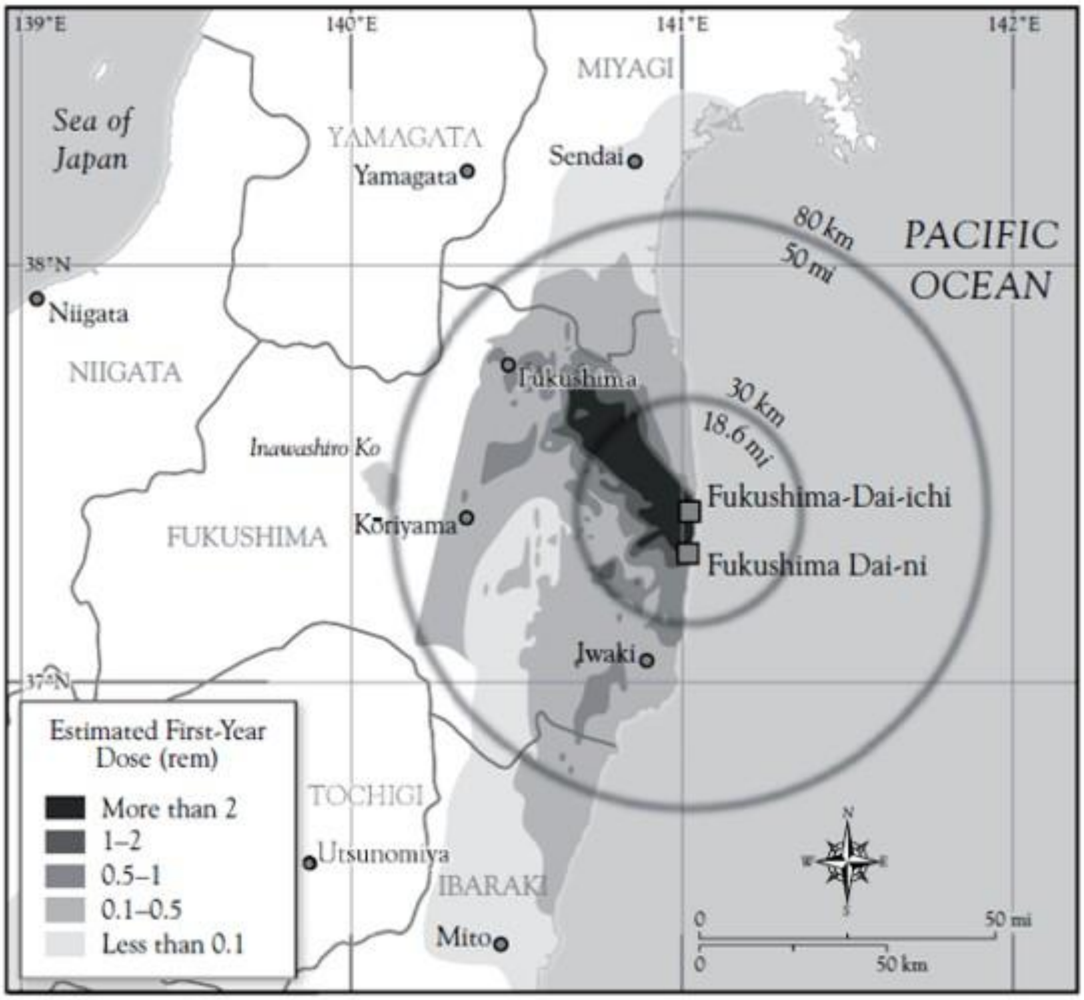
Energy for Future Presidents

The Science Behind the Headlines

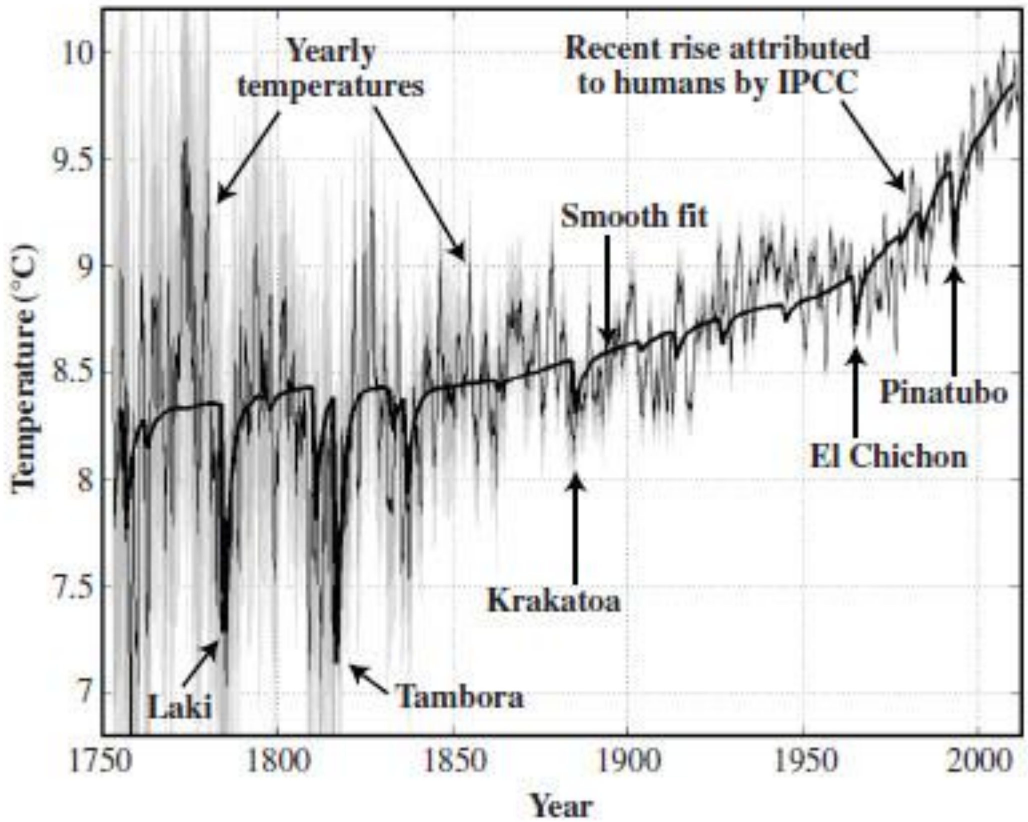
By Richard A. Muller

Figure 1.1



Map of the Fukushima region, showing the expected dose for each location that would have been received by any person who remained there for a year after the accident. The darkest region, running from the coast to the northwest, is marked as greater than 2 rem. Distant regions are below 0.1 rem.

Figure 3.1

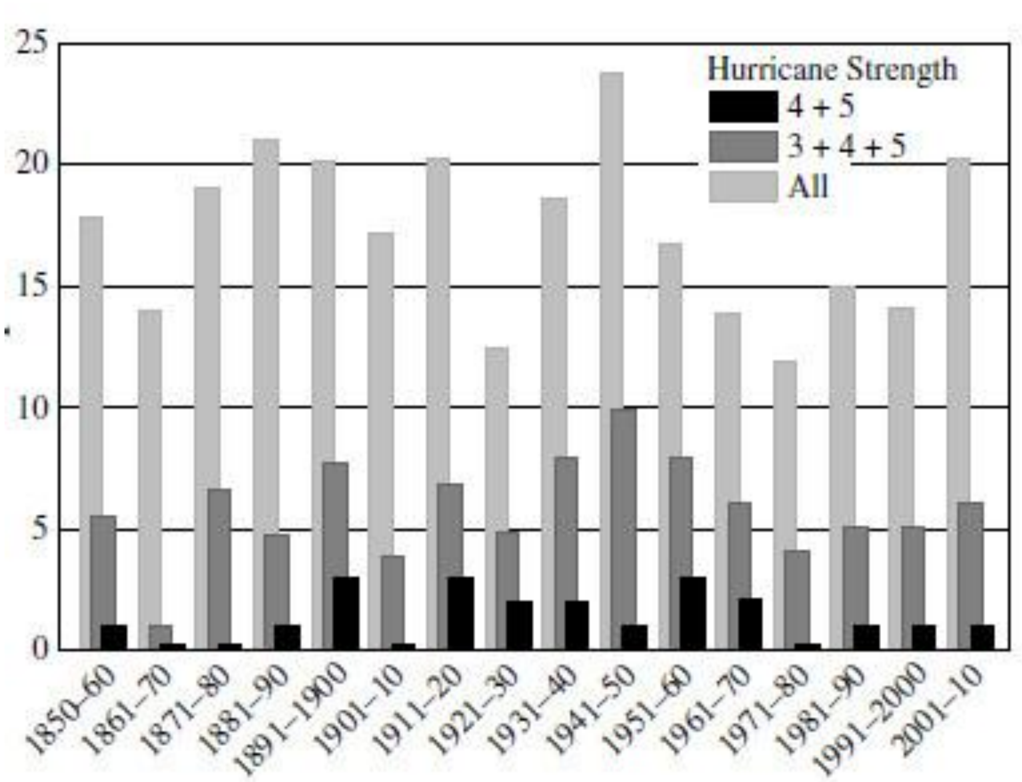


Average global temperature rise over land from 1800 to the present. The thin line shows the temperature estimates; the gray region shows the estimated uncertainty limits. The dark line is described in the text; it is a smooth curve with dips derived from measurements of large volcanic eruptions.

Figure 3.2

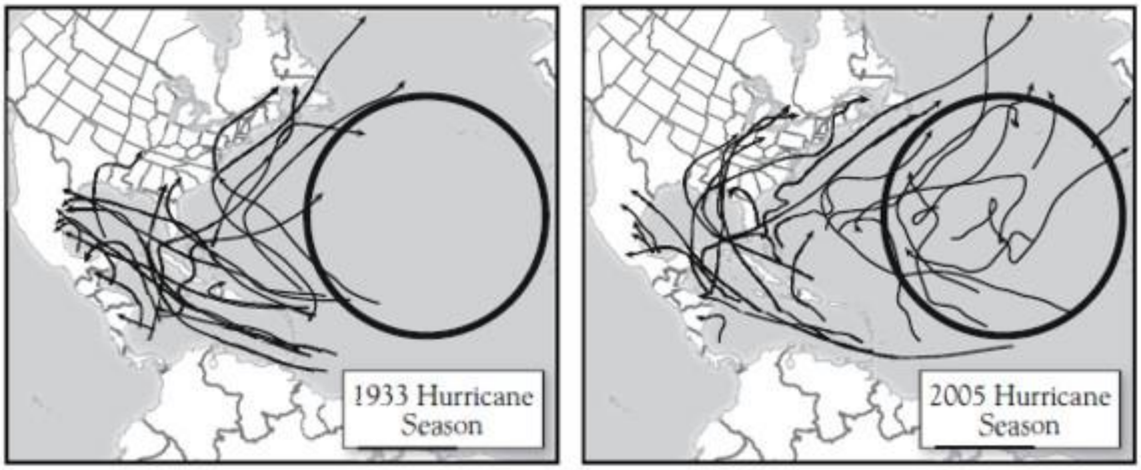
Map showing the temperature stations in the United States and neighboring countries that have been recording for at least 100 years. Locations with rising temperatures are marked with plus signs; those with cooling temperatures are marked with circles. One-third of the stations have cooled; two-thirds, warmed.

Figure 3.3



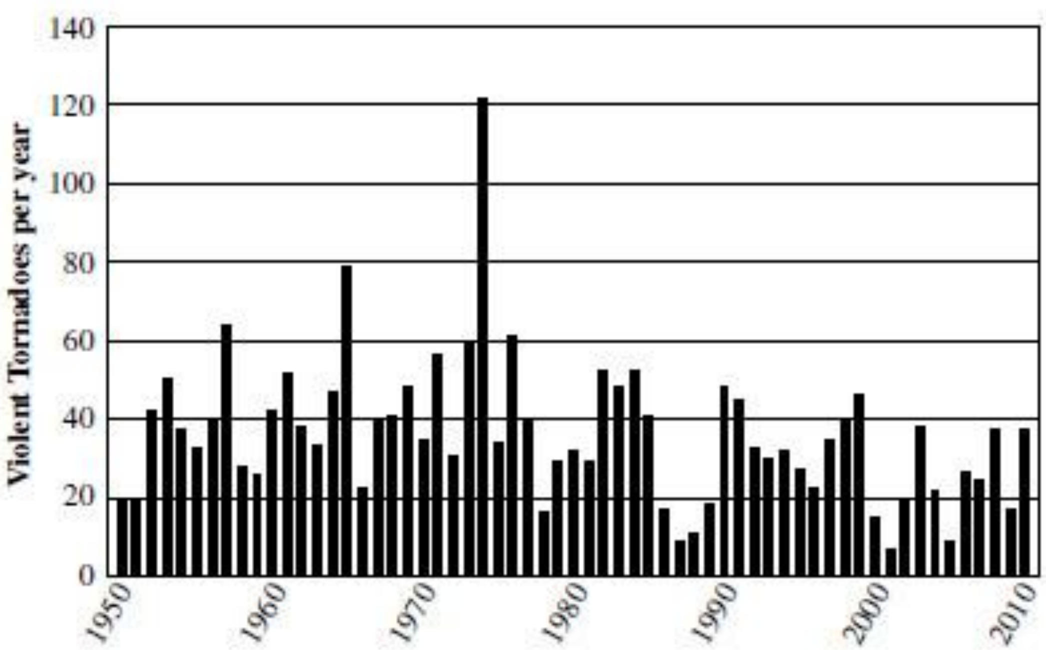
Number of hurricanes hitting the United States every decade. The black bars (in the back) show all hurricanes; the small bars in the foreground indicate the most intense hurricanes (categories 4 and 5), and the intermediate hurricanes are shown by the bars in between. The rate of hurricanes hitting the United States has not been increasing.

Figure 3.4



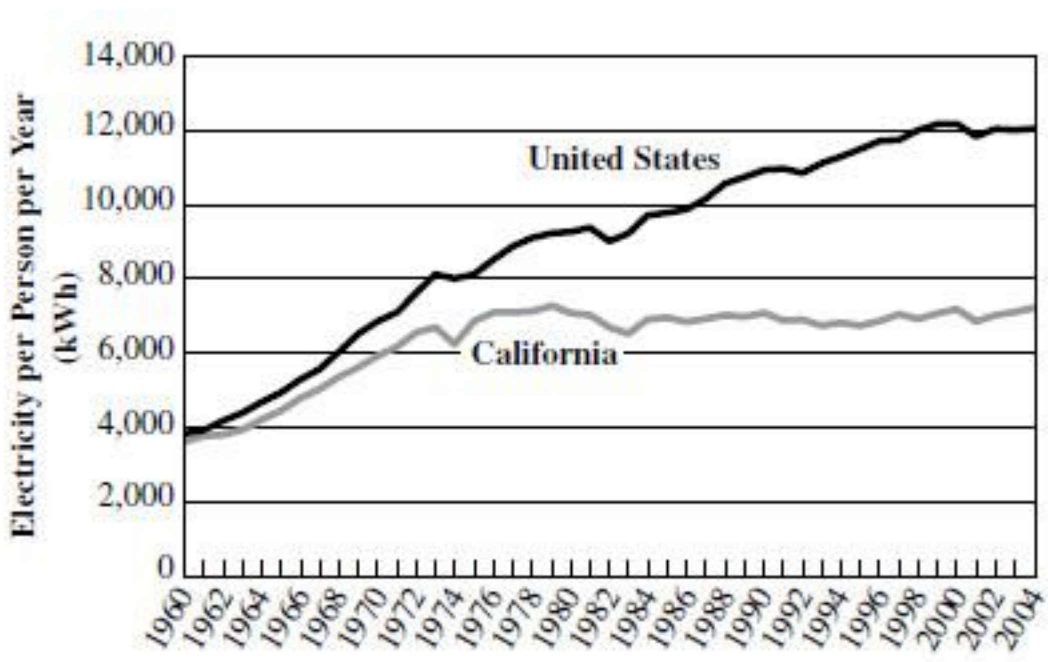
Hurricane tracking maps based on those of Chris Landsea of the National Hurricane Center, showing the two busiest hurricane years on record for the Atlantic: 1933 and 2005. The circles highlight open-ocean areas showing large differences in activity. Note that in 1933 no hurricanes were detected in the deep Atlantic. However, few observations were made in that region, so we can’t know whether hurricanes were there or not.

Figure 3.5



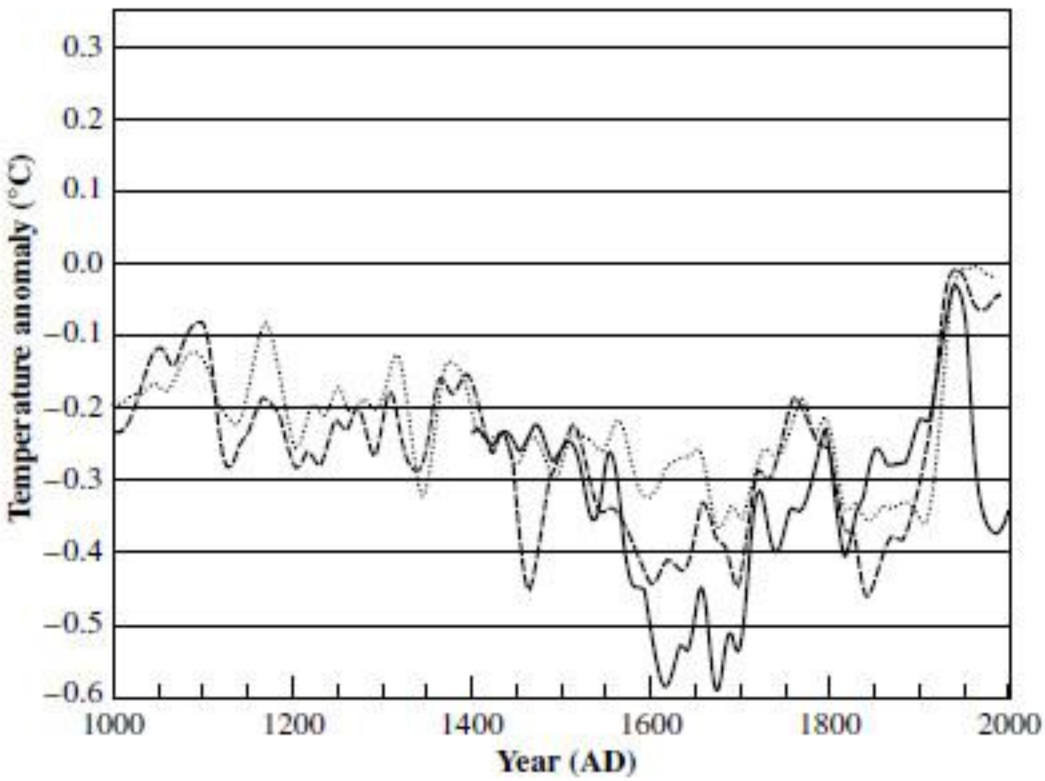
The number of intense tornadoes from 1950 to the present.

Figure 3.6



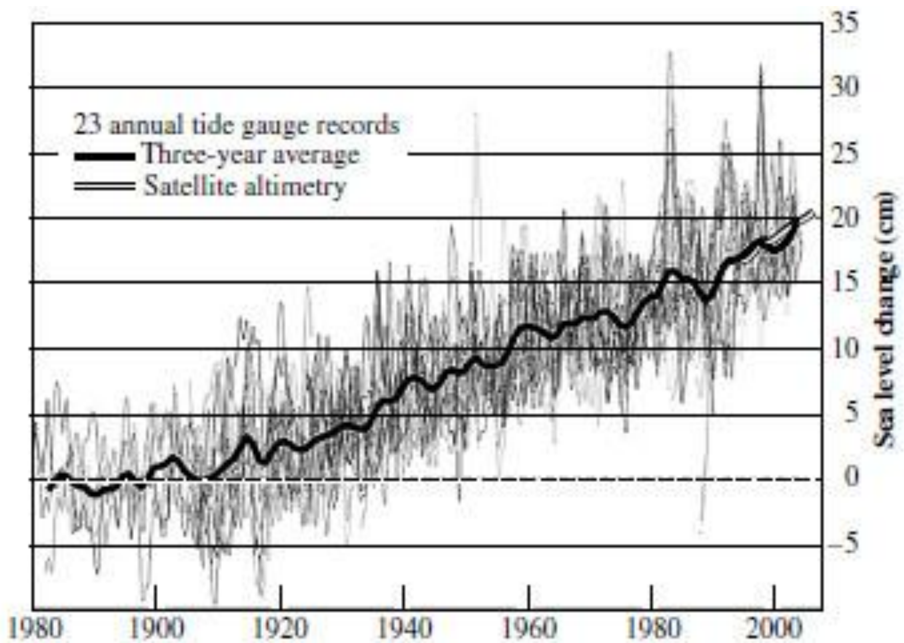
Estimated temperature trends over the last 1,000 years, as published by the World Meteorological Organization in 1999. Most of the plot was based on "proxy" data—indirect estimates such as from tree ring widths and coral growth rates; the recent data (post-1960) came from thermometers. The three plots show the analysis of three groups analyzing different selections of the data.

Figure 3.7



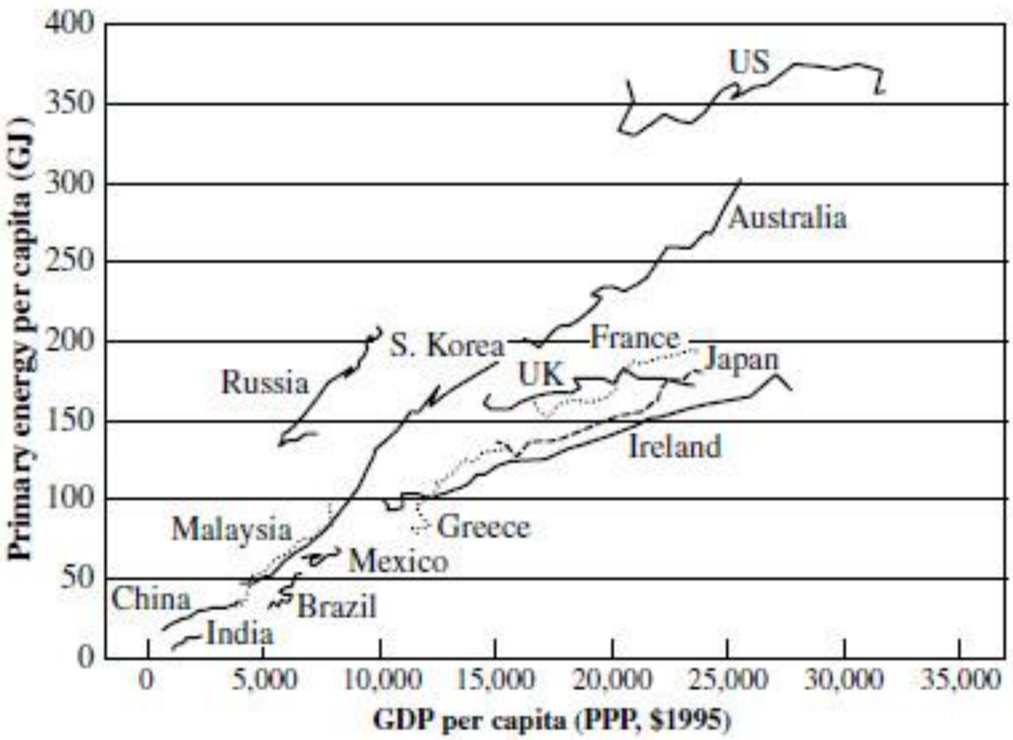
This is the same plot as in Figure 3.6, but it includes the proxy data from 1960 onward that had not been included in the originally published plot. This plot does not include the thermometer data that had been used to replace the recent proxy data.

Figure 3.8



Records of tide levels show a clear rise in sea level in the last 130 years.

Figure 3.9



The relationship between energy use and gross domestic product, per capita. Each country is shown as a squiggly line indicating the ratio over the period 1980–2002. Energy is measured in gigajoules (GJ); 1 GJ is the energy in about 8 gallons of gasoline. The GDP is given in terms of purchasing power parity (PPP), which takes into account the fact that living costs are lower in many countries.

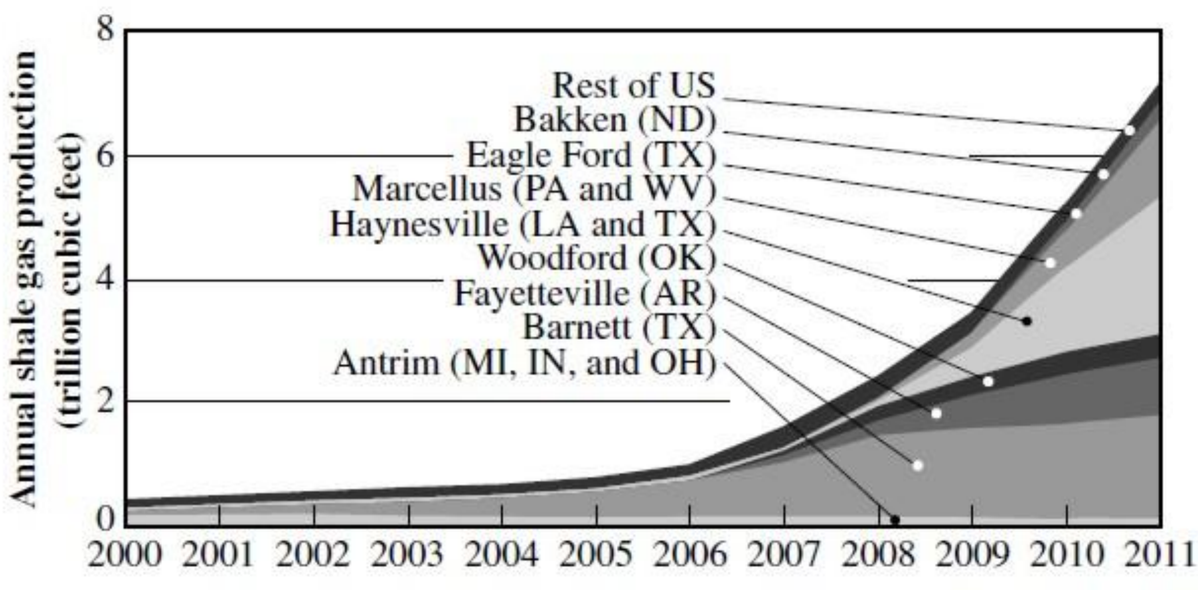
Figure 3.10

Fuel	Cost of fuel	Cost per kWh used for heating	Cost per kWh of electricity
Coal	$60 per ton	0.6¢	2¢
Natural gas	$4 per thousand cubic feet	1.4¢	4¢
Gasoline[a]	$3.50 per gallon	10¢	50¢
Electricity to home[b]	10¢ per kWh	10¢	10¢
AAA battery	$1.50 each	$1,000	$1,000

[a]For gasoline, assumed internal combustion efficiency is 20%.
[b]For power plant electricity generation, assumed efficiency is 35%.

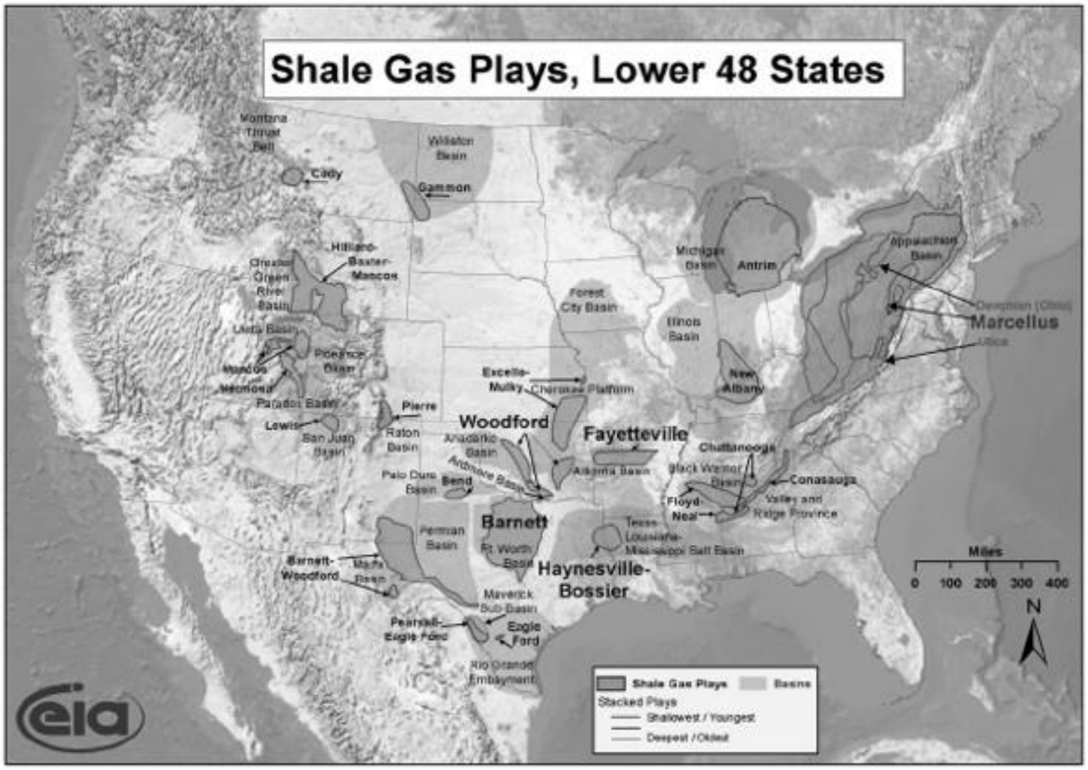
The cost of energy. The entry for coal is the price for anthracite; other coals are cheaper. The cost of natural gas has been changing, and in 2012 dropped to $2.50 per thousand cubic feet.

Figure 4.1



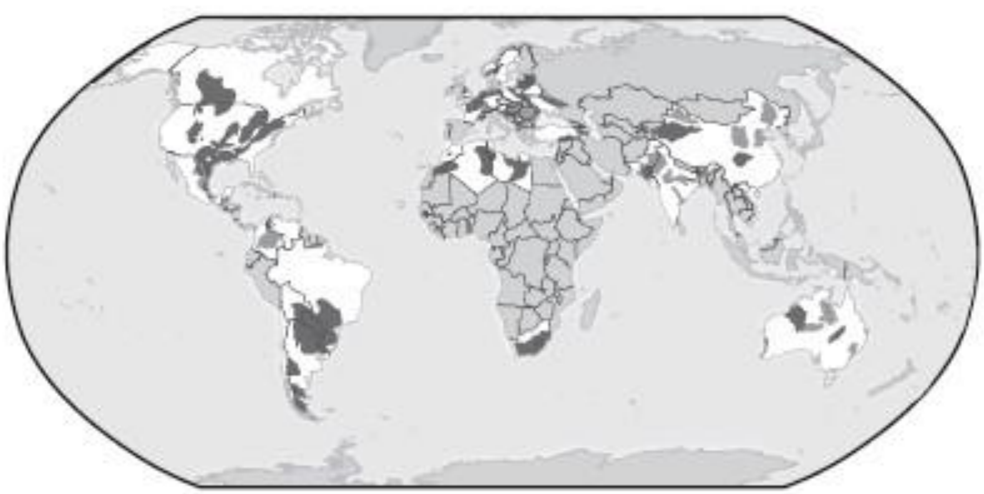
Average US production of shale gas in trillion cubic feet per year
(from the Energy Information Administration).

Figure 4.2



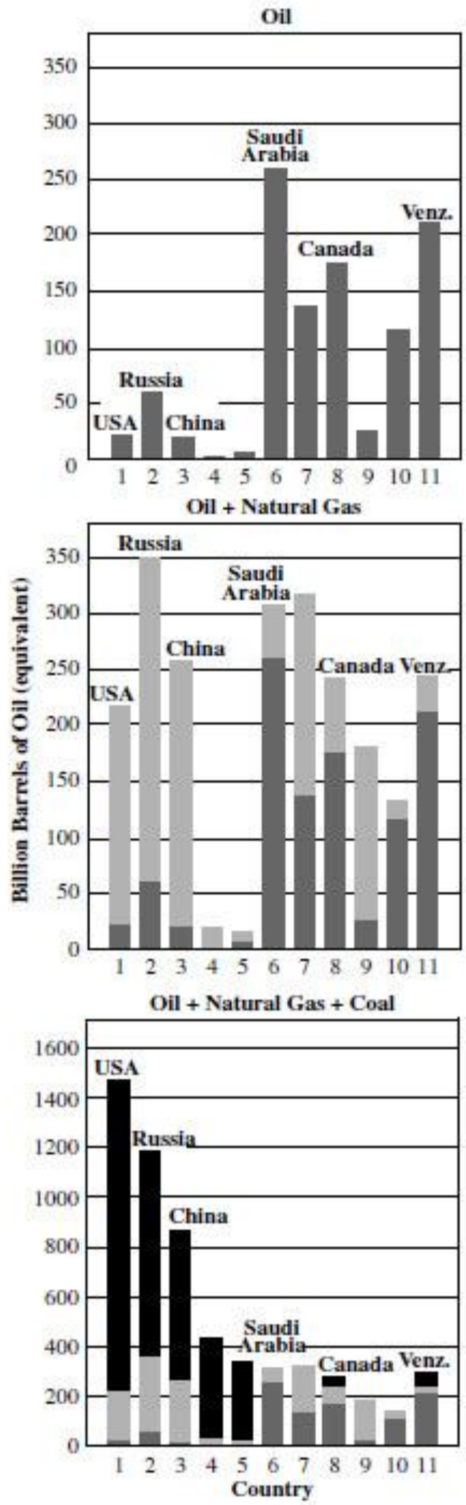
Shale gas regions in the continental United States.

Figure 4.3



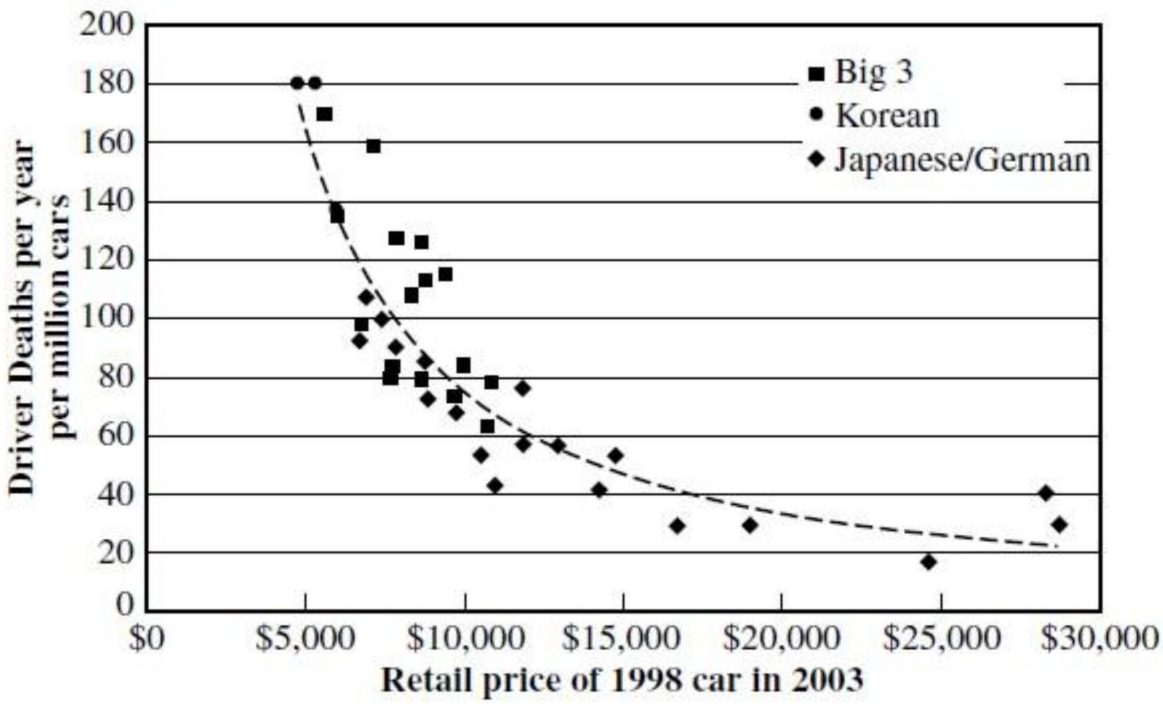
The EIA's map of 48 shale gas basins in 32 countries. Only reserves in the countries indicated in white are included.

Figure 5.1



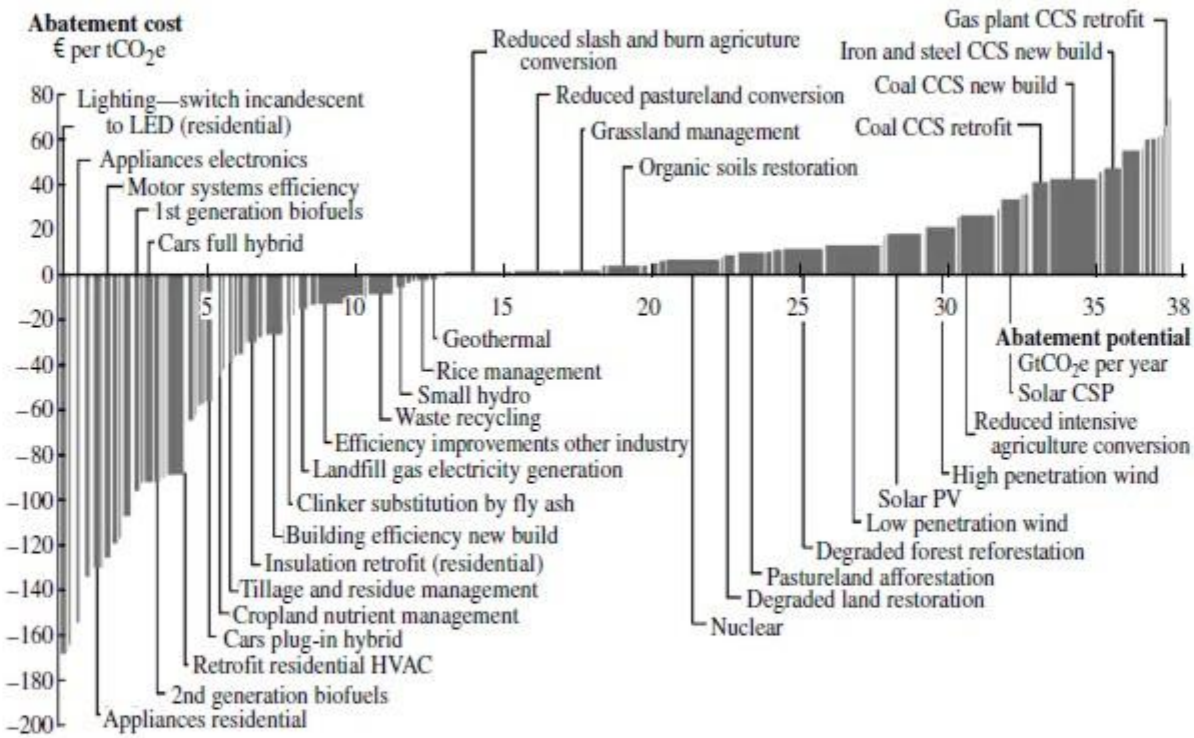
Fossil fuel energy reserves, in barrels of oil equivalent. Note the different scales for the three charts. The United States is running out of conventional oil, but not natural gas or coal.

Figure 7.1



Cars with high resale value are safer, regardless of price when new.

Figure 7.2



The McKinsey chart shows that many approaches to reducing carbon emissions can be profitable.

Figure 7.3

Plant type	Capacity factor	Capital cost per kWh	Operation and maintenance per kWh	Fuel per kWh	Transmission investiment per kWh	Total cost per kWh	Lowest possible cost per kWh
Conventional coal	85%	6.5¢	0.4¢	2.4¢	0.1¢	9.5¢	8.5¢
Advanced coal	85%	7.5¢	0.8¢	2.6¢	0.1¢	10.9¢	10.1¢
Advanced coal with CCS[a]	85%	9.3¢	0.9¢	3.3¢	0.1¢	13.6¢	12.6¢
Natural gas							
Conventional combined cycle	87%	1.8¢	0.2¢	4.6¢	0.1¢	6.6¢	6.0¢
Advanced combined cycle	87%	1.8¢	0.2¢	4.2¢	0.1¢	6.3¢	5.7¢
Advanced CC[b] with CCS[a]	87%	3.5¢	0.4¢	5.0¢	0.1¢	8.9¢	8.1¢
Conventional combustion turbine	30%	4.6¢	0.4¢	7.2¢	0.4¢	12.4¢	9.9¢
Advanced combustion turbine	30%	3.2¢	0.6¢	6.3¢	0.4¢	10.3¢	8.7¢
Advanced nuclear	90%	9.0¢	1.1¢	1.2¢	0.1¢	11.4¢	11.0¢
Wind	34%	8.4¢	1.0¢	0.0¢	0.4¢	9.7¢	8.1¢
Wind – offshore	40%	20.9¢	2.8¢	0.0¢	0.6¢	24.3¢	18.7¢
Solar PV	22%	19.5¢	1.2¢	0.0¢	0.4¢	21.1¢	15.9¢
Solar thermal	31%	25.9¢	4.7¢	0.0¢	0.6¢	31.2¢	19.2¢
Geothermal	90%	7.9¢	1.2¢	1.0¢	0.1¢	10.2¢	9.2¢
Biomass	83%	5.5¢	1.4¢	4.2¢	0.1¢	11.2¢	10.0¢
Hydro	51%	7.5¢	0.4¢	0.6¢	0.2¢	0.9¢	0.6¢

[a]CCS stands for "carbon capture and sequestration" or "carbon capture and storage."
[b]CC stands for "combined cycle," a method that uses both gas and steam turbines.
Source: Based on the Energy Information Administration's *Annual Energy Outlook 2011* (December 2010), http://www.eia.gov/oiaf/aeo/pdf/2016levelized_costs_aeo2011.pdf.

A breakdown of the cost to produce a kilowatt-hour of electricity, for different kinds of power plants.

Figure 19.1

	Food calories	*Kilowatt-hours*	*Compared to TNT*
Bullet (1,000 ft/s)	4.5	0.005	0.015
Auto battery	14	0.016	0.046
Computer battery	45	0.053	0.15
Alkaline battery	68	0.079	0.23
TNT	295	0.343	1
High explosive (PETN)	454	0.528	1.5
Chocolate chip cookies	2,269	2.6	7.7
Coal	2,723	3.2	9.2
Butter	3,176	3.7	11
Ethanol	2,723	3.2	9
Gasoline	4,538	5.3	15
Natural gas (methane)	5,899	6.9	20
Hydrogen	11,798	14	40
Asteroid (30 km/s)	48,435	57	165
U-235	9 billion	11 million	32 million

Energy per pound for various objects and substances.