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 coasts, and whether melting is not at all sudden.

IN THE SOUTH

The Antarctic Continent is about 9,000,000 square miles. It is

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 of the world's largest island. The ice covers about 764,000 square miles, leaving a sparse fringe of exposed rock around the coast. The thickness is believed to average about 1,500 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. Sinking most of the Arctic gets only about 8 inches of precipitation a year. Glaciers all around the northern world are receding at a steady measurable pace, and have been for several generations. Yet the rate of retreat is so slow as to leave no rise in tide levels sufficient to alarm mariners. 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, alarming 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 about such a catastrophe are not of such a catastrophic 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


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°C fevers and “Choosing our future.” Very well done. It also shows that with a first-class honors
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:


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,


Professor Stephen Schneider’s climate website, [stephenschneider.stanford.edu](http://stephenschneider.stanford.edu),

American Institute of Physics, [www.aip.org/history/climate/links.htm](http://www.aip.org/history/climate/links.htm)

Pew Center on Climate Change, [www.PewClimate.org](http://www.PewClimate.org),

Climate Institute at [Climate.org](http://Climate.org),

*ClimatePrediction.net*

The National Center for Atmospheric Research at [www.ucar.edu/research/climate/future.jsp](http://www.ucar.edu/research/climate/future.jsp).

Union of Concerned Scientists at [ClimateChoices.org](http://ClimateChoices.org).

Rocky Mountain Institute at [www.RMI.org](http://www.RMI.org).

World Resources Institute, at [WRI.org](http://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/](http://www.bbc.co.uk/sn/hottopics/climatechange/)

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

Edvard Munch, *The Scream of Nature*  

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**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.


Chapter 1.  The Big Picture


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](http://www.joanneum.at/Carboinvent/post2012_/Bird/santilli_et_al_2005.pdf).

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.”


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.


Chapter 3. Will This Overheated Frog Move?


Roger Revelle and Hans E. Suess. “Carbon dioxide exchange between atmosphere and ocean and the question of an increase of CO2 during the past decades.” Tellus 9 (1957) 18-27.

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

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


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.

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.


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.


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 km² 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


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.


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

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 ccr.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.


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


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


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


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.


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.


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

news%20reports/ebexp.htm.


Chapter 8. What Makes a Cycle Vicious?


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.


95 Water vapor amplifies CO2 warming by 40–50 percent: IPCC 2007 WG1 SPM.

96 “When CO2 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.


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


Chapter 9. That Pale Blue Sky


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.


Chapter 10. **Slip Locally, Crash Globally**

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


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


112 The Google Earth software is at earth.google.com; once installed, go to WilliamCalvin.com/2006/GoogleEarth_PlacemarkGreenlandShoulder.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.


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.
NOTES

115 Quoted by Pearce (2006): 70.


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 CO2 problem.


122 Richard Alley quote from Pearce (2006).


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).


135 PATH station in Hoboken during a 1992 nor’easter. This and the WTC entry photos are from the Metro New York Hurricane Transportation Study, 1995.


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.

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![Image](https://global-fever.org/poster.png)

*Where you are standing was underwater the last time Mother Earth spiked a 3°F fever. Will the cooking frog leap in time?*

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.


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**

CO₂, CH₄ and temperature records from James E. Hansen, *Climate Change* 68 (2005): 269.


When you hear the phrase, “Doubling CO₂,” it refers to the pre-industrial CO₂ level of 275 ppm being doubled to 550 ppm of CO₂ equivalents. The natural range for CO₂ 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 CO₂ equivalents of the increased concentrations of methane and other GHGs.

concentration of the air, anoxia likely affected the Oracle.


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


159 Agricultural waste problem, see www.virtualcentre.org/en/library/key_pub/longshad/A0701E00.pdf.

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.


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.


Chapter 14.

A Sea of CO2

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).


The wave-driven pump to raise deep water to the surface is best seen in the archived presentations at atmoccean.com.
Chapter 15. The Extended Forecast

188 The 2020 turnaround is modified from a slide in John Holdren’s MBL talk (November 2006), see www.whrc.org/resources/PPT/JPH_MBL_11-03-06_Clim-Chg-Challenge.ppt.
190 The photograph shows a 1 meter section of the GISP2 ice core from a depth of 1837 meters in the Greenland Ice Sheet. From GlobalWarmingArt.com/wiki/Image:GISP2_Ice_Core.jpg.
201 Wind turbine in Skåne, Sweden. Photograph by Väsk at commons.wikimedia.org/wiki/Image:Vindkraftverk_i_Sk%C3%A5ne_febru...

Chapter 16. Doing Things Differently

206 California vs. US electrical use per person from www.eia.doe.gov/emeu/states/sep_use/total/use_csv. Table of all states at www.eia.doe.gov/emeu/states/sep_sum/plain_html/rank_use_per_cap.html.

Chapter 17. Cleaning Up Our Act

222 Wedges, see www.princeton.edu/~cmi/resources/stabwedge.htm.
224 UN’s 2007 expert group: www.UNfoundation.org/SEG/.

Chapter 18. The Climate Optimist

231 E. O. Wilson (personal communication, 2006) put the extra-long, extra-warm El Niño time frame this way: “…could burn down so much of the remaining rain forests in Southeast Asia and the Amazon that as many as half the remaining species of plants and animals could face early extinction.”
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-

232 In the U.S., many people pay far more in payroll taxes (mostly Social Security, Medicare, and unemployment taxes) than they have withheld for income tax.


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

237 Jack Doyle, Taken for a ride: Detroit’s Big Three and the politics of air pollution (2000). Indeed, I’d say that Detroit’s automakers may need a new purpose in life (and I’d suggest temporarily repurposing the manned part of NASA’s space program as well). All of that talent is badly needed for more important tasks.


Chapter 19.

Turnaround by 2020


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.”


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

Capture CO2, see “Future of ‘Clean Coal’ Power Tied to (Uncertain) Success of Carbon Capture and Storage” at www.sciam.com.

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


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 (CO2).
- The United States produces about 1.5 billion tons per year of CO2 from coal-burning power plants.
- If all of this CO2 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 CO2 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 (CO2) from the Sleipner gas field into a saline aquifer under the North Sea.


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 geotherm.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
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 superheated 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 earthquakes 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 earthquakes 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.


Photo credits: Ormat.com for Lyete, The Philippines. For the
much-altered diagram, the MIT geothermal report of 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 CO2 captured and sunk. It still has the hazards of CO2 storage burps, and I cannot imagining it having the sheer capacity for sinking the accumulated atmospheric CO2 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


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


292 The quote is attributed to Edmund Burke.

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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