New York Times
24 October 1954

About—Polar Ice

How fast does it melt? An expedition seeks the answer.

By BENJAMIN POWELL

ONE of the objectives in the forthcoming American expedition to Antarctica is to check on the status of the stupendous ice fields and glaciers of that little-known continent. The particular point of inquiry concerns whether the ice is melting at such a rate as to imperil low-lying coastal areas through raising the level of the sea in the near future. There is no saying as yet how imminent that threat might be, but there is little question that there is enough of the frozen stuff around to cause trouble if it all melted suddenly.

IN THE SOUTH

The Antarctic Continent i- about 5,000,000 squa- area, and ' onl' fr

An ice breaker off Ross Barrier.

... of ... not be likely ... great effect if it ...

HOW MUCH DANGER?

A greater potential danger (nevertheless remote) is the Greenland Ice Cap. Here is an enormous, rounded hump of ice, piled over the mountains and valleys of the world's largest island. The ice covers about 700,000 square miles, leaving a sparse fringe of exposed rock around the coast. The thickness is believed to average about 1,000 feet, but soundings have indicated depths of 10,000 feet or more.

Elsewhere in the northern hemisphere are great deposits of ice and snow in the Himalayas, Alaska, the Alps and the Scandinavian mountains.

There is no doubt that the ice of the far north is melting faster than it is replaced by new snowfalls (actually most of the Arctic gets only about 8 inches of precipitation a year). Glaciers all around the northern world are receding at a clearly measurable pace, and have been for several generations. Yet the rate of melt is so slow as to leave no rise in tide levels sufficient to alarm humans. Greater solar radiation is given as the cause of the recession, but greater solar radiation also increases the rate of evaporation.

Assuming a very rapid, almost instantaneous melting of Greenland's ice alone, it has been estimated that the level of the oceans would be increased about twenty-five feet. But, scientists point out, conditions bringing that about would be of such a cataclysmic nature that there would probably be no one left around to do the worrying, anyway.

Read Widely

This section and the chapter notes are also available at *Global-Fever.org*, augmented with live links.

When undertaking this book on our global fever, I decided to write a cheerful book in parallel. It became *Almost Us: Portraits of the Apes*. You might wish to employ a similar back-and-forth strategy when reading more about our big problem.

If you haven't already, I'd suggest reading

Jared Diamond. *Collapse: How Societies Choose to Fail or Succeed*. Viking, 2005. Anthropology and ecology of past societies, not specifically global warming but the essential stage-setting. Excellent, as usual.

Al Gore. *An Inconvenient Truth*. Rodale Press, 2006. Closely follows the world-famous film that won an Oscar. As Jim Hansen says, "Al Gore may have done for global warming what 'Silent Spring' did for pesticides."

Then consider reading one or more of these books:

Robert Henson. *The Rough Guide to Climate Change.* Rough Guides, 2006. Don't be fooled by the travel-books connection. It's one of the best of the reader-friendly books that could also be used for climate courses. The author is a science writer at the National Center for Atmospheric Research in Boulder, Colorado.

Mark Lynas. *Six Degrees.* Fourth Estate, 2007. His chapter on the consequences of a 1°C fever is sobering enough, but then he works his way through the consequences of the 2, 3, 4, 5, and 6° fevers and "Choosing our future." Very well done. It also shows that with a first-class honours

degree in history and politics, you can read and understand much of climate science.

Joseph J. Romm. *Hell and High Water.* William Morrow, 2007. An excellent book of climate science plus advocacy by a former acting Assistant Secretary in the U.S. Department of Energy. The author is a Ph.D. physicist and oceanographer by training but his father was a journalist—and it shows.

Then consider these when branching out:

Brian Fagan. *The Long Summer: How Climate Changed Civilization*. Basic Books, 2004.

Tim Flannery. *The Weather Makers*. Atlantic Monthly Press, 2005.

Ross Gelbspan. *Boiling Point*. Basic Books, 2004.

Elizabeth Kolbert. *Field Notes from a Catastrophe.* Bloomsbury, 2006.

Eugene Linden. *The Winds of Change*. Simon & Schuster, 2006.

James Lovelock. *The Revenge of Gaia*. Penguin/Allen Lane, UK, 2006.

George Monbiot. *Heat: How to Stop the Planet Burning*. Penguin/Allen Lane, UK, 2006.

Fred Pearce. *The Last Generation: How Nature Will Take her Revenge for Climate Change.* Eden Project Books, UK, 2006.

A. Barrie Pittock. *Climate Change: Turning Up the Heat.* CSIRO, Australia, 2005.

Phillip W. Schewe. *The Grid*. Joseph Henry Press , Washington DC, 2007.

Spencer R. Weart. *The Discovery of Global Warming*. Harvard University Press, 2003. Updated version at *www.aip.org/history/climate.*

On the web, I would initially avoid search engines because of the disinformation problem for climate matters. Try

RealClimate.org, done by real climate scientists,

Society for Environmental Journalism at *www.sej.org/resource/index18.htm*.

Professor Stephen Schneider's climate website, *stephenschneider.stanford.edu*,

American Institute of Physics, *www.aip.org/history/climate/links.htm*

Pew Center on Climate Change, *www.PewClimate.org,*

Climate Institute at *Climate.org,*

ClimatePrediction.net

The National Center for Atmospheric Research at *www.ucar.edu/research/climate/future.jsp*.

Union of Concerned Scientists at *ClimateChoices.org*.

Rocky Mountain Institute at *www.RMI.org.*

World Resources Institute, at *WRI.org*. Their *Navigating Numbers*, by Kevin A. Baumert, Timothy Herzog, and Jonathan Pershing, is quite useful.

BBC's updated climate pages at *www.bbc.co.uk/sn/hottopics-/climatechange/*

New York Times at *topics.nytimes.com/top/news/science/topics-/globalwarming/index.html?8qa*.

American Association for the Advancement of Science at *www.aaas.org/climate/*

They all have a list of recommended links to other sites, regularly updated. The Society of Environmental Journalists has an excellent list of lists for all sides of climate change at *www.sej.org/resource-/index18.htm*—it even includes the Birdwatcher's Guide to Global Warming!

Armed with some of the science, you can gradually branch out to the wider web. See how quickly you can spot the front organizations for the not-a-problem promoters of business as usual through more delay. Most of them have invented fancy names for themselves in order to slip past your guard; most include some good science to help disguise their propaganda. Once you are good at it, test your skills at *GlobalWarming.org*. See the Union of Concerned Scientists' 2007 report on ExxonMobil's $23-million attempt to mislead the public at *ucsusa.org/assets/documents/global_warming/exxon_report.pdf*.

More advanced readers should take a look at

Intergovernmental Panel on Climate Change, *2007 Summary for Policymakers* for each of the three working IPCC groups, at *www.ipcc.ch*. There are also Technical Chapters with all the references up to late 2005.

U.S. Global Change Research Program, *Climate Change Impacts on the United States*, USGCRP, 2001 *www.usgcrp.gov/usgcrp/Library/nationalassessment/*

The Arctic Council, *Arctic Climate Impact Assessment*, Arctic Council, 2005. *www.acia.uaf.edu*

James Hansen, "A slippery slope," *Climatic Change* 68 (February 2005): 269-279. At *dx.doi.org/10.1007/s10584-005-4135-0*.

Illustration List

Most of these illustrations may be freely borrowed for non-commercial and educational uses. They may be downloaded from *Global-Fever.org*.

10. Slip Locally, Crash Globally

11. Come Hell and High Water

12. Methane Is the Double Threat

Notes

The following notes are also on the web at *Global-Fever.org*, referenced by this book's page numbers and including web links to many of the citations. Author (year) citations usually refer to a book in the **What to Read** section.

vii Munch lithograph at *www.jesuits.ca/orientations/Munch2.html*. Letter from *en.wikipedia.org/wiki/The_Scream.*

Chapter 1. The Big Picture

3 Guy Callendar, "The Artificial Production of Carbon Dioxide and Its Influence on Temperature." *Quart. J. Roy. Meteorol. Soc.* 64 (1938): 223–40.

6 Coal twice as bad, per kilowatt-hour generated: *en.wikipedia.org/wiki/Energy_content_of_biofuel*.

7 These estimates do not include the effects of tropical forest fires on carbon emissions, which are much more difficult to measure. When the 1997/98 El Niño episode provoked severe droughts in the Amazon and Indonesia, large areas of tropical forest burned, releasing 0.2 to 0.4 Pg of carbon to the atmosphere. If droughts become more severe in the future through more frequent and severe El Niño episodes, or the dry season becomes lengthier due to deforestation induced rainfall inhibition, or there are rainfall reductions due to global warming, then substantial portions of the 200 Pg of carbon stored globally in tropical forest trees could be transferred to the atmosphere in the coming decades. Global carbon emissions from fires during 1997/98 El Niño are estimated at 2.1 ± 0.8 PgC and South and Central America contributed ~30% of global emissions from fires. See *www.joanneum.at/Carboinvent/post2012_/Bird/santilli_et_al_2005.pdf*.

11 Bill McKibben, in the *New York Review of Books* (16 November 2006) at *www.nybooks.com/articles/19596*.

Chapter 2. We're Not in Kansas Anymore

12 Tornado in Dimmit, Texas: photograph by Harald Richter at *www.photolib.noaa.gov/nssl/nssl0179.htm*

14 Three hurricanes south of Japan on August 7, 2006, from *visibleearth.nasa.gov/view_rec.php?id=20946*, credit Jeff Schmaltz. "The slanting diagonal feature through the image is sunlight bouncing off the ocean into the MODIS instrument [on the satellite], a phenomenon called sunglint. The very bright swath is where the reflection is strongest."

14 Goran Ekstrom, Meredith Nettles, Victor C. Tsai, "Seasonality and increasing frequency of Greenland glacial earthquakes." *Science* 311 (2006): 1756–1758.

15 Jared Diamond, *Collapse: How Societies Choose to Fail or Succeed.* (Viking 2005), 6.

16 David Montgomery, *Dirt: The Erosion of Civilizations* (University of California Press, 2007).

17 Muir glacier pair: *nsidc.org/cgi-bin/gpd_run_pairs.pl*

19 Richard Lindzen, in *Newsweek* (2007) at *www.msnbc.msn.com/id /17997788/site/newsweek*. See also Daniel Grossman's interview, "Profile: Dissent in the Maelstrom," *Scientific American* (November 2001). Lindzen is a serious climate scientist who thinks that an "infrared Iris" associated with stratus cloud production and tall thunderheads will result in a climate sensitivity of only one-third the IPCC estimates. I hope he is right, though personally I would not go around telling people not to worry on the strength of a preliminary theory—nor describe ExxonMobil as "the only principled oil and gas company I know in the US." See *news.bbc.co.uk/2/low/business/ 6595369.stm*.

For the less established climate dissenters, a tendency to shift targets with time raises questions of whether it's really about the science or about something else. "Whatever the science is, they will try to find ways to question it," says Naomi Oreskes, a geologist and science historian at the University of California, San Diego. "That makes it clear that the issue for them is not the science." See Michael Hopkin, "Climate sceptics switch focus to economics: As the scientific case strengthens, dissenters change tack." *Nature* (10 February 2007) 582, at *dx.doi.org/10.1038/445582a*.

Floods and wildfires are from the figures in the 2007 IPCC report, in the WG 1 Summary for Policymakers at *www.ipcc.ch*. For zonal precipitation: Xuebin Zhang, et al, "Detection of human influence on twentieth-century precipitation trends," *Nature* 448(26 July 2007): 461–465, at *dx.doi.org/10.1038/nature06025*.

Governor Arnold Schwarzenegger of California, quoted by Thomas Friedman, "The power of green," *New York Times* Magazine (15 April 2007) at *www.nytimes.com/2007/04/15/magazine/15green.t.html*.

The correlation of temperature with western U.S. wildfires is from A. L. Westerling, H. G. Hidalgo, D. R. Cayan, and T. W. Swetnam. "Warming and earlier spring increase western U.S. forest wildfire activity." *Science* 313 (5789): 940 (18 August 2006). See *dx.doi.org/10.1126/science.1128834*.

19 John Holdren, "The energy innovation imperative." *Innovation* (Spring 2006): 11.

Chapter 3. Will This Overheated Frog Move?

22 Svante Arrhenius, "On the influence of carbonic acid in the air upon the temperature of the ground." *Philosophical Magazine and Journal of Science (fifth series)* 41 (1896): 237–275. See Weart's history at *www.aip.org/history/climate*.

Roger Revelle and Hans E. Suess. "Carbon dioxide exchange between atmosphere and ocean and the question of an increase of CO_2 during the past decades." *Tellus* 9 (1957) 18-27.

26 Jim Hansen's presentation at the National Academy of Sciences in April 2006 is on his Columbia University website, *www.columbia.edu/~jeh1*.

28 Ozone hole, see *earthobservatory.nasa.gov/Newsroom/NewImages /images.php3?img_id=17436*.

29 *www.monbiot.com/archives/2005/10/25/our-own-nuclear-salesman/*.

30 Ten recommendations for reducing U.S. carbon emissions:

1. Immediately freeze carbon dioxide emissions and then begin a program to reduce them by at least 90% by 2050.
2. Replace the payroll tax for Social Security and Medicare with a tax on pollution, particularly carbon dioxide.
3. Use a portion of the tax on pollution to help low-income individuals adapt as carbon emissions are reduced.

4. Work towards de-facto compliance with the Kyoto Protocol to the United Nations Framework Convention on Climate Change, and create a new, strong international treaty with a starting date of 2010 instead of 2012.

5. Enact a moratorium on the construction of any new coal-fired power plants that are not compatible with carbon capture and sequestration.

6. Create an 'Electranet,' a smart grid in which power generation is widely distributed. Homeowners and small businesses could use solar and wind energy generators and sell that energy into the grid at a rate that is determined by the market.

7. Raise Corporate Average Fuel Economy (CAFE) standards for automobiles, and set energy standards for other industries.

8. Set a date for a ban on incandescent light bulbs.

9. Create a 'Connie Mae,' a carbon-neutral mortgage association that would help homebuyers pay for energy reduction measures such as insulation and energy-efficient windows that can have high upfront expenses.

10. Have the Securities and Exchange Commission (SEC) require the disclosure of carbon emissions in corporate reporting.

From The Honorable Al Gore's testimony to the U.S. Congress in March 2007. See *EOS* 88(10 April 2007): 171.

All necessary, but far too weak. Maybe this is what it takes to get Congress moving at last, but those ten are the easy stuff, what would have been appropriate twenty years ago. If we don't do considerably more, and quickly, it will be like rearranging the desk chairs on the *Titanic*.

I would instead emphasize the 2020 urgency requiring many new nuclear or geothermal power plants, retiring many old coal plants, converting to plug-in hybrid electric vehicles, and subsidizing DC power lines to developing countries with coal.

30 UN Secretary-General Ban Ki-moon, at press conference (8 June 2007). See *www.UN.org/apps/sg/offthecuff.asp?nid=1035*.

31 Andrew Revkin, "Global meltdown," *AARP Magazine* (July 2007) at *www.aarpmagazine.org/lifestyle/global_meltdown.html.*

32 R. A. Bindschadler et al, "Tidally controlled stick-slip discharge of a West Antarctic ice stream," *Science* 301 (2003):1087–89.

32 Joseph J. Romm, *Hell and High Water* (William Morrow, 2007), 2.

32 General Gordon R. Sullivan, *securityandclimate.cna.org/report* at p.10.

Chapter 4. "Pop!" Goes the Climate

39 This satellite image shows the 2002 breakup of the Larsen B Ice Shelf. See Eugene Domack et al, "Stability of the Larsen B ice shelf on the Antarctic Peninsula during the Holocene epoch." *Nature* 436 (2005): 681–685. This region, covering approximately 3250 km^2 with 200 m thick ice, had been continuously glaciated since before the end of the last glacial period. Adapted from NASA Terra/MODIS imagery via *www.GlobalWarmingArt.com*. The 2005 melt/refreeze episode is at *earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17661*

37 William H. Calvin, "The great climate flip-flop," *Atlantic Monthly* (January 1998). The story is elaborated in *A Brain for All Seasons: Human Evolution and Abrupt Climate Change.* (University of Chicago Press, 2002).

Chapter 5. Drought's Slippery Slope

40 *woodyguthrie.org/Lyrics/Dust_Storm_Disaster.htm*.

43 My synopsis of drought feedbacks derives from a brief talk in 2000 by J. M. Wallace.

43 "Fleeing a dust storm" shows farmer Arthur Coble and his sons in Cimmaron County, Oklahoma. By Arthur Rothstein, U.S. government photographer, April, 1936 (Library of Congress LOC-00241v.jpg).

44 Recent evaporation seeding the next rainfall: that is going to be a big problem in the Amazon. Today, the flat bottom of the clouds (where the dew point is) isn't very high off the ground. But with greenhouse warming, that flat bottom will move up to much higher in the sky—and so not mix very well with the recent evaporation. The clouds will continue westward until running into the Andes and dropping some rain there. It will flow down the Amazon river as it does now but the lush vegetation on the riverbanks will be gone—likely burned off during the onset of drought.

47 Connie A. Woodhouse, Jonathan T. Overpeck, "2,000 Years of

Drought Variability in the Central United States," *Bulletin of the American Meteorological Society* 79(1998): 2693–2714.

49 Worster quote at *www.pbs.org/wgbh/amex/dustbowl/peopleevents /pandeAMEX06.html*.

51 Also from Woodhouse and Overpeck (1998).

51 A 1 m rise in sea level would change the frequency of what are now 100-year floods in metropolitan New York to once in every four years events. See *ccir.ciesin.columbia.edu/nyc/ccir-ny_q2a.html* and C. Rosenzweig and W.D. Solecki (Eds.). *Climate Change and a Global City: The Potential Consequences of Climate Variability and Change - Metro East Coast*. Report for the U.S. Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States (Columbia Earth Institute, New York, 2001).

52 Although originally named the Medieval Warm Period, the temperature change does not seem to have been uniform around the globe. It is best thought of as a period of widespread climate anomalies preceding the better-defined Little Ice Age.

53 Drought frequency: Richard Seager et al, "Model projections of an imminent transition to a more arid climate in southwestern North America," *Science* 316 (25 May 2007): 1181–1184 at *dx.doi.org /10.1126/science.1139601*.

53 Eleanor J. Burke, Simon J. Brown, Nikolaos Christidis, "Modeling the Recent Evolution of Global Drought and Projections for the Twenty-First Century with the Hadley Centre Climate Model," *Journal of Hydrometeorology* 7 (October 2006): 1113–1125.

54 Dust wall photos from NOAA's George E. Marsh Album via *commons.wikimedia.org/wiki/Image:Dust*.

57 Irrigation, see *ga.water.usgs.gov/edu/irsprayhigh.html* and *www.worldwatch.org/node/811.*

58 Kansas crop circle irrigation photo from *earthobservatory.nasa.gov /Newsroom/NewImages/Images/kansas_AST_2001175_lrg.jpg*.

Chapter 6 **Why Deserts Expand**

59 Kim Stanley Robinson, "Imagining Abrupt Climate Change: Terraforming Earth." Amazon Short essay (2005).

61 George Hadley, "Concerning the cause of the general trade winds," *Philosophical Transactions*, 39 (1735).

62 Qiang Fu, Celeste M. Johanson, John M. Wallace, Thomas Reichler. "Enhanced mid-latitude tropospheric warming in satellite measurements," *Science* 312 (26 May 2006): 1179.

62 Richard Seager, et al., "Model projections of an imminent transition to a more arid climate in southwestern North America." *Science* 316 (25 May 2007): 1181–1184 at *dx.doi.org/10.1126/science.1139601*.

62 Perth: Flannery (2005): 130. Pittock (2005): 141.

63 Long-term drought indicator blends at *www.drought.unl.edu/dm/monitor.html.*

68 Daniel Nepstad, see *www.whrc.org/resources/online_publications/essays/2006-08-Nepstad-Independent.htm.*

68 George Monbiot, *Heat* (2006): xi.

68 Fred Pearce, "Global meltdown." *The Guardian* (30 August 2006). *environment.guardian.co.uk/climatechange/story/0,,1860560,00.html*

Chapter 7. From Creeps to Leaps

70 U.S. Coast Guard photograph of New Orleans on the day after Hurricane Katrina, 2005, after three levees had failed.

72 Robert Frost, in *Selected Prose of Robert Frost*, edited by H. Cox and E. C. Lathem (Collier, 1986), 33–46.

73 Snowballing, see Pittock (2005): 110ff, for an excellent discussion on nonlinear effects in climate.

75 The Teton Dam, 44 miles northeast of Idaho Falls in southeastern Idaho, failed abruptly on June 5, 1976 when being filled for the first time. Engineers were actively looking for leaks and saw a wet spot. However, the collapse progressed so rapidly that several large bulldozers were lost and downstream communities only had one hour of warning. The dam failure released nearly 300,000 acre feet of water, which flooded farmland and towns downstream at the loss of 14 lives and a cost of $1 billion. See *npdp.stanford.edu/npdphome/npdpimages/Photo%20Gallery/fullimages/IDS00007_003_f.jpg*.

76 Thomas R. Malthus, *An Essay on the Principle of Population* (printed for J. Johnson, London, 1798).

77 Restaurant lead-lag dynamics: *muller.lbl.gov/pages/*

news%20reports/ebexp.htm.

81 David Montgomery, *Dirt: The Erosion of Civilizations (*University of California Press, Berkeley, 2007).

82 James Martin, *The Meaning of the 21st Century* (Eden Project, London, 2007): 30. Graph of cod catch from *www.fao.org/docrep/005 /y3684e/y3684e05.htm*.

85 Al Gore, on the Charlie Rose Show (September 2006).

85 Raymond T. Pierrehumbert, "Climate Change: A Catastrophe in Slow Motion," *Chicago Journal of International Law* 6 (Winter 2006): 573. See *cjil.uchicago.edu/past-issues/win06.html*.

Chapter 8. What Makes a Cycle Vicious?

88 Watt story from James Lovelock, *The Revenge of Gaia* (Allen Lane: London, 2006). See *en.wikipedia.org/wiki/Centrifugal_governor*. The figure is from "Discoveries & Inventions of the Nineteenth Century" by R. Routledge, 13th edition, published 1900.

89 Good use is made of positive feedback by nerve cells and muscles. It's what makes things happen quickly. It shortens your reaction time enough so that you have quick reflexes and don't go bouncing down a flight of steps. Your computer uses positive feedback in much the same way to shorten each step of the computing cycle. When the first flip-flop circuits were invented for computer bits, they operated on about the same timescale as nerve cells (milliseconds). Now they (but not the nerve cells) are a million times faster, operating in nanoseconds.

92 James Hansen, Makiko Sato, Pushker Kharecha, Gary Russell, David W Lea, Mark Siddall, "Climate change and trace gases." *Philosophical Transactions of the Royal Society A* (July 15, 2007) at *dx.doi.org/10.1098/rsta.2007.2052.*

94 K. Steffen, R. Huff, *Greenland Melt Extent, 2005* (Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, 2005); available at *cires.colorado.edu/science /groups/steffen/greenland/melt2005/*.

95 Water vapor amplifies CO_2 warming by 40–50 percent: IPCC 2007 WG1 SPM.

96 "When CO_2 increases the storage of heat in the lower atmosphere, it promotes more evaporation from the tropical oceans." By itself, this positive feedback is somewhat self-regulating as high humidity means more clouds and their whiteness reflects some sunlight back out into space, somewhat countering the heating effect of more water vapor in the atmosphere. Since cloud formation also depends on a number of other things such as the size of smoke particles, the balancing act is not well understood yet. For example, agricultural fires create soot whose particles are large enough to seed water droplet formation. Power plants burning fossil fuels produce smaller particles and less rainfall downwind.

96 Frank J. Wentz, Lucrezia Ricciardulli, Kyle Hilburn, Carl Mears, "How Much More Rain Will Global Warming Bring?" *Science* (31 May 2007) at *dx.doi.org/10.1126/science.1140746*.

98 Ted Scambos quote at *earthobservatory.nasa.gov/Newsroom/MediaAlerts/2006/2006100323310.html.*

99 Eleanor J. Burke, Simon J. Brown, Nikolaos Christidis, "Modeling the Recent Evolution of Global Drought and Projections for the Twenty-First Century with the Hadley Centre Climate Model," *Journal of Hydrometeorology* 7 (October 2006): 1113–1125.

Chapter 9. That Pale Blue Sky

101 David Appell, news article "The darkening Earth," *Scientific American* (August 2004): 16–17.

In addition to balloons, sulfur could be distributed via jet fuel. To avoid adding sulfur to the lower atmosphere, one fuel tank on an airliner would be filled with sulfur-free fuel and used on the climb up to cruising altitude (which accounts for about one-quarter of a long flight's fuel consumption). But when cruising above the weather, the sulfur-enhanced jet fuel would be used.

106 V. Ramanathan, quoted by Pearce (2006).

107 Richard A. Feely, Christopher L. Sabine, and Victoria J. Fabry, "Carbon dioxide and our ocean legacy." National Environment Trust brochure (2006), see *www.NET.org/documents/ocean_acidification*.

107 Oliver Morton, "Is this what it takes to save the world?" *Nature* 447 (10 May 2007):132-136 news feature at *dx.doi.org/10.1038/447132a*.

107 El Niño reduces primary production: Michael J. Behrenfeld, et al, **"**Climate-driven trends in contemporary ocean productivity," *Nature* 444 (7 Dec 2006): 752–755. At *dx.doi.org/10.1038/nature05317*.

107 Power plant fallout map adapted from exhibit 3–1 in *cta.policy.net/fact/mortality/mortalityabt.pdf*

108 Tim Flannery (2006): 219.

109 Fire maps created by Jacques Descloitres, MODIS Rapid Response System at NASA/GSFC. See *rapidfire.sci.gsfc.nasa.gov /firemaps/.*

110 Deaths from coal, adapted from Exhibit 6–1 Premature Mortality Risk Attributable to PM2.5 from Power Plants, 2010 Baseline, at *www.cleartheair.org/dirtypower/docs/abt_powerplant_whitepaper.pdf*

Chapter 10. Slip Locally, Crash Globally

111 Richard Alley, quoted by Pearce (2006).

112 The Google Earth software is at *earth.google.com*; once installed, go to *WilliamCalvin.com/2006/GoogleEarth_PlacemarkGreenland Shoulder.kmz* for a view of the pockmarked western shoulder of Greenland. Startup and find the terrain toggle so there is a readout of Lat/Long/Elev. Once positioned over the west coast of Greenland at about 70°N, start moving south, zooming in on the long east-west tongue of Jakobshaven Isbrae (once an ice shelf, until warmer waters undermined it and broke it up like Larsen B). Then move east to see the lakes on the shoulder of the ice sheet. Finally travel south, keeping lakes in sight. The drainage of these lakes is likely setting up the collapse of the southern half of the central Greenland ice sheet.

113 Melt water lake photograph is by climate scientist Sarah Das. *www.whoi.edu/oceanus/viewImage.do?id=17710&aid=9126*. See NASA photos at *earthobservatory.nasa.gov/Newsroom/NewImages /images.php3?img_id=17607*.

114 Greasing the skids: Jay Zwally et al, "Surface melt-induced acceleration of Greenland ice-sheet flow," *Science* 297(2002): 218–222. Also, from studies in Iceland, the water that gets trapped under the ice cannot refreeze if it is under so much pressure that it cannot expand into ice. And so it is forced up into whatever cracks the icy bottom affords. If finding space to expand, it freezes. The heat given up in freezing warms the surrounding ice, beginning a self-destructive cycle along the bottom of the ice sheet that crumbles the attachment to the bedrock. There's more at *www.pbs.org/wgbh/nova /transcripts/3211_megafloo.html.*

115 Quoted by Pearce (2006): 70.

119 Sea-level rise, modified from figure 5.5.2 of the 2007 IPCC report SPM. It comes from an oxygen isotope record for the Red Sea over the past 470 kyr. See Siddall et al., *Nature* 423 (2003): 853–858.

119 Plankton appear in various roles in scenarios for pumping down carbon in an ice age. Fertilization: the higher winds of an ice age should carry a lot more iron-rich dust into the Atlantic from the Sahara and Namib deserts. Expanded habitat: the reduced meridional heat transport during an ice age cools the North Atlantic, and Lovelock (2006) argues for the cooler oceans allowing plankton to thrive in more places and so pumping down carbon faster. The jury is still out on their relative importance, and certainly regarding how they might be manipulated to solve our CO_2 problem.

120 J. W. Day, Jr., et al, "Emergence of complex societies after sea level stabilized." *EOS* 88 (10 April 2007): 169.

122 Richard Alley quote from Pearce (2006).

122 David D. Zhang, Jane Zhang, Harry F. Lee, Yuan-qing He. "Climate Change and War Frequency in Eastern China over the Last Millennium." *Human Ecology* 35 (2007):403–414 at *dx.doi.org/10.1007/s10745-007-9115-8*.

127 Flannery (2006): 140.

Chapter 11. Come Hell and High Water

131 Most of the sea-level maps were produced, thanks to Jonathan Overpeck and Jeremy Weiss, with the mapping software at the University of Arizona. See *www.geo.arizona.edu/dgesl/research/other/climate_change_and_sea_level/sea_level_rise/sea_level_rise.htm*.

133 Max Mayfield, director of the National Hurricane Center, quoted in Reuters interview (22 August 2006).

134 NYC storm surge proposal, see *www.nyas.org/ebriefreps/main.asp?intSubsectionID=2247* and *metroeast_climate.ciesin.-columbia.edu/reports/infrastructure.pdf*. For more on storm surges, with New York City and Long Island examples, see *stormy.msrc.sunysb.edu*. Includes real-time forecasts.

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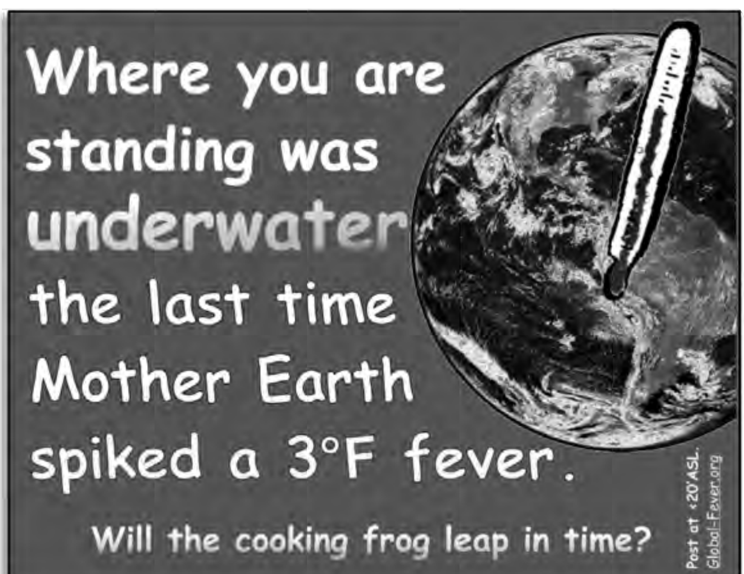
Sir David King, "Climate Change Science: Adapt, Mitigate, or Ignore?" *Science* 303 (9 January 2004): 176–177.

141 Claudia Dreifus, "A Conversation With Jeffrey Mount: Giving Sacramento Good Reason to Have New Orleans on Its Mind." *New York Times* (April 18, 2006). *www.nytimes.com/2006/04/18/science/18conv.html*.

142 David Biello, "Conservative Climate: Consensus document may understate the climate change problem," On the Scientific American web site (18 March 2007) at *www.sciam.com/print_version.cfm?-articleID=5B9E73AD-E7F2-99DF-3F71280BCE41ED77*.

145 The graph of sea-level rise in the last 24,000 years is from the 2007 IPCC Summary for Policymakers WG1. I have extensively modified the Washington Monument photograph at *en.wikipedia.org-/wiki/Image:Washington_Monument_Dusk_Jan_2006.jpg*.



My print-your-own color poster, suitable for posting within 20 ft of sea level. is in a PDF file at *Global-Fever.org/#posters*, together with directions for determining where to post it using GPS units or Google Earth. For a similar project, see *nytimes.com/2007/06/16/arts/design/16chal.html*.

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146 Eric Rignot and Pannir Kanagaratnam, "Changes in the velocity structure of the Greenland Ice Sheet," *Science* (17 February 2006): 986–990. At *dx.doi.org/10.1126/science.1121381.*

147 For a discussion of the 2007 IPCC estimates of sea-level rise, see Stefan Rahmstorf's discussion at *www.realclimate.org/index.php /archives/2007/03/the-ipcc-sea-level-numbers/#more-427*.

148 Mark Lynas, *Six Degrees* (Fourth Estate, 2007): 171.

149 Modeling data from Kurt M. Cuffey and Shawn J. Marshall, "Substantial contribution to sea-level rise during the last interglacial from the Greenland ice sheet," *Nature* 404 (6 April 2000): 591-594. At *dx.doi.org/10.1038/35007053*.

149 Greenland ice about 125,000 years ago is inferred from models; see 2007 IPCC report WG1 technical chapters.

Chapter 12. Methane Is the Double Threat

150 CO_2, CH_4 and temperature records from James E. Hansen, *Climate Change* 68 (2005): 269.

151 Kirpotkin, quoted by Pearce (2006): 111.

152 When you hear the phrase, "Doubling CO_2," it refers to the pre-industrial CO_2 level of 275 ppm being doubled to 550 ppm of CO_2 equivalents. The natural range for CO_2 between ice-age minima and maxima is about 100 parts per million. We have already gone 110 ppm past the historical maximum and need to add at least 50 ppm for the CO_2 equivalents of the increased concentrations of methane and other GHGs.

152 Guiseppe Etiope, "The geological links of the ancient Delphic Oracle (Greece): A reappraisal of natural gas occurrence and origin." *Geology* (October 2006): 825–828. Since methane dilutes the oxygen concentration of the air, anoxia likely affected the Oracle.

152 Renato Spahni, Jérôme Chappellaz, Thomas F. Stocker, Laetitia Loulergue, Gregor Hausammann, Kenji Kawamura, Jacqueline Flückiger, Jakob Schwander, Dominique Raynaud, Valérie Masson-Delmotte, and Jean Jouzel. "Atmospheric Methane and Nitrous Oxide of the Late Pleistocene from Antarctic Ice Cores," *Science* (25 November 2005): 1317–1321.

152 John M. Barry, *Rising Tide: The Great Mississippi Flood of 1927 and How It Changed America* (Simon and Shuster, 1997) 69.

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David A. Kirchgessner, Robert A. Lott, R. Michael Cowgill, Matthew R. Harrison, Theresa M. Shires, "Estimate of methane emissions from the U.S. natural gas industry," n.d., at *www.epa.gov/ttn/chief/ap42/ch14/related/methane.pdf.*

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154 T. M. Hill et al, "Climatically driven emissions of hydrocarbons from marine sediments during deglaciation," *Proceedings of the National Academy of Sciences (U.S.)* 103 (12 September 2006):13570 at *dx.doi.org/10.1073/pnas.0601304103*.

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David Archer, "Methane hydrates and anthropogenic climate change." *Biosci. Discuss.* 4 (2007): 993–1057 and see *RealClimate.org/index.php?p=227*.

Burning methane hydrate photograph from *www.giss.nasa.gov/research/features/methane/hydrate.jpg*.

157 I. J. Simpson, F. S. Rowland, S. Meinardi, and D. R. Blake, "Influence of biomass burning during recent fluctuations in the slow growth of global tropospheric methane," *Geophysiocal Research Letters* 33 (2006): L22808, *dx.doi.org/10.1029/2006GL027330*.

157 David Archer and Victor Brovkin, "Millennial Atmospheric Lifetime of Anthropogenic CO_2," *Climatic Change* (to appear, 2007).

158 Ocean acidification figure adapted from the Hadley Centre's HadOCC model; via John Holdren's MBL slide (2006).

159 Marten Scheffer, Victor Brovkin and Peter Cox, "Positive feedback between global warming and atmospheric CO_2 concentration inferred from past climate change." *Geophysical Research Letters* (2006) at *dx.doi.org/10.1029/2005GL025044*.

159 M. S. Torn and J. Harte, "Missing feedbacks, asymmetric uncertainties, and the underestimation of future warming," *Geophysical Research Letters* (2006) at *dx.doi.org/10.1029/2005GL025540*.

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Chapter 13. Sudden Shifts in Climate

162 "Winds gusting to more than 100 mph swept across northern Utah on Friday, overturning 20 tractor-trailers.…Winds reached 113 mph setting a state record…." Photo by Marta Storwick for the *Standard-Examiner* of Ogden, Utah (23 April 1999), with permission.

163 Claudia Tebaldi et al, "Going to Extremes," *Climatic Change* (December 2006). See *www.ucar.edu/news/releases/2006 /wetterworld.shtml.*

Richard B. Alley, et al., "Abrupt climate change." *Science* 299 (2003): 2005–10.

164 See "How Likely are Major or Abrupt Climate Changes, such as Loss of Ice Sheets or Changes in Global Ocean Circulation?"in G. A. Meehl, et al, "Global Climate Projections. Section 10.2 in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by Susan Solomon, et al. (Cambridge University Press, Cambridge and New York) at *ipcc-wg1.ucar.edu/wg1/Report /AR4WG1_10.pdf*.

164 William H. Calvin, "The great climate flip-flop," *Atlantic Monthly* (January 1998). The story is elaborated in *A Brain for All Seasons: Human Evolution and Abrupt Climate Change.* (University of

Chicago Press, 2002).

166 Illustration adapted from the National Oceanic and Atmospheric Administration's El Niño Web site, *www.pmel.noaa.gov/tao/elnino*. Technically, an El Niño is when mid-Pacific sea surface temperature stays more than 0.5°C above normal for four months. A La Niña is when it cools more than 0.5°C for four months (although some may use La Niña for the normal midrange as well). A La Niña situation often follows an El Niño episode and is essentially its opposite. During a La Niña, the easterly trade winds near the equator are stronger than normal. They push more warm surface waters westward across the Pacific. The colder, deeper waters that well up to the surface in their place extend far out into the central equatorial Pacific. The historical El Niño chart is at *www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.ppt*

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Chapter 14. A Sea of CO_2

172 The data snapshot is from March to June, the northern sunlight making the bloom there more than in the southern hemisphere winter. Nutrients are a major limitation. Besides nutrients from rivers, they are also up-welled to the surface in some areas (line in mid-Pacific Ocean where trade winds converge, also on the west coast of continents). For the original color version of the world phytoplankton imaging, see *earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17332*. Maps, see *neo.sci.gsfc.nasa.gov/Search.html?group=12*. If you have Google Earth installed, see *neo.sci.gsfc.nasa.gov/RenderData?si=493385&cs=rgb&format=KMZ.*

The pictures are thanks to Russell Hopcroft (*Cavolinia uncinata*, left), Victoria Fabry (*C. tridentata*, right), and Laurence Madin (*Salpa aspera*).

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174 Michael P. Lesser, "Coral reef bleaching and global climate change: Can corals survive the next century?" *Proceedings of the National Academy of Sciences (U.S.)* (2007) at *dx.doi.org/10.1073-/pnas.0700910104*.

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175 J. F. Bruno, et al., “Thermal stress and coral cover as drivers of coral disease outbreaks.” *PLoS Biology* 5 (2007): e124 at *dx.doi.org /10.1371/journal.pbio.0050124*.

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181 Kerguelen analysis: Stèphane Blain, et al. “Effect of natural iron fertilization on carbon sequestration in the Southern Ocean.” *Nature* 446 (26 April 2007): 1070–1074 at *dx.doi.org/10.1038/nature05700.* Kerguelen figure modified from the accompanying news article.

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Chapter 15. The Extended Forecast

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187 Mark Lynas, *Six Degrees* (Fourth Estate, London, 2007): 171.

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Chapter 16. Doing Things Differently

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207 Paul Krugman, "Colorless green ideas." *New York Times* (23 February 2007), *select.nytimes.com/2007/02/23/opinion/23krugman.html*.

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Chapter 17. Cleaning Up Our Act

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221 Paul Falkowski, et al., "The Global Carbon Cycle: A Test of Our Knowledge of Earth as a System." *Science* 290 (13 October 2000): 291. At *dx.doi.org/10.1126/science.290.5490.291.*

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Chapter 18. The Climate Optimist

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232 High-speed toll gates: A quick method that avoids the high costs of creating a new roadside network would be to install old cell-phone technology in the vehicle and simply use it to detect when the vehicle crosses from one cell to another—and billing accordingly. See *www.newscientisttech.com/channel/tech/mg19225815.600-cellphone-*

networks-could-help-with-road-tolls.html.

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235 Artificial photosynthesis, see Frédéric Goettmann, Arne Thomas, Markus Antonietti, "Metal-Free Activation of CO_2 by Mesoporous Graphitic Carbon Nitride." *Angewandte Chemie* (2007) at *dx.doi.org/10.1002/anie.200603478.*

236 FDR 1940–1941 leadership, see pp. 44–59 in Doris Kearns Goodwin's *No ordinary time* (Simon and Shuster, 1994).

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Chapter 19. Turnaround by 2020

238 James Hansen, "How Can We Avert Dangerous Climate Change?**"** Testimony before U.S. Congress (2007) at *arxiv.org/abs/0706.3720*.

239 M. Meinshausen "What does a 2°C target mean for greenhouse gas concentrations? A brief analysis based on multi-gas emission pathways and several climate sensitivity uncertainty estimates," in *Avoiding Dangerous Climate Change*, H. J. Schellnhuber, W. Cramer, N. Nakicenovic, T. Wigley, G. Yohe eds., (Cambridge University Press, Cambridge, 2006) at *www.cgd.ucar.edu/~mmalte/simcap /publications/meinshausenm_risk_of_overshooting_final_webversion.pdf.*

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Laboratory (2007) at *www.pnl.gov/energy/eed/etd/pdfs/phev_feasibility_analysis_combined.pdf*

244 Compressed air car: see *en.wikipedia.org/wiki/Air_car* and "World's First Air-Powered Car: Zero Emissions by Next Summer" in *Popular Mechanics* (June 2007) at *www.popularmechanics.com/automotive/new_cars/4217016.html.* "India's largest automaker is set to start producing the world's first commercial air-powered vehicle. [It] can hit 68 mph and has a range of 125 miles. It will take only a few minutes for the CityCAT to refuel at gas stations equipped with custom air compressor units; MDI says it should cost around $2 to fill the car's carbon-fiber tanks with 340 liters of air at 4350 psi. Drivers also will be able to plug into the electrical grid and use the car's built-in compressor to refill the tanks in about 4 hours."

246 Zimmer Power Station photograph and data thanks to George Campbell. See *tallgeorge.com/Zimmer.htm*. Platt's provides an excellent selection of free maps for energy resources at *www.platts.com/Resources/map/archive/map_archive.html*.

246 For the nuclear fuels in the fly ash, see Alex Gabbard's analysis at *www.ornl.gov/info/ornlreview/rev26-34/text/colmain.html*.

246 Capture CO_2, see "Future of 'Clean Coal' Power Tied to (Uncertain) Success of Carbon Capture and Storage" at *www.sciam.com*.

246 Jeff Goodell, *Big Coal* (Houghton Mifflin, 2006).

246 MIT report, "The future of coal: options for a carbon-constrained world" (2007) at *web.mit.edu/coal/The_Future_of_Coal.pdf*.

From its summary illustrating the challenge of scale for carbon capture and long-term storage:

- Today fossil sources account for 80% of energy demand: Coal (25%), natural gas (21%), petroleum (34%), nuclear (6.5%), hydro (2.2%), and biomass and waste (11%). Only 0.4% of global energy demand is met by geothermal, solar and wind.
- 50% of the electricity generated in the U.S. is from coal.
- There are the equivalent of more than five hundred, 500 megawatt, coal-fired power plants in the United States with an average age of 35 years.
- China is currently constructing the equivalent of two, 500 megawatt, coal-fired power plants per week and a capacity

comparable to the entire UK power grid each year.

- One 500 megawatt coal-fired power plant produces approximately 3 million tons/year of carbon dioxide (CO_2).
- The United States produces about 1.5 billion tons per year of CO_2 from coal-burning power plants.
- If all of this CO_2 is transported for sequestration, the quantity is equivalent to three times the weight and, under typical operating conditions, one-third of the annual volume of natural gas transported by the U.S. gas pipeline system.
- If 60% of the CO_2 produced from U.S. coal-based power generation were to be captured and compressed to a liquid for geologic sequestration, its volume would about equal the total U.S. oil consumption of 20 million barrels per day.
- At present the largest sequestration project is injecting one million tons/year of carbon dioxide (CO_2) from the Sleipner gas field into a saline aquifer under the North Sea.

254 MIT also assembled a panel of 18 experts in 2006 to evaluate large-scale use of deep geothermal, led by Jefferson W. Tester, the H.P. Meissner Professor of Chemical Engineering. The report, entitled "The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century," is at *geothermal.inel.gov/publications/future_of_geothermal_energy.pdf*.

254 The Hot Dry Rock concept at the Los Alamos National Laboratory in 1972, see *www-geo.lanl.gov/expertise/geotherm.htm*. R. M. Potter, E. S. Robinson, and M. C. Smith, "Method of extracting heat from dry geothermal reservoirs," U.S. Patent 3,786,858 (1974).

Dave Duchane and Don Brown, "Hot Dry Rock (HDR) geothermal energy research and development at Fenton Hill, New Mexico," *GHC Bulletin* (December 2002): 13–19, at *geoheat.oit.edu-/bulletin/bull23-4/art4.pdf*. "It was found entirely feasible to operate the plant for extended periods of time with no on-site personnel, a fact that has important economic implications for the ultimate commercialization of HDR technology." This refers to the recirculating well side of the system with heat exchanger, not a complete plant with subsequent electricity generation from the heat exchanger. From "Building a Hot Rock Energy System" at *hotrock.anu.edu.au*:

Heat is extracted by pumping water through an engineered heat exchanger connecting two or more wells. This heat exchanger is a volume of hot dry rock with enhanced permeability. It is fabricated by hydraulic stimulation. This involves pumping high pressure water into the pre-existing fracture system that is present in all rocks to varying degrees. The high pressure water opens the stressed natural fractures and facilitates micro-slippage along them. When the water pressure is released, the fractures close once more but the slippage that occurred prevents them from mating perfectly again. The result is a million-fold permanent increase in permeability along the fracture systems and a heat exchanger that can be used to extract energy.

In a typical system, an initial borehole is sunk into the hot rock mass and a hydraulic stimulation is performed. A three dimensional microseismic network deployed on the surface and in nearby wells is used to record the little noises caused by the fractures widening as the pumping continues over several weeks. In this way, the progress of the stimulation is monitored and the size and shape of the growing heat exchanger is mapped.

A second well is then drilled into the margin of the heat exchanger 500 m or more from the first well. Now water can be pumped through the underground heat exchanger and in super-heated form it can be returned to the surface. There it can have its energy extracted before being reinjected to go around the loop again.

Of course, if you drill in an earthquake-prone area, the little earth-quakes that result may become strong enough to feel (see *en.wikipedia.org/wiki/Hot_dry_rock_geothermal*). If there are also a lot of people around to notice—as was the case in a Basel suburb in December 2006—much fuss may result even for 3.4 strength earth-quakes with no injuries. The reason for locating the wells within the city was presumably the 2,700 households to be heated from the plant's excess (in addition to the 10,000 people who would get their electricity from it. It might speed deployment for Hot Rock Energy to locate wells elsewhere and use the spare heat for co-located greenhouses and such.

255 For a survey of Australia's hot rock projects, see *www.pir.sa.gov.au/byteserve/petrol/prospectivity/apia_29_march07.pdf*

255 Photo credits: *Ormat.com* for Lyete, The Philippines. For the much-altered diagram, the MIT geothermal report of 2006.

257 Jon Gertner, "Atomic balm?" *New York Times* Magazine (16 July 2006).

259 Updated death toll for energy sources can be found at *www.uic.com.au/nip14app.htm*.

263 Advanced fast reactors: "If developed sensibly, nuclear power could be truly sustainable and essentially inexhaustible and could operate without contributing to climate change. In particular, a relatively new form of nuclear technology could overcome the principal drawbacks of current methods—namely, worries about reactor accidents, the potential for diversion of nuclear fuel into highly destructive weapons, the management of dangerous, long-lived radioactive waste, and the depletion of global reserves of economically available uranium." William H. Hannum, Gerald E. Marsh, George S. Stanford, "Smarter use of nuclear waste," *Scientific American* (December 2005): 84. At *gemarsh.com/wp-content/uploads/SciAm-Dec05.pdf.*

265 AC vs DC transmissions lines, illustration adapted from "Bulk power transmission at extra high voltages, a comparison between transmission lines for HVDC at voltages above 600 kV DC and 800 kV AC," an ABB Power Technologies presentation by Lars Weimers, n.d.

268 One interesting use of biofuels would be if they were burned for electricity and the CO_2 captured and sunk. It still has the hazards of CO_2 storage burps, and I cannot imaging it having the sheer capacity for sinking the accumulated atmospheric CO_2 that plankton enhancement would have. Biofuels news story by Stephen Leahy at *www.ipsnews.net/news.asp?idnews=38384*.

Chapter 20. Arming for a Great War

272 Flannery quote at *www.news.com.au/heraldsun/story/0,21985,21225432-661,00.html*.

277 FDR in 1940: "I know that private business cannot be expected to make all of the capital investments required for expansion of plants and factories and personnel which this program calls for at once… [The] Government of the United States stands ready to advance the necessary money to help provide for the enlargement of factories, of necessary workers, the development of new sources of supply for the hundreds of raw materials required, the development of quick mass transportation of supplies."

A new "cost plus fixed fee" contract allowed the government to defray all costs essential to the execution of defense contracts and guarantee the contractor a profit through a fixed fee determined in advance. In other words, the government assumed primary financial responsibility for the mobilization process. From Doris Kearns Goodwin's *No Ordinary Time* (Simon and Shuster, 1994), 59.

Chapter 21. Get It Right on the First Try

278 David Attenborough (2006), quoted at *books.guardian.co.uk/review/politicsphilosophyandsociety/0,,1945625,00.html*

280 Michael R. Raupach, Gregg Marland, Philippe Ciais, Corinne Le Quéré, Josep G. Canadell, Gernot Klepper, and Christopher B. Field. "Global and regional drivers of accelerating CO_2 emissions" *PNAS* 104 (10 June 2007): 10288–10293 at *dx.doi.org/10.1073/pnas.0700609104*.

288 Wikipedia Projects illustrate how a Recovery Manual could be done without top-down organization: *en.wikipedia.org/wiki/Wikipedia:WikiProject.*

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About the Author

WILLIAM H. CALVIN

Born in 1939 in Kansas City, I grew up in real Middle America, though I now have an overlay from living in Seattle since 1962. I did a lot of journalism and photography before college, majored in physics at Northwestern University, then branched out into neurophysiology via studies at MIT, Harvard Medical School, and the University of Washington (Ph.D., Physiology & Biophysics, 1966). That biophysics background, plus a quarter-century of following the literature, is why I can talk shop with the climate scientists and oceanographers.

I'm now Affiliate Professor Emeritus at the University of Washington School of Medicine. I've had a long association with academic neurosurgeons and psychiatrists without ever having had to treat a patient. Most of my research has been about brain cells and circuits, along with the big-brain evolutionary history. I started paying attention to climate when trying to understand how our big brains evolved so rapidly during the Ice Ages. I've written fourteen books in twenty-eight years and have begun incorporating my photographs (many of which can be found via my website, *WilliamCalvin.org*).

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