Shinjuku and high Tokyo readings, 2014 and 2011—*The Japan Times,* Wednesday, March 12, 2014, p. 2 (Jacob Adelman, "Tokyo radiation less than the level in Paris").

Information on how Iitate got its name—Interview with Mr. Shigihara Yoshitomo, October 23, 2014.

"There every day 7500 workers are 'decontaminating' the village where 6500 lived"—Masae Yuasa, section "Life with radiation."

Iitate's first cesium, iodine and tellurium; its distance from Plant No. 1—Information from Lochbaum et al., p. 118. According to Mr. Shigihara Yoshitomo, Iitate is 35 kilometers, not 40, from No. 1. *The Japan Times* (Thursday, January 30, 2014, p. 3 [Tetsuiji Ida, "Farmer's Tepco grudge runs deep: Retiree found new life on the land until nuke crisis took toll"]) put it at 40, so I voted with the majority.

Plutonium at Iitate—*The Japan Times,* Thursday, August 23, 2012, p. 1 (unattrib., "Plutonium traces detected at 10 locations in Fukushima").

Information about March 15–17, April 6 and 31, July 4, 2011—Shigihara Yoshitomo, typescript headed "Dec. 15, 2011. Report of the situation regarding Fukushima No. 1 nuclear power accident." Translation for WTV by Ms. Kawai Takako.

Slaughter of cattle; date of evacuation—Information from Lochbaum et al., p. 120.

Compensation of the Nagadoro people + Mr. Shigihara's conclusions and radiation measurements in 2013—Shigihara Yoshitomo, typescript headed "Compilation of Interview Record. October 12, 2014." Translation for WTV by Ms. Kawai Takako.

The dose of Colonel Vodolazhsky—Alexievich, p. 135.

The taxi driver—He spoke of *hama-dori,* the danger zone. Right now we were still in the zone called *nakedori.*

Footnote: 90% of Okuma's tax revenues from Daiichi—Lochbaum et al., p. 40.

Description of Iitate—After a visit on October 23, 2014.

1.0 and 1.1 micros an hour as "the average 2015 air dose for Iitate"—According to Masae Yuasa, sec. "Life with radiation," the 2015 air dose was 1 micro an hour. I presume this was for the yellow zone only, not for Mr. Shigihara's subdistrict.

"March 17—95.1 microsieverts an hour!"—At the time we stood at this spot, the interpreter translated the date as March 16. But since the typescript headed "Dec. 15, 2011" stated that this dose was measured two days after March 15, I have emended it.

Footnote: "heritable mutations in pale blue grass butterfly populations"—*The Japan Times,* Saturday, March 5, 2016, p. 2 (unattrib., "DNA damage found in Fukushima forests: Greenpeace says mutations are just beginning to be seen five years on").

Effects of leaf-ammonia on cesium—*The Japan Times,* Sunday, June 2, 2013, pp. 7–8 (Tomoko Otake, "Fukushima farmer plows own anti-radiation furrow").

Footnote: "The US has no formal limits . . ."—Crownover to WTV, June 2017.

Footnote: The Tepco official, and the supposed 0.8 microsieverts per hour in Gifu Prefecture—When I interviewed the Tepco officials in Tokyo, Mr. Togawa Satoshi of the International Public Relations Group said to me: "I was in Naraha yesterday, and it read 1.5 microSv per hour." (My own 11 outdoor frisks in that area averaged only 0.32 micros. But he might have been in "hotter" places than I.) "The natural dose to the human body, world average," he continued, "is 2.4 millisieverts per year. So considering that number, the current values are not that high, we believe. In Japan, it is known that in areas where there is a lot of granite the radiation level is high. The level is 0.8 microsieverts per hour in Gifu Prefecture naturally. There are no health problems in that prefecture."—So I asked the interpreter to e-mail the prefectural clinic in Gifu as follows: "Is this truly the radiation level there, and are there truly no health problems from it?"—She soon answered: "The prefectural office in Gifu responded that the real time air dose was 0.08 micros an hour, not 0.8 micros," the cause being "a lot of granite. There is even a uranium mine (no commercial base)." This is 0.7008 *versus* 7.008 annual millis. More to the point, .08 micros is less than Tokyo's typical (and hardly dangerous dose) of 0.12 micros.—Who slipped the decimal point? Perhaps the interpreter did, and Mr. Togawa actually said 0.08 micros, but why then would he even mention this case? He must have meant to say 0.8 micros, in which case his data was wrong. (But then why did the official in Gifu refer to granite and uranium as causative agents, when the air dose was so remarkably low? One would think that Gifu's inhabitants would be delighted with their radiation level.) The interpreter insisted that Mr. Togawa did say 0.8 micros.

"Cesium Concentrations in Iitate Mushrooms, 2014"—Information from *The Japan Times,* Thursday, January 30, 2014, p. 3 (Tetsuiji Ida, "Farmer's Tepco grudge runs deep: Retiree found new life on the land until nuke crisis took toll"). In my opinion the best way to measure the radioactivity of mushrooms is by sitting on a tatami (in this case in Fukushima city), with a beer and several chicken yakitori skewers on the table, the waitress kneeling to write the order on her little pad, and looking through the half-open sliding door at the counter with its high-backed chairs, a man's crossed legs just within this frame, and longnecked bottles each of a different color and transparency lined up like a file of swans against one of those long bamboo sheets which can be scrolled up around soft rice to make it into a cylinder of maki sushi, the dosimeter still at 0.570, the frisker measuring 0.12 micros per hour (36 cpms) when held sideways against the floor, smell of cigarette smoke; on NORMAL it was a mild 0.148 microsieverts per hour; then I conscientiously frisked a delicious appetizer of small brown local mushrooms which had been garnished with chilis and beansprouts (an innocuous 0.212 to .250 microsieverts at NORMAL); and just for your information, the interpreter's air dose was 0.006 microsieverts per hour.

Footnote: The Brookhaven experiment—Odum, pp. 457–59, citing Woodwell, 1962 and 1965. Figures expressed in rads per 20 hours (the source was shielded for 4 hours a day so that the scientists could observe the area). 1 rad = 10 millis = 10,000 micros, so 1 rad per 20 hours = 500 micros an hour. I have converted accordingly. Occasionally, where no value was stated in the text, I had to approximate by "eyeballing" the original graph, so in the interest of transparency, here are my conversions:

rads/day	millis/hr
2	1 milli
5	2.5 millis
1	5 millis
20	10 millis
40	20 millis
100	50 millis
300	150 millis
400	200 millis

"In the Savannah River area . . ."—Graf, p. 10.

Cesium: "an extremely active member of the Sodium Family"—Metcalfe, Williams and Castka, p. 490.

Information on waste storage plans for Fukushima—*The Japan Times,* Friday, August 1, 2014, p. 1 (unattrib., "Tochigi town protests nomination as atomic dump site"; August 31, 2014, p. 3 (unattrib., "Fukushima OKs storage plan").

"Mr. Kojima organized these tours as a member of a private organization . . ."—Extract from a letter of explanation from Ms. Kawai Takako to WTV, 2014.

Information on exposures of Tepco nuclear workers through 2016—*The Japan Times,* Tuesday, March 8, 2016, p. 1 (unattrib., "32,000 at Fukushima No. 1 got high radiation dose").

"They typically work on three- to six-month contracts . . ."—*The Japan Times On Sunday,* March 13, 2016, p. 1 (Mari Yamaguchi, "Fukushima workers 'exploited'").

Footnote: "The cesium in this ampoule melts . . ."—Gray, p. 131.

Footnote: "a conventional power plant would need to burn about 3.6 million gallons of heavy fuel oil"—Converted as follows: [1 kWh = 3,413.0 BTUs/hr] × 45.5 million kWh = 155,291,500,000 BTUs per hour. Multiplying this × 3 to account for the wastage in a fossil fuel power plant, then dividing by 18,450, the HHV of heavy grade commercial fuel oil [table of Calorific Efficiencies, p. 214, multiple header **201**], we obtain 25,250,650 lbs, which when divided by [7.036 lbs/gallon, the density of diesel fuel, which is my best approximation] becomes 3,588,779 gallons.

Footnote: "At least these paddies were no longer warming the atmosphere . . ." —*Greenhouse Gas Inventory Japan,* 2015, p. 6-47: "*Conversion from Cropland:*

For former rice fields, upland fields, and orchards, the area classified as 'other, natural disaster damage' is used according to *the Area Statistics for Cultivated and Commercially Planted Land*." Table 6-47 ("Area of land converted to other land (single year)" gives a figure from 1990 through 210 of 0.8 to 4.5 kilohectares per year; most numbers are in the 2's. Then comes 2011: 16.8 kha, of which 14.9 were ricefields, got "converted."

Description of Tomioka—Okuma (from car)—Namie—Tomioka—After a visit on October 26, 2014.

Footnote: "Volume reduction of contaminated soil"—Ministry of the Environment, Japan, pamphlet: "Japan's Decontamination Efforts and Its Effects" (2014), p. 42 (Ref. 7).

"before the accident Yonomori's air dose had been 0.042 micros—97 times less"—Citizens' Study Group on Internal Exposure of Radiation website, January 2017, 2nd table [labeled "B" in Kawai-san's annotated printout, and translated "Monthly air dose rate from April 2010 to March 2011 (till the previous day of the Great East Japan Earth Quake and Tsunami)." Row 10 refers to Yonomori, whose monthly measured dose was a flat 42 Gy/hr for the 12 months before the accident.

Pampas grass: "Growth is astoundingly fast . . ."—Terri Dunn Chace, *How to Eradicate Invasive Plants* (Portland, OR: Timber Press, 2013), p. 176. The species referred to is *Cortaderia selloana.* "Hails from Argentina, Brazil and Uruguay," although Beecher Crampton, *Grasses in California* (Berkeley: University of California Press, California Natural History Guides, No. 33, 1974), p. 122, claims: "Introduced from . . . Brazil, Argentina and Chile" (and "becoming naturalized especially along the [California] coast").

Pampas grass: "hardy to frost hardy . . ."—Lance Hattatt, *The Gardener's Encyclopedia of Plants and Flowers* (Philadelphia: Courage Books, "an imprint of Running Press," 1998), p. 82. A panicle is "a central axis provided with solitary, several, or whorls of branches that bear pediceled flowers" (Crampton, p. 169).

Footnote on the Futaba Town Recovery Promotion Committee—*Yomiuri Shimbun,* October 28, 2014, p. 33, headline and reporter not trans. (trans. by Ms. Kawai Takako): "The Futaba Town Recovery Promotion Committee compiled a long-term plan. The final version will be submitted to the town mayor after consulting with townspeople and the parliament. The plan includes: JR Futaba station and North East area, where the air dose is relatively low (are to prepare for lift of restriction and) will be designated as a "recovery base." In this area, decontamination and building demolition will be carried out in stages, to recover life infrastructure. Corporations related to abandonment of reactor, solar power generation and vegetable factory will be introduced (get special treatment in setting up facilities there). There are many high dose areas in the town. Also, there is a plan to build an intermediate storage facility. So the proposed plan is not clear about the time when the evacuation order will be lifted or how many residents may return."

Goldenrod's "racemes or spikes of golden-yellow flowers . . ."—Hattatt, p. 227. The genus is Solidago. What I saw in Fukushima resembled *Solidago canadensis,* tall goldenrod: 2 to 8 feet tall, flowerhead ¼ inches wide, "flowerheads golden, in arching spikes that form pyramid at top of downy stem; leaves lance-shaped, rough-textured."—Reader's Digest, *Wildflowers* (New York: Reader's Digest Association, Inc., 1998 rev. of 1982 material).

Description of Tomioka—Okuma (including Plant No. 1)—Tomioka—After a visit on October 27, 2014.

Footnote: Official return date for Okuma residents of 2022—Lochbaum et al., p. 188.

Final description of Tomioka—After a visit on October 28, 2014.

Cesium-137 Released in the World's Two Worst Nuclear Disasters

Information from *The Japan Times,* Sunday, May 11, 2014, p. 1 (unattrib., "Cesium levels from Fukushima disaster eclipse Tepco claims"). The Fukushima University study (led by Prof. Aoyama Michio) asserted that "of the amount on land," as much as 400 tBq could have reached North America. The source of the Chernobyl data is not given.

The Red Zones (continued)

"All 11,000 residents [of Okuma] remained evacuated"—Information from *The Japan Times,* Wednesday, March 5, 2014, p. 3 (Aiko Kaneshi and Tonomi Miura, "Students seek out Bikini, Fukushima parallels").

"In the year previous to the reactor failures, Ono's air dose had varied between 0.041 and 0.042 micros an hour"—Citizens' Study Group on Internal Exposure of Radiation website, January 2017, 4th table [labeled "D" in Kawai-san's annotated printout, and translated "Monthly air dose rate from April 2010 to March 2011 (till the previous day of the Great East Japan Earth Quake and Tsunami)." Row 14 refers to Ohno [so spelled here] whose monthly measured dose varied between 41 and 42 Gy/hr for the 12 months before the accident.

Footnote: "those working with radiation are required to keep their dosage below 5 rems . . ."—Magill, vol. 2, p. 2186 ("radiation monitoring").

Footnote: Disposal of "captured wild harmful animals"—Ministry of the Environment, Japan, pamphlet: "Japan's Decontamination Efforts and Its Effects" (2014), p. 40 (Ref. 4: "Demonstration Project for Decontamination Technologies").

Measurement of site "outside the port": 4.3 Bq of tritium—*The Japan Times,* Sunday, May 18, 2014, p. 2 (unattrib., "Fukushima radiation at all-time high"). Another site "outside the port" measured 8.7 Bq. The footnoted measurements "inside the port" also derive from this source.

Footnote on Namie's irradiated cows—*The Japan Times,* Saturday, September 24, 2016, p. 2 (Miki Toda, "Nuked cows' fate takes scientific twist: Fukushima rancher keeps livestock alive for radiation research, not hamburgers").

Same footnote: "DNA-damaged worms in highly contaminated areas"—*The Japan Times,* Saturday, March 5, 2016, p. 2 (unattrib., "DNA damage found in Fukushima forests: Greenpeace says mutations are just beginning to be seen five years on").

Footnote on "Atom Fukushima No. 86"—Honma, p. 15 (booklet by Tepco, November 1990, "Atom Fukushima No. 86," translated by Mrs. Keiko Golden).

Footnote: From Aki's blog—Excerpted from a 1-p. undated typescript translation for WTV by Ms. Kawai Takako (received by me in 2014), now deposited in my archive at the Ohio State University.

"by 1973 Okuma had achieved the highest per capita income in Fukushima Prefecture"—Information from the same source, p. 41 (article in *Fukushima Minyu,* August 5, 1973, translated by Mrs. Keiko Golden).

Footnote: "As with all kinds of stress . . ."—Odum, p. 459.

"the pipes, opened walls, rubble . . ." of the crippled reactors—After *The Japan Times,* Monday, September 15, 2014, p. 3 (Hideki Takahashi, Shinya Kokubun and Yukiko Maeda, "Responders cowed by explosion at No. 3 reactor building"), photo of Reactor No. 3; *International New York Times,* Thursday, June 19, 2014, p. 1 (Matthew L. Wald, "3-D is coming to cleanup of Fukushima").

The cesium level in the trench by Reactor No. 1—*Fukushima Minpo,* October 24, 2014, p. 2 (unattrib., "Trench cesium at highest value," translated by Ms. Kawai Takako).

Description of Ganjo-ji and of my final visit to Tomioka—From notes made on site, October 29, 2014.

Footnote: Mr. Togawa on the time to reinhabiting Tomioka—Tepco interview of October 20, 2014.

The dreary convenience store in Naraha—A Seventeen Eleven (isn't that how they spell it?). I see no reason to conspicuously advertise this chain.

The Emporium Kindergarten in Koriyama—In March 2011 its vicinity measured 3.1 to 3.7 micros an hour. *The Japan Times,* March 11, 2014, p. 1 (Toru Hanai and Elaine Lies, "Life indoors exacts toll on Koriyama children").

My old physics book: "For the general public, it is recommended . . ."—Tilley and Thumm, p. 27.

"Atomic energy is revolutionizing life today . . ."—Loyce B. McIlhenny, "Careers in Atomic Energy," "Understanding the Atom" ser. (Oak Ridge, Tenn.: United States Atomic Energy Commission Division of Technical Information, 1964 rev. of 1962 ed.), p. 22.

Normalization on the Rocks

The Fukushima City bartender—Interviewed October 22, 2014.

Footnote: "precipitation extremes are *very likely* to increase . . ."—IPCC, 2013, p. 1271.

Footnote: "Most high contaminated horizons . . ."—Voitsekhovych and Jakubik, 2014, p. 17.

"things that have grown sad are wicked"—W. B. Yeats, *When You Are Old: Early Poems and Fairy Tales* (New York: Penguin Books, Penguin Drop Caps ser., 2014), p. 54 ("The Wanderings of Oisin").

The Ministry of the Environment's dose calculation—Ministry of the Environment, Japan, pamphlet: "Japan's Decontamination Efforts and Its Effects" (2014), section 6-4. The assumed hourly dose was based on radiocontamination of 0.19 microSv/hr plus a background radiation of 0.04 micros. Hence the yearly dose as they calculated it would be 365 × ([8 × .23] + [16 × .23 × .4]) = 365 × (1.84 + 1.472) = 1.209 millis. The yearly dose for someone outside all the time would be 0.23 × 24 × 365 = 2.0148 millis. To receive exactly one milli and be out all the time one would have to take in 1,000 / (24 × 365) = 0.1142 micros an hour.

"Individual additional exposure is approximately 1 mSv/yr . . ."—Ibid., section 7.1. This section went on to state that "annual additional exposure of 1 mSv is converted to air dose rate of 0.23 microSv/hr."

"Japanese institutions are encouraged to increase efforts to communicate that . . . in remediation situations . . ."—Ibid., section 6-1.

Remarks of Dr. Ed Lyman—Interviewed by phone, January 25, 2017.

"1 mSv/yr 'is not a limit of exposure . . .'"—Ministry of the Environment pamphlet, section 7-1.

"an additional individual dose of 1 mSv per year is a long-term goal . . ."—Ibid., section 6-1.

Interview with Mr. Abe Masahiko—In Fukushima City, October 22, 2014. He worked for the Public Relations Office, Administrative Section, Ministry of the Environment, Fukushima Environmental Recovery Office.

Their Standard Is as Arbitrary as Ours

Food data—Originally based on: *The Japan Times,* Sunday, June 2, 2013, pp. 7–8 (Tomoko Otake, "Fukushima farmer plows own anti-radiation furrow"). However, the 40-Bq limit for milk and infant foods did not seem to be correct, since the Ministry of Health, Labour and Welfare website (www.mhlw.go.jp/english/topics/2011eq/dl/new_standard.pdf, accessed by Jordan Rothacker on December 10, 2015) stated it as 50, so I corrected it thus. Bread, potatoes, root and leaf vegetables, meat, rice and most other items appeared to have been folded into "general foods" at 100 Bq/kg. The note on changes from 2011 to 2012 (5 mSv to 1 mSv) comes from this same website. The article's summary of Ukraine's standards was much abbreviated; these contain more subcategories than Japan's, as I saw from (correcting my table accordingly): Ministry of Health of Ukraine, 03.05.2006 N 256, document z0845, version of 15.07.2008, "Registered with the Ministry of Justice of Ukraine, July 17, 2006," "On Approval of the State Hygienic Standards: Permissible Levels of Radionuclides Cs-137 and Sr-90 in Food and Drinking Water," as amended by Decree of the Ministry of Health N 240 (z590-08) of 08.05.2008 (13-pp. typescript). [Henceforth cited: "Ministry of Health of Ukraine."] Pages. 9/13–13/13 (section 3, "Acceptable levels of radionuclides Cs-137 and Sr-90 in food and drinking water").

Footnote on Cs-137 reduction in rice—Hitoshi Aoki, Technical Advisor, Decontamination Information Plaza, Fukushima Office for Environmental Restoration, Ministry of Environment, *Fukushima Daiichi NPS Accident, Its Health Effects & Progress of Counter Measures* (28-pp. leaflet, n.d. but collected 2014, and in the passage cited it mentions "all of the rice crops of year 2013"), p. 17. I corrected the spelling of the first "Becquerel," which had left out the "u." The illustrations in this publication, by the way, are very "cute" and cartoonish. All radionuclide atoms are represented as yellow heads with humanoid (if at least unsmiling) faces. Cs-137 are like sea urchins; I-131 has an I-shaped face, Pu-239 is squarefaced with four girlish pink ribbons in her nonexistent hair, and Sr-90 has round red ears and a sort of stocking cap on his square yellow head. I am of two minds about this. On the one hand, if families got hold of this pamphlet, their children might have been saved from additional anxiety. On the other, what if the result were complacency, and children therefore met harm?

Description of the camera emporium in Koriyama—After a visit there on October 25, 2014.

My Koriyama dose on that day—0.4 micros in [2 hours 18 min = 2.3 hrs] is 0.17 micros an hour.

"I very much hate my psychological state . . ."—Masae Yuasa, section "Who disturbed their voices?"

"Improve the measures to start a new life . . ."—Previously cited Ministry of the Environment pamphlet, sec. 7-4.

Comprehensive accident management plan for Daiichi: "The possibility of a severe accident . . ."—Lochbaum et al., p. 16.

Allison Macfarlane: "What I would say in terms of lessons learned . . ."—Ibid., p. 176. Continuing on this topic, let me now cite *USA Today,* Thursday, May 29, 2016, p. 4A (News, State-by-State): "ILLINOIS. Springfield: A House committee unanimously approved a plan urging environmental agencies to adopt nuclear-power-friendly rules. The non-binding resolution comes as government agencies are scheduled to require new standards for nuclear power plants this year."

Average air dose throughout Fukushima before the accident and in 2017—Information from Citizens' Study Group on Internal Exposure of Radiation website, January 2017, Kawai-san's translation of paragraph A.

"Is this really not enough?"—Arkady and Boris Strugatsky, *A Roadside Picnic,* trans. Olena Bormashenko (Chicago: Chicago Review Press, 2012; orig. Russian serial pub., 1972), p. 155.

Postscript: Japan Sees the Light

Most information and citations in this section come from *The Japan Times,* Tuesday, April 15, 2014, p. 7 (Chisaki Watanabe and Masumi Suga, "Analysis: Renewables get raked over coals under Abe").

Proportion of Japanese coal from Australia and America—Tepco interview of Monday, October 20, 2014. Mr. Sakakibara: "I hear we [Tepco] import from Australia. 80 percent comes from Australia, 1 percent from United States." However, according to the *Coal Valley News,* Wednesday, March 6, 2013, p. A1 (Fred Pace, "West Virginia exports reach record high"), the state's top markets were (1) Japan, whose purchases increased from $29 million in 2011 to $395 million in 2012, and (2) China, which bought $93 million worth of coal in 2011 and $567 million in 2012. ("Coal continues to be our traditional strength," proclaimed Governor Tomblin.) Of course both Mr. Sakakibara and Fred Pace might have been right.

Footnote on small coal plants—*The Japan Times,* Saturday, May 30, 2015, p. 3 (Chisaki Watanabe, "Coal revival 'ducks scrutiny' with small plants").

Lochbaum et al. note (p. 228) that with all her reactors off line, Japan fell "shy of roughly 50 gigawatts of operating capacity . . . With no nuclear power in the mix, Japan would require an additional three hundred thousand barrels of oil every day, along with an additional 23 billion cubic meters of liquefied natural gas" (an International Energy Agency estimate).

Tale of Chibu Electric's 11 wind turbines—*The Japan Times,* Wednesday, March 12, 2014, p. 2 (cont'd from p. 1; unattrib., "Reactors still feared despite new rules").

Japan's greenhouse gas report: Carbon dioxide "emissions from fuel . . ."—*Greenhouse Gas Inventory Japan,* 2015, p. 2-3. Ibid., p. 3-1: "GHG emissions from fuel combustion in FY2013 had increased by 1.1% compared to FY2012. The primary reason for the emission increase in FY2013 as compared to FY2012 was the increase of CO2 emissions from electric power generation in the energy industries due to the increase of coal consumption at the thermal power plants."

Footnote: "Substantial [CO_2] emission increases . . ."—EU greenhouse report, 2014, p. 113.

Global Distribution of Nuclear Reactors in 2014

Proportion of Japanese power generation from nuclear until the accident (30%), and number of reactors available (43)—*The Japan Times,* Tuesday, August 11, 2015, p. A5 (Alexander Martin, "Japan Restarts First Plant Since Accident").

All other data from Schneider, Froggatt et al., p. 13.

Net capacity in GW, converted to BTUs per minute: = 337 GW × [1 billion watts / GW] × [0.056884 BTUs per minute / watt] = 19,169,908,000.

Postscript: Japan Sees the Light (continued)

And, by the way (Australian Government: India, 2015, p. 51): "In 2005, India was around 90 per cent self-sufficient in coal supply. By 2013, India's coal self-sufficiency had declined to around 75 per cent, with thermal coal accounting for around 80 per cent of total imports. The rapid rise in thermal coal imports resulted in India overtaking Japan as the second largest importer of thermal coal in 2013 despite higher imports into Japan to help its electricity industry cope with the idling of its nuclear reactors after the Fukushima incident in 2011."

Definitions, Units and Conversions

This section is intended as a convenience for the reader; much of its matter has already been introduced here and there in the text. To increase that convenience, I have re-cited here the few explicit citations already appearing elsewhere (e.g., "normal background (mrem)."

North American and world 1991 kilowatt-hours—Kroschwitz and Howe-Grant, vol. 12, p. 13 ("fuel resources," Table 14, "World Net Energy Consumption, 1982–91, kW-h × 10^9")

North American and world 1991 BTUs—Loc. cit. (Table 13, "World Energy Consumption, 1991, EJ"), converted by WTV from EJs to BTUs: I multiplied by 9.48 × 10^{14}.

Energy, Electricity, Efficiency, Power, Work, Manufacturing and Engines

Ampere—Leckie et al., p. 34. "Amperes = volts / ohms" is derived from Robert S. Carrow, *Electrician's Technical Reference: Variable-Frequency Drives* (Albany, New York: Delmar / Thomson Learning, 2001), p. 18: E = IR, which means: Volts = amperes × ohms.

Coulomb: "approximately 6 million million million electrons"—*American Electricians' Handbook,* p. 1.24.

Current: "A movement or flow of electricity . . . "—*American Electricians' Handbook,* p. 1.23. "The movement of charges . . ."—Camara, p. 16-13.

Efficiency: "The ratio of output to input"—*American Electricians' Handbook,* p. 1.31. "The efficiency of an ideal machine . . ." + "When the rate of work is constant . . ."—Camara, p. 2-7.

Electricity: "A form of energy . . ."—Carrow, p. 15. "Any manifestation of energy . . ."—Camara, p. 16-2. "The electron theory states . . ." + "Electricity cannot be generated . . ."—*American Electricians' Handbook,* pp. 1.22, 1.23.

Energy: "Since in and of itself . . ." These three sentences are derived from information in Marion, p. 222.—"Energy is a measurement of power . . ."—Michael Boxwell, *Solar Energy Handbook, 2012 Edition* (Ryton on Dunsmore, Warwickshire, U.K.: Greenstream Publishing, 2012; orig. ed. 2001), pp. 16–17.

Energy flow—USDA Report 24, p. 5.

Embodied energy—Gutowski et al., *Phil. Trans. R. Soc. A* 2013 371, 20120003, p. 3.

Ergs, kilowatts and watts to other units—Richard Stevens Burington, *Handbook of Mathematical Tables and Formulas,* 5th ed. (New York: McGraw-Hill, 1973), pp. 451–54; Marion, p. 215 (and here I also took the definition of a dyne).

"Earth's annual energy from Sun," etc.—Marion, p. 224 (Table 7.1: "Range of Energies").

Exergy—Gutowski and Sekulic, pp. 4, 6–7.

"The units of pounds-mass and pounds-force . . ."—Camara, p. 1-10.

Fuel cell: "An *electrochemical device* . . ."—G. J. Young, President, Surface Processes Research and Development Corporation, Dallas, Pennsylvania, ed., *Fuel Cells* (New York: Reinhold Publishing Corp., 1963), vol. I, pp. 1–3 (H. A. Liebhafsky and D. L. Douglas, "Introduction").

Horsepower: Thermal efficiency of a horse—Ellis and Rumely, p. 31. "You may assume that 1 HP equals 3 ft lbs . . ." + equivalence in ft-lbs—Carrow, pp. 13–14.

Footnote: "746 watts are theoretically equivalent to 1 h.p. . . ."—Culpin, p. 510.

Internal combustion engine: "A machine for converting chemical energy . . ."—USNRMS "Prairie State," p. 51. The two kinds of engines—Information from the same, p. 69.

Definitions and conversions of joule, international watt, watt-second—Baumeister and Marks, pp. 15-4, 15-5 (Chester L. Dawes, "Electrical Engineering").

Joule: "a unit of mechanical energy"—Camara, p. 2-1. Gutowski's comments—Letter to WTV, e-mailed on March 17, 2016, to Jordan Rothacker, who printed it out for this book.

Joule to calories, etc.—Daniels and Alberty, p. 752; Baumeister and Marks, pp. 1-80, 1-81; Burington, p. 452. Joules to kWh, kcal and hp-hrs given [to replace my originals, which were off by several decimal points] by Prof. Anna Mummert.

MJ/kg to BTUs/gal—Kroschwitz and Howe-Grant, vol. 12 ("Fuel Resources" to "Heat Stabilizers"), p. 342 ("gasoline and other motor fuels"), p. 369.

One terajoule = 948.1 MBTU—*Coal Information 2012,* p. 1.34.

"One petajoule is enough to run the Montréal subway system for a year"—*Canada Yearbook 2011,* p. 156.

Total Canadian energy consumption for 2009—Ibid.

"1 EJ consumed in a year is equivalent to 1,803,652,968.037 BTUs/min"—Calculated as follows: 1 EJ/yr = [0.948 quadrillion / 365 × 24 × 60] BTUs/min.

Rough conversion from EJ to bb/d—Robert S. Livingston et al., p. 50.

Kilowatt: "indicates the measure of power . . ."—*American Electricians' Handbook,* 2002, p. 1.58.

Kilowatt *versus* kilowatt-hour—Quotation from Marion, p. 217.

Kilowatt-hour: "The common engineering unit of electrical energy"—Baumeister and Marks, p. 15-13 (Dawes). "If you play a radio (80 watts) . . ."—Leckie, p. 37. "To store 1 kwhr of energy in a reservoir . . ." + the business of 2,650 sandsacks—Daniels, pp. 239–40.

Kilowatt-hour and watt absolute—Baumeister and Marks, pp. 1-73, 1-180–1-181 (Franklin and Judson, "Mathematical Tables and Weights and Measures").

1 kWh/day = 2.37 BTUs/min—Calculated by WTV.

"1 gram U-235 yields 8 kilowatt-days"—Information from Baumeister and Marks, p. 9-197 (Etherington, article on atomic power).

Megawatt (both citations)—Phillip F. Schewe, *The Grid: A Journey Through the Heart of Our Electrified World* (Washington, D.C.: Joseph Henry Press, 2007), p. 25.

Ohm—Baumeister and Marks, p. 15-4.

Power: "Power measures the rate of energy conversion . . ."—Boxwell, pp. 16–17. ". . . the amount of work done [per] unit time . . ."—Camara, p. 2-6. "Output power per unit volume . . ."—Austin Hughes and Bill Drury, *Electric Motors and Drives: Fundamentals, Types and Applications,* 4th ed. (Boston: Elsevier, 2013; orig. pub. 1990), p. 37.

"Watts of power = volts × current (amps)" + "If you have a mobile phone charger that uses 1.2 amps . . ."—Boxwell, p. 36.

Primary power [which this source refers to as "total primary power"]—Gutowski et al., *Phil. Trans. R. Soc. A* 2013 371, 20120003, p. 3.

Resistance—Carrow, p. 16.

Terawatt-hour: 1 TWh = 0.086 mtoe—*Coal Information 2012,* p. 1.14.

Volt: "a measure of the 'pressure' . . ."—Leckie et al., p. 34. "the electromotive force (EMF) which causes electrons to flow . . ."—Carrow, p. 16. "An electric potential or voltage . . ."—Camara, p. 16-21. "1 V shall be taken as that emf . . ."—*American Electricians' Handbook,* p. 1.27.

"Volts = power / current"—Equation (and example of 48-watt motor) from Boxwell, p. 18.

Watt: "not a unit of energy per se . . ."—Darling and Sisterson, p. xix.

Watt: "Power measures the rate of energy conversion . . ."—Boxwell, pp. 16–17.

1 watt per square meter = 0.317 BTUs per hour per square foot—1 W = 3.413 BTUs per hour. 1 sq m = 10.758 sq ft. Therefore, [3.413 / 10.758] gives the result.

Watt-hour—Leckie et al., p. 37.

Work: "the overcoming of mechanical resistance . . ."—*American Electricians' Handbook,* p. 1.28. "If a system undergoes a displacement . . ."—Zemansky, p. 51. ". . . a signed, scalar quantity . . ."—Camara, p. 2-2.

Work of explosives—Kurt Saxon, comp., *The Poor Man's James Bond,* vol. 2 (El Dorado, Arkansas: Desert Publications, 1991), p. 397: reduced facsimile of Tenney L. Davis, Ph.D., *The Chemistry of Powder and Explosives,* complete in 1 vol. (New York: John Wiley & Sons, Inc., 1941–43) (facsimile p. 210).

Heat and Refrigeration

Blackbody—Zemansky, p. 98. "The amount of electromagnetic radiation emitted . . ."—Dr. Canek Fuentes-Hernandez to WTV, May 2017.

BTU—Tilley and Thumm, endpaper; Burington, p. 451 (Table 31, "A Table of Conversion Factors: Weights and Measures"). BTU rating of a ton of coal from *Coal Facts* 2013, p. 72. 1 BTU is in 1 match tip—National Coal Association, p. 90. Gutowski's comments—Letter to WTV, e-mailed on March 17, 2016, to Jordan Rothacker, who printed it out for this book.

BTU: "The selection of the BTU as a standard energy unit . . ."—Leckie et al., p. 76.

BTUs/gal to [MJ]/liter—Kroschwitz and Howe-Grant, vol. 12 ("Fuel Resources" to "Heat Stabilizers"), p. 342 ("gasoline and other motor fuels"), p. 369 (MJ/kg to BTUs/gal). I took the reciprocal of this figure, which was 2.78×10^{8}.

1 million BTUs = 1.0551×10^{-3} terajoules = 2.931×10^{-4} gigawatts—Australian Government: India, 2015, p. 28 (Table 1, "Conversion equivalents between units of energy").

Thermochemical calorie—Daniels and Alberty, p. 751; Burington, p. 451 (for gram-mean).

"The availability of ammonia . . ."—Kroschwitz and Howe-Grant, vol. 6, p. 485 ("coal").

Efficiency of a heat engine—Information from Zemansky, p. 167.

Fuel: "... whether for the furnace ..."—Metcalfe, Williams and Castka, p. 394.

Heat—Somewhat after the same source, p. 15.

Heat of combustion—All molar weights and heats of combustion are from Metcalfe, Williams and Castka, p. 658 (Table 14, "Heat of Combustion").

"High heat[ing] value of a fuel"—Kroschwitz and Howe-Grant, vol. 6, p. 1049 ("combustion science and technology"). "I never use the term hhv . . ."—Finkelman e-mail, February 2016.

Low heating value: "for coal and oil, net calorific value is usually around 5% less than gross ..."—*Coal Information 2012,* p. 1.16. The Argonne National Laboratory's 2010 list is from GREET, 2010.

Quad: Conversion from EJ—Based on Robert S. Livingston et al., p. 4: The 1979 total energy consumption in the U.S. was 83.3 EJ = 79.0 quads.

Refrigeration ton—Kroschwitz and Howe-Grant, vol. 21 ("Recycling, Oil" to "Silicon"), p. 129 ("refrigeration").

Specific heat—Camara, p. 2-1.

Specific heats of various substances—Selected from Camara, p. 2-4 (Table 2.1, "Approximate Specific Heats of Selected Liquids and Solids").

Therm—Camara, p. 2-1.

Thermal efficiencies of natural gas and propane—Leffler, p. 214.

Thermie—OECD, 1974, p. ii (Definitions).

Nuclear Energy

Alpha particle: "The nucleus of a helium atom ..."—Tabak, p. 184. "But on being stopped they produce a very large amount of ionization . . ."—Odum, p. 451. "... particularly damaging, because it is doubly charged ..." + "alpha radiation is 20 times worse ..."—Mahaffey, pp. 37, 33.

Beta particle: "An electron ejected ..."—Tabak, p. 184. "the conversion of a neutron into a proton . . ."—Marion, p. 568. "may travel . . . up to a couple of centimeters ..."—Odum, loc. cit.

"When an element transmutes itself through radioactive decay ..."—Rhodes, p. 86 (original not italicized).

Fallout—Odom, p. 461.

MOX: "Mixed fuel oxide ..."—Tabak, p. 57. "MOX fuel is manufactured from plutonium ..."—World Nuclear Association, 2016.

Radioisotope—Information on the three hydrogen isotopes from Metcalfe, Williams and Castka, pp. 50–51.

NISA and NRA: "whose goal had been to promote and expand . . ." + '"We will never allow the myth . . ."—*The Japan Times,* Sunday, March 9, 2013, p. 1 (Kazuaki Nagata, "NRA gets strict, must prove credibility").

Plant No. 1: No. 3's radiation emission compared to recommended annual exposure—Hirose, p. 59.

"These ten reactors in Fukushima Prefecture produced one-fifth of the nation's nuclear power"—Information from *Documentary Record of Iwaki City*, p. 2.

Reactor: LWRs: So named "because the reactor core is covered with water to allow the nuclear reaction to take place and to keep the core cool"—Federal Emergency Management Agency, Emergency Management Institute, *Home Study Course . . . Radiological Emergency Management* (Emmitsburg, Maryland, HS-3, May 1998 p. 3-1 ("Nuclear Power Accidents").

Becquerel: "It is estimated that the detonation of a nuclear weapon in Hiroshima . . ."—Mahaffey, p. 29.

Equivalency of becquerel and cps—I have also found the following conversion, on the Internet site [which, violating my most cherished principles, I actually looked up myself, in the library] called http://hps.org/publicinformation/ate/faqs/gammaandexposure.html: George Cabot, CHP, Ph.D, "Relationship between radionuclide gamma emission and exposure rate," accessed March 14, 2014:

> 1 Bq Cs-137 produces 0.0087 microSv for inhalation and 0.014 microSv for ingestion. RAPPORT Annexe Deux CNS 2003. Since this must be per second, I have multiplied by 60 to get microSv/hr. Hence:
>
>> 1 Bq Cs-137 produces 0.522 microSv/hr for inhalation and 0.84 microSv/hr for ingestion.
>
> Since this does not correspond with the results of either of the other two conversions, I have simply parked it right here.
>
>> From WendyMcElroy.com, 2011 (see "electron volt" for full citation): 1 Bq *inhaled* Cs-137 = 4.6 × 10^{-9} Sv = .0046 microSv [presumably per hour but no units given], while 1 Bq *ingested* Cs-137 = 0.013 microSv[/hr?].

Curie—Information from Tilley and Thumm, p. 18; Baumeister and Marks, p. 9-187 [Etherington, "Atomic Power"]. "neither the curie nor the becquerel identified the isotope . . ."—Graf, p. 30.

Curie: Disintegration rates of Cs-137, Sr-90 and tritium—Beyond Nuclear, p. 10.

0.000006 g iodine-131 = 1 Ci = 5.6 kg iodine-129—Thomas Dersee and Sebastian Pflugbeil, Foodwatch report: "Calculated Fatalities from Radiation / Officially Permissible Limits for Radioactively Contaminated Food in the European Union and Japan" (Berlin: German Society for Radiation Protection, in cooperation with the German Section of the International Physicians for the Prevention of Nuclear War [IPPNW]), 2011, p. 35 ("Terms and Units of Measure").

Picocurie, 1 picocurie per gram + "One picocurie per gram of plutonium in sediment . . ."—Loc. cit.

Permissible tritium levels in water—Beyond Nuclear, p. 11.

Curies released at Three Mile Island and Fukushima—Lochbaum et al., p. 146.

"More than 140 million curies of radioactivity were released" from Hanford + weapons testing produced "largest release of artificial radiation . . ."—Gephart, pp. 4.17, 4.25.

Figures for Sr-90 and tritium—*The Japan Times,* Thursday, June 20, 2013 (Reiji Yoshida, "Strontium in groundwater at No. 1 soars: Tepco trying to keep flow from reaching sea, will build bank").

1 cpm = 0.001 mrem per hour for Cs-137 (beta only)—Phone interviews with Edwin Lyman, March 13, 2014, March 24, 2014.

Apparent equivalence of 10 Bq/kg of cesium in drinking water with 0.1 mSv /year—www.mhlw.go.jp/english/topics/2011eq/dl/new_standard.pdf, accessed by Jordan Rothacker on December 10, 2015: p. 7 ("The concept of standard limit for "General Foods").

10 Bq/liter of tritium = 270 pCi/liter—Beyond Nuclear, p. 11 (which states that 540 picocuries per liter = 20 Bq per liter).

Table of Bq to Sv for various isotopes—Extracted from a Japanese-language hard copy (with interpolated handwritten translations by Ms. Kawai Takako), downloaded for WTV by her, on October 12, 2014, from http://menorva.jp/school /life/radiation_bq/sv.php, beside which Ms. Kawai has written: "Min. of Education, Science . . ." Above the table has been printed "http:/www.remnet.jp/lec ture/b05 01/4 1.html."

Electron volt—Definition nearly verbatim from Baumeister and Marks, p. 9-183 (C. H. Etherington, "Atomic Power"). Indented conversions are also from here. But the two figures in mevs for Cs-137 [which I have converted to BTUs based on the indented figure of 1 fission [of uranium-235] = 200 mev = 3.04×10^{-14} BTUs] originally came from WendyMcElroy.com, "News Item: Becquerel, Gray, and Sievert, "posted by Brad," Wednesday, 13 April 2011; downloaded for WTV by David M. Golden in 2015 from www.wendy.mcelroy.com/print.php?news.3895. Dave notes: "Not authoritative source but seems reasonable summary description." On another part of this document (conversion from Bq to Sv ingested Cs-137) he writes: "Matches Quora." [This source henceforth cited: "WendyMcElroy.com, 2011."] Prof. Mummert substituted a different figure for the conversion from 0.66 mev, and I have trusted her. I have also taken information from Marion, pp. 240–41.

Mevs for $E = mc^2$—Norman A. Frigerio, *Your Body and Radiation,* "Understanding the Atom" ser. (Oak Ridge, Tenn.: United States Atomic Energy Commission, Division of Technical Information, 1967 rev. of 1966 ed.), p. 6. [This source defines 1 ev as "the energy an electron gains in moving from the negative to the positive pole of a 1-volt battery."]

Gray: Average radiation dose from a pelvic CT scan—Mahaffey, p. 34. Gy to Sv for gamma and alpha—WendyMcElroy.com, 2011.

Gray: Maximum doses for Iwaki, etc., "updated," November 2, 2014, 15:40—Hard copy of Japanese-language web page, with translations interleaved by Ms. Kawai Takako, downloaded for WTV by her on that same date from http:/www.[h or b]ousai.[p?]e.i.[p]?]./y or v]is/iichitai/fukushima/index/[p?][B or h][p?]. [Some i's might be j's.] [Bottom is cut off.]

Gray: Highest and lowest prefectural doses, November 2, 2014, 15:50—Disaster Prevention and Nuclear Safety Network for Nuclear Environment, Nuclear Regulation Authority (NRA), "Environmental radioactivity and radiation information: Realtime radiation data collected via the System for Prediction of Environment Emergency Dose Information (SPEEDI): Radiation Maximum Data List," downloaded for WTV by Ms. Kawai Takako on November 2, 2014, from http:/www.bousai.ne.jp/eng/.

Rad—Mahaffey, p. 31.

Rem: Acronym for "roentgen equivalent [in] man"—Glasstone and Dolan, p. 576.

1 rem = 1.07185 roentgens—Mahaffey, p. 30.

1 rem = 0.01 sievert—Loc. cit.

1 mrem defined in joules per kg—Bernard L. Cohen, p. 42. Number of radiation particles, risk of fatal cancer, reduction of life expectancy, Three Mile Island exposures, all from the same source, pp. 13–14.

Normal background exposure (mrem); maximum rem exposure for incident responder, etc., etc., up to 5,000-rem lethal dose—Levy, pp. 153, 46–48, 93–96.

Roentgen: "The ionizing effect of radiation on a standard mass of air"—Tilley and Thumm, p. 30. "One roetngen . . . strips off one outer electron . . ."—Mahaffey, p. 29. The following quotation is from Daniels and Alberty, p. 719.

Conversion from ergs to joules and other units—Daniels and Alberty, p. 752.

Sievert: A "unit of equivalent dose . . ."—*CRC Handbook,* pp. I-39–I-40 ("CONVERSION FACTORS FOR IONIZING RADIATION"); p. 16-46 ("Protection Against Ionizing Radiation").

1 sievert = 1 joule [J]/kg—*CRC Handbook,* loc. cit.

1 mg U per g biological tissue = 0.006 Sv—Kroschwitz and Howe-Grant, vol. 24, p. 686. Prof. Mummert could not check this.

EPA standard for U in drinking water (40 microSv/yr)—Ibid., vol. 17, p. 388 ("nuclear fuel reserves").

Anna Mummert: "There is not a direct conversion from Sieverts to BTU . . ."—"Report on Carbon Ideologies" (letter to WTV), March 2017.

1,000 rads = 0.0024 cal. + damage by "direct ionization . . ."—Norman A. Frigerio, *Your Body and Radiation* "Understanding the Atom" ser. (Oak Ridge, Tenn.: United States Atomic Energy Commission, Division of Technical Information, 1967 rev. of 1966 ed.), pp. 16–17.

"Regarding the conversion from Sv to BTU . . ."—Crownover to WTV, June 2017.

1 millisievert (mSv) = . . . 100 mrad, or in our units ~100 mrem—*CRC Handbook,* loc. cit.

Two claims for the strength of a chest X-ray in microSv—Tabak, p. 93, ADD.

"An American oncologist supplied the following X-ray dosage figures . . ."—She was Dr. Janice Ryu (personal communication, May 2017).

Millisievert/year to microSv/hr—My calculation.

1 microSv = . . . 10^{-4} rem—*CRC Handbook,* loc. cit.

Curie to gigabecquerels—Glasstone and Dolan, loc. cit. The "G" is capitalized in the original.

1 watt = 5 curies—Baumeister and Marks, p. 9-197 (Etherington article).

Coal

Blast furnace gas: "A low-grade producer gas . . ."—Paul W. Thrush and the Staff of the Bureau of Mines, comp. and ed., *A Dictionary of Mining, Mineral, and*

Related Terms (Washington, D.C.: U. S. Department of the Interior, 1968), p. 111. [Hereafter cited: "Thrush et al."] "Since the composition of BFG is unstable . . ."—*Greenhouse Gas Inventory Japan,* 2015, p. 3-19.

Coal: "A solid, brittle . . ."—Thrush et al., p. 222. "A combustible layered rock . . ."—Bangladesh MPEMR report, unnumbered early p., "Coal Exploration and Development" [this is probably p. 4]. "In its most general sense . . ." + "Coal is the result . . ."—*Britannica,* 11th ed., pp. 575, 577 ("coal").

Anthracite, bituminous coal and lignite—*Britannica,* loc. cit., pp. 575–76. All not otherwise cited information on various moisture contents comes from Baumeister and Marks, p. 7-2 (J. F. Barkley, article on coal). "The highest rank of economically useable coal . . ."—National Coal Association, p. 11. One detail on anthracite ("Used mainly for heating homes") derives from *Coal Facts* 2013, p. 72. "The rarest and most desirable form . . ."—Olah, Goeppert and Prakash, pp. 32–33. "A smokeless coal of high fuel efficiency . . ."—Thrush et al., loc. cit. The proximate analysis of Virginia coal is from Baumeister and Marks, p. 7-3 (Barkley article, Table 1). "All the anthracite mines in the U.S. are located in northeast Pennsylvania"—U.S. EIA, "Today in energy," p. 1/2. [So cited henceforth. This source comes from http://www.eia.gov/todayinenergy/detail.cfm?id=2670; downloaded by Jordan Rothacker, June 2016.] Less liable to spontaneous combustion—Kroschwitz and Howe-Grant, vol. 6, p. 468 ("coal"). "Most poets must have subsisted on anthracite"—Aldo Leopold, *A Sand County Almanac and Other Writings on Ecology and Conservation*, ed. Curt Meine (New York: Library of America, 2013; orig. posthumous pub. of *SCA* 1949), p. 127 ("Chihuahua and Sonora," in *SCA*).

Metallurgical coal—*Coal Facts* 2013, p. 73.

Bituminous: "Sometimes called 'soft coal' . . ." + 45–86% carbon—National Coal Association, p. 11. [In accord with the NCA for carbon composition: U.S. EIA, "Today in energy," p. 1/2. This source also for: "West Virginia leads production."] "Fixed carbon and volatile matter are about equal"—Thrush et al., p. 222. "A medium soft classification . . ."—*Coal Facts* 2013, loc. cit. Likewise "Bituminous coals used to make coke are classified as 'metallurgical'" (p. 65, Jason Bostick, V.P., "Coal and Steel"). The caking of bituminous coal is explained in Baumeister and Marks, pp. 7-9–7-10 (Barkley article). Stanley Sturgill's remark is taken from the interview of July 24, 2015.

Subbituminous: "A dull black coal . . ."—National Coal Association, p. 11. "A poor name for coal of higher rank . . ."—Thrush et al., loc. cit. 35–45% carbon—U.S. EIA, "Today in energy," p. 1/2.

Steam coal—Thrush et al., p. 74.

Lignite: "Mined primarily in the western U.S. . . ." also comes from this source, p. 73. "Either markedly woody . . ."—Thrush et al., p. 222. "A brownish-black coal . . ." + carbon content of 25–35%—National Coal Association, p. 11. 30–70% moisture content—*Encyclopaedia Britannica,* Macropaedia, vol. 4 (Chicago: Encyclopaedia Britannica, Inc., 1976), p. 773 ("coal mining").

Coal sizes—Baumeister and Marks, p. 7-15 (Barkley article). A table on p. 7-16 gives slightly different names.

Coal tar: Information on explosive properties—Kurt Saxon, comp., *The Poor Man's James Bond,* vol. 2 (El Dorado, Arkansas: Desert Publications, 1991), p. 372: reduced facsimile of Tenney L. Davis, Ph.D., *The Chemistry of Powder and Explosives,* complete in 1 vol. (New York: John Wiley & Sons, Inc., 1941–43) (facsimile p. 130).

Coke: "an excellent reducing agent—Metcalfe, Williams and Castka, p. 326. Coke as a precursor to acetylene—Kroschwitz and Howe-Grant, vol. 6, pp. 476–77 ("coal"). "Coke from any coker is nearly all carbon . . ."—Leffler, p. 118. "Western coals are weakly coking . . ."—Baumeister and Marks, p. 7-17 (J. F. Barkley, article on coke).

Bench, resources, reserve (including proven + probable)—Bangladesh MPEMR report, unnumbered early page "Coal Exploration and Development" [this is probably p. 4].

Beneficiation—Executive Office of the President, Office of Management and Budget, *North American Industry Classification System, United States, 2012* (Lanham, Maryland: Bernan Press / Rowman and Littlefield, 2012), p. 161. [Henceforth cited: *North American Industry Classification System.*]

Blast furnace: "A shaft furnace . . ."—Thrush et al., p. 111.

Dragline—National Coal Association, p. 21.

Highwall—*Coal Facts* 2013, p. 73.

IGCC: Remarks of Sakakibara Kohji—Tepco interview of October 20, 2014.

Mantrip: Use of "trip" by Upton Sinclair—Op. cit., p. 29.

Producer gas—"Composed of carbon monoxide . . ."—Richard J. Lewis, Sr., *Hazardous Chemicals Desk Reference*, 4th ed. (New York: John Wiley & Sons, Inc., 1997), p. 986.

Subsidence—Bangladesh MPEMR report, p. 43.

Surface mine (including auger, single bench, multiple bench and strip mines)—Bangladesh MPEMR report, pp. 7–8, 46. Open pit mine as cheaper in dollars—W. A. Hustrulid, ed., *Underground Mining Methods Handbook* (New York: Society of Mining Engineers and The American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., 1982), p. 71 (Dan Nilsson, "Open-Pit or Underground Mining").

Auger mine: "Sometimes employed . . ."—National Coal Association, p. 20. Yield rate of 33%—*Mountaintop Mining,* p. 11 (Jason Bostic, "West Virginia Coal Mining Methods").

Mountaintop removal mine—National Coal Association, p. 20. "Rugged mountaintops and steep hollows are transformed . . ."—Nicholas P. Chironis, *Coal Age Operating Handbook of Coal Surface Mining and Reclamation* (New York: McGraw-Hill, Inc., Coal Age Mining Information Services, vol. 2, 1978), p. 10. "As of 2005, 2700 ridges . . ."—Melissa M. Ahern, Michael Hendryx, Jamison Conley, Evan Fedorko, Alan Ducatman and Keith J. Zullig, "The association between mountaintop mining and birth defects among live births in central Appalachia, 1996–2003," in *Environmental Research*, 111 (2011), part 1: Introduction, citing Skytruth, 2009a; at www.elsevier.com/locate/envres; "available 22 June 2011"; accessed by Laura Michele Diener in early August 2014 and sent to WTV via memory stick. [Henceforth cited: "Ahern et al."]

Strip mine: "Mining then continues laterally . . ."—National Coal Association, p. 20.

Valley fill mine—Chironis, p. 9.

Tipple—*Coal Facts* 2013, p. 74; Hustrulid, p. 1724.

Underground mine—Bangladesh MPEMR report, pp. 9–10.

Block mine; room-and-pillar mine—Bangladesh MPEMR report, pp. 10, 43. "fully developed in a section"—Syd S. Peng, *Coal Mine Ground Control,* 2nd ed. (New York: John Wiley & Sons, 1986), p. 7. Room-and-pillar mine—Kroschwitz and Howe-Grant, vol. 6, pp. 465–66 ("coal").]

Longwall mine: "Longwall mining employs a steel plow . . ."—National Coal Association, p. 12, "Two parallel headings are made . . ."—Kroschwitz and Howe-Grant, vol. 6, pp. 465–66 ("coal"). "The retreating method is almost exclusively used . . ."—Peng, p. 15. "the most capital intensive but also the most capital efficient method . . ."—*Coal Valley News,* Wednesday, January 7, 2015, p. 5A (Anya Litvak, "Pennsylvania coal comes of age"). Amount of coal left behind—Bangladesh MPEMR report, p. 43.

Shortwall mine, longwall with shoring—Bangladesh MPEMR report, p. 10.

Aluminum—Al_2O_3 percentages in coal ash are from Baumeister and Marks, p. 7-9 (Table 3).

Black lung: From the mining methods handbook, 1978—Hustrulid, pp. 1687–88 (ch. 8, Welby G. Courtney, "Dust Control"). Quotation from Senator Jay Rockefeller—*Coal Valley News,* Wednesday, September 11, 2013, p. B7 (Fred Pace, "Push continues for 'Black Lung' protections").

Coal ash: "The inorganic residue"—Baumeister and Marks, p. 7-7 (Barkley article on coal). "The ash contains heavy metals . . ."—*Eden's Own / Country Star,* April 2014, p. 18. "America's coal plants produce 140 million tons . . ."—*The Ecologist,* Friday, October 23, 2015, Ben Whitford (*Coal Puddle* via Shutterstock), "Coal Ash: The United States' Multibillion-Ton Toxic Legacy" (4-pp. typescript as downloaded and printed for WTV by Teresa A. McFarland, October 27, 2015).

Coal dust—Baumeister and Marks, p. 7-45 (Table 28, "Explosion Characteristics of Various Dusts").

Coal sludge: "The liquid waste created . . ."—Brochure *ca.* 2013 from the Sludge Safety Project ("a project of Coal River Mountain Watch, Ohio Valley Environmental Coalition and West Virginia communities"), Huntington, West Virginia.

Conductivity: "It goes up as the water gets saltier . . ."—Ohio Valley Environmental Coalition, "Winds of Change," Fall 2015, p. 25 ("What Is This Conductivity, Anyway?" (cont'd from p. 5). [This issue henceforth cited: "OVEC 2015."] Legal liabilities of named companies—Ibid., p. 11 (Dianne Bady, "Another Conductivity Court Victory").

pH: Measurement ranges of various substances—*CRC Handbook,* 2006, p. 7-17 ("Typical pH Values of Biological Materials and Foods"), except for: 1.0 normal sodium hydroxide, 0.1 normal sodium hydroxide, and seawater, which I have taken from Metcalfe, Williams and Castka, p. 281 (Table 14.4, "Approximate pH of Some Common Substances"). A 1.0 normal solution contains 1 gram-equivalent of solute per liter of solvent (in this case, water).

Yellowboy + its generation equation—Richard M. Stapleton, ed.-in-chief, *Pollution A to Z* (New York: Macmillan Reference USA [Thomson / Gale], 2004), vol. 2, p. 48 ("yellowboy"). [Henceforth cited: "Stapleton."]

Asia Energy, BHP—From interview with Mr. Mohammed Aminul Islam Bablu June 2015.

BHP: "BHP did not want to create another environmental disaster . . ."—Anu Muhammad, "Phulbari Day: Celebrating people's power: August 26, 2014" (4-pp. typescript provided by Nakeeb). This article goes on to say: "In 1997, Asia Energy (AEC) was formed mysteriously, and in 1998 BHP transferred its license to this newly formed company."

Dinajpur—Manoranjam Pegu, FK Fellow, SUPRO "The Phulbari Movement: Resisting Neo-liberalism in Bangladesh" (15?-pp. undated typescript, downloaded by Nakeeb), pp. 14, 4.

National Committee: "Formed in 1998. . ."—Pegu, p. 12. "Organized a long march from Dhaka . . ."—Redtimesbd.com, Dhaka, Friday, September 11, 2009, downloaded by Nakeeb. "Phulbari Resistance: Communities Resisting GCM Resources Plc (GCM) Open Pit Coal Mining Project in Phulbari, Bangladesh. 'Mineral Resources is the Blood Flown [*sic*] in Our Veins: Interview with Anu Mohammad.'" Exclusive interview by Audity Falguni, p. 2. [Henceforth cited: "*Redtimes* interview."]

OECD: "The region previously called Latin America . . ."—*Coal Information 2012,* p. I.10.

Phulbari: "The coal-field will extend over 135 square kilometers" + number of people potentially displaced—Pegu, p. 4.

Regulated community: "It took long enough in all conscience . . ."—Hermann Hesse, *Magister Ludi* (*The Glass Bead Game*), trans. Richard and Clara Winston (New York: Bantam, 1972 repr. of 1969 ed.; orig. German ed. 1943), p. 26.

Units and conversions: The U.S. Department of Energy 1993 claim: 1 ton coal = 2,000 kWh—National Coal Association, p. 58.

Ton of coal equivalent—*Coal Information 2012,* p. 1.14.

Natural Gas and Fracking

Liquefied petroleum gases—Kroschwitz and Howe-Grant, vol. 13, p. 744 ("hydrocarbons": "survey").

Methane: "A gas similar in nature . . ." + "A major coal mining nuisance . . ."—National Coal Association, p. 12. "the end product of the anaerobic . . . decay of plants"—Morrison and Boyd, p. 36. Dangerous concentration of 1.25% "for a sustained time"—*Charleston Gazette,* March 26, 2013, p. 1A (Ken Ward Jr., "Mine safety board delays key methane rule decision"). "As much as . . . 400 trillion . . . cubic feet . . ."—Kroschwitz and Howe-Grant, vol. 13, p. 812 ("hydrocarbons": "C_1–C_6"). "If the methane is accompanied by ethane and butane . . ."—*High Country News,* September 8, 2015 news analysis, n.p. (Internet download, printed for WTV by a friend in September 2015) (Sarah Tory, "Scientists Track Energy's 'Fugitive Emissions' from Above"). That methane is in coal is also stated in Stapleton, vol. 1, p. 101. "Methane is colorless and, when liquefied . . ."—Morrison and Boyd, p. 36. Molecular weight and combustion heat of methane—Ibid., pp. 67, 38.

Natural gas: "The ideal fossil fuel . . ."—Waples, pp. 7–8. "The main component of all natural gas is methane . . ."—Lom and Williams, p. 27. Other components, from ethane to air—Information (and order) from Kroschwitz and Howe-Grant, vol. 12 ("Fuel Resources" to "Heat Stabilizers"), p. 325 (Table 5: "Physical Constants of Natural Gas Constituents").

Fracking: "Fracturing the formation . . ."—Raymond and Leffler, p. 216. "water, sand and trace chemicals"—Chris Faulkner, p. x. "In effect, fracking creates additional permeability . . ."—Ibid., p. 64.

Frack[ing] fluid—Waples, p. 245; Food and Water Watch brochure, p. 3 (citing House Energy and Commerce Committee, January 2011, April 2011).

Injection wells—Waples, p. 301.

Produced water: "Water from the rock formation"—Food and Water Watch brochure, p. 4.

Separator: "A piece of equipment . . ."—Waples, p. 305.

Separator tanks—Loc. cit.

Stripper well, unconventional formation, unconventional gas well, vertical gas well—OIL AND GAS (58 PA.C.S.)—OMNIBUS AMENDMENTS Act of Feb. 14, 2012, P.L. 87, No. 13. Session of 2012 No. 2012–13. AN ACT [Cl. 58] Amending Title 58 (Oil and Gas) of the Pennsylvania Consolidated Statutes. Downloaded for WTV by Jordan Rothacker, May 2017.

Cubic foot, billion cubic feet, quad—Waples, pp. 296, 294, 304.

Oil

Carbon content of petroleum and other liquid fuels—From Baumeister and Marks, p. 7-21, Table 14. The carbon content in this table ranges only from 84–86%, but on p. 7-26 kerosene is stated as having 85–88% carbon.

Crude oil: "Raw petroleum as it comes from the earth . . ."—Thrush et al., p. 283. A "liquid mineral"—*North American Industry Classification System*, p. 161. "The higher the crude, the higher the API . . ."—T. E. W. Nind, *Principles of Oil Well Production* (New York: McGraw-Hill Book Company, 1964), p. 27.

API: Computation of API specific gravity—Nind, p. 27. Same computation, and list of examples of API—Leffler, pp. 19–20, p. 20 (Table 3-3, "Typical gravities"). "The logic of this arcane formula . . ."—Martin S. Raymond and William L. Leffler, *Oil and Gas Production in Nontechnical Language* (Tulsa, Oklahoma: PennWell Corporation, 2001), p. 64.

Heavy crude: "Defined here as oil of 20° gravity . . ."—*Long-Term Energy Resources,* p. 55 (Richard Meyer, "Speculations on Oil and Gas Resources . . .").

Crude oil (cont'd): ". . . largely made up of flammable hydrocarbons"—Duffy and Smith, p. 62.

Hydrocarbons—Duffy and Smith, loc. cit. "Chemicals composed of only the two elements . . ."—Mecalfe, Williams and Castka, p. 342. "Hydrocarbons in gasoline . . ."—USNRMS "Prairie State," p. 81.

Okie gas—Raymond and Leffler, p. 65.

Light crude: More than 30° API—Information from Nind, p. 27. Colorless—Raymond and Leffler, p. 65. "The light crudes tend to have more gasoline . . ."—Leffler, pp. 18, 20. "Probably has few percent natural gas liquids"—Raymond and Leffler, p. 63.

Medium crude: 20 to 30° API—Information from Nind, p. 27. Varying colors—Raymond and Leffler, p. 65.

Heavy crude: 10 to 20° API—Information from Nind, p. 27. Black colored—Raymond and Leffler, p. 65. "The heavy crudes tend to have more gas oil . . ."—Leffler, pp. 18, 20. "Has little or no natural gas liquids . . ."—Raymond and Leffler, p. 63.

Information on sweet and sour crudes—Leffler, pp. 18, 20. Information on crudes of Bakken and Venezuela—*Time,* vol. 185, no. 3, February 2, 2015, p. 37 (various reporters, "Economy: The Cost of Cheap Gas"). Odors of sweet, sour and aromatic crudes—Raymond and Leffler, p. 65.

Diesel fuel—Baumeister and Marks, p. 7-27. Efficiency in comparison to gasoline—Duffy and Smith, p. 76.

Diesel grades 1-D, 2-D and 4-D—Duffy and Smith, p. 75.

Gasoline: "A complex mixture of hydrocarbons . . ."—Baumeister and Marks, p. 7-24. "commonly called distillates"—Kroschwitz and Howe-Grant, vol. 13, p. 744 ("hydrocarbons": "survey"). "Mildly toxic by inhalation . . ."—Richard J. Lewis, Sr., p. 550. "The combustion of gasoline, pound for pound . . ."—Duffy and Smith, p. 83.

Kerosene—Baumeister and Marks, p. 7-26. "Except for severe arctic areas . . ." —Kroschwitz and Howe-Grant, vol. 3 ("Antibiotics [Beta-Lactams]" to "Batteries"), p. 792 ("aviation and other gas turbine fuels").

Naphtha: "Refers to the light end fractions . . ."—*Chemtech IV,* p. 2.21 (ch. 2: "Petrochemicals").

Octane rating—Duffy and Smith, p. 68.

Oil: Description of the transformation of plankton into oil, including direct quote from "initiating chemical reactions" to "between 2 and 4 kilometres"—Salomon Kroonenberg, *Why Hell Stinks of Sulfur: Mythology and Geology of the Underworld,* trans. Andy Brown (London: Reaktion Books, 2013; orig. Dutch ed. 2011), p. 210. "Of the light oils . . ."—*Britannica,* 11th ed., vol. XX (ODE to PAYMENT OF MEMBERS), p. 35 ("oil").

Production ratios of oil from coal, oil from tar sands, gasoline from oil; cited table of average yield—Duffy and Smith, pp. 83, 65.

Tar sands: "Also known as oil sands . . ."—Chris Faulkner, p. 46. "Heavy hydrocarbons mixed with sand . . ."—Duffy and Smith, p. 83.

"In 2009, 16.9 billion barrels . . ."—*Canada Yearbook 2011,* p. 158.

Oil shale: "A convenient expression . . ."—Waples, p. 303. "a sedimentary mineral . . ."—Kroschwitz and Howe-Grant, vol. 17 ("Nickel and Nickel Alloys" to "Paint"), p. 674 ("oil shale").

Petroleum, petroleum distillate, petroleum spirits—Richard J. Lewis, Sr., pp. 907–8.

Plastic: "Often designed to mimic the properties of natural materials . . ."—American Chemistry Council, 2016, p. 1.

Residual fuel oil: "The source fuel for combustion . . ."—Camara, p. 33-2.

Synthesis gas—*McGraw-Hill Encyclopedia of Science & Technology,* 11th ed. (New York: McGraw-Hill, 2012), vol. 13 ("Par" to "Plan"), p. 261 ("petroleum processing and refining").

Alkylation, catalytic cracking, hydrocracking, polymerization, thermal cracking—Duffy and Smith, p. 65.

Condensate: "A vaporous mixture of gas and water . . ."—March 24, 1984, *Greeley Tribune* article. "The liquid resulting . . ."—Waples, p. 296.

Distillation: Gasoline produced—Duffy and Smith, p. 64.

Fractionating: Information on various boiling points—Leffler, p. 16 (Table 3-1, "Boiling temperatures for selected hydrocarbons").

Roughneck—Jeanne Marie Laskas, *Hidden America: From Coal Miners to Cowboys, an Extraordinary Exploration of the Unseen People Who Make This Country Work* (New York: G. P. Putnam's Sons, 2012), p. 221.

Wellhead—March 24, 1984, *Greeley Tribune* article.

Car-generated pollution—Stambler, pp. 12–13.

Hydrocarbons (as pollutants)—Information from Odum, p. 444.

Lead—Duffy and Smith, p. 67; Stambler, p. 19.

ADCO, ADNOC, Halliburton—Abu Dhabi yellow pages, 2016, pp. 200, 202.

Barrel: "Conversion factors vary depending on oil source"—Kroschwitz and Howe-Grant, vol. 13, p. 744 ("hydrocarbons": "survey"). "To convert t/d to bbl/d, multiply by 7" (ibid., p. 746). 1 barrel of petroleum = 42 gallons = 159 liters—Olah, Goeppert and Prakash, p. xvi; the same conversion is given in U.S. DOE, 1982, p. 101 (Appendix C, "Volume and Weight Conversions").

Barrels per metric ton of refined product—Data from U.S. DOE, 1982, loc. cit.

Ton of oil equivalent—*Coal Information 2012,* p. 1.16. But that 1 toe = 10 tons TNT equivalent comes from the Electropaedia website, accessed June 22, 2016.

"One metric ton of crude oil varies from about 1.5 per cent . . ."—OECD, 1974, vol. 2, p. 3.

TWH produced by 1 mtoe "in a modern power station"—*BP Statistical Review, 2017,* p. 47.

Solar Energy and Light

Adoption constraints—Fuentes-Hernandez to WTV, May 2017.

Candle and candela—*American Electricians' Handbook,* 2002, p. 10.10-12.

International candle—Baumeister and Marks, p. 12-132 (Howard E. Murphy, "Illumination").

Foot-candle—Odum, p. 43.

Relative brightnesses of moonlight and sunlight—Baumeister and Marks, loc. cit.

Langley—Daniels, p. 14.

"Radiation of 1 langley [per minute] is a reasonable average value . . ."—Ibid., p. 15.

Lumen—*American Electricians' Handbook,* 2002, p. 10.12, 10.15.

Efficiency of Edison's lamp and of a Mazda fluorescent—Baumeister and Marks, p. 12-136 (Howard E. Murphy, "Illumination," Table 1, "Relative Luminous Efficiencies of Electric Illuminants"). Date of Edison's lamp (1879)—*Britannica,* 15th ed., Micropaedia, vol. II (COLEMANI to EXCLUSI), p. 791 ("Edison, Thomas Alva").

Solar absorption, solar efficiency, solar energy—Fuentes-Hernandez to WTV, May 2017.

Environmental Terms Relevant to Resource Extraction

Aquifer—Waples, p. 294.

Physical Data

Density conversions of lb/gal to and from kg/liter or cubic meter—*CRC Handbook,* 2006, p. 1-31.

Density of aviation fuel: Light and medium distillate—Kroschwitz and Howe-Grant, vol. 3 ("Antibiotics [Beta-Lactams]" to "Batteries"), p. 793 (Table 4: "Specifications for Ground Gas Turbine Fuels"). Parenthetical densities in lb/gal calculated by WTV.

Densities of butane and propane in lbs/gal—Leffler, p. 16 (Table 3-1, "Boiling temperatures for selected hydrocarbons"). I originally wrote down 4.9 lbs/gal, which must have been my mistake or Leffler's; I have substituted Prof. Mummert's value. For propane I had 4.2 lbs/gal, which I also switched out for Prof. Mummert's figure.

Density of carbon—Prof. Mummert.

Densities of anthracite, bituminous coal, lignite and gasoline, per cubic foot—Baumeister, p. 6-7 ("Approximate Specific Gravities and Densities").

Densities of anthracite and bituminous coal, in g/cc—*CRC Handbook,* 2006, p. 15-39 ("Density of Various Solids").

Density of diesel fuel: "Diesel fuel varies greatly in its characteristics, ranging from light distillates, which are practically heavy kerosenes, to residual fuels or crude oils, which are used in a few instances"—Baumeister, p. 7-27. Accordingly, I averaged the densities of kerosene (6.819 lbs/gal) and 31.0 API Oklahoma crude (7.253) [p. 7-21], to obtain 7.036 lbs/gal.

Density of gasoline, per gallon—Baumeister p. 6-7.

Densities of hydrogen, carbon dioxide—Metcalf, Williams and Castka, p. 652 (Table 9, "Density and Specific Gravity of Gases").

Density of "common engine kerosene"—Ellis and Rumely, p. 119. See also note for density of diesel fuel, almost immediately above.

Density of methane—Baumeister p. 6-7, and Metcalf, Williams and Castka, p. 652 (Table 9, "Density and Specific Gravity of Gases").

Specific gravities of Pittsburgh natural gas and coal gas—Baumeister, p. 7-32.

Density of peat blocks—*CRC Handbook,* 2006, loc. cit.

Density of plutonium—Prof. Mummert.

Densities of uranium hexafluoride [at 135° F: 13.00 kg/m^3] and of steam—*McGraw-Hill Encyclopaedia of Science and Technology,* vol. 5 (COT to EAT), p. 371, "density" (Table 1: "Selected gas densities"). Density in lbs/cu ft (like that of U-235) is from Prof. Mummert.

Densities of air and water—Burington, p. 449 (Table 29, "Important Constants").

Densities of PBXN-109 and TNT—Maienschein, 2002, pp. 6–7.

Chemical Abbreviations

$CaCO_3$—F. W. Taylor, 2001: "Most of the carbon dioxide that was originally outgassed . . ."—Op. cit., pp. 98–99.

Lakhs, Crores and Other Enumeration Terms, with Standard Conversions

Pound per cubic foot = 0.0160 g/cm^2—Prof. Mummert.

Teragram, metric ton—Prof. Mummert.

Metric ton—U.S. DOE, 1982, p. 101 (Appendix C, "Volume and Weight Conversions"). Prof. Mummert kindly presented me with two more digits.

Climate Change

Carbon dioxide, Kyoto Protocol Gases, methane and nitrous oxide—*Greenhouse Gas Inventory Germany, 1990–2007,* p. 101. "This spectrum of distribution of greenhouse-gas emissions is typical for a highly developed and industrialised country."

Carbonic acid: "The acid assumed to be formed . . ."—*Britannica,* 11th ed., vol. V, p. 653 ("cement").

Carbon dioxide: "The most important GHG by far is CO_2 . . ."—EU greenhouse report, 2014, p. x.

Carbon equivalents—OECD/IEA, 2016, p. 165.

CFCs: Use as low-viscosity cleaning agents—Magill, p. 421 ("Chlorofluorocarbons").

Climate—IPCC, p. 126.

Climate change, global warming—Darling and Sisterson, p. xvi.

Climate change evidence—IPCC, p. 121.

Forcings—Ibid., pp. 108, 117, 155. "It seems likely that natural changes . . ."—Allaby, vol. 1, p. 112 ("Climatic Forcing"); Darling and Sisterson, p. 141; IPCC, pp. 666, 676—"Globally averaged climate forcing . . ." E-mail to WTV via Jordan Rothacker from Pieter Tans, NOAA Federal, Thursday, July 6, 2017, at 2:27 pm.

Freon—*Britannica,* 15th ed., Micropaedia, vol. IV, p. 314 ("Freon").

Global warming—"The Earth's average land and ocean surface temperature . . ."—Darling and Sisterson, p. 53.

Global warming potential—EPA, 2016, p. 58; A "measure of how much [solar] energy . . ."—Understanding Global Warming Potentials | Greenhouse Gas (GHG) Emissions | US EPA [last updated on February 14, 2017], downloaded for WTV by Jordan Rothacker, July 2017, p. 1/3.

Greenhouse effect—National Coal Association, p. 95.

Halocarbons—IPCC, 2013, p. 1455.

HCFCs: "The ideal CFC substitute . . ."—Kroschwitz and Howe-Grant, vol. 6, pp. 510–11 ("fluorine compounds, organic—[aliphatic]"). "the continued refrigeration use of HCFC-22 . . ."—Ibid., p. 477. GWP of HCFC-22—Ibid., vol. 21, p. 134 (Table 2, "Refrigerant Toxicity and Environmental Data").

HFCs: "Halocarbons that contain only carbon . . ."—Kroschwitz and Howe-Grant, vol. 21 ("Recycling, Oil" to "Silicon"), p. 128 ("refrigeration"). "Atmospheric HFC abundances are low . . ."—IPCC, 2013, p. 168.

Intergovernmental Panel on Climate Change—Darling and Sisterson, p. 6. [The WMO is defined on p. 5.]

International Energy Agency—OECD/IEA, 2016, p. 2.

CO_2 *Emissions from Fuel Combustion: Highlights* (Paris: International Energy Agency, OECD/IEA, 2016); downloaded from www.iea.org for WTV by Jordan Rothacker, October 2017.

Nitrous oxide—IPCC, p. 676.

Social cost of carbon—Ibid., p. 155.

Temperature extremes—Wendy M. Middleton, ed.-in-chief, *Reference Data for Engineers: Radio, Electronics, Computer, and Communications,* 9th ed (Boston: Newnes, 1998, 2002), p. 49-4.

VOCs—IPCC, 2013, p. 1464.

Well-mixed greenhouse gases—IPCC, 2013, p. 13. “There are also several other substances . . .”—EPA, 2016, p. 1-5.

“Increasing atmospheric burdens of well-mixed GHGs resulted in a 9% increase in their RF from 1998 to 2005.”—IPCC, p. 165, which continues: “Based on updated *in situ* observations, this assessment concludes that these trends resulted in a 7.5% increase in RF from GHGs from 2005 to 2011, with carbon dioxide (CO_2) contributing 80%.”

Carbon Dioxide Emissions of Various Fuels When Producing 2013 American Winter Peak Electrical Load Capacity

All emissions per pound of fuel from pp. 212, 214, 216, Carbon Dioxide Emissions of Common Fuels, in multiples of lignite’s. All HHVs from pp. 208–218, table of Calorific Efficiencies. Then I divided 9 trillion by each fuel’s HHV to determine the required number of pounds, which I multiplied by its emissions per pound to get the total emissions.

Footnote: Combustion products of 1 lb methane—Baumeister and Marks, p. 4-72 (G. A. Hawkins, “Thermal Properties of Bodies and Thermodynamics”).

“Finally, I must be permitted to say that the writing of this book . . .”—Digby, p. xxv.