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Coal, Nuclear, Natural Gas, Oil, or Renewable: Which Type of Power Plant Should We Build?

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It was January 2008 and Bill Waterford had just finished a presentation to Citizens for the Environment, a local advocacy group. During the question and answer session, a member of the audience stood up, loudly stated that neither Waterford nor his company, PowerCo, had any concern whatsoever about the environment, and then abruptly walked out. Waterford felt his face flush hot. His anger lingered as a bad aftertaste even after the group's president came forward and apologized for the person's hotheaded comment. Waterford knew he and his fellow managers were very concerned about the environment—after all they too lived on the same planet and had families and kids—but people and businesses needed electricity, and shareholders expected profits and dividends. For the first time, his company's planning efforts involved significant stakeholder discussion and involvement. During 2007, Waterford's team conducted more than two dozen meetings with organizations that included consumer advocates, representatives who served low-income customers, advocates for large business interests, environmental activists and local and state government officials. Nearly 200 citizens had attended these meetings and offered comments. It was up to Waterford to combine this diverse set of inputs and his knowledge of power generating options into an integrated resource plan (IRP). The IRP was a planning tool used by electric utilities to evaluate the many different options for meeting future electricity demands.

Integrated resource planning, originally mandated by the Energy Policy Act of 1992, and then replaced by semi-annual presentations by the end of the 1990s, had come back into favor. The IRP was increasingly viewed as the way to logically analyze and plan for future utility investment. Nearly half of all states, including the one in which PowerCo resided, required formal IRPs. The IRP was seen as a means to provide the public with safe and reliable energy services at a reasonable rate and in a way that served the public interest while satisfying the many regulations by local, state, and federal authorities. Integrated resource planning followed a classic process of carefully exploring all options, entering into discussions with stakeholders, and developing a decision model that applied probabilities to all of the sensitive, uncertain factors for all plausible alternatives.

Waterford was a senior vice president at PowerCo,[1] a utility that generated electricity and distributed it to over one million residential and industrial customers in the central part of the U.S. As a utility, PowerCo was responsible for electricity generation and the grid on which the electricity flowed. PowerCo was typical of utilities in the region in that they used a mix of technologies (see **Figure 1**). PowerCo used

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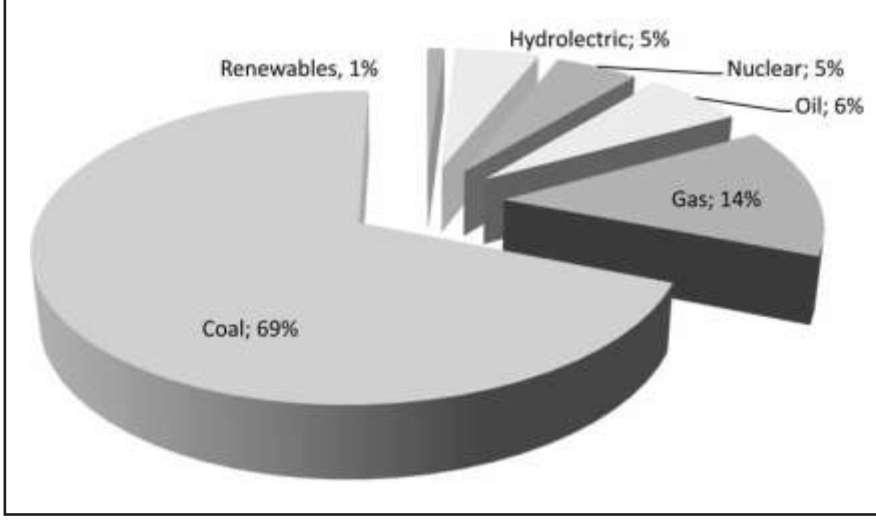
low-polluting energy sources including hydroelectric and a small amount of wind energy, and was in the process of adding 100 megawatts (MWs) of wind capacity to meet growing demand. The firm had safely operated a nuclear power plant and several coal and natural gas-fired power plants for decades. The predominant source of base-load power,[2] however, was coal, and PowerCo owned and operated an old, inefficient coal plant that needed to be decommissioned by January 2016. Management had recently gone through an extensive capacity-planning process to ensure adequate future energy supply, while protecting the environment and minimizing costs to the rate payers.

Figure Regional Generating Capacity by Energy



In the past twenty years, consumption by PowerCo customers had increased by 50 percent while residential rates decreased by 13 percent. Growing demand, declining rates, rising fuel costs, and environmental considerations had driven utilities to take a hard look at the benefits of energy efficiency and demand side management initiatives. PowerCo had budgeted more than $100 million over the next five years on programs to reduce the growth rate of electricity consumption. Efficiency and conservation initiatives, however, could not offset the base-load capacity that would be lost with retiring the old coal-fired plant. PowerCo decided to build a power plant with a capacity of between 350 and 700 megawatts with first power generation in January 2016. The fact that PowerCo had the ability to buy or sell modest amounts of power gave managers flexibility in terms of the capacity for the new power plant. In the last year, approximately 40 percent of their earnings were due to wholesale power. A basic problem remained in terms of which of the following technologies to pursue for the additional capacity: oil, natural gas, coal, nuclear, or renewables.[3]

Among numerous other requirements, the applicable state laws required that PowerCo build the type of power plant that would minimize costs to rate payers. Unknowns, including the future costs of fuel, construction materials, and labor; potential taxes or caps on carbon emissions; and costs of disposing of wastes made this a very difficult task. In addition, PowerCo needed to operate any plant reliably, safely, and profitably. The decision on the type of power source was the first step in a lengthy and involved process. From experience, Waterford knew that it would require years to communicate with all stakeholders, work with the local community and regulatory authorities to identify a specific location, obtain the necessary permits and financing, and build the power plant while simultaneously making any needed changes to power transmission systems and the grid. Importantly, the decision of whether to move forward with the option of a nuclear power plant had to be made very quickly. No one had built a nuclear power plant in the U.S. in more than thirty years and there were still pockets of resistance to the use of nuclear power. Furthermore, no one knew how long it would *really take* to permit and build a nuclear power plant, even though recent legislation had supposedly simplified and shortened the permitting process.[4]

POWERCO FINANCIAL PERFORMANCE

PowerCo was exposed to a variety of business risks. The costs to generate electricity fluctuated significantly due to global economic and political events, supply and demand, weather, and a variety of other factors beyond the control of the firm. Operational and financial results were also affected by seasonal fluctuations including winter heating and summer cooling demands. Most of PowerCo's revenues were subject to state or federal regulation. The rates that PowerCo charged for electricity were established in a regulatory process that required up to eighteen months for approval. Rates established in those proceedings were primarily based on historical costs and included an allowed return on investments by the regulator. The firm was unable to increase rates without permission from the regulatory authorities.

PowerCo, and the industry as a whole, was going through a period of rising costs, including fuel, purchased power, labor, and materials. To make matter worse, these were coupled with significant increases in costs targeted at enhanced distribution, system reliability, and environmental compliance. Rising costs in an environment in which rates were primarily based on historical costs resulted in PowerCo earning less than the allowed return established by regulators. The time lag between the experienced higher costs and eventual rate relief from regulatory agencies was a problem for managers at all utilities.

PowerCo's summary financial information and comparison ratios are summarized and presented in **Tables 1–4**. Its 9.3 percent return on equity for the five years presented was below the industry average of 12.9 percent—primarily because PowerCo's rates were significantly below the cost and investment levels it was incurring. The situation was not expected to improve until appropriate levels of rate relief were granted by the regulatory authorities. Residential electricity rates in this region were among the lowest in the United States, with 2008 rates at less than 8 cents per kilowatt hour (kWh). Management planned to achieve earnings growth by filing more frequent requests for moderate rate increases, and also by seeking appropriate cost recovery mechanisms to mitigate regulatory lag.

PowerCo's 2007 net income increased $42 million and earnings per share increased 12 cents compared to the prior year. Earnings in 2007 benefited from, among other things, sales of higher-priced, non-rate-regulated electricity and greater demand caused by a warmer summer and cooler winter than in 2006. Cash flows from operations of $1.247 billion in 2007, along with other funds, were used to pay dividends to common shareholders of $628 million and to fund capital expenditures of $1.54 billion.[5]

Table 1 PowerCo Income Statement (in millions of U.S. dollars)[6]

	2007	2006	2005	2004	2003
Operating Revenues:					
Electric	7,140	6,353	6,180	4,625	4,097
Gas	1,462	1,490	1,545	1,229	1,156
Total	8,602	7,843	7,725	5,854	5,253
Cost of Goods Sold	3,957	3,529	3,399	2,342	1,944
Gross Profit	**4,645**	**4,314**	**4,326**	**3,512**	**3,309**
Operating Expenses:					
Operations and Maintenance	1,979	1,774	1,772	1,346	1,208
Depreciation and Amortization	776	754	720	585	473
Taxes Other than Income Taxes	434	446	416	351	315
Total	3,189	2,973	2,909	2,283	1,996
Operating Income	**1,456**	**1,341**	**1,417**	**1,229**	**1,313**
Non-Operating Income (Expense)	67	46	17	(10)	(15)
Interest	(423)	(350)	(301)	(268)	(273)
Income Before Taxes	1,100	1,037	1,133	951	1,025
Income Taxes	363	342	374	314	338
Net Income	**737**	**695**	**759**	**637**	**687**
Earnings per Share	3.28	3.16	3.53	3.37	3.82
Dividends per Share	2.79	2.79	2.79	2.79	2.79
Millions of Shares	225	220	215	189	180

Financing activities primarily consisted of refinancing debt and funding capital investment with borrowings under credit facilities.

PowerCo Capital Expenditures and Sources of Capital

PowerCo had adopted a policy that its long-term liabilities should be approximately 50 percent of total capital (total debt plus shareholder's equity). In the last three years, the long-term debt-to-capital ratios were trending down toward this target ratio (see **Table 5**).

The company's capital structure policy was feasible because of the nature of its business. Historically, utilities have had somewhat lower business risks and more stable cash

Table 2 PowerCo Balance Sheet (in millions of U.S. dollars)[7]

	2007	2006	2005	2004	2003
Assets					
Cash	405	156	169	112	127
Receivables	650	477	481	392	341
Total Inventories	409	352	351	299	278
Raw Materials	838	738	671	567	549
Notes Receivable	319	182	178	157	136
Other Current Assets	206	231	220	152	89
Total Current Assets	2,827	2,136	2,070	1,678	1,520
Property and Plant, Net	17,179	16,286	15,472	15,159	12,449
Nuclear Decommissioning Trust Fund	350	325	190	159	143
Goodwill	947	947	947	945	831
Intangible Assets	226	247	63	14	2
Regulatory Assets	1,320	1,696	1,117	1,072	654
Other Assets	781	746	1,039	880	620
Total Assets	**23,630**	**22,384**	**20,898**	**19,906**	**16,220**
Liabilities					
Notes Payable	1,678	698	353	475	154
Accounts Payable	783	765	805	646	547
Current Long-Term Debt	252	520	109	482	568
Other Current Liabilities	595	528	561	442	363
Total Current Liabilities	3,308	2,510	1,828	2,046	1,631
Mortgages	4,029	2,946	3,097	2,483	2,042
Deferred Charges/Inc.	2,457	2,579	2,392	2,340	2,285
Long-Term Debt	2,106	2,723	2,922	3,154	2,432
Non-Current Capital Leases	372	376	106	109	190
Other Long-Term Liabilities	3,414	3,439	2,996	2,909	2,424
Total Liabilities	**15,685**	**14,574**	**13,341**	**13,043**	**11,003**
Shareholder Equity					
Minority Interest (Liability)	25	18	19	16	25
Preferred Stock	222	222	222	222	207
Common Stock	7	7	7	7	7
Capital Surplus	5,290	5,255	5,074	4,439	2,849
Retained Earnings	2,400	2,308	2,235	2,180	2,128
Total Shareholders Equity	**7,944**	**7,811**	**7,557**	**6,864**	**5,217**
Total Liabilities and Equity	**23,629**	**22,384**	**20,898**	**19,907**	**16,220**

Table 3	PowerCo Statement of Cash Flow (in millions of U.S. dollars)[8]				
	2007	**2006**	**2005**	**2004**	**2003**
Operating Activities					
Net Income/Starting Line	737	695	759	637	687
Depreciation/Depletion	776	754	720	585	473
Deferred Taxes	(30)	96	63	359	13
Non-Cash Items	89	(6)	22	—	(23)
Changes in Working Capital	(325)	(10)	(96)	(358)	(12)
Cash from Operating Activities	1,247	1,529	1,468	1,223	1,138
Capital Expenditures	(1,536)	(1,093)	(1,009)	(888)	(747)
Other Investing Cash Flow Items, Total	(20)	(249)	(10)	(436)	(505)
Cash from Investing Activities	(1,556)	(1,342)	(1,019)	(1,324)	(1,252)
Financing Cash Flow Items	(27)	(34)	(6)	(51)	(5)
Total Cash Dividends Paid	(628)	(614)	(600)	(527)	(502)
Issuance (Retirement) of Stock, Net	95	101	480	1,526	350
Issuance (Retirement) of Debt, Net	1,109	516	(211)	(867)	(289)
Cash from Financing Activities	549	(31)	(337)	81	(446)
Net Change in Cash	240	156	112	(20)	(560)

flows than many other types of businesses. However, risk seemed to be increasing due to increased volatility of the costs of materials used to build power plants, increased volatility of some fuel prices, and looming legislation related to controlling carbon emissions. PowerCo's leverage ratios were lower than the industry average. Its beta, however, was higher than the industry average. This suggested substantial operating leverage, and represented a source of risk for shareholders. PowerCo expected to incur significant capital expenditures over the next five years in order to be in compliance with environmental regulations and to make significant infrastructure investments to improve overall system reliability. It was expensive to maintain systems and continually improve operations (see **Table 6** for information that can be used to estimate the cost of capital).

To pursue its corporate strategy, PowerCo needed assured access to the capital markets. Efficient capital spending was viewed as critical to the firm's success, since it was the key to minimizing costs. Investment in PowerCo's regulated operations was expected to be recovered from rate payers. Expenditures not funded with operating cash flows were expected to be funded primarily with debt or through the use of a more flexible plan such as the use of available cash, cash equivalents, issue of incremental debt, and the issuance of common equity. Standard & Poor's (S&P) gave PowerCo a bond rating of BBB.[9] PowerCo's policy was to use the yield to maturity on non-callable ten-year obligations as its cost of debt—this is 10 percent.

Since the majority of PowerCo's anticipated future capital expenditures were related to its regulated operations, the major risk to the firm was its ability to recover costs related to any such expansion in a timely manner. Waterford knew that the issue of

Table 4 Selected Financial Ratios

	PowerCo	Industry	S&P 500
Return on Equity	9.28	12.90	16.90
Return on Assets	3.12	3.65	8.98
Return on Capital	3.8	4.5	8.2
Return on Equity (5-Year Average)	10.31	14.33	16.3
Return on Assets (5-Year Average)	3.46	2.99	9.08
Return on Capital (5-Year Average)	3.90	3.8	7.7
Book Value/Share	34.32	21.1	15.43
Sales Growth Rate (5-Year Average)	13.4	7.3	12.9
% Operating Margin (5-Year Average)	19.67	17.43	18.66
% Net Profit Margin (TTM)	10.24	9.8	11.76
% EBITD Margin (5-Year Average)	29.21	26.65	22.82
% Effective Tax Rate (5-Year Average)	34.46	33.57	30.92
Beta	0.85	0.65	1

Table 5 Selected Data Related to PowerCo's Financial Leverage

Financial Leverage (Averages)	3-Year	5-Year	10-Year
Total Assets/Common Equity %	287	293	291
LT Debt/Market Cap %	50	51	49
Total Debt/Total Assets %	33	34	34
LT Debt/Total Capital %	53	55	49
Total Debt/Market Cap %	50	51	49

building a new nuclear power plant was particularly troublesome due to its high construction cost and very-long lead times. PowerCo planned to seek permission from state regulators to increase electricity rates during the construction phase in June 2008. Another nuclear plant financing option being discussed was a joint venture where the state would provide some of the financing and receive some of the profit in return. Waterford did not anticipate beginning the construction of a new nuclear power plant without adequate assurance of cost recovery from regulators. All of these negotiations required information comparing the costs and benefits of nuclear power in comparison to other sources.

POWER SOURCES

Electricity had long been generated by burning one of the fossil fuels (oil, coal, or natural gas), through nuclear reaction, or by harnessing the energy of flowing water. The approach to electrical power generation has varied greatly across countries (see **Table 7**) depending on available resources. Brazil and Canada harnessed the abundant hydroelectric power of their rivers; China and India used cheap, available coal; and France focused on nuclear power. France produced sufficient electricity using nuclear power to export it to other countries in Europe. Nearly 40 percent of all of the electricity in the world

Table 6 Capital Market Return Data

Historic Average Annual Return on Securities, Bonds, and Common Stocks

1926–2007	Average Annual Return	Standard Deviation
US T-Bills	3.78%	3.07%
LT US Gov't Bonds	5.81%	9.10%
LT US Corporate Bonds	6.24%	8.35%
US Large Stocks	12.26%	19.85%
US Small Stocks	17.09%	32.43%
Inflation	3.13%	4.21%
1967–2007	Average Annual Return	Standard Deviation
US T-Bills	5.94%	2.73%
LT US Gov't Bonds	8.34%	11.35%
LT US Corporate Bonds	8.62%	10.54%
US Large Stocks	12.09%	16.21%
US Small Stocks	16.82%	24.91%
Inflation	4.67%	2.95%
1997–2007	Average Annual Return	Standard Deviation
US T-Bills	3.70%	1.64%
LT US Gov't Bonds	8.16%	8.54%
LT US Corporate Bonds	8.00%	5.99%
US Large Stocks	9.60%	17.36%
US Small Stocks	13.40%	20.32%
Inflation	2.60%	0.84%

Notes: *All return data for 2007 is preliminary and subject to revision. US Large Stocks:* Standard and Poor's 500 Index. *US Small Stocks*: Smallest Quintile of NYSE Stocks; DFA Small Co. Fund, DFA MicroCap. *LT US Corporate Bonds:* Salomon Brothers Long-term High-grade Index. *LT US Gov't Bonds:* One-bond portfolio with Maturity Near 20 years. *US T-Bills:* One-bill portfolio with Shortest Maturity not less than one month. *Inflation*: Consumer Price Index.

Source: Ibbotson Associates.

Table 7 Electrical Power Generation by Type of Fuel and Country (2004)

	Coal	Natural Gas	Oil	Nuclear	Hydro	Total (TWH*)	% of World Total
U.S.	50.0%	17.5%	3.3%	19.5%	7.1%	4,174	23.8%
China	77.9%	0.4%	3.3%	2.3%	16.1%	2,200	12.5%
Japan	27.2%	22.6%	12.3%	26.1%	9.5%	1,080	6.2%
Russia	17.2%	45.2%	2.7%	15.5%	19.1%	932	5.3%
India	69.0%	9.5%	5.4%	2.5%	12.7%	668	3.8%
Germany	50.0%	10.0%	1.6%	27.1%	4.5%	617	3.5%
Canada	17.2%	5.4%	3.6%	15.1%	57.0%	598	3.4%
France	5.0%	3.2%	1.0%	78.3%	11.3%	572	3.3%
U.K.	33.8%	40.3%	1.2%	20.2%	1.9%	396	2.3%
Brazil	2.7%	5.0%	3.2%	3.0%	82.8%	387	2.2%
S. Korea	38.6%	16.1%	8.0%	35.5%	1.6%	368	2.1%
World	39.6%	19.5%	6.7%	15.6%	16.5%	17,530	

* Trillion watt hours

Source: Energy Information Agency

came from burning coal. At the end of 2007, very little of the world's electricity came from the renewable sources of wind, solar, tides, or biofuels.

There were pros and cons with each of the power sources.[10] The technologies to build and operate power plants fueled by fossil fuels were well understood, even though technologies were changing as engineers designed ever more efficient plants. Power generation from these sources was reliable and could be ramped up and down quickly to meet the daily and weekly cycles in demand. However, the use of any of the fossil fuels resulted in numerous pollutants, including the leakage of methane and worldwide emissions of nearly 30 billion metric tons of carbon dioxide, into the atmosphere each year. Both methane and carbon dioxide are greenhouse gases, with methane being twenty times worse than carbon dioxide.

Coal was the dirtiest of all the fossil fuels, and it also produced the most carbon per unit of energy, but it was also particularly abundant in the world (especially in the U.S., Russia, and China) and therefore cheap. Coal mines resulted in methane leakages into the atmosphere, acid-laced soils, numerous emissions, and sometimes dangerous conditions for miners including exposure to coal dust resulting in black lung. Clean coal referred to the use of a wide range of technologies to remove particulates and various pollutants from coal, including sulfur dioxide and carbon dioxide (see Case Supplement). However, as of 2008, there were no truly "clean coal" power plants. When burned, even relatively clean coal produced very significant amounts of carbon dioxide, other greenhouse gases, mercury, and many other pollutants including particulate matter and waste products that had to be deposited in landfills. Coal waste storage and disposal had proved to be a difficult challenge in the past decade, with major waste spills in Martin County, Kentucky, (2000) and Martin's Creek, Pennsylvania (2005). Due to the abundance of coal in the U.S., it was unlikely that coal prices would be excessively volatile or high in the U.S. in the near term, although substantial additional power generation from coal would undoubtedly result in higher coal prices.

Oil was plentiful in OPEC countries but some experts believed that world oil production would peak in the not-too-distant future and then decline, driving prices wildly higher. Natural gas was the cleanest burning of the three fossil fuels and produced the least amount of carbon per unit of energy, but some experts believed that world natural gas production would peak a few decades after world oil production peaked, resulting in volatile prices in time. Another problem with oil and natural gas related to geographic distribution. Saudi Arabia, Canada, Iran, and Iraq had a lot of oil, and much of Canada's oil was in the oil sands. Most other countries did not have a lot of oil. Russia, Iran, and Qatar had a lot of natural gas—many other countries did not. Exploration in the U.S., in addition to new drilling and well completion technologies, had recently resulted in the discovery of significant additional natural gas reserves in so-called tight shale formations. Although this had resulted in increased reserves, it was not clear in early 2008 how much additional recoverable natural gas would be found.

Once built, nuclear power plants produced very cheap electricity with no carbon emissions. However, nuclear power resulted in by-products that were radioactive for thousands of years. The problem of waste disposal from nuclear reactors had not been satisfactorily resolved in spite of long, detailed scientific study. The 1979 and 1986 accidents, at the Three Mile Island and Chernobyl nuclear power plants, respectively, caused many to worry about the long-term safety of using nuclear power. By the late 1970s, the perceived risk of using nuclear power had effectively closed that option for power generation in the U.S. No nuclear power plant had been built in the U.S. since then, but the climate change issue was forcing everyone to rethink the nuclear option. According to a Nuclear Energy Institute fact sheet, the Nuclear Regulatory Commission had recently changed procedures to streamline the permit process for power plant construction and operation. This effectively allowed plant designers to secure NRC approval of standard plant designs which could then be ordered, licensed for a particular site, and built.

In the 1970s, firms wanting to build and operate a nuclear power plant had to first apply for a license to build a plant and then later apply for a license to operate the plant after construction was near completion. However, the Nuclear Regulatory Commission (NRC) had recently streamlined the permitting process, allowing a firm to apply for a combined construction and operating license. This was expected to shorten and simplify the process of building a nuclear power plant, but no firm had progressed very far in this regard as of 2008.

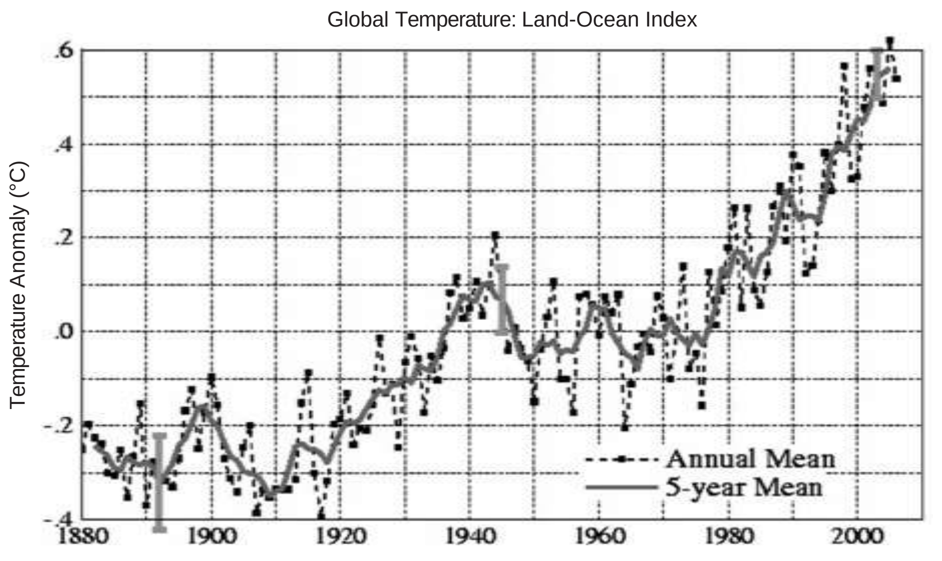
Other than hydroelectric, renewable sources of energy were the "new kids on the block" for generating electricity, and no one had yet reached a truly large scale using these technologies. Hydroelectric had long been used to produce clean, cheap electricity, but most of the available capacity at rivers and dams had already been developed. A clear advantage of renewable energy was the very low emissions of carbon dioxide and methane into the atmosphere.[11] One disadvantage of renewable sources was the availability of power. Wind resources only created power when the wind was blowing and solar only when the sun was shining. As a result, in order to use either wind or solar for constant base-load power, a utility had to build much more capacity than was actually needed. To rely on large-scale wind or solar systems, power companies needed to find ways to store large volumes of power produced at one time (say when the wind was blowing or the sun shining) that was not needed until later, even if on the same day.

In the past, cost minimization and reliability were the primary criteria when deciding how to increase capacity. However, the issues were becoming more complex. Now, Waterford also needed to address the diverse concerns of multiple stakeholders. He knew that his analysis must consider the impact of rising fuel and transportation costs; the need for fuel diversity to mitigate price risks, regulatory, and legislative mandates; concerns for environmental and animal rights groups; and the benefits of developing renewable energy sources. Generating and delivering electricity affects the environment through the extraction of raw materials (coal, oil, natural gas, uranium) and the discharge of emissions and wastes. Renewable sources can also have detrimental effects to the environment through destruction of natural habitat. Tradeoffs and acceptance of risk would be required. Permanent storage of nuclear waste was still unsolved; natural gas and oil prices were volatile; imported oil had national security implications; and a large composite renewable source for base-load electricity had yet to be built. The greatest risk, however, may be associated with climate change and the likely regulations that would come about to reduce greenhouse gases.

Greenhouse Gases, Climate Change, and Regulation

In the past decade, climate scientists had come to the conclusion that the buildup of carbon dioxide and methane in the atmosphere was causing a greenhouse gas effect on earth. The increased concentration of these gases in the atmosphere prevented heat from radiating back out from the earth, resulting in a gradual warming. The earth had warmed roughly one degree Celsius since 1880 (trend depicted in **Figure 2**). Some

Figure 2 Global Temperature (NASA)



debated the role of humans in global warming, noting that the earth had long warmed and cooled throughout geologic history. However, the overall alarm increased as data showed that the warming was more rapid than in previous epochs, and as evidence mounted of the widespread melting of the ice in glaciers on Greenland and in the Arctic.

The U.S. and China were the top emitters of carbon dioxide in the world (emissions by country depicted in **Table 8**). Although the U.S. was at the top of the list in 2005, many believed that China surpassed the U.S. in carbon dioxide emissions by the end of 2007 due to its increased reliance on coal-fired power plants and growing use of automobiles. China was completing the construction of one to two coal-fired power plants each week at the end of 2007. The U.S. had the highest per capita emission of carbon dioxide. Canada also had a high per capita emission of carbon dioxide, but this was due to the extensive oil-sands mining in Alberta, which was one of the fastest growing sources of carbon emissions in Canada. Much of the oil produced in the oil-sands mining was exported to the U.S. China's per-capita emissions were four times those of India

Table 8 World Carbon Dioxide Emissions from All Sources (2005)

Country	Carbon Dioxide Emissions (million metric tons)	Percent of Total	Per Capita Emission (metric tons per person)
United States	5,957	21.1%	20.1
China	5,323	18.9%	4.1
Russia	1,696	6.0%	11.9
Japan	1,230	4.4%	9.7
India	1,166	4.1%	1.1
Germany	844	3.0%	10.2
Canada	631	2.2%	19.2
Total	28,193	World Average	4.4

Source: Energy Information Agency

due to China's heavy reliance on power-hungry manufacturing. India had specialized in information and services, which required less power and resulted in far lower carbon emissions. The first four countries in the table emitted 50 percent of all carbon dioxide emitted by humans.

Scientists and industry representatives were studying the sequestering of carbon dioxide. Sequestration referred to the capturing of carbon emissions at the source and their storage or reuse. To be successful at sequestering carbon, a technique had to be effective, cost-competitive, provide stable and long-term storage, and not be harmful to the environment. The Department of Energy estimated that the capture of carbon dioxide might result in up to 75 percent of the cost of sequestration. In 2008, no one knew the best way to sequester carbon dioxide or other greenhouse gases and no one expected commercially viable options within five years, if then. In fact, there were serious debates about our ability to sequester the billions of tons of carbon dioxide emitted annually. Sequestration was a complicated but very important issue, given the huge volumes of carbon emissions around the world and the urgency related to global warming.

Utilities in the U.S. had been heavily regulated at the state and federal level since they first began producing power in the early 1900s. Some of the more important acts are summarized in **Table 9**. Waterford could take some comfort in that PowerCo was not dealing with the regulation challenge alone. The trend was clear to everyone in the utility industry. The climate change issue, and therefore greenhouse gas emissions, was a significant factor affecting all existing and new power generation. Many expected additional legislation related to the emission of greenhouse gases at some point after a new president took office in January 2009. Whether it would be in the form of a cap on carbon emissions or a tax, no one knew for sure, but the industry was in the "eye of the storm."

The Problem

Waterford decided to proceed assuming that the new power source would be completed at the end of 2015, with first power generation and sales in January 2016. The wind capacity that PowerCo was currently developing was only enough to offset growth in demand and not enough to replace the 350 to 700 megawatts provided by the coal-fired plant targeted for decommission. Waterford carefully considered the option of renewable sources of energy. The engineers told him that PowerCo might be able to modestly expand hydroelectric capacity at an existing facility, although it would be costly and the expansion depended on obtaining the appropriate permits, which was uncertain. The firm was already operating wind turbines, but he felt they also needed to consider biomass, solar, and landfill gas to fully consider the options. It was not clear which of the renewable sources would be best for a long-term strategy since there were so many developing technologies out there. He knew that PowerCo needed to "stay in the game" of all of the renewable technologies, since it remained to be seen which would be the most effective in the future.

PowerCo had always approached renewable energy in terms of small projects and incremental additions of power. For this IRP, Waterford decided to think about renewable power in a novel way. He framed the renewable alternative in terms of a single composite power plant based on several different renewable sources of energy: biomass (30 percent), landfill gas (15 percent), hydroelectric (30 percent), wind (15 percent), and solar (10 percent). He believed these percentages were the most applicable in PowerCo's

Table 9 Important Energy Legislation and Regulation

Year	Legislation/Regulation
1920	Federal Power Act—Authorized the Federal Power Commission (FPC) to issue licenses for hydroelectric projects and regulate the transmission and sale of electricity in interstate markets. The FPC regulated interstate flows of electricity and natural gas by 1940 and was later reorganized into the Federal Energy Regulatory Commission (FERC).
1970	Creation of the Environmental Protection Agency (EPA) and passage of the Clean Air Act—The EPA helped determine air quality standards and supported the Clean Water Act of 1977. Both greatly affected the power generation industry, which used significant amounts of water and emitted large volumes of pollutants. The emission of carbon dioxide was not regulated at this time.
1992	Energy Policy Act—Required utilities to submit an integrated resource plan that compared all practicable energy supply options, described efforts to minimize adverse environment effects and demand growth and shift demand to off-peak times, and provided ample opportunity for public participation. Importantly, it required managers to look at cost minimization for all stakeholders, including those harmed by the emissions of greenhouse gases or particulate matter, not just the utility company.
1997	Kyoto Protocol—International act ratified by 174 countries but not by the U.S. or Kazakhstan. It separated countries into developed countries with specific, accepted limits to greenhouse gas emissions and developing countries which were required to monitor, but not reduce, greenhouse gases. To give countries time to prepare, it was not effective until 2005. In response, the European Union (EU) launched the European Union Emission Trading Scheme (EU ETS) on January 1, 2005, with the idea of first capping carbon emissions and then reducing them.
2005	Energy Policy Act—Among a number of widely divergent features, this act supported the construction of nuclear power plants.
2006	California Law—Required a very-aggressive reduction of carbon dioxide emissions in California to 80 percent below 1990 levels by 2050. The application of this bill to automobiles was thwarted by the EPA in 2007 when it effectively stated that the requirements were too strict.
2007	Supreme Court decision in the case of *Massachusetts v. EPA*—The Supreme Court ruled that carbon dioxide and other global warming pollutants could be regulated under the Clean Air Act of the 1970s. The court rejected the EPA's argument that the Clean Air Act did not refer to carbon emissions. It also ruled that the EPA was unjustified in delaying any decision due to policy considerations, and that it must consider whether greenhouse gas emissions contribute to climate change when considering any delay.

region of operations. To interpret the percentages, the conversion of plant matter to biomass would represent 30 percent of the capacity of the composite renewable power plant, landfill gas would represent 15 percent, etc. Adding new sources of power generation, such as biomass and solar, would require the development of additional technical and operational expertise within PowerCo, but Waterford believed his firm needed to look at all options at this point. Solar in particular was not cost effective without the federal Production Tax Credit on energy, which was set to expire at the end of 2008. However, great strides were being made in terms of the efficiency of solar systems, and in time, solar might be very efficient. Waterford knew that PowerCo could not afford to be left behind, especially when there were discussions about governmental subsidies of various renewable technologies.

It required several months of work for Waterford's team to compile the data in **Table 10**. During the process, the team talked with technical and finance people both within and outside PowerCo, spent considerable time studying trade publications, and carefully examined data such as that provided in the *Annual Energy Outlook*, published by the Energy Information Agency. The data in the table represented high efficiency plants (e.g., combined cycle natural gas plants). The effective capacity numbers reported in Table 10 made allowances for utilization and maintenance, so that it represented the deliverable capacity of power that PowerCo could expect from the various sources.

Table 10 Basic Data Related to Costs of New Capacity

	Coal	Natural Gas	Oil	Nuclear*	Composite Renewables
Effective Capacity (MW)	550	400	350	690	500
Latest Start Date	2012	2012	2012	2008	2010
Cost to Build Plant					
Low ($000s/MW)	$2,600	$1,800	$1,050	$3,400	$3,500
High ($000s/MW)	N/A	N/A	N/A	$4,250	$4,900
Production (000s of MWH/year)	4,818	3,504	3,066	6,044	4,380
Useful Life of Plant (years)	40	40	40	40	40
Operating Cost in 2016 ($/MWH)	$6.90	$3.14	$3.24	$8.26	$15.30
Cost of Fuel in 2016 ($/MWH)	$12.53	$24.70	$64.20	$5.40	$1.68
CO2 Emissions (tons/MWH)	1.004	0.579	0.91	0.001	0.038
Decommission Cost (% of build)	5%	3%	3%	15%	3%

* The optimal size for a modern nuclear power plant is 1,350 MW. PowerCo had arrangements with other utilities to share construction and operating costs to an effective capacity of 690 MW.

The installed capacity would be higher than the effective capacity for all of the power sources. This was particularly true for the renewable sources of wind and solar, since days without wind or sun required the installation of far more capacity than needed. Indeed, the use of wind required the installation of about five times as much capacity as needed at peak demand. The effective capacity had also been adjusted for maintenance shutdowns and other operational issues that would decrease utilization.

The latest start date was an estimate of the latest reasonable start date for communicating with stakeholders and planning, permitting, and constructing each power plant in order to deliver power by January 2016. It was based on the complexity and uncertainty associated with each technology. The cost estimate to build each plant was adjusted to reflect the cost if the project was started on the latest start date. Because nuclear and renewables had by far the most uncertainty in terms of cost, Waterford listed what his team believed were the low and high costs for those two power sources. All capital costs were given in 2015 dollars and incorporated the fact that the capital expenditures would be spread out over different periods for each power source. Production referred to the actual power expected to be delivered into the grid each year. Operating cost in 2016 was an estimate of the operating costs per megawatt hour (MWH)[12] for the first year of operation, or 2016. The operating cost in 2016 did not include the cost of oil, natural gas, coal, or uranium for the various plants.

The cost of fuel in Table 10 was Waterford's best guess for the 2016 cost of the fuel needed to produce one megawatt hour of power for each technology type. As you can see in Table 10, even renewable technologies required small amounts of fossil fuel. CO2 emissions was the amount of carbon dioxide emitted per megawatt hour generated, assuming no sequestration of greenhouse gases. The decommission cost was the expected cost to decommission the respective power plant at the end of its useful life, given as a percent of original construction cost. The decommissioning cost was particularly high for the nuclear option to account for the dismantling of the power plant and the long-term storage of radioactive materials.

Finally, Waterford believed that operating costs at coal, oil, gas, and nuclear power plants would grow at a nominal rate of 1 percent above inflation, or at about 4 percent

Table 11 Annual Nominal Growth Rates in Fuel Costs

	Nominal Growth Rates in Fuel Costs	
	Moderate	High
Coal	3.5%	—
Natural Gas	4.0%	—
Oil	4.0%	7.0%
Nuclear	4.0%	—
Renewables	4.0%	—

per year. However, there was evidence that the operating costs of some of the renewable technologies, such as wind and solar, would increase more rapidly with age since, for example, wind turbines were out in the weather and not sheltered in a building. As a result, he decided to use 2 percent above inflation, or 5 percent per year, as the annual rate of increase in operating costs for the composite renewable technology. No one knew for sure, but Waterford guessed that the growth rate of the tax on carbon emissions was likely to be higher, and estimated 6 percent per year. His best estimates of the nominal growth rates of fuel costs for the various technologies are summarized in **Table 11**.

Waterford knew that the applicable state laws required that PowerCo choose a power alternative that minimized costs to rate payers, so he decided to look at minimizing the cost per megawatt hour. He made the following list of several important issues:

- The costs of oil, natural gas, coal, and uranium varied widely. It was difficult to estimate costs of these fuel types for the forty years of useful life of a power plant, especially given demand growth in India and China.
- No one knew when or if carbon taxes would be levied on emissions, or how fast those taxes would be increased. Industry insiders talked about an imminent tax of $5 to $15 per ton, and some even talked about a tax of $25 per ton or more. Waterford anticipated that there would be more information on carbon tax issues within a year or two after a new presidential administration came to power in January 2009.
- No one knew the best way to efficiently sequester carbon, or if the large volumes of carbon being produced could in fact be sequestered without creating additional environmental problems.
- Sharply rising commodity prices, due to economic growth in China and elsewhere, resulted in uncertainty in the construction costs of the various power plants. However, there was particular uncertainty in the construction costs of nuclear and renewable sources.
- The effective capacity of the nuclear power plant in Table 10 was 1,350 megawatts, which was more than PowerCo needed. However, managers had already held discussions with a nearby utility where management expressed a strong interest in forming a joint venture on any nuclear power plant. Waterford decided to assume that PowerCo would retain 51 percent of any such joint venture if they proceeded with the nuclear option. This would result in an effective capacity of 51 percent of 1,350 megawatts, or roughly 690 megawatts, if the nuclear option were chosen.

- In particular, the long-term price of oil, and potentially of natural gas, was uncertain due to a possible peaking of world production within the useful life of a power plant completed by January 2016.[13]
- After serious thought and discussion with a wide range of experts, Waterford decided to use the following probabilities:

  P(world oil production peaking in next 10–25 years) = 50%
  P(high construction costs for nuclear power plant) = 40%
  P(high construction costs for renewables) = 40%
  P(high carbon tax in 2016) = 60%

Waterford knew that he needed to test any model results for sensitivity to such things as carbon taxes, costs of fuel, construction costs, etc. before supporting any one of the power sources. He was worried about risk in the event the unexpected happened. It was difficult to predict the future. After all, the costs of building the power plants had almost doubled in just the past two years, as commodity prices worldwide had soared with increased demand from China and India. He was also concerned about the long-term outlook for the price of oil, natural gas, coal, and uranium. The prices of all of these had been very volatile throughout 2007 and it was not clear where prices would be in the coming decades.

Finally, Waterford was very concerned about timing. He knew that PowerCo needed to go to work immediately if management decided to build a nuclear power plant. No one knew for sure how long it would take to find a location, obtain permits and financing, and build one. It had not been done in decades in the U.S. Waterford knew that it was critical to explore all reasonable options before making a decision about a nuclear plant. He was also worried about whether PowerCo could afford the nuclear option—the early cost figures to build a nuclear power plant appeared higher than they had originally anticipated. The composite renewable plant also appeared to be very expensive. Some kind of rate relief adjustment may be needed in order to build either the nuclear or renewables power plant. Waterford needed to complete the cost minimization and sensitivity analyses, and then incorporate the findings into the IRP before PowerCo applied for rate relief from the state regulators in June 2008. Gaining the support from all of the various stakeholders was critical. The next meeting of Citizens for the Environment was just four weeks away. Waterford thought this would be a good place to launch discussions of his recommendations and the IRP.

Appendix A: Definitions

Units of Capacity

Power plant capacity: The amount of energy a plant could produce at any instant in time when running at full power.

Effective capacity: The actual or expected amount of energy a plant could produce in any period (day, month, or year) after allowances for maintenance, shutdowns, etc.

Kilowatt (KW) = 1,000 watts, or enough to light ten 100-watt light bulbs

Megawatt (MW) = 1,000,000 watts

Example: A 550 MW plant was capable of producing 550 megawatts of energy at full power. Thus, it would generate sufficient electrical power to simultaneously light 550,000,000 ÷ 100 = 5,500,000 100-watt light bulbs.

Units of Total Amount of Energy

Total energy:The amount of energy generated by a power plant in a unit of time such as one hour, one day, etc.

Kilowatt hour (KWH) = 1,000 watts of electricity produced for one hour

Megawatt hour (MWH) = 1,000,000 watts produced for one hour

Example: A 550 MW plant producing at full capacity for one hour produced 550 MWH (megawatt hours) or 550,000,000 watts of energy. That was enough energy to light 5,500,000 100-watt light bulbs for one hour.

The invention of the first electric light bulb by Thomas Edison in 1879 radically changed the world. No longer were people limited to the use of candles, kerosene, or whale oil for light. A dream was born: electricity could be generated, widely distributed, and used for lighting. The first central power plant was the Pearl Street Station in lower Manhattan. It was built in 1882 and only generated enough power for 800 light bulbs. Since the costs to build power plants and distribute power were huge and returns were small, it quickly became evident that a single firm could produce and deliver electricity in one region more efficiently than could a group of competing firms. Thus, regional monopolies formed. The prevailing view was to grant a single franchise in each area and then empower a regulatory commission to set prices (Griffin et al. 2005). Thus, the market was slowly created by vertically-integrated firms in one geographic area after another. Initially, regulation was at the state level—thirty-three states had formed regulatory agencies by 1916 (Edison Electric Institute). However, the role of federal regulation grew quickly.

Trends in Federal Regulation

The Federal Power Act of 1920 was part of a broader legislative package that gave various responsibilities related to water power and resources to the Federal Power Commission (FPC), and authorized it to issue licenses for hydroelectric projects, including dams and reservoirs. It also authorized the FPC to regulate the transmission and sale of electric energy in interstate markets, or markets in which electricity flowed across state lines. By the 1940s, this organization regulated interstate flows of electricity and natural gas throughout the United States. The FPC was reorganized into the Federal Energy Regulatory Commission (FERC) in 1977.

Government regulatory agencies emerged not only to control the production and transmission of power, but also to control effects on the environment. The heavily polluted Cuyahoga River in Ohio caught fire in 1969, contributing to the creation of the Environmental Protection Agency (EPA) and the passage of the Clean Air Act of 1970. This was followed by the passage of the Clean Water Act of 1977. As one of the largest polluters of both air and water, power generation immediately caught the attention of the EPA.

Some deregulation in the generation of power occurred with the Public Utility Regulatory Policies Act of 1978 (PURPA), which was passed during the Carter administration in response to the unstable energy climate of the late 1970s.[14] The act opened up a new category of nonutility generators as it sought to promote conservation of electricity. The nonutility generators were able to produce electrical power to sell to utilities, which transported and delivered the power to users. In fact, PURPA required electric utilities to buy and transmit electricity from any *qualifying power generator*. The nonutility generators became qualified to sell all power produced by either producing power from alternative sources or through meeting modest efficiency goals. Although PURPA was only the first step, it spurred the construction of new power generation and effectively set the foundation for disaggregating the vertically integrated industry within two decades (Makansi 2007).

The Fuel Use Act of 1979 (FUA) prohibited utilities from using natural gas to make electricity, although nonutilities could still use natural gas for power generation. The combined effects of PURPA and FUA were to motivate nonutility generators to build large electricity generating plants that used natural gas. This act was repealed in 1986, the same year that the regulation of the transmission of natural gas through pipelines was deregulated. One unintended consequence of FUA was an oversupply of natural gas in the U.S. that lasted for fifteen years.

The trend of deregulation continued with the passage of the National Energy Policy Act of 1992 (NEPA). This act forced utilities to transmit and deliver power through their systems for other generators. This gave consumers the choice of which company to use for power, even though the power was delivered by the company with transmission and distribution lines to their home or place of business. This law allowed wholesale generators of power to sell directly to an end user by moving power through the transmission systems of existing utilities. NEPA increased competition by creating new entities that delivered electricity to end users, without being regulated as utilities.

The combined effects of PURPA, FUA, and NEPA, in addition to the disdain for nuclear power at the time, resulted mostly in the construction of natural-gas power plants during 1980–2000, although a few coal-fired plants were also built. By 1997, most of the power plant capacity being added was natural gas and it was being built by a new class of independent power producers called merchant power producers. These independent power producers were not utilities, but firms that found a profitable niche making electrical energy and selling it to either utilities or the general public.

The California electricity market collapsed in 2000–2001, partially as a result of energy companies taking advantage of a mostly deregulated energy system to increase their profits. A notable example was Enron, which subsequently went bankrupt in 2002 as a result of an accounting scandal. At its worst, the California market was marked by a combination of extremely high prices and rolling blackouts. Price controls resulted in local utility companies paying more for electricity than they were allowed to charge customers, resulting in the bankruptcy of Pacific Gas and Electric and the public bailout of Southern California Edison. The state had to buy power on highly unfavorable terms in the open market and the resulting massive long-term debt obligations added to the state budget crisis and effectively resulted in the removal of Governor Gray Davis.

In 2005, President George W. Bush signed into law the Energy Policy Act of 2005, which had a goal of combating growing energy problems. The Act had wide-ranging provisions related to biofuels, clean coal, wind, geothermal, oil shales, and tidal power. The nuclear-specific provisions included cost overrun support for the construction of the first six nuclear power plants to be built after 2005. It also authorized the expenditure of $1.25 billion to the U.S. Department of Energy to build one nuclear power plant. The act even changed daylight savings times in an effort to reduce consumption. Proponents suggested that this act enabled the construction of nuclear power plants beginning in 2010 with operation potentially in 2014. Critics of the Act suggested that it was a broad collection of subsidies for the oil and nuclear industries, especially those located in Texas, the home state of former President Bush.

Climate Change

Climate change is the idea that the world's climate is rapidly warming. By 2008, many, but not all, climate experts believed that human activity was causing much of climate change through the emission of greenhouse gases,[15] deforestation, farming practices, etc. Some had suggested that climate change was a time bomb with many possible negative ramifications, including:

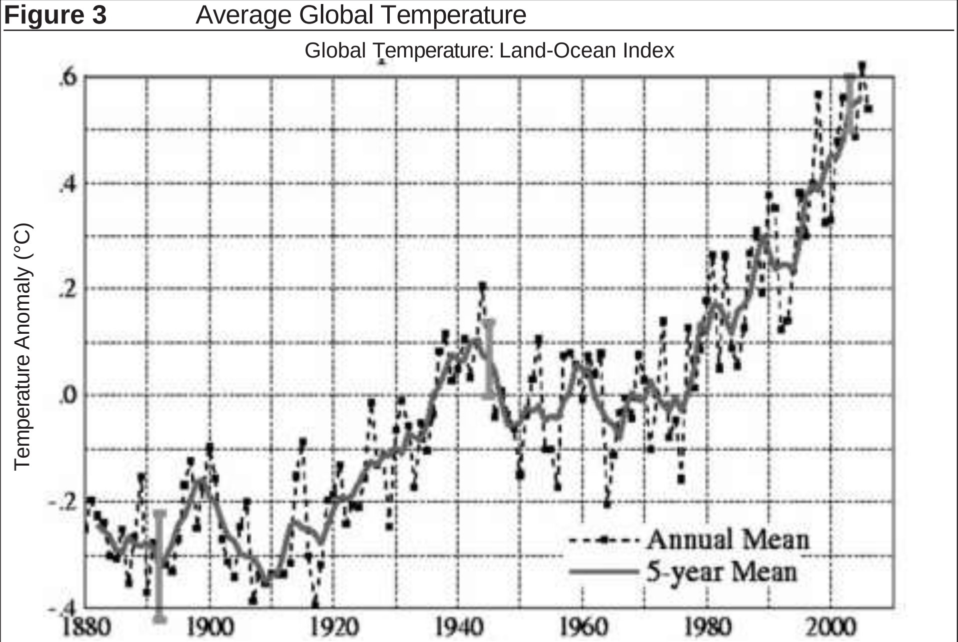
- melting ice (glaciers, Greenland, Arctic, and Antarctica)—some predicted the Arctic would be ice-free in the summers by 2013
- rising sea levels

- more frequent and more intense hurricanes
- migration of some animal populations, extinction of others
- flooding of many major cities at sea levels and accelerating coastal erosion
- drought in some areas and flooding in other areas
- problems in growing food
- death of coral reefs
- increased spread of disease as the range of mosquitoes expanded

Many of these issues were dramatized in the popular film about former Vice President Al Gore's efforts of educate the public on global warming, *An Inconvenient Truth*, released in 2006.

Figure 3 shows that world temperatures increased during 1910–1940. However, temperatures then fell slightly and were flat for thirty years, until 1978, when they again increased. Few questioned that the world had become warmer, however, some debated the role of human activity as the cause of global warming. Skeptics pointed out that world temperatures fell during 1944–1950 and were then stable for a thirty-year period of time during which carbon dioxide emissions by humans were rapidly increasing. Furthermore, it was well known that the temperature at the surface of the earth had varied greatly through geologic time. Some believed we were entering a period of warming that was primarily driven by natural forces, rather than driven by human-related factors. Some scientists believed that as a society, we had moved beyond the data to near hysteria. For example, in 2007 ecologist Daniel Botkin stated: "We may be moving away from an irrational lack of concern about climate change to an equally irrational panic about it."[16] Also in 2007, BBC science correspondent David Whitehouse pointed out that "For the past decade the world has not warmed. Global warming has stopped. It's not a viewpoint or a skeptic's inaccuracy. It's an observational fact."[17] Most climate scientists believed that the ever-increasing carbon emissions by humans was resulting in a warming of the earth. Many further believed that we were destabilizing the overall system with potentially dire consequences for humanity.

Figure 3 Average Global Temperature



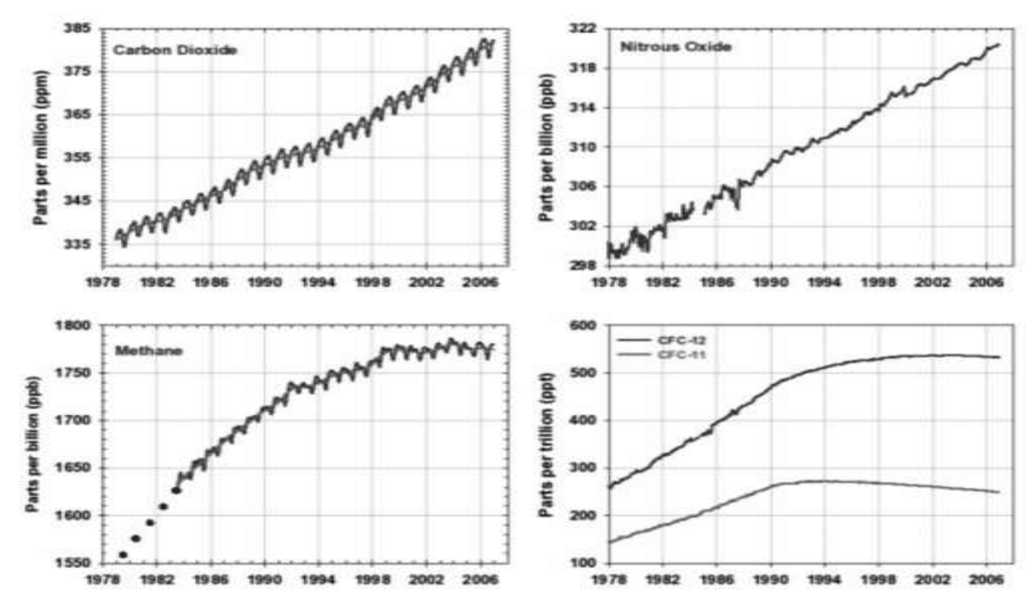
Source: NASA

Some scientists looked at the levels of chlorofluorocarbons[18] (CFCs) in the atmosphere as an analog in terms of what humans had done and what humans could do about it. The graph at the lower right of **Figure 4** shows that CFC concentrations in the atmosphere increased rapidly until the early 1990s. At the time, CFCs were used by humans in many applications throughout the world, including most refrigeration and air conditioning systems. Scientists believed that CFCs were largely responsible for the increase in the size of the ozone hole over Antarctica and posited a number of associated health and environmental hazards. As a result, the worldwide use of CFCs was phased out beginning in the 1990s, and the level of the CFCs quickly began to level off or decrease. Advocates applauded the success, although many worried about the other gases shown in Figure 4. The five gases in the figure were believed by some to be the cause of as much as 97 percent of global warming since 1750.

The first serious global movement to limit carbon dioxide emissions was the Kyoto Protocol on climate change, which was agreed to in December 1997, and went into force in 2005. By early 2008, 174 countries had ratified the treaty representing all original signatory nations other than the U.S. and Kazakhstan. The treaty separated countries into developed countries with specific, accepted limits on greenhouse gas emissions and developing countries which were required to monitor, but not reduce, greenhouse gases. President George W. Bush of the United States refused to support the Kyoto treaty on the grounds that China, a developing country with large carbon emissions, was not required to limit emissions, and limiting emissions would hurt the U.S. economy.

In keeping with the theme and timing of the Kyoto Protocol, the European Union (EU) launched the European Union Emission Trading Scheme (EU ETS) on January 1, 2005. The EU ETS was the backbone of the European Union's response on climate and covered more than 11,500 energy producers in the European Union, representing more than one-half of all carbon dioxide emissions in Europe. The goal of the EU ETS was to help EU member states achieve compliance with their commitments to the Kyoto Protocol at the lowest cost. Emissions trading of itself did not result in meeting

Figure 4 Atmospheric Concentrations of Various Greehouse Gases



Source: National Oceanic and Atmospheric Administraion environmental targets or bringing down carbon emissions. Rather, it allowed for cheaper compliance with existing targets by allowing participating companies to buy or sell emission allowances. The price for emission allowances was set in a free market. Total carbon dioxide emissions would be lowered over time by reducing total allowances. A major review of the effectiveness of the EU ETS system was expected in 2008.

There was no legal framework for regulating carbon emission in the United States until the Supreme Court decision in the case of *Massachusetts v. EPA* (2007). The Supreme Court ruled that carbon dioxide and other global warming pollutants could be regulated under the Clean Air Act of the 1970s. It further ruled that the EPA could not justify a delay in action due to policy considerations and that any delay must consider whether greenhouse gas emissions contribute to climate change. However, the EPA did not immediately use its power to limit emissions, and many doubted it would do so during the tenure of President Bush. However, President Bush would leave office in January 2009 and no one knew what would follow.

The cost of emitting carbon dioxide into the atmosphere had essentially been ignored everywhere for centuries. Of course, the total carbon dioxide released by humans before 1900 was miniscule compared to that released since then. However, many in the power industry believed that new legislation would soon be passed that would tax carbon emissions. Several organizations and companies had funded research and development projects to identify ways to capture and store carbon dioxide and any other remaining emissions. Techniques being studied included chemical, mechanical, and biological processes. One storage idea was to inject carbon dioxide into old, nearly depleted oil and gas fields, simultaneously increasing hydrocarbon production. Another idea was to store carbon dioxide in domes at the bottom of the oceans. Some scientists were exploring ways to increase the carbon uptake of plants through genetic alterations. Another creative idea was to find a way to inject carbon into outer space to get it out of the atmosphere. Methane is another greenhouse gas that is twenty times worse than carbon dioxide. Methane leaked from oil and gas fields everywhere and seeped out of coal mines, but it was also belched in amazing abundance by cattle. Some scientists were researching ways to change the genetics of cattle to lower methane emissions from belching.

As of 2008, no one knew the best way to sequester carbon dioxide or other greenhouse gases, or even if they could be sequestered in the huge volumes produced. No one expected commercially viable answers for at least five years, if then. In fact, some believed that the long-term storage of such large volumes of carbon dioxide could of itself present significant environment problems.

Sources of Power

Coal

Table 7 shows that coal was used to generate nearly 40 percent of all of the electricity produced in the world. About 75 percent of all coal mined in the world, and 90 percent of the coal mined in the U.S., was used to generate electricity. Coal that was not used to generate electricity was used in furnaces, or burned in homes for heat or cooking. Coal is a hard, brownish-black rock thought to be formed in ancient swamps where the remains of plants were saved from degradation by water and mud. It is easily moved by trains and stored in outdoor piles.

Table 12 lists proved recoverable reserves of coal by country. Coal was particularly plentiful in the United States, Russia, and China, with a combined 58 percent of the world's proved recoverable reserves and the end of 2004. In fact, the U.S. was sometimes referred to as the "Saudi Arabia of coal" since it had far more proved reserves[19] of coal than any other country. The Department of Energy reported that the energy content of U.S. coal reserves exceeded that of all of the known oil reserves in the world. The table shows that the seven countries with the largest coal reserves had about 86 percent of the world's proved recoverable reserves of coal. **Table 15** at the end of this Case Supplement shows a history of the price for and U.S. consumption of coal, natural gas, crude oil, and uranium for electrical power.

There are many different types and grades of coal. Ranked from lowest energy content to highest energy content (and generally from dirtiest to cleanest), the types of coal are: lignite, sub-bituminous coal, bituminous coal, and anthracite. The carbon content in the various types of coal ranges from 30 percent to 90 percent by weight. Coal inherently contains a lot of carbon, more than oil or natural gas. It also contains more pollutants and it is easily the dirtiest of all of the fossil fuels, although the purity of coal varied widely.

Coal is occasionally found on the surface, but most coal is buried by overburden. Coal that is not buried deeply is often mined by strip mining, requiring removal of the overburden, working mines in vast open pits, or sometimes removing entire mountains mostly made up of coal. Most of the coal being mined in Montana, Wyoming, and Texas is strip mined. Wyoming and Montana are respectively the number one and two coal-producing states in the U.S., and both states have huge remaining reserves of high-quality coal. Most companies implemented plans to reclaim the open-pits by covering them up and planting vegetation after the coal was removed. Coal that is buried more deeply, such as most coal mined in Appalachia, requires miners to go underground. According to the U.S. Department of Energy, proved coal reserves in the U.S., including highly polluting, low energy types of coal, are sufficient for as much as 300 years of use at current levels of consumption. However, much of that coal is buried deeply, even in Wyoming and Montana, and the costs of extraction are likely to eventually increase.

The use of coal is not without potential hazards. Without careful controls, the use of coal has historically resulted in harmful effects including each of the following:

- Exposed coal surfaces in open-pit mines resulted in sulfuric acid that flowed into waterways and killed sensitive plants, fish, and other aquatic animals.
- The burning of coal created huge volumes of greenhouse gases including carbon dioxide, sulfur dioxide, and various oxides of nitrogen.

Table 12 Proved Recoverable Coal Reserves at End of 2004

	Proved Recoverable Reserves (millions of short tons)	Percent of World Total
United States	279,506	28%
Russia	173,074	17%
China	126,215	13%
India	101,903	10%
Australia	86,531	9%
South Africa	53,738	5%
Ukraine	37,647	4%
World Total	1,000,912	

Source: Energy Information Agency

- Burning coal resulted in acid rain which returned to the earth as rain potentially hundreds of miles from the source of the emissions. Acid rain polluted streams, rivers, and lakes where it often killed plants and animals. It was a particular problem in China, however acid rain had even polluted the waterways in New York and several states in the Midwest, making fish inedible for decades.
- The greenhouse gas methane leaked out of exposed coal seams in mines.
- Coal was dirty with many contaminates including traces of heavy metals such as arsenic, lead, and mercury as well as low levels of radioactive materials such as radium, uranium, and thorium and very toxic chemicals such as hydrogen cyanide. Without controls, the burning of coal resulted in significant polluting emissions and substantial amounts of toxic ash.
- Hundreds of underground coal seams were burning at the end of 2007. Most fires had been started by human activity, such as one coal fire accidentally started in Pennsylvania in 1962 that still burned. However, the "Australian Burning Mountain" may have been smoldering for more than 5,000 years and was once thought to be a volcano. Coal fires released greenhouse gases, various toxic pollutants, and particulate matter into the atmosphere.
- The burning of coal also resulted in toxic ash that polluted streams, aquifers, and land areas.

Mining coal was dangerous for humans, especially in third world countries without an adequate focus on safety. However, it was also dangerous in the U.S., as evidenced by the deaths of forty-seven coal miners working in mines in 2006. Additionally, many coal miners in the U.S. and worldwide had developed a deadly disease called black lung from prolonged exposure to coal dust. Black lung usually resulted in suffering, disability, and premature death and it had been the focus of a long-lasting, class-action lawsuit in the U.S.

The traditional design for obtaining electricity from coal is first to pulverize it into a powder and then burn it in a furnace. The heat created is used to create steam in a boiler which turns big turbines that generate electricity. Energy is lost at every stage, so only about 35 percent of the energy in coal is turned into electricity by the many coal-fired power plants in existence in the U.S. The remainder of the energy is simply lost to the environment as waste heat. New designs for coal-fired power plants improved the efficiency and captured up to 45 percent of the energy within coal. Cogeneration units that also captured the waste heat generated from burning coal increased efficiency up to 60–85 percent, but they were expensive. Scrubbers and other devices had been used for decades in coal plants in the developed world to remove particulates and many chemicals including sulfur. But carbon dioxide, nitrous oxide, and other chemicals were freely emitted to the atmosphere.

Natural Gas

Natural gas consists primarily of methane and other heavier gas hydrocarbons. It is found in underground geologic traps, similar to crude oil. Most crude oil fields contain some natural gas, although there are many natural gas fields that contain little to no crude oil. Although some geologists believe that methane was formed early in the geologic history of the earth and that substantial natural gas may still be trapped deep within the earth, the most commonly accepted view is that natural gas was formed by the decay of animal and plant life left long ago in sediments.

Due to ease of use, modest prices, low level of pollution, and regulation, natural gas had been the fastest growing energy source for electric power generation since 1980.

However, Table 7 shows that natural gas still lagged far behind coal for power generation in the U.S., producing only 17.5 percent of all electricity. Indeed, only 26 percent of the natural gas used in the U.S. in 2005 was for electric power generation. Much of the remainder was used by residential customers (for heating/cooking) and industrial customers, which together consumed more than 50 percent of the natural gas in the country. However, significant amounts of natural gas were used in the production of fertilizers for agricultural crops, lawns, and gardens. As a result, electric power generators effectively faced competition from residential users, industrial users, and even farmers who used fertilizers.

Natural gas was an attractive choice for power generation for many reasons. First, it was efficient, since up to 85 percent of the energy could be converted to electricity in the most efficient plants. Natural gas also offered power generators the most flexibility since natural gas-fired power plants could be brought online and delivering power in minutes, compared to hours for coal-fired plant. This allowed power producers to use natural gas to quickly ramp up and shut down electricity production based on demand, which often varied greatly from hour to hour. Natural gas power plants could also be built much more quickly than nuclear power plants in particular. Importantly, burning natural gas produced about 35 percent less carbon dioxide per unit of energy than burning oil and about 45 percent less than burning coal. Further, the use of natural gas resulted in significantly lower emissions of sulfur, nitrous oxides, mercury, hydrogen cyanide, radioactive materials and the particulate matter found in the other fossil fuels. It was the cleanest burning of the fossil fuels. Finally, the safety record using natural gas was excellent, although coal- and oil-fired power plants also had excellent safety records.

It was more difficult to transport and store natural gas (a gas) than coal (a rock) or crude oil (a liquid). Oil could readily be stored in above-ground tanks and moved in pipelines or trucks. Coal could be moved by train and stored in piles. The best alternative was to move natural gas by pipeline and store it in one of 200 or so underground geologic traps in the U.S. from whence it could be removed on demand. Most of these geologic traps were old oil or gas fields. It was also much easier to move crude oil by sea-going tankers than it was to move natural gas by tankers. To be moved cost-effectively by sea-going tanker, natural gas had to be liquefied (LNG), which was done using high pressure and a very low temperature. The low-temperature, high-pressure LNG tankers moving gas in the Persian Gulf posed significant security risks, since a small weapon could potentially result in the complete destruction of a tanker, natural gas and all. Due to the difficulty and cost of transporting natural gas, about 95 percent of the natural gas burned in the U.S. in 2007 was produced in North America and moved by pipeline from gas wells to power plants. The remaining 5 percent was brought to the U.S. in the specialized LNG tankers.

Another issue of importance was the long-term supply of natural gas. **Table 13** shows estimated proved reserves of natural gas at the end of 2006.[20] Note that Russia, Iran, and Qatar had huge quantities of natural gas (58 percent of world's total) whereas the U.S. had only 3 percent of the world's total. Yet the consumption of natural gas in the U.S. was high. The Energy Information Agency estimated that as of 2005, the U.S. had an eleven-year supply of proved natural gas reserves, not including natural gas potentially moved from either Canada or Mexico into the U.S. However, new technological developments in producing natural gas from shale formations had recently resulted in significant additional commercial natural gas discoveries in the U.S. with expectations of more commercially viable reserves to be found and produced. These gas reserves were so new

Table 13 Proved Reserves of Natural Gas at End of 2006

	Proved Recoverable Reserves (trillion cubic feet)	Percent of World Total
Russia	1,689	27%
Iran	965	16%
Qatar	906	15%
Saudi Arabia	244	4%
United Arab Emirates	206	3%
United States	204	3%
Nigeria	182	3%
Algeria	162	3%
Venezuela	152	2%
Iraq	112	2%
World Total	6,183	

Source: *Oil and Gas Journal* (2007) and the EIA.

that they are not fully reflected in Table 13. It was also important to note that both Canada and Mexico were using increasing amounts of their own natural gas, potentially leaving less natural gas for export to the U.S. In fact, Canada was using increasing amounts of natural gas in the production of oil from their abundant oil sands reserves.

Similar to the situation with crude oil, the U.S. was likely to become a large importer of natural gas in the future. In 2008, there were six terminals offshore of the continental U.S. whose purpose was to receive LNG shipments and to move that natural gas to shore through pipelines. An additional forty LNG terminals had recently been proposed, including a $1 billion proposal in December 2007 by Exxon Mobil to build a terminal twenty miles off of the New Jersey shore. This one terminal was expected to handle the natural gas needs of over 5 million customers.

Oil

Crude oil in very small amounts has been used by humans for thousands of years, but produced in volume from oil wells only since the late nineteenth century. Crude is chemically very complex, with significant differences in pollutants among the different oils. Crudes range from the top-quality grades produced by Saudi Arabia to a tar-like substance from the Canadian oil sands that literally could not be stirred with a stick without being treated or heated. Similar to natural gas, oil is burned at power plants to create heat, which is used to make steam, which is used to turn turbines and create electricity. The efficiency of existing oil-fired power plants was on the order of 38 percent, meaning that 38 percent of the energy in the oil was converted to electricity, although newer designs promised to increase the efficiency of oil-fired power plants.

Traditionally, crude oil is produced from oil wells and then transported to refineries by pipeline, ship, or truck. However, nonconventional oil from the Canadian oil sands was of such poor quality that it would not flow from the oil sands. The sands either had to be mined and the oil separated with steam, or steam had to be injected into the oil-bearing sands to extract the heavy oil. Most of the steam used in the oil-sands mining processes is produced by burning natural gas produced locally in Canada. No matter the source of crude oil, once produced, refiners remove some of the often abundant impurities such as sulfur, nitrogen, and metals. It is then refined into formulations that are used for thousands of products including gasoline, diesel, heating oil, jet fuel, plastics, sneakers, crayons, bubble gum, tires, eyeglasses, and asphalt.

The use of crude oil resulted in numerous environmental issues. The drilling and fracing of wells consumed prodigious amounts of water and the required use of hazardous chemicals.[21] The oil wells and associated production equipment and transportation processes often resulted in the leakage of methane and other hydrocarbons into the atmosphere and the spillage of oil onto the ground or in waterways. Underground leakage from well bores sometimes polluted fresh water aquifers. There had been a long-standing battle in the U.S. about whether to allow drilling in the Arctic National Wildlife Refuge in northeast Alaska. Advocates argued that the area likely contained abundant oil[22] and that drilling and production could be done with minimal environmental impact. Opponents argued that drilling and the associated production would result in significant environmental impacts in one of the last undisturbed wilderness areas in the world. As of 2008, oil companies had not been given permission to drill in the Wildlife Refuge. Furthermore, environmental restrictions had effectively resulted in a moratorium on drilling offshore in many areas in the U.S., including parts of California and along the east coast.

The refining of oil resulted in the release of chemicals into the air and created materials that required disposal on land. Oil-fired power plants commonly produce nitrous and sulfur oxides, methane, mercury compounds, and significant amounts of carbon dioxide. Similar to gas-fired power plants, oil-fired plants require large quantities of water for the production of steam and cooling. The effluent from these power plants warms the waters and affects the fauna and flora of those bodies of water. The use of oil at power plants also results in residues called sludge that are not completely burned, and therefore require disposal in landfills.

There was another very important issue related to the supply of crude oil. Crude oil had been used intensively since the first automobiles were sold in the early part of the twentieth century. Oil production in the U.S. reached a peak in 1970 and had continued to fall since then, in spite of the late 1970s production from the giant oil fields of Prudhoe Bay in Alaska. By 2008, oil production in the U.S. had fallen to about 50 percent of the peak of production in 1970. However, U.S. demand had grown significantly since 1970, so the country had become very reliant on imports of oil, adding significantly to the U.S. trade deficit.

Table 14 shows proven reserves of oil by country. The figure for Canada includes the tremendous nonconventional oil-sand reserves of northern Alberta. However, Table 14 data does not include the tremendous amounts of unconventional oil trapped in the oil shales of Colorado, Utah, and Wyoming. It was very difficult to produce the oil from this shale. Neither conventional producing wells nor mining methods had worked to date. One idea under consideration was to heat chunks of 600-foot-thick sections of oil-bearing rock, called shale, to 600 degrees Fahrenheit over a period of several years and effectively bake the oil out. Of course, it would require a tremendous amount of electricity to heat thick sections of rock, requiring the building of additional power plants using some fuel source. There was no commercial production from the oil shale in 2008, nor was any expected in the near future. Table 14 also does not include any figure for the unknown oil reserves in the Arctic, which some optimistically estimated to contain as much as 90 billion barrels. Those reserve figures were estimates and not proven reserves.

Table 14 Proved Oil Reserves at End of 2006

	Proved Recoverable Reserves (billions of barrels)	Percent of World Total
Saudi Arabia	262	20%
Canada	179	14%
Iran	136	10%
Iraq	115	9%
Kuwait	102	8%
United Arab Emirates	98	7%
Venezuala	80	6%
Russia	60	5%
Libya	41	3%
Nigeria	36	3%
Kazakhstan	30	2%
United States	22	2%
World Total	1,317	

Source: Oil & Gas Journal (2007) and Energy Information Agency

Table 14 shows that the U.S. had only 2 percent of the world's remaining proved reserves of crude oil. Essentially, most of the oil originally located in the U.S. had already been found, produced, and consumed by 2008. In contrast, the OPEC countries of Saudi Arabia, Iran, Iraq, Kuwait, United Arab Emirates, Venezuela, and Nigeria had more than 60 percent of the world's remaining proven reserves of oil. This did not include the other OPEC oil-exporting countries such as Angola, Qatar, and Ecuador whose reserves fell below those of the U.S. and therefore are not included in Table 14. In 2007, Brazil announced several very large, new oil discoveries in the deep offshore waters.

By the end of 2007, the Brazilian oil company Petrobras had begun to lock up much of the deep-water drilling rig capacity of the world, making it more difficult for major oil companies with deep-water prospects in other parts of the worlds. Top-ranking Brazilians had stated that the country would aggressively develop their deep-water oil reserves and join OPEC at some point. However, it requires roughly a decade to fully develop deep-water reserves, so those reserves were not expected to come to the market in the near future.

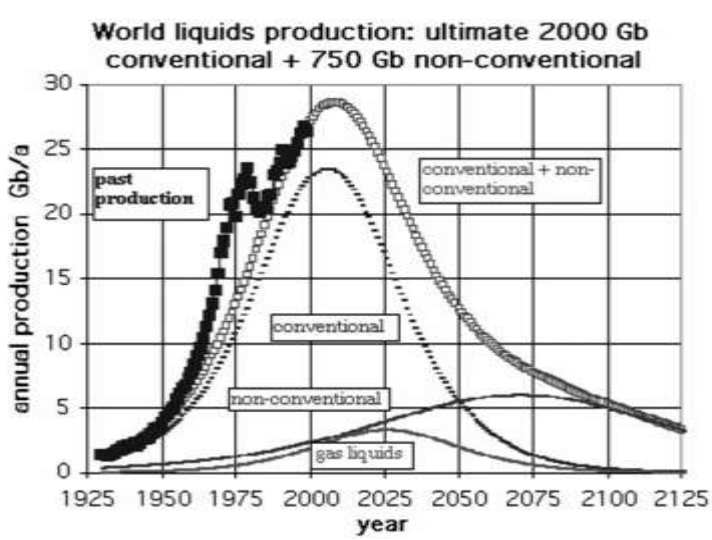
By early 2008, serious competition for oil had developed worldwide as demand increased in China and India, driving prices to over $90 per barrel. Some geologists and a few oil company executives believed that the era of unlimited oil production had either arrived or would arrive in the near future (Latherer 2000 and Deffeyes 2005). This idea of peak oil, or the reaching of a peak in world oil production followed by a decline, is shown in **Figure 5**. The Energy Information Agency (EIA) also published a report indicating that world oil production would peak. However, EIA personnel strongly suggested that the peak would not come until *after* 2040 and possibly as late as 2060, barring serious political disruptions from the oil exporting nations of OPEC and assuming significant investments of trillions of dollars in exploration, production, refining, and transportation during the coming decades. Many people believed that it was unlikely that political disruptions would cease to exist in oil-producing countries in the future. Others debated whether the required trillions of dollars of capital investments would materialize to keep oil supplies growing. In summary, there was significant debate about if and when world oil production would peak before falling off. Some believed the high oil prices of 2007–2008 were caused by speculation, others believed high prices were here to stay.

By 2008, China had developed an aggressive strategy of developing oil and gas reserves in producing countries for export to China. The Chinese had no qualms about working with the governments of countries that were "out of favor" with the current administration in the U.S. such as Iran, Venezuela, and Russia. But they had also worked to develop oil supplies in Indonesia, Kazakhstan, Peru, Tunisia, Argentina, Defer, and Sudan. The Chinese tried to buy U.S. oil company Unocal in 2005 for its significant oil reserves. However, Chevron stepped in to buy Unocal even as the U.S. Congress was debating whether it should allow China to buy Unocal. Particularly worrisome to some in the U.S. was China's work with Iran, which had huge reserves of both natural gas and oil (see Tables 13 and 14). Many believed that China was moving aggressively throughout the world to assure supplies of oil and gas in a time of declining supplies worldwide. It was clear that China's appetite for energy was growing rapidly, more rapidly than could be supplied by new discoveries in China. In the meantime, the U.S. had set up a strategic oil reserve that stored oil in salt domes along the Gulf Coast in the event of shocks to the supply of oil. This strategic oil reserve held 1.7 billion barrels in August 2007. At the same time, Europe had accumulated 1.4 billion barrels in reserves and Asia/Australia had accumulated an additional 0.8 billion barrels in reserves. China had recently announced a further buildup in oil reserves. It appeared to some that a period of hoarding potentially scarce resources of oil had begun.

Nuclear

The generation of electrical power using nuclear reactors requires a very different fuel source and processes. Rather than burning fossil fuels, which create significant quanti-

Figure 5 Projections of World Oil Production



Source: Latherer (2000)

ties of carbon dioxide and other greenhouse gases, nuclear reactors split atoms of special isotopes of uranium or other similar materials (e.g., thorium) to create heat. The splitting of these atoms does not result in carbon dioxide or other greenhouse gases, although the mining of uranium/thorium does result in the emission of tiny amounts of carbon dioxide. Nuclear power has been used for power generation since the first commercial nuclear reactor was built in England in 1956.[23] In 2007, the Energy Information Agency reported that there were 439 operating nuclear power plants in the world. Most of these were located in the U.S., France, and Japan although many other countries also used nuclear power. Table 4 shows the dependence of several countries on nuclear power. The U.S. actually produced more nuclear power than France, which generated nearly 80 percent of its power this way.

Nuclear power plants results in highly toxic radioactive byproducts, some of which have to be safely stored for tens of thousands of years to prevent the contamination of water, the surface of the earth, or the atmosphere. These materials need to be stored where they will not be affected by earthquakes, floods, geologic faulting, riots, accidents, or terrorist actions. There had been a long-running debate about where to store these materials. The Yucca Mountain Reserve in Nevada had been studied extensively since 1978 as a possible final repository for highly radioactive wastes from nuclear power plants. Although the site accepted some wastes as early as 1998, scientific debate on the merits of using the site for such a long-term repository had resulted in a postponement of its use until 2020 or later. There was still a lot of indecision in the U.S. about exactly where to put such toxic materials. Similarly, France had not decided where to put their nuclear wastes for the long term either. Currently, countries store the highly radioactive wastes in sealed containers at or near the various nuclear reactors. It is widely accepted that this is not a permanent solution, but no one has resolved the issue to date.

Uranium and thorium are relatively common in nature and power generation from these materials required such small quantities that the fuel cost was relatively small in the production of electricity using nuclear reactors. Proved reserves of these materials were sufficient to last from seventy years to as many as 1 billion years, depending on the specific isotope of material and type of reactor (different reactors use different fuel sources and have different waste products).

Two major accidents had occurred at nuclear power plants: one at Three Mile Island in Pennsylvania in 1979, and a second at Chernobyl in Ukraine in Eastern Europe 1986. The accident at Three Mile Island resulted in no deaths or injuries to either workers or any of the 25,000 people that lived within five miles of the reactor. In contrast, the accident at Chernobyl resulted in several explosions and a fire that sent a plume of more than fifty tons of highly radioactive fallout into the atmosphere, where it was spread by air currents over an extensive geographical area including parts of Russia, Europe, and eastern North America. Large areas in Ukraine, Belarus, and Russia were badly contaminated, resulting in the evacuation and resettlement of over 336,000 people. It has been estimated that the radiation caused more than 5,000 deaths by cancer and other related illnesses, although follow up studies were still underway.

Even before the 1979 accident at Three Mile Island, it had become substantially more difficult to build a nuclear power plant due to actions of a number of environmental groups. However, the Three Mile Island accident sharply drew attention to the risks of nuclear power in the U.S., even as nuclear power remained a mainstay for electrical power generation in France. The Nuclear Regulatory Commission (NRC) responded with extensive regulations related to the construction of nuclear power plants, resulting in sharply higher costs. The increasing costs and uncertain regulatory environment resulted in the scuttling of dozens of nuclear power plants on the drawing boards at the time. No firm in the U.S. had been awarded the permits to build a nuclear power plant since the 1970s.

The NRC did an about face in 1992, when it made it easier to permit the building and operation of new nuclear reactors. First, it streamlined the process, allowing a company to apply for an early site permit and for a separate but combined construction and operating license. No longer would a company have to build a reactor, incorporating design changes during construction, and then face the possibility of yet more design changes as the NRC debated whether to give the company an operating license after the reactor was built. Further, the NRC promised to speed up the approval process. Still, no one applied to build a nuclear reactor until 2003, when three nuclear utilities (Exelon Generation, Dominion, and Entergy Nuclear) tested the early site permit process. These three firms worked together to standardize the application process and also standardize 70–80 percent of the many design elements of a nuclear reactor. The standardization approach was expected to shorten the construction time by as much as two years and reduce the cost of building a nuclear reactor. The early work of these three companies, in combination with the incentives in the Energy Policy Act of 2005 and the fear of future taxes on carbon emissions, resulted in significant interest in nuclear power. By the beginning of 2008, many utility companies in the U.S. were at least contemplating the construction of a nuclear power plant even as the prices of oil, natural gas, and coal increased sharply.

All nuclear power plants operating in 2008 were based on the splitting of atoms in a process named *fission*. Early theoretical models by Albert Einstein and others suggested that the combining of certain small atoms (*fusion*) potentially resulted in far more power generation and fewer waste products than the splitting of large atoms (fission). For example, the tremendous energy generated by the sun comes from fusion. The two nuclear bombs used in World War II were based on fission, but subsequent bombs, such as the hydrogen bomb, were based on fusion. Since nuclear energy has war-time implications, significant experimentation has been done in this area including the exploding of at least 2,000 nuclear bombs in the world, many based on fusion. Scientists have experimented for more than fifty years, trying to control fusion so that energy would be released slowly to generate electricity. However, they have not been successful. Fusion came with the lure of tremendous amounts of cheap electricity with few emissions or byproducts. Estimates of the natural resources needed for possible future fusion reactors (deuterium and lithium) suggested that humanity would have superabundant and cheap energy for billions of years, *if* fusion could be harnessed. However, most thought it very unlikely that fusion would be controlled and commercialized in the near future, certainly not within the next ten years.

Renewables

Renewable sources of energy are those that renew naturally and include power generation from rivers, sunlight, wind, tides, geothermal, natural gas from landfills, and the conversion of biomass. These sources of energy often generate relatively little in the way of greenhouse gases, although both landfill gas and biomass result in the emission of some greenhouse gases. The use of the various types of renewable sources of power depends on the availability of rivers and lakes, abundant wind, abundant sunshine, significant tides, shallow and hot geothermal areas, significant landfills, and sufficient areas to grow plant matter for conversion to energy. Thus, each renewable source is only applicable in certain areas within the U.S. Other than hydroelectric (for which it was very difficult to obtain permits), none of these renewable sources of energy were very practical in 2008 without a federal subsidy referred to as the production tax credit (PTC). This tax credit was originally set to expire in December 2007, but had been extended by Congress for one year, or until December 2008. Many expected the PTC to be continued, but no one knew what form the continuation would take, and of course there were no guarantees. Importantly, the economics of renewables would change quite dramatically and immediately should a cap or a large tax be placed on the emissions of greenhouse gases. Such a tax would immediately make renewables much more cost-effective compared to alternatives and potentially drive up the cost of electricity at the same time.

A major issue with renewables is that many produced power intermittently depending, for example, on such things such as the amount of wind or whether the sun was shining. PowerCo was retiring a coal-fired plant that ran at full capacity to supply a constant base load of electrical power. In order to replace the base load capacity of the coal-fired plant using wind and solar, it would be necessary to install roughly 70 percent more capacity than currently in place. Of course, additional capacity would require more land, cost more to build, cost more to operate, and potentially require significant additional expenditures for transmission systems. The generation of significant amounts of power using wind, solar, or biomass required thousands of acres of land, especially given the capacity issue. Given the intermittent nature of power generated using wind and solar, management would also potentially also have to figure out ways to store electricity until it was needed. For effective use, the production of large scale power using renewables came with several complex problems that had to be resolved.

Table 15 U.S. Consumption per Year for Electricity Generation and Nominal Prices of Each Fuel Source

Year	Coal Consumption for Electricity	$/ton	Natural Gas Consumption for Electricity (millions of ft^3)	$/MCF	Oil Consumption for Electricity (barrels)	$/Bl	Uranium Consumption for Electricity (lbs.)	$/lb.	Price Index (1950)	CPI-U Values
1950	91,900,000	$5.19	629,000	$0.07	75,555,000	$2.51			1.00	24.10
1955	143,800,000	$4.69	1,153,000	$0.10	75,190,000	$2.77			1.11	26.80
1960	179,700,000	$4.83	1,725,000	$0.14	87,965,000	$2.88			1.23	29.60
1965	244,800,000	$4.55	2,321,000	$0.16	115,340,000	$2.85			1.31	31.50
1970	320,200,000	$6.34	3,932,000	$0.17	338,720,000	$3.18			1.61	38.80
1975	406,100,000	$19.35	3,158,000	$0.44	506,620,000	$7.67			2.23	53.80
1980	569,300,000	$24.65	3,682,000	$1.59	420,115,000	$21.59	32,600,000	$32.90	3.42	82.40
1985	693,800,000	$25.20	3,044,000	$2.51	174,470,000	$24.09	21,700,000	$20.08	4.46	107.60
1990	774,200,000	$21.76	2,794,000	$1.71	201,115,000	$20.03	20,500,000	$12.55	5.45	130.70
1995	832,900,000	$18.83	3,288,000	$1.55	108,040,000	$14.62	22,300,000	$10.20	6.32	152.40
2000	967,100,000	$16.78	4,093,000	$3.68	170,090,000	$26.72	24,300,000	$9.84	7.15	172.20
2005	1,015,600,000	$23.59	4,592,000	$7.33	190,165,000	$50.28	27,300,000	$14.83	8.10	195.30
2007	1,024,500,000	$25.40	5,607,000	$6.39	99,645,000	$66.52	18,500,000	$34.18	8.60	207.34

Notes

1. At the request of management, the name of the company and location in which it operates has been disguised, as has the name of the manager.
2. Plants used for base-load power usually have low operating costs and are run continuously at or near full capacity.
3. The term "renewables" refers to renewable sources of energy such as hydroelectric, wind, tides, solar, biofuels, etc.
4. The most recent Nuclear Regulatory Commission licensing process provided for design certification, early site approval, and combined licensing for construction and operation.
5. Capital expenditures increased in 2007 as a result of the costs of installing power plant scrubbers to decrease sulfur dioxide emissions, other upgrades at various power plants, and reliability improvements of the transmission and distribution systems.
6. Financial data has been disguised at the request of management. Data is based on company's 2007 Annual Report published in early 2008. Data is presented for fiscal years ending December 31.
7. Financial data has been disguised at the request of management.
8. PowerCo's cash from operating activities decreased in 2007, as compared with 2006. This was primarily because of an increase in working capital investment as the collection of higher electric rates from electric customers lagged payments for power purchases, and past-due accounts increased because of the higher rates.
9. According to Standard & Poor's, companies within this industry with a BBB bond rating had a median interest coverage ratio (operating income/interest expense) of less than four and a median total debt to capital ratio that was greater than 50 percent.
10. See Case Supplement.
11. Building these types of power facilities resulted in some greenhouse gas emissions. Mining uranium for nuclear, and using biogas/landfill gas, also resulted in the emission of some greenhouse gases.
12. See Appendix A for definitions for units of capacity and total amount of energy.
13. Refer to the Case Supplement for further information.
14. Two oil price shocks occurred during the 1970s. Crude oil went from roughly $3 to $12 per barrel in 1973–74 and from nearly $16 to over $35 per barrel in 1979.
15. Greenhouse gases are gases that some scientists believe act like a blanket around the world by holding in energy radiated by the sun.
16. D. Botkin, "Global Warming Delusions," *The Wall Street Journal* Oct. 21, 2007.
17. D. Whitehouse, "Has Global Warming Stopped?" *New Statesman* Dec. 2007.
18. CFCs were historically used in many places including refrigerators, fire extinguishers, and in dry cleaning.
19. Proved reserves indicate reserves that have been proven through engineering studies but have not yet been mined or produced.
20. Actually, very abundant supplies of natural gas had been located in nodules under the sea. But this source of natural gas was not included in the table, since the gas was so widely dispersed.

21. Fracing refers to the use of high pressure fluids to carry sand or other proppants into formations. The high pressure creates micro-fractures in the formation which are maintained by the proppant.
22. The Arctic Wildlife Refuge was estimated by the USGC to contain as much as 11 billion barrels of recoverable oil, or enough to supply the world for about 130 days.
23. Actually, the first nuclear reactor in the world was built in the Soviet Union in 1954, but it was not used for commercial power.

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