Impact of U.S. Nuclear Generation on Greenhouse Gas Emissions

Ronald E. Hagen, John R. Moens, and Zdenek D. Nikodem
Energy Information Administration
U.S. Department of Energy

International Atomic Energy Agency
Vienna, Austria
November 6-9, 2001

Contents

Chronology

- On May 17, 2001, President George W. Bush informed the Capital City Partnership in St. Paul, Minnesota, that "America should also expand a clean and unlimited source of energy–nuclear." On June 13, 2001, this view was expanded by Vice President Richard Cheney when he addressed the 12th Annual Energy Efficiency Forum. When asked about the Kyoto Protocol, he stated, "...one of the reasons we're advocates of nuclear power. If you're really concerned about global warming and carbon dioxide emissions, then we need to ... aggressively pursue the use of nuclear power, which we can do safely and sanely, but for 20-some years [this] has been a big no-no politically. Some of the same people who yell the loudest about global warming and carbon dioxide emissions are also the first ones to scream when somebody says, 'Gee, we ought to use nuclear power.'"

- On July 23, 2001, delegates at the COP6 Conference in Bonn, Germany, reached a consensus that could prove essential to implementing the Kyoto Protocol. The agreement preserved the original targets of the Protocol. The consensus, however, was achieved at a price that could make the goals impossible to attain. The United Nations Framework Convention on Climate Change noted that the Kyoto accord could now be ratified without U.S. approval. But the United States, which did not participate, is the world's largest consumer of fossil fuels. The accord was also achieved at the expense of the nuclear industry. Nuclear is not to be included among the 'flexible mechanisms' for reaching emissions targets.[1]

- On September 11, 2001, terrorists' attacks on the World Trade Center in New York and the Pentagon in Virginia claimed 5,000 lives. The attacks immediately raised new concerns about airline security. With the United States in a heightened state of alert, the concerns soon spread to security at nuclear facilities and petrochemical plants.

- On September 25, 2001, two months after the Bonn agreement dealt nuclear a significant reversal, the European Commission's Director-General, Francois Lamoureux, declared that nuclear power is unavoidable if the European Union hopes to succeed in both maintaining adequate energy supplies and reducing emissions levels. He estimated that "nuclear energy will account for savings of around 300 million tonnes in CO_2 (carbon dioxide) emissions between now and 2010–equivalent to halving the number of vehicles on (European Union) roads."[2]

---

[1] NucNet, News No. 236, "Nuclear Excluded as Governments Reach Kyoto Protocol Accord," edited by Chris Lewis, July 23, 2001.

[2] NucNet, News No. 288-B, "Use of N-Power 'Unavoidable' for EU Energy Security and Environment," edited by John Shepherd, September 25, 2001.

I. The Electric Power Industry and the Greenhouse Gas Issue

Twenty-four percent of the Earth's energy-related carbon emissions are produced in the United States. Forty percent of the U.S. energy-related greenhouse gases are attributable to the electric power industry. Eighty-two percent of the U.S. energy-related carbon emissions stem from the combustion of fossil fuels (coal, petroleum, natural and other gases). Ninety-two percent of the coal burned in the United States is used to power electric generators.

The Energy Information Administration (EIA) estimates that U.S. carbon dioxide emissions attributable to consumption and flaring of fossil fuels rose from 1,340 million metric tons of carbon equivalent (MMTC) in 1990 (Table 1) to 1,517 million metric tons of carbon (MMTC) in 1999. EIA reported that emissions in year 2000 rose to 1,562 MMTC, an annual growth rate of 3.0 percent, the largest increase since 1996 (3.6 percent).

In the final decade of the 20th century, U.S. carbon dioxide emissions continued to trend upwards despite a modest drop in other greenhouse emissions (Table 1).

Although the total emissions of greenhouse gases continue to increase, the National Energy Policy report noted some progress.[3] While the United States has experienced strong economic growth in recent years, there has actually been a slight decline in the rate of growth of CO_2 (carbon dioxide) emissions. According to the report, greenhouse gas emissions had been growing at a rate roughly equal to half that of the Gross Domestic Product (GDP). In 1998 and 1999, the GDP grew at a rate of 4 percent while the rate of growth for CO_2 emissions was 1.5 percent. "In addition, the carbon intensity of the U.S. economy—the amount of CO_2 emitted per unit of GDP—declined by 15 percent during the 1990's."[4]

Table 1. Recent Trends in U.S. Greenhouse Gas Emissions
(Millions of Metric Tons, Carbon Equivalent)

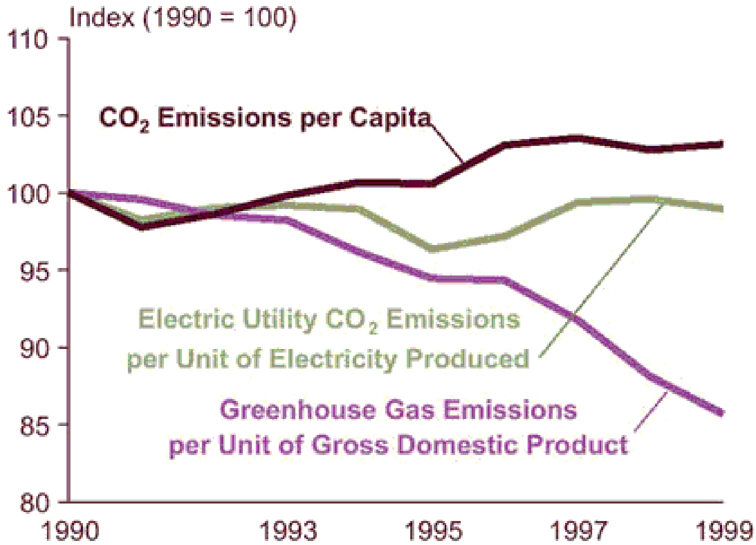
Gas/Source	1990	1995	1998	1999	2000
Energy Related CO_2	1,340	1,424	1,497	1,517	1,562
CH_4	176	178	170	169	177
N_20	108	118	118	118	99
HFCs, PFCs, SF_6	23	27	38	37	47
Total Emissions	1,647	1,746	1,824	1,840	1,885

Source: U.S. Environmental Protection Agency, *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-1999,* April 15, 2001, Washington, DC. U.S. Department of Energy, Energy Information Administration, *U.S. Greenhouse Gas Emissions* (November 2001).

[3] *National Energy Policy: Report of the National Energy Policy Development Group*, May 2001, pp. 3-11.

[4] *Ibid*., pp. 3-11.

Figure 1. Carbon Dioxide Emissions Intensity of U.S. Gross Domestic Product, Population, and Electricity Production, 1990-1999



U.S. carbon dioxide emissions (Figure 1) rose from 1,517.1 million metric tons of carbon (MMTC) in 1999 to 1,561.7 MMTC in 2000. The resulting 2.9 percent growth rate was the highest since 1996 (when it increased by 3.6 percent over 1995 levels). Between 1990 and 2000, emissions increased by 16 percent while the U.S. economy grew at a rate of 39 percent. During this time, CO_2 emissions at electric utilities rose from 476.7 MMTC in 1990 to 641.6 in 2000, an increase of 34.6 percent. Carbon dioxide emissions represent 81 percent of U.S. gross greenhouse emissions. Methane emissions declined during the period while the increases in nitrous oxide emissions were much less significant, especially since 1995.

Whether or not nuclear power can solve the greenhouse gas problem has been (and will probably continue to be) debated but nuclear power clearly can significantly reduce emissions levels when it replaces fossil fuels. Unlike fossil fuels, nuclear emits no carbon dioxide (CO_2) or other greenhouse gases. About one fifth of U.S. electricity is generated by nuclear power. Replacing all or most of nuclear-generated electricity with fossil fuels without a corresponding rise in emissions would be a substantial technological challenge. Alternatively, the modest supply contribution by solar, wind, and geothermal, and difficulties increasing hydropower supplies suggest that replacing nuclear with alternative clean-burning technologies would be difficult.

There is at least one option on the demand side of the issue—conservation programs. Less electricity consumed results in less electricity generated and more fuel saved for future use. To suggest that conservation efforts alone can substantially reduce emissions from the electric power sector, however, contradicts the most consistent energy trend in the United States. For more than half a century—through recession and recovery, bear markets and bull markets, utility bankruptcies and economic booms, blackouts, oil embargoes, conservation campaigns, wicked winters and searing summers—the annual electricity output has consistently exceeded each previous year. Total retail sales of electric power throughout the United States were less than 300 billion kilowatthours in 1950. Between 1996 and 2000 sales rose by 316 billion kilowatthours to a total of 3,621 billion kilowatthours. EIA projects that electricity demand will continue to climb into the 21st century.

The United States relies heavily on fossil fuels and nuclear power to generate its electricity. Of all fossil fuels, coal provides the largest volume of carbon emissions—an average of 7 times the total for comparable amounts of natural gas. Fossil fuels supply slightly over 70 percent of the U.S. electricity market. Nuclear is the only non-fossil fuel that generates more than 10 percent of total electricity. Fossil fuels are so dominant in the electric power industry that EIA projects continued reliance on them for at least two decades. Rather than abandoning fossil fuels, the electric power industry is expected to rely on clean technologies, emphasize those fossil fuels that do not have substantial sulfur content, or shift from reliance on one fossil fuel to reliance on another. EIA projects that 90 percent of the new electric generating capacity that comes on line by 2020 will burn natural gas.

Coal presently generates more electricity than all other fuels combined. Coal-fired generation was 52 percent of total electricity in 2000; nuclear was nearly 20 percent and natural gas ranked third with about 17 percent. Each of the other fuels produced less than 10 percent. Although new technologies and the increased use of low sulfur coal will enable coal to retain the largest share of the electricity market for decades, its share is expected to shrink from a majority to a plurality as new gas units come on line.

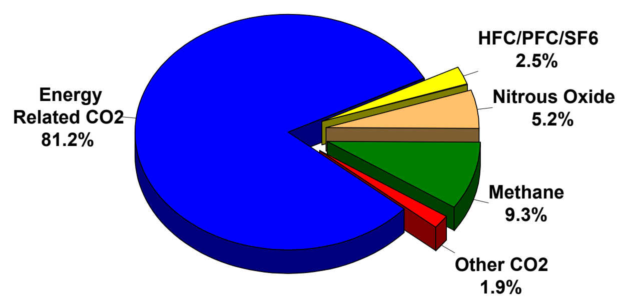
Fossil fuels are composed primarily of carbon (Table 2) and hydrogen elements though many other elements can be involved. The two principal emissions from generation of fossil fuels are carbon dioxide and water, both of which can function as a greenhouse gas. Water cycles are fairly well understood and to date have not been a central subject of global warming concerns. Carbon dioxide emissions, because of their complex cycles and their significant volume, are considered are a principal concern in this matter.

Table 2. Electricity Industry Carbon Emissions
Metric Tons per MWh, Carbon Equivalent

	Metric Tons per MWh
Coal	.266
Petroleum	.208
Natural Gas	.132

Source: Energy Information Administration, calculated from *Annual Energy Outlook 2001*

U.S. Greenhouse Gas Emissions, by Gas, 2000



The Carbon Issue

The amount of carbon emitted directly from a nuclear power plant is, essentially, zero. Most coal-fired generation in the United States comes from steam turbine-based plants using pulverized coal, although a few other types of coal plants exist. Petroleum is a more complex issue, involving a variety of technologies ranging from combined-cycle to stand-alone gas turbines to steam turbines to diesel generators. Natural gas generation is also mixed with a few steam turbine facilities remaining but a large portion composed of gas turbine and combined cycle-based technologies.

Changing the technology mix can alter the amount of carbon-based emission from a fuel. This is because the thermal efficiency of power generation varies with the generation technology applied. Natural gas has a lower carbon content per energy content than does petroleum. Petroleum contains less carbon per energy content than does coal. Added to this is a general tendency for natural gas to be used in more thermally efficient generation facilities than petroleum. Petroleum is more often used in thermally efficient facilities than coal.

Thermal efficiency is not always cost free, especially when dealing with coal. Thus while carbon emissions from coal might be reduced by using more efficient plant designs, economic incentives to do so might not be great. Moreover, most forms of power generation exist because they either are or were intended to fit an economic niche better than available alternatives. Thus higher fuel costs might make combined-cycle based natural gas-based power unsuitable for base load power generation in many locations, especially when low cost coal or nuclear power is available. A decision to use a fuel that is more suitable for managing carbon emission might also involve using a fuel that is less economically attractive. Many other issues are involved in the power choice decision including the regulatory environment and national and local policies concerning fuel choice.

The issue then arises regarding the potential carbon emission displacements if nuclear power capacity is expanded or contracted. The average nuclear power plant in the United States is slightly less than 1,000 MWe capacity. The proposed AP1000 design is slightly greater (planned capacity is around 1,092 MWe) than this but significantly less than the ABWR design (about 1,350 MWe). Also, it is significantly larger than the AP600 (600 MWe) and the pebble bed reactor (130 MWe). If a new U.S. reactor is built, it might typically be described as around 1,000 MWe. When a reactor is permanently shut down, it might be among the older reactors and thus also among the smaller units. A closed reactor should also be a "less efficient" reactor, thus it typically might operate below the industry mean capacity factor, about 90 percent. It should typically be less than 1,000 MWe and less successfully operated.

Increases and decreases in operating capacity by one unit are thus probably not equivalent. Moreover, because nuclear power operates at a higher capacity factor than do either typical coal- or gas-fired plants, 1,000 MWe of nuclear capacity usually displaces or is displaced by more than 1,000 MW (Table 3) of coal or gas capacity. For the purposes of discussion however a "typical" reactor of 1000 MW operating at 90 percent capacity will be discussed. When gas or coal or petroleum are compared to nuclear capacity, it is the generation of electricity that is compared and not the capacity of the generating unit. The "typical" nuclear power plant generates 7,889,400 MWh/yr of electricity. The carbon emissions displaced or added as such capacity is opened or closed are shown on the following chart and are based on the preceding table of emissions.

Table 3. Annual Carbon Displaced by 1,000 MWe Nuclear Plant Operating at 90 Percent Capacity Factor

Alternative Fuel	Carbon Displaced (Metric Tons Carbon Equivalent)
Coal	2,098,580
Petroleum	1,640,995
Natural Gas	1,041,401

Clearly, the potential contribution of a single nuclear power plant is substantial although its contribution would be affected by what fuel is displaced and less apparently by how effectively the plant is managed.

II. The Current Role of the U.S. Nuclear Industry

Nuclear Power's Role

"The investments that the Department of Energy proposes to make in nuclear energy, science and technology are driven by the recognition that nuclear technology serves the national interest for reliable, affordable and environmentally sustainable electricity."[5]

Before any meaningful discussion on new nuclear construction, environmental impacts, capacity upgrades, or training of future plant operators can take place, the question must be asked, "is nuclear power necessary?" There continues to be much passionate debate about whether "nuclear technology serves the national interest." Only a few years ago, most energy forecasts projected no new construction, no re-licensing, and a decline in capacity as aging units retired. The passage of 'nuclear dinosaurs' into extinction would be offset by the discoveries of vast resources of natural gas.

Although both the first Bush and the Clinton administrations projected increased reliance on natural gas, there are concerns that existing gas wells might not be sufficient to supply future needs. President George W. Bush, declared that "...our ability to develop gas resources has been hampered by restrictions on natural gas exploration. Our ability to deliver gas to consumers has been hindered by opposition to construction of new pipelines that today are more safe and more efficient. I will call on Congress to pass legislation to bring more gas to market while improving pipeline safety and protecting the environment."[6]

Setting aside the question of whether or not natural gas resources are sufficient to meet all future demands, nuclear power itself should be examined in the dispassionate light of statistics. Eighty percent of U.S. electricity is supplied by non-nuclear sources. It is clear that there are alternative fuels in the market place. Natural gas, petroleum, and other gases (such as coke oven gas, butane gas, waste gases from coal) combined produced about 19 percent of U.S. electricity in 2000—only slightly less electricity than nuclear provided. But, to replace the 103 operating nuclear reactors in the United States with oil and gas units would involve significant construction.[7] The United States operated more than 3,000 oil-fired generating units and more than 2,000 gas-fired units in 1999.

Even in the absence of new nuclear construction since 1996, the prospect of replacing nuclear has become more difficult rather than less. U.S. nuclear power plants are among the world's leaders in capacity utilization. This industry leadership has contributed to record levels of electricity generation from nuclear resources. In 1999, the United States was one of 14 countries that set national records for nuclear generation. U.S. nuclear generation jumped 4 percent in 2000 to a new national and world record of 754 billion kilowatthours. But 'world records' alone do not fully answer the question, can the United States meet its energy needs without nuclear power?

---

[5] Statement of Spencer Abraham, U.S. Secretary of Energy, before the Senate Committee on Energy and Natural Resources, May 10, 2001.

[6] Address to the Capital City Partnership, President George W. Bush, Jr., St. Paul, Minnesota, May 17, 2001.

[7] The Brown's Ferry 1 unit, still fully licensed, is not operating and would make the number of commercial reactors 104 units

The nuclear option is omitted in the Energy Information Administration's "Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants: Sulfur Dioxide. Nitrogen Oxides, Carbon Dioxide, and Mercury and a Renewable Portfolio."[8] Rather clearly nuclear power has a contribution to make to each of these emission factors though there is a legitimate question whether the costs of building new commercial nuclear reactors might still be prohibitive and thus excluding nuclear power from practical options. The report's conclusion regarding setting a cap on carbon dioxide emissions is noteworthy:

> When a cap on power sector CO_2 emissions is assumed, it is projected to have significant impacts on all aspects of the electricity production business. The key CO_2 compliance strategy is expected to be the retirement of coal-fired capacity in favor of natural gas and, to a lesser extent, renewables, as well as the continued operation of more existing nuclear power plants. Consumers are also expected to reduce their use of electricity in response to higher electricity prices. (page x)

It is a rather direct affair to add new nuclear power units to this scenario although the extent of any nuclear contribution would have to depend on modeling that has yet to take place. First, nuclear might potentially join gas among the alternatives to closed coal plants. Indeed a valid nuclear option might increase the rate of coal plant retirements. Retirements of existing nuclear reactors are consistent with previous EIA analyses of nuclear power options. We have been slowly decreasing our anticipated rate of plant retirements in the United States as we better understand the operating cost implications of the Nuclear Regulatory Commission's relicensing process. This direction of our forecasts might be anticipated to continue for yet a while though some reactor retirements are to be anticipated nonetheless. Clearly, any CO_2 cap would provide incentives not to retire nuclear power plants.

The basic principle that comes from the cost requirements on nuclear power and the issue of greenhouse gas emissions is that the most direct method for allowing nuclear power to make a contribution to greenhouse gas mitigation is to lower the cost of building nuclear power plants. A second contribution would be to find ways to facilitate nuclear power's contributions to base load power production. These promote the nuclear power industry's advantages. Facilitating the removal of nuclear's disadvantages would allow nuclear power to more readily displace emitting technologies.

Nuclear Offsets

For each U.S. commercial reactor, the reduction in emissions levels when compared to using fossil fuel is calculated for 1960 through 2000 for this report. To assess the impact of nuclear power generation on GHG emissions over the historical period 1960-2000, it was necessary to answer the question: What would the GHG emissions have been in the absence of nuclear power? Annual offsets were calculated for each nuclear unit, unit results were aggregated into regional offsets, and regional offsets were combined into national offsets.

Methodology

To perform this analysis, a list of nuclear units, operators, locations, and commercial operating dates was developed. The annual electricity generated in megawatt hours by each nuclear unit that operated for any part

[8] This analysis is essentially repeated in two other recent EIA reports, "Reducing Emissions of Sulfur Dioxide, Nitrogen Oxides, and Mercury from Electric Power Plants" (September 2001) and "Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants with Advanced Technology Scenarios" (October 2001)

of the period 1960-2000 was then identified. Next, a substitute fuel for each specified nuclear unit was selected, based on the identification of a reference fossil-fired unit within the applicable utility's portfolio. Coefficients linking GHG carbon to electric energy generation for oil, coal, and natural gas were identified.[9] Using these established carbon-release coefficients, the total amounts (in million metric tons) of offset GHG carbon were calculated by year (1960 through 1998) for each hypothetical fossil-fired unit. These amounts were then aggregated into (1) unit totals for the period 1960 through 2000, (2) totals by census region, and (3) national totals by year.

Several assumptions were made in calculating the historical offsets from 1960 through 2000. These assumptions include:

Exactly the same amount of electricity would have been generated had nuclear been replaced by the fossil fuel substitute.

A utility would have selected a fossil fuel that reflected its buying preferences for units beginning operation on the same, or approximately the same, schedule as the nuclear unit actually ordered.

- In cases where there was no reference unit, the fuel most commonly used by a utility or group of utilities in a region was selected.

- The electrical energy consumed in fuel cycle activities (especially uranium enrichment by gaseous diffusion), which would only have occurred in nuclear plant operations, was not taken into account.

- The 1997 carbon emission coefficient values were used for residual fuel oil, electric utility coal, and natural gas, respectively.

- In selecting replacement fuels, hydroelectric generation was not an option, as it had already been utilized to the maximum extent possible.

- None of the replacement oil units were converted to coal during the early 1980s.

- Where data on unit gross production were not available for a specific year and only net production was reported, the ratio of net to gross production was calculated based on the average for that unit for the previous five years.

- In converting from gross electrical energy produced to thermal energy consumed (MWh to quadrillion Btu), a 33-percent thermal efficiency factor was used for all units, both fossil and nuclear.

For each census region, Table 4 notes the number of nuclear units that were replaced by coal, oil, or natural gas, in calculating GHG offsets. Census regions (Figure 3) include: New England, East South Central, Middle Atlantic, West South Central, East North Central, Mountain, West North Central, Pacific Contiguous, South Atlantic, and Pacific Non-Contiguous. The total electrical generation replaced and the associated GHG carbon offset were calculated for each region. In each case, the grand totals for the United States are also presented.

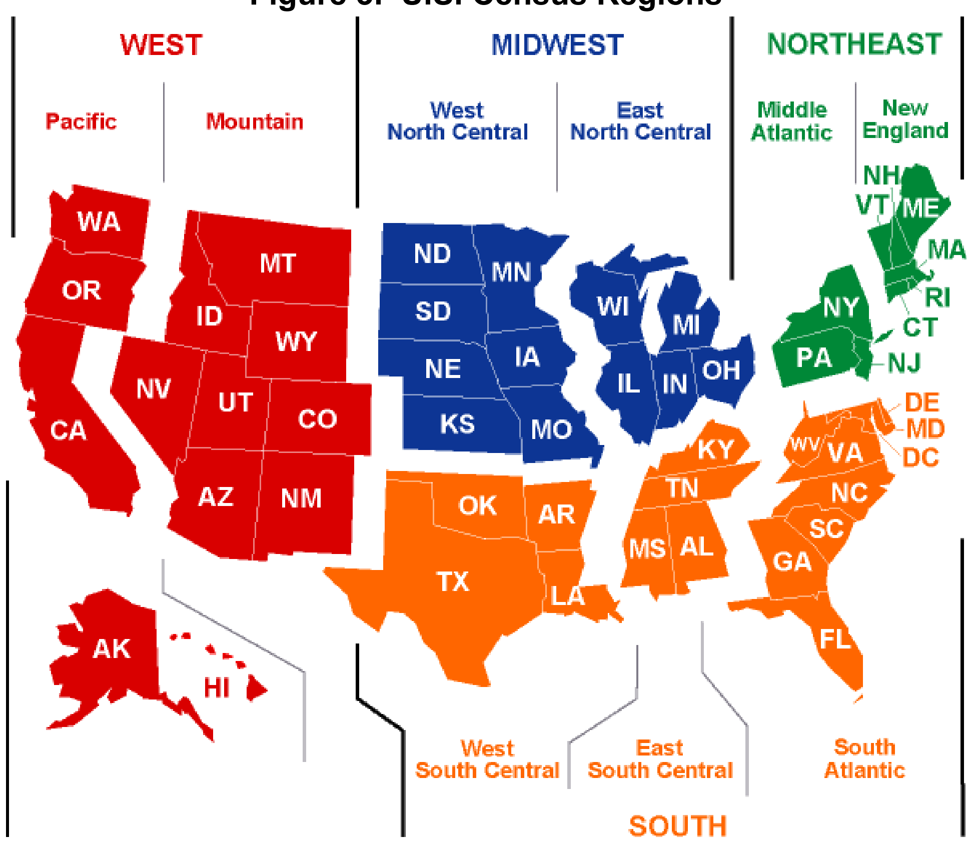
---

[9] The values of these coefficients in million metric tons carbon/quadrillion BTU are as follows: oil 21.49, coal 25.74, natural gas 14.47.

Table 4. U.S. Nuclear Power Generation Greenhouse Gas Offset, Totals by Region 1960-2000

U.S. Census Regions	Replacement Units			Total Replaced Generation in Gross Megawatthours	Total Carbon Offset in Million Metric Tons
	Total	Coal	Oil/NG		
New England	9	1	8	858,935,592	192
Middle Atlantic	21	8	13	2,225,405,414	535
East North Central	25	25	0	2,445,271,740	651
West North Central	8	8	0	885,633,096	236
South Atlantic	27	19	8	3,384,745,903	848
East South Central	9	8	1	947,525,934	236
West South Central	8	7	1	816,502,898	203
Mountain	4	4	0	371,307,740	99
Pacific	9	2	7	800,446,388	142
U.S. Totals	120	82	38	12,735,774,705	3,142

Figure 3. U.S. Census Regions



Separately, EIA has estimated that a total of 641.6 million metric tons of carbon were released by the nation's electric utilities during 2000.[10] The operation of nuclear plants through 2000, therefore, has effectively offset over five equivalent years of carbon emissions by the utility sector. Once the inventory of nuclear units began to increase through the 1970s and 1980s, the annual carbon offsets rose significantly. The rate of increase leveled off through the 1990s (with actual decreases in two years), as new plant additions ended, several nuclear units were shut down permanently, and nuclear capacity factors gradually increased.

The process of selecting substitute fuels for nuclear units introduces uncertainty into the offset results. As one way to gauge the possible level of uncertainty, the offsets were recalculated under a different fuel replacement scenario. Under this scenario, it was assumed that all replacement units burning oil would become coal-fired in 1981 and remain coal-fired through 2000. (1981 was selected because it was the time frame for the utility industry's oil-to-coal conversion campaign.) Under the alternative scenario, the national total offset becomes 2,832 million metric tons of carbon. From this we can deduce that the assumptions made in selecting replacement fuel do not appear to introduce significant uncertainty into the results.

Available Choices

Although the nuclear industry continues to produce enough electricity to more than offset the declining capacity due to permanent reactor shutdowns, it can not offset the environmental impact of permanent shutdowns. In 1998, Zion 1 and 2 nuclear reactors were permanently shut down. The closure of this pair, each with a net capacity of 1,040 MWe was the largest loss of U.S. nuclear capacity in a single month. EIA calculated that if the electricity generated by the Zion power plant had been displaced by coal (the most likely alternative fuel), greenhouse gas emissions for 1975 through 1998 would have risen by 68.9 million metric tons.

The largest single U.S. reactor to close in the 1990's was California's Trojan 1 with a net capacity of 1,130 MWe. As with Zion 1 and 2, coal would have been the most likely alternative fuel. The use of coal in place of Trojan's nuclear output throughout the period 1976 to 1992 would have added 23.7 million metric tons to greenhouse gas levels in this country. According to the study, of the 104 commercial nuclear reactors licensed in the United States, fossil fuels would be the alternative source of energy for all, with coal the most frequent choice.

During the California energy crisis, there was speculation in the media about some of America's shutdown reactors being returned to service. Discussions included California's Rancho Seco (918 net MWe capacity, retired 1989) or the two Zion units in Illinois have dissipated with the passage of the crisis and the realization of potential obstacles. Increasingly, however, the return to service of Brown's Ferry 1 has received attention. This reactor benefits from two detailed feasibility studies, interested investors, a ready market for its output and an operating license that has not been abandoned. While observers dispute which of these factors ranks first in importance, the presence of these factors has led a few analysts to label the return of Browns Ferry 1 a certainty. The plant's owner, the Tennessee Valley Authority, appears to be more cautious in its views however. Brown's Ferry 1 was shut down in 1985 following a fire in the control room. The fire was not nuclear-related and did not pose a nuclear hazard. During its decade of active service (1975-1985), the reactor

[10] Energy Information Administration, *Emissions of Greenhouse Gases in the United States 2000* (November 2001).

is estimated to have offset 14.88 million metric tons of greenhouse gas emissions.[11] This estimate is based on the assumption that coal would have been the most likely replacement fuel if this unit had not operated.

The Kyoto Protocol (see Appendix) seemed to offer new opportunities for commercial nuclear expansion both at home and abroad, but that door may have closed. The decision at the Hague by the international community to reject nuclear as a clean development mechanism was viewed by the nuclear industry with disappointment. Sixteen percent of the world's energy is supplied by 438 commercial nuclear reactors. For countries that lack abundant domestic energy resources, nuclear power can be attractive option. Developing countries dependent on fuel imports are especially vulnerable in times of supply shortages. Even when these countries have adequate funds to meet their energy needs, will they also have adequate funds to meet international environmental standards? If so, will they also have sufficient funds to research and develop new energy sources to meet increasingly stringent emissions standards?

The focus of this report is on emissions, but mention should be made of the environmental problem unique to nuclear power, radioactive waste. Because radioactive waste is a solid rather than a gas, it does not have a significant impact on the air–especially if properly controlled. After the first U.S. commercial nuclear power plant went on-line in 1957, the U.S. nuclear industry has produced an estimated 38,000 tons of high-level nuclear waste (mostly in the form of spent fuel rods). This is a very low volume of waste compared to the amount of energy generated.

[11] *Ibid*., p. A-2-4.

III. The Future Role of Nuclear Power

Although the EIA does not project any new nuclear construction, nuclear power is anticipated to remain a leading non-emitting source of electricity. Hydroelectric power, the most significant competitor among renewable sources, provides less than 10 percent of U.S. electricity. Although hydro generation is expected to ris slightly by 2020, its share of the electricity market should slips to 7 percent. Solar and wind power are often not cost effective for large scale power generation. With further research and development, both will experience some growth–although biomass, urban waste, geothermal are expected to grow faster. These five fuels now account for about 1 percent of the electricity market. EIA projects that they might account for 3 percent of the market by 2020.[12]

To calculate the potential impact of new technology in coping with the greenhouse gas problem, the Department of Energy commissioned the *Clean Energy Futures* (CEF) Study. The study analyzed three cases: business-as-usual, moderate, and advanced.

The most significant changes in the business-as-usual case were revisions to three of the energy-intensive industries in the industrial sector, which reduced projected primary energy consumption in 2020 by 1 quadrillion Btu, ***and a reduction in the costs of nuclear plant refurbishment and relicensing,*** *resulting in fewer nuclear retirements and making it easier to reduce CO2 emissions."*[13]

The EIA noted that "nuclear power could be the key to reducing carbon dioxide emissions" in the United States.[14] EIA projected that by 2015 the average annual capacity factor of the nuclear industry will rise to 90 percent. Capacity factors had already averaged 89 percent by 2000 and were on a pace to do even better in 2001. The increased output of emissions-free electricity makes nuclear more attractive and even more difficult to replace. After nearly a decade of stagnation in the nuclear market, the record performance of 1999 and 2000 may seem irreversible. Just as a reliable analysis would have taken into account all the positive factors in the nuclear industry during the gloomy 1990's, it is no less important to consider the potential problems during the "nuclear renaissance" of today. Lengthy construction periods, public concerns about nuclear waste, the potential shortage of trained nuclear engineers, aging equipment, competition from other fuels, and the uncertainties created by deregulation and new legislation are some, but not all, of the obstacles to nuclear expansion. In EIA's low nuclear growth scenario, the Nation would experience significant retirements of reactors by 2020. To offset the retirements, nearly 60 new fossil-fired plants (each averaging 300 MWe of capacity) would be needed.

No U.S. nuclear power reactors are now under construction or slated for construction. There is however a smattering of fairly large and experienced electric utilities that now indicate they might like to build a new nuclear power reactor in the not too distant future. Several additional firms say they might soon seek to license sites for potential nuclear reactor construction. A number of half-completed power reactors and mothballed

---

[12] Nuclear Energy Institute, *Meeting Our Clean Air Needs with Emission-free Generation* (Washington, DC, May 1999).

[13] Energy Information Administration, *Strategies for Reducing Multiple Emissions from Electric Power Plants* (October 2001), p. xviii.

[14] Energy Information Administration, *Annual Energy Outlook 2001*, p. 76.

facilities are also being carefully examined as potential subject for repair or renewed building activity. Finally, capacity upgrades of various classes are now being undertaken by reactor owners. Projects under active consideration have a potential of increasing individual reactor capacities by as much as 5-20 percent. Full potential upgrades would total around 10 GW or the equivalent of ten new reactors. Not all reactors, however, are anticipated to be upgraded to their full potential capacity.

Locating the Renaissance

The recent activity and optimism within the U.S. nuclear power industry contrasts with the view that new nuclear reactors are too expensive to build. While some of the refreshed look at nuclear power stems from technology and engineering changes over the past two decades, the fact remains that none of the more promising new reactor designs has yet been built. No one really knows what future nuclear power construction will cost. The more pragmatic low assessments of future construction costs indicate that, at best, new reactors will be priced at levels that might compete with other fuels. Even under optimistic assumptions, nuclear expansion will not drive competing fuels out of the market in the near future.

This picture becomes one of uncertainty tinged with optimism. If options or opportunities can be found to enhance the attractiveness of nuclear power, then its future share of power demand could be larger. The nuclear industry now sees environmental emissions from power plants, especially greenhouse gas emissions, as an area that promises potential advantages over alternative available fuels. Rather clearly because economic comparisons among fuels are at best now competitive, the lower the relative costs of building or operating nuclear power plants can be made, the larger will be the potential share of nuclear power in the future.

The Importance of Sub-Markets

Projections of electric power capacity requirements can be misleading because they do not distinguish among sub-markets of the electric power industry. The most clear sub-market distinction is between base and peak load markets. Base load markets are in demand during all times of the day and during all seasons. Peak load markets are fundamentally everything else. Peaks can be daily, weekly, and seasonal. If peak load power is demanded relatively persistently, then it is sometimes referred to as intermediate load. Because steam turbine based nuclear power output levels are usually difficult to rapidly increase or decrease without venting surplus steam, nuclear power is usually viewed as base load supply source. This view is reinforced by nuclear power's relatively low operating costs relative to other power sources. Other power generation systems including hydroelectric turbines, gas turbines, and diesel generators are usually more suitable for changeable peak requirements. Intermediate load is exactly that, intermediate. Various fuels and power generation systems contribute different assets to intermediate supplies. Other electricity sub-markets follow from traits such as supply reliability and locational advantages.

Given the sub-markets for electricity, it is notable that specific claims of total volumes of electricity generating capacity that are required are of limited value. If some recent claims of generation requirements were applied to 2000, for example, the issue would not be adding new capacity. More than enough, by such standards, was built during 2001. The issue is rather meeting an array of sub-market needs. Peaking capacity will be unused when demand is off-peak. Solar power or wind power would not always be available when required or would require expensive power storage. Similarly, nuclear power does not meet all market requirements. A nuclear power supply projection that meets all new demand might run risks parallel to those that assume meeting no new power needs. The markets that nuclear might meet, if all goes well, should be somewhere between all and none.

Proponents of nuclear power point out that the technology emits virtually no greenhouse gases, no acid gases, no particulates, and, except in the form of spent fuel, no heavy metals. Critics of nuclear power assert that any of these benefits are outweighed by costs related to safety and by costs related to the actual construction and operation of nuclear power plants, including spent fuel disposition and plant retirement costs. The twofollowing projections of the potential for nuclear power in the United States represent the extremes of assessments for the potential for nuclear power over the next two decades (to 2020).

Forecasts of Nuclear Power in the United States

The Energy Information Administration's latest projections (Figure 4, Figure 5)for the U.S. nuclear power industry are in the *Annual Energy Outlook 2001,* published December 2000. The recent series of nuclear power industry success have gradually influenced EIA assumptions and the updated publication may reflect this in the *Annual Energy Outlook 2002*. Its release is anticipated late in 2001. So long as such good times continue for nuclear, similar revisions might be anticipated.

Figure 4. Projected Electricity Generation by Fuel, 1999 and 2020 (Billion Kilowatthours)

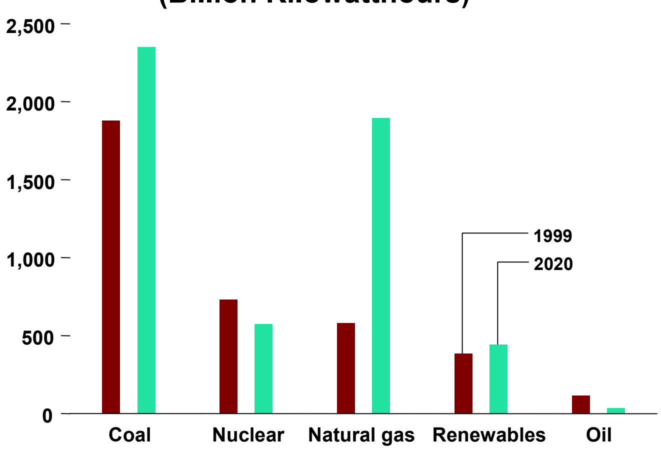
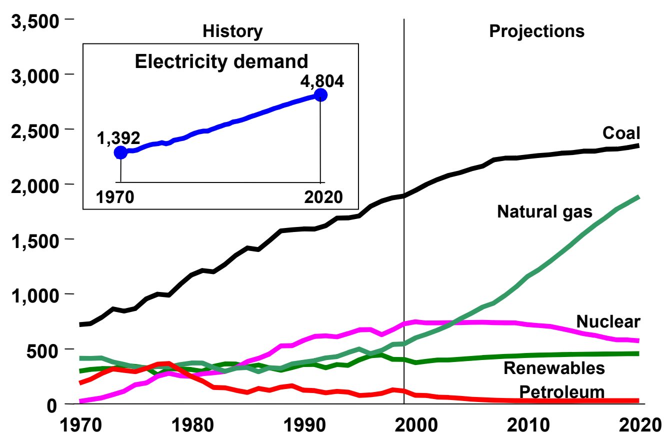


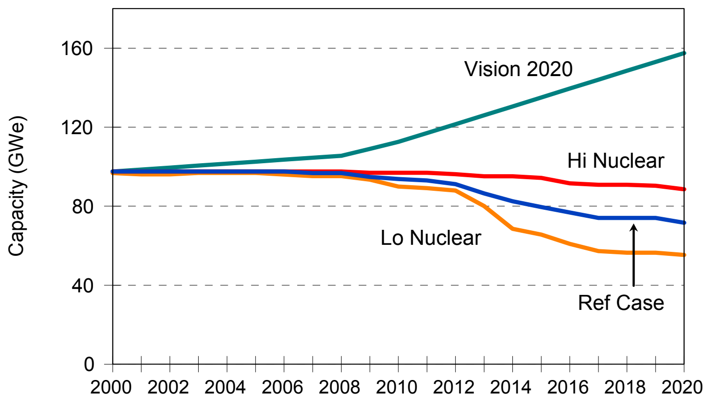
Figure 5. Electricity Generation by Fuel, 1970-2020 (Billion Kilowatthours)



The high and low nuclear cases (Figure 6) reflect different assumptions regarding the capital investments required to ensure plant life extension. In the low nuclear case, all three stages of investment were increased by $50 million. In the high nuclear case, the first stage investment was eliminated, and second and third stage investments were reduced by $100 million and $125 million, respectively. In the high nuclear case, relative to the reference case, 16 gigawatts of new fossil fuel capacity would not be required due to continued nuclear generation, by 2020.

The low nuclear case would require the addition of 13.2 gigawatts of fossil fuel capacity in the same comparison. The high case represents an avoidance of 14 million metric tons of carbon emissions in 2020,

Figure 6. Operable Nuclear Capacity in Four Cases



relative to the reference case. The low case, however, indicates an additional 15 million metric tons of carbon emissions in 2020, relative to the reference case.[15]

EIA projections have been criticized as being unusually conservative. This is partly the result of the assumptions under which these projections are made. They do not allow for major changes in laws or policies. The approach to technology and its impact on cost does not allow for reference case cost reductions as substantial as those claimed by vendors, although similiar claims were allowed for in a side case in the *Annual Energy Outlook 2001*. A second criticism might be applied to the high level of anticipated retirements of existing nuclear reactors within the United States in the *AEO2001*. This is a product of the essentially conservative approach to forecasting and of the fact that much new evidence on this matter has arisen since the projections were published.

A different view on the potential for nuclear power in the United States is presented in the "Vision 20/20" forecasts of the Nuclear Energy Institute (NEI), an organization that represents the interests of the nuclear power industry. The "Vision 20/20" program anticipates a strengthening of the U.S. nuclear power industry during the next twenty years.[16] The Vision 20/20 approach starts with the Energy Information Administration's *Annual Energy Outlook 2001* projections for electric power but alter the assumptions for nuclear power. In particular, Vision 20/20 excludes EIA projections for the retirement of existing nuclear power reactors by 2020 and assumes that all reactors will be relicensed and will continue operation. To this the NEI adds an assumption that plant owners will upgrade existing U.S. nuclear capacity by 10 GW and that 50 GW of new capacity would be built (Table 5). The outgrowth of these changed assumptions would that non-emitting (Table 6) (renewables and nuclear) electricity generation would remain around 30 percent of U.S. generation.

Table 5. Increases in Nuclear Power Capacity and Electricity Generation, 2000-2020

	Capacity	Generation
New Nuclear Capability	50,000 MW	Up 394 billion kWh
Enhanced Capability	10,000 MW	Up 79 billion kWh

Table 6. Changes in Non-Emitting Electricity Generation

Year	Nuclear Generation	Renewable Generation	Nuclear and Renewables	Share of Total
2000	754 billion kWh	362 billion kWh	1,116 billion kWh	29.3 percent
2020	1,227 billion kWh	444 billion kWh	1,671 billion kWh	31.4 percent

[15] United States Department of Energy, Energy Information Administration, *Annual Energy Outlook 2001*.

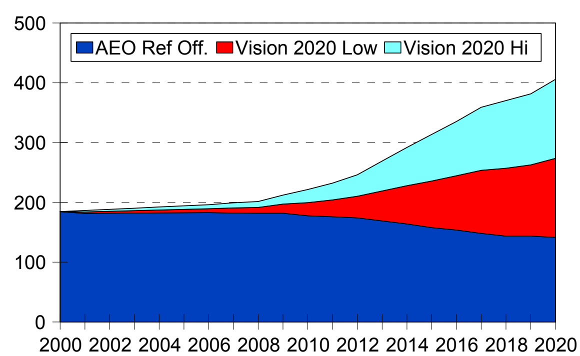
[16] See Nuclear Energy Institute, "From Renaissance to Reality," which summarizes the NEI's Vision 20/20 program.

NEI's Power Projections

While EIA's forecasts are criticized as too conservative, the NEI projections might be criticized as too ambitious. The 10 GW increase in capacity at U.S. reactors assumes that virtually all feasible upgrades at existing reactors will be undertaken. Costs and technical bottlenecks make this unlikely. Moreover the projections of 50 GW in new capacity appear particularly high. No power generating firm in the United States has yet indicated its intentions to build any of the three licensed designs, the AP600 (Westinghouse BNFL), the ABWR (General Electric), and the System 80+ (Westinghouse-BNFL). Some have publicly indicated interest in possibly building the next generation of new reactors: the AP1000 (Westinghouse BNFL) and the pebble bed modular reactor (South African-led group). These designs are only in the earliest stages of licensing. If there are no unanticipated obstructions, these might be licensed around 2004-2005. Full construction would have to await licensing though preliminary activities might precede that event. This would mean that construction could probably not begin until the end of this decade. The NEI numbers would then require significant financial or political advantages over alternative electricity sources for the new designs that have not yet been demonstrated.

The *AEO2001* and *Vision 20/20* projections (Figure 7) thus might represent lower and upper limits of any potential course for the nuclear power industry. This is a vast range of uncertainty which will only be close with time and information.The Vision 2020 conclusions are more of an optimistic vision than a forecast. As such they represent an unlikely upper limit of where nuclear power production might go. We have in the following figure presented the alternative carbon emission offsets for the AEO2001 Reference Case, the AEO2001 Low Nuclear Case, the AEO2001 High Nuclear Case, and Vision 2020.

Figure 7. Carbon Emissions Offsets: Three Cases
(Million Metric Tons Carbon Equivalent)



The assumptions behind the AEO2001 offsets were discussed above. They represent the alternative fuel that each nuclear plant in the United States is believed to have displaced. This view involves more displacement of coal than other fuels. The Vision 2020 projection involves at least two assumptions on our part. First we have selected the schedule for the capacity adjustments under the Vision 2020 plan. This places all capacity upgrades in the 2001-2010 period and most new plant construction in the 2008-2020 period. The second assumption is that the proportion of fuels displaced is assumed to be proportional to the fuels displaced under AEO2001 Reference Case assumptions. This makes a large portion of the displacement in the area of coal even though most alternative new construction during 2001-2020 is anticipated to involve natural gas based units. If natural gas is displaced, carbon emission offsets might be considerably lower. Under these assumptions, the Vision 2020 offsets would exceed 200 million metric tons of carbon equivalent.

The following charts illustrate how significant the carbon offsets envisioned by the nuclear power industry might be.

Figure 8. Projected Carbon Dioxide Emissions from Electricity Generation by Fuel, 2000, 2010, and 2020
(Million Metric Tons Carbon Equivalent)

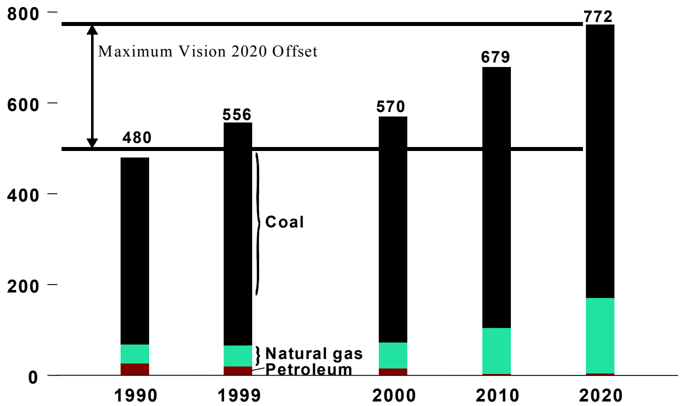


Figure 9. Projected Carbon Dioxide Emissions by Sector, 2000, 2010, and 2020
(Million Metric Tons Carbon Equivalent)

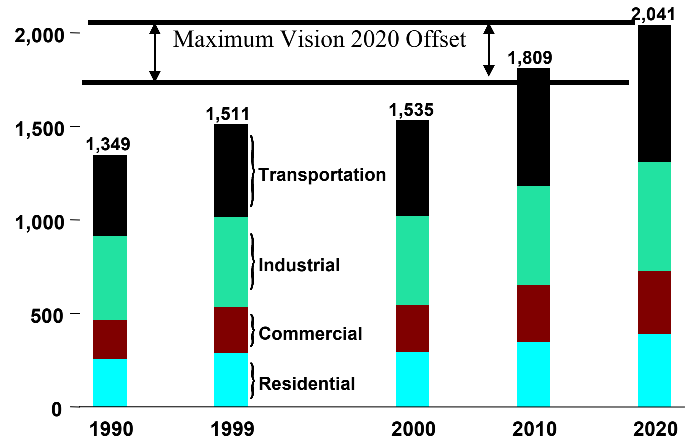


Figure 8 shows the AEO2001 Reference Case carbon dioxide emissions anticipated from the U.S. electric power industry. The Vision 2020 reduction in emissions would be equal to the incremental amount of carbon dioxide emission anticipated from the industry. Figure 9 shows the anticipated incremental additions to U.S. carbon dioxide emissions by all economic sectors. The 200 million metric ton reduction envisioned by the industry would eliminate the anticipated carbon emissions increment for the last decade of the forecast period. This would be the decade during which nuclear investments are more likely to be commercially viable.

This outlook should be tempered by a realization that the Nuclear Energy Institute's Vision 2020 requires an unlikely scale of nuclear plant construction during the latter decade of the forecast period. Even the most optimistic assessments of the cost of building nuclear power plants tend to place the costs of construction at best as competitive rather than dominating during this period. The Vision 2020 interpretation however illustrates that there are alternatives available to carbon taxes and carbon trading that carry the potential of moderating the growth of carbon emissions. The policy judgment that would emerge would require evaluating the relative costs and benefits of each mitigation approach, including non-market costs and benefits.

The emissions problems of fossil fuels go beyond the area of greenhouse gases to include acid gases (sulfur dioxide and nitrogen oxides), particulates, heavy metals (notably mercury, but also including radioactive materials), and solid wastes such as ash. Some of these including nitrogen oxides are also greenhouse gases. Nuclear power produces essentially none of these wastes beyond spent fuels, a unique solid waste problem. Because spent nuclear fuels are radioactive they are pound for pound a more substantial problem than fossil fuel plant solid wastes. In volume spent fuels are a substantially lesser problem.

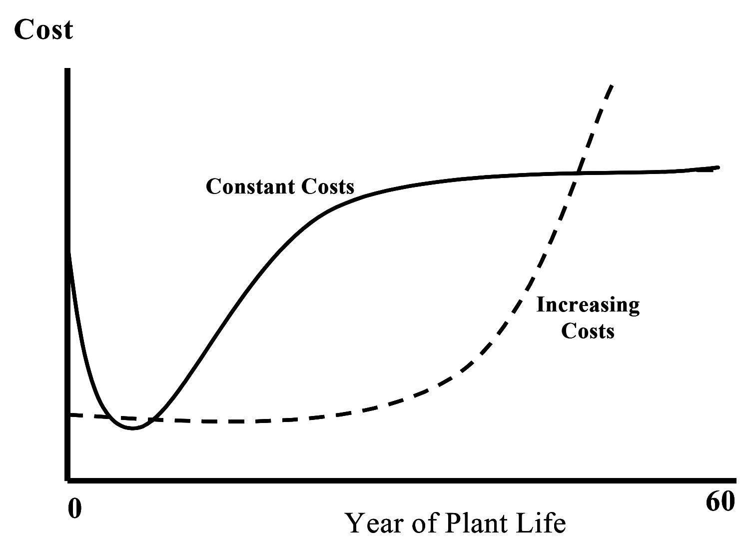
IV. Factors That Affect Nuclear Expansion

There are various factors that could affect future nuclear capacity in the United States. Certainly two would be the construction of new nuclear power plants, which would increase capacity, and the permanent shutdown of existing plants, which has the opposite effect. Less clear but no less important are capacity expansions and the impact of aging equipment at existing plants. More recently the potential impact of terrorism since 11 September 2001 must be added.

Plant Aging and Retirements

Plant aging is in many ways a question of operating costs and replacement capital investments at existing facilities. Although there is some evidence that the operating costs at U.S. nuclear power plants, adjusted for capacity utilization and fuel cost changes, might have declined over recent years, most interpretations of aging costs, including capital replacement, anticipate either constant or increasing operating costs. If electricity prices were unchanged, a constant cost approach would assert that a facility could persist forever, provided nothing more economical came along to replace it. Capital replacement would thus be a recurring cost that would even out over time. An increasing cost assumption would imply that such costs would accumulate over time forcing any facility to be eventually retired as it effectively wears out.

Figure 10. Alternate Theories Regarding Plant Aging Cost



EIA projections assume increasing operating costs, thus plants are retired as they age. This is the idea behind the declining number of operating units in *AEO2001*. Most projected retirements come after forty or more years of operations. Because the oldest operating commercial power reactor in the United States is only 32 years old, there is no empirical evidence to support this view. There is also no reason to deny the interpretation. Retirement schedules are thus also one of the more conscious components of the EIA projections. EIA modeling is also a bit do it yourself. Anyone who chooses can revise it to meet their own needs. It was earlier shown that the Vision 2020 outlook did this. There is indeed one piece of evidence that shows increasing costs to be the long-term case. Except for medieval cathedrals, truly old capital equipment is not the global norm. Age-related cost increases could result in increased ongoing capital costs, decreases in performance, and/or increased maintenance expenditures to mitigate the effects of aging.

The decision to retire a plant is based on the relative economics of the alternatives. In AEO2001, the retirement decision for each nuclear unit is evaluated every 10 years, starting after 30 years of operation. It is assumed that operating costs remain level until 30 years of age, at which point they increase by $0.25 per kilowatt per year over the next 10 years. At age 40 the costs increase by $13.50 per kilowatt per year for 10 years, and after 50 years costs increase by about $25 per kilowatt per year. If the newly projected operating costs are lower than the cost of building new capacity, then the nuclear unit continues to operate for another 10 years, until the next evaluation.

The cost increases at plants that have recently incurred a major expenditure (such as a steam generator replacement) are assumed to be 50 percent lower at 30 years and 75 percent lower at 40 years. The same adjustments were made for the newest vintage of nuclear reactors, to reflect improvements in construction and design. An adjustment was also made for the fact that if a plant continues to operate, a portion of the decommissioning costs would be deferred.

The relationship of nuclear plant retirement to greenhouse gas production is rather straightforward. Without new construction, some nuclear plants will retire. Without new nuclear construction, nuclear plants will most likely be replaced by facilities that burn fossil fuels and thus produce greenhouse gases.

Capacity Expansions

Despite publicity given to interests in building entirely new nuclear capacity in the United States, the most certain source of expansion of nuclear capacity is coming from existing reactors. A recent staff report by the U.S. Nuclear Regulatory Commission indicated that the NRC anticipates requests from reactor owners to expand the capacity of existing reactors in the United States by 1,600 MW over the next 4 years. This is just a fraction of the potential for such expansions if the same technologies were applied to the entire fleet. Indeed some further intentions to increase existing plant capacity have been since received by the NRC. Independent investigations funded by EIA indicate that the potential for such changes is around 10 GW. This is, probably not coincidentally, the same number attained by the Nuclear Energy Institute in its Vision 20/20 program.

It is reasonably certain that the full capacity potential of 10 GW expansion will not be attained. Despite historic efforts at standardization, each operating reactor in the United States is essentially different from the others. Moreover, potential capacity expansions vary considerably by cost. For example, one particular category of capacity expansion, "measurement uncertainty," carries the potential of increasing reactor capacities across the board by 1.0-1.6 percent. The process is relatively inexpensive and can be implemented during routine reactor shut downs. It is reasonable to anticipate the most reactor owners will take advantage of this opportunity, though not all have yet applied for NRC approval for the uprate.

Potential capacity expansions, beyond measurement uncertainty, lie roughly in the 5-10 percent range for pressurized water reactors and in the 10-20 percent range for boiling water reactors. The costs of these investments are particularly variable. Also, because several actions might be required to attain full capacity options, these capacity increases, if they do occur, could take place in stages. While it might be reasonable to anticipate that most such capacity increases might take place over the next decade, the process need not be immediate and will most probably not reach the full 10 GW potential. Moreover the NRC and reactor owners tend to separate the timing of capacity upgrades from plant relicensing. This delays some uprating plans while relicensing takes place. The NRC anticipation of 1.6 GW in uprates is thus too low for eventual achievements while the full 10 GW potential for capacity increases is highly unlikely. Each 1 GW of expansion at existing reactors is roughly equivalent to building one new reactor of traditional design. Such expansion is likely to displace power generation using fossil fuels with the closest competition to nuclear power coming from existing coal and new natural gas plant construction.

As a general rule natural gas-fired combined-cycle power plants cost much less to build than do steam-based coal-fired plants of the same capacity. Coal-fired power plants cost significantly less to build than do nuclear-based power plants of the same capacity. Moreover, it takes much less time to build a gas-fired combined-cycle power plant than it does to build a coal-fired power plant. Nuclear plants take much longer to complete than it takes to build coal-fired power plants. Because a power plant does not earn money during construction, the longer it takes to build a power plant, the higher will be the charges for interest during construction (IDC) on borrowed construction funds.

These charges, taken together require that coal- and especially nuclear-based power plants, must demonstrate operating cost advantages over natural gas if they are to be commercially favored. This is indeed the case, with coal and nuclear experiencing roughly the same operating costs (operations and maintenance plus fuel costs). Nuclear and coal do differ in the source of their operating cost components. Nuclear has much lower fuel costs but much higher operating and maintenance costs than does coal. In recent times in the United States these operating cost advantages have not been sufficient for nuclear to overcome its high investment costs. Thus new nuclear reactors have not been built in the United States. Coal's operating cost advantages have only rarely been sufficient to encourage the construction new coal-based power generation. Around 90-95 percent of new power plant construction in the United States has been natural gas-fired. These numbers exclude capacity expansions at existing coal and nuclear units.

These cost conditions have presented the U.S. coal and nuclear power industries with quite clear targets for their future plans. Most clearly, both nuclear and coal face circumstances under which they must reduce new plant investment costs and construction time. The burden is clearly higher on nuclear producers than on coal producers, because investment costs are higher for nuclear plants with no visible advantage in operating costs over coal. The burden on operating costs on nuclear power plants is also greater with operation and maintenance costs particularly important simply because operation and maintenance costs are a large portion of nuclear operating costs.

Given the financial disadvantages of nuclear power, it is understandable that the nuclear industry also has sought to find additional benefits to using nuclear power. Additional benefits would translate into a willingness to pay higher prices for building nuclear-based power generation. If all market conditions for generating power were otherwise equal, the difference that one might be willing to pay to build a new nuclear power plant would be a measure of perceived environmental gains. Because coal-fired plants produce more emissions, clearly the price differential accepted between nuclear and coal-based power would be greater than the acceptable difference between nuclear power and natural gas.

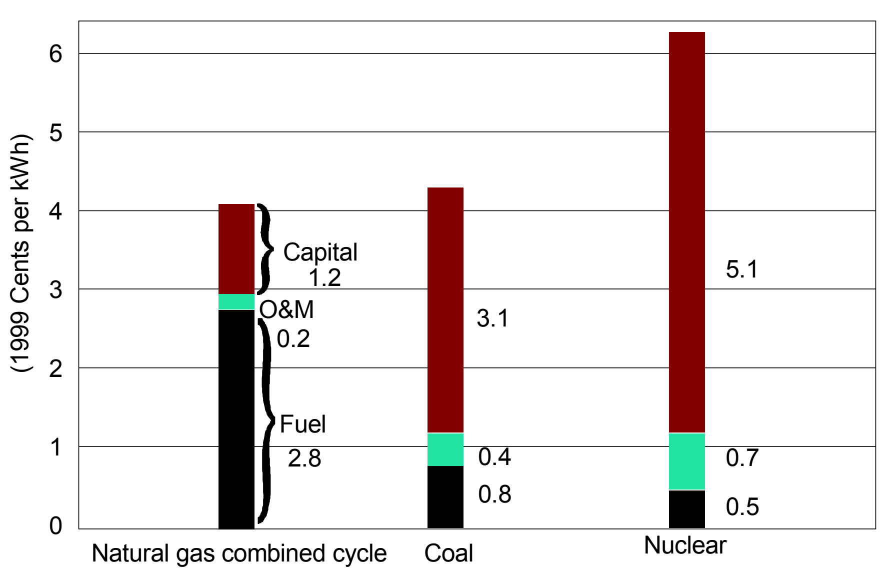
Some advantage might also be gained for nuclear power if nuclear power more suitably filled some niche markets than do other fuels. There is substantial evidence that this is the case because existing nuclear power plants are used at the highest capacity factor of any major source of power generation. While some of this might reflect a technical feasibility of operating nuclear plants at higher capacity factors, some advantages also come from the relatively low fuel costs for nuclear power. Fuel is the principal component of short-term marginal costs for power generation. Thus, if nuclear capacity exists, there is usually an incentive to use that capacity in preference to other, more expensive fuels. Fuel costs are particularly high for natural gas-based plants but are also higher for coal. Nuclear power is thus advantaged for base load power generation because there is less incentive to shut down the plant off peak.

New Construction (Costs and Technology)

The most intense debate regarding the future of nuclear power in the United States is whether new reactor capacity might be built over coming decades. The Energy Information Administration's *Annual Energy Outlook 2001* takes a decidedly negative view of this possibility. The chief reason for this interpretation comes from the essentially conservative character of *AEO* projections. The projections exclude changes in laws and policies and in practice tend to exclude the adoption of technologies that are not already well on the way to becoming established. This overwhelmingly moves our conclusions to the traditional view that nuclear power's investment costs are too high to make investments commercially viable as long as competitive natural gas and coal fired options are available. The following chart summarizes the *AEO2001* assumptions for the costs of building new natural gas combined-cycle, coal, and nuclear construction within the United States. Costs are projections for new capacity to be installed during the year 2005.

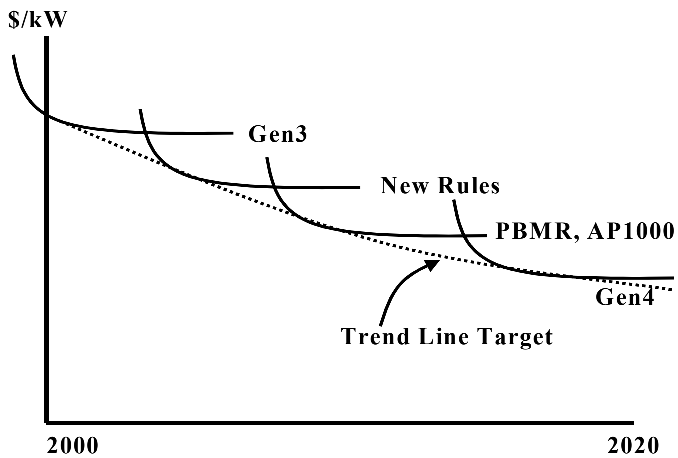
The cost used (Figure 11) in the projection are based on the Westinghouse-BNFL AP600 design though they are intended to be also representative of the other two presently U.S. licensed designs, the General Electric Advanced Boiling Water Reactor (ABWR) and the Westinghouse-BNFL System 80+. No U.S. utility has yet expressed an active interest in building any of these designs, although some are evaluating one or more of these designs.

Figure 11. Nuclear Power's Cost Advantages & Disadvantages



There has been greater success in international markets. The ABWR has been built (twice) in Japan and the design is being built at Lungmen (two reactors) in Taiwan. Japanese utilities are also focusing on the ABWR for their future plans. The System 80+ is the basis for future plans in Korea and Korean vendors are interested in exporting any lessons that they might derive from their own construction experience. An AP600 bid was submitted for a now cancelled construction project in Hungary. Overseas interest in the AP600 has been seen more recently with BNFL discussing possible construction within the United Kingdom. A summary of this experience is that each presently licensed design has attracted some, often potential, interest overseas, the designs have yet to attract widespread commercial interest within the United States. The experience of the licensed designs along with estimates of their construction costs imply that if new nuclear construction (Figure 12) is to be anticipated in the United States, investment is more likely to be directed toward new reactor designs and that these designs will be required to meet tight commercial standards regarding investment costs.

Figure 12. Reactor Technology and Construction Costs (An Example)



There are presently four new designs that have received considerable publicity regarding initial licensing inquiries in the United States though additional designs are excluded here if for no other reason than their lack of public eclat. Two of the designs, the Westinghouse-BNFL AP1000 and the South African-led pebble bed reactor (PBMR) project, presently being developed, are targeted by their developers for full license approval by 2005 if not a year or so earlier. The other two designs, General Atomics' GT-MHR and Westinghouse-BNFL's IRIS design are slated for 2010 completion though later is likely. Of the four designs, the AP1000 and the IRIS are pressurized water reactors. Except for new safety components, the AP1000 is a rather traditional design while the IRIS is more innovative. The PBMR and GT-MHR are also somewhat innovative, though tested, designs involving helium-coolants and gas-turbine generators. The four designs thus require some success in implementing new technologies though this requirement is least burdensome on the AP1000.

The time required to build the earlier potential reactor is also speculative with PBMR reactors usually targeted at around two or three years and the AP600 (similar to the AP1000) at perhaps 4 years. A measure of the feasibility of these targets, which dramatically reduce most nuclear power experience, can be seen with the first two Japanese ABWRs that took a bit more than four years to build. The PBMR, GT-MHR, and IRIS designs are comparatively small in capacity and thus might take less time to complete. It is unlikely that construction will precede design licensing even if such were to be permitted.

Circumstances might be imagined where complete financing might not be required before initial construction begins, but some outside financial support would be required for most new reactors. Lenders are not yet comfortable with new nuclear power designs. Financial requirements might be less stringent for smaller reactors but would be likely to affect the implementation of larger designs such as the AP1000 or the three presently licensed designs.

The licensing, build time, and financial limitations on nuclear construction in the United States would appear to limit the earliest possible completion date to perhaps 2008 or 2009. This would occur only if no unanticipated roadblocks were to arise. First among such potential roadblocks might be the actual cost of building the reactor. No one has succeeded in building a nuclear reactor in recent times at anything resembling construction costs now targeted by vendors and utilities. The nuclear industry has earned its skeptics through a remarkable history of cost overruns. Thus the nuclear power industry might now be beginning a "renaissance" but it will be some time before any renaissance can come into full fruitition. Future construction of large numbers of nuclear plants does not seem likely until the decade of the 2010s, if the event occurs at all. Even then the competition among potential fuels, notable natural gas and coal, should be strong enough to limit construction levels significantly.

Security Issues

The Nuclear Regulatory Commission's response to the 11 September 2001 terrorist incidents was summarized in their *NRC News* press release No. 01-112. The basic conclusions was, as might be anticipated, two-sided, but generally reassuring. Containment at most commercial nuclear facilities is hardened to protect considerable impacts though direct hits by modern scale aircraft were not anticipated in initial designs. Nor have full studies of such threats been undertaken. Security at existing facilities has been enhanced and is likely to remain at high levels. A collision by an aircraft would not however trigger a nuclear explosion and procedures are in place to handle resulting accidents. A summary would be that it is recognized that more needs to be done on the matter and that the need is being addressed. There is no present indication that any existing facility will have its commercial performance seriously affected.

If, subject to events, major changes might not be anticipated at existing nuclear power facilities, the question is not so clear regarding new or anticipated facilities. Designers of new facilities have tended to see containment as a point where nuclear reactor costs might be cut. Indeed, proponents of the PBMR and GT-MHR designs have asserted that fuel degradation is not a reasonable consideration at their proposed units because of technical limitations on the fuel itself and on the temperatures at which the facilities operate. The risks from an aircraft collision, intentional or otherwise, or from a terrorist attack might force reconsideration of this view. Additionally, both the PBMR and GT-MHR designs envision a greater degree of enrichment of the nuclear fuel. This might also affect plant safety assessments. If either of these considerations lead to a higher assessment of plant risk than was initially proposed, containment requirements might be imposed on these technologies. In a parallel manner, reassessments might be made regarding the appropriateness of proposed containment at conventionally-designed reactors. Any decision that revises initial designs might raise the costs of new technologies. Costs are already a sensitive issue at such units, thus their relative commercial attractiveness could decline.

While the threat of terrorist inspired violence might diminish the commercial viability of nuclear reactors,energy security considerations that arise from the same events might raise their attractiveness. Nuclear power proponents in Asia and parts of Europe have long used energy security as a major reason for promoting nuclear power, even if construction costs for nuclear power are higher than the costs of alternative energy sources. If political instability in oil or energy producing regions becomes an issue of heightened concern, energy sources with a higher "domestic" profile, including nuclear, would become more attractive. National policies might promote their development, even if they cost more than internationally supplied energy resources.

V. Conclusion

The environmental advantages of nuclear power are well publicized, even if they are not often paired with the relative disadvantages of spent fuel management and plant decommissioning costs. Any decision to utilize the advantages of nuclear power in meeting greenhouse emissions will arise from a combination of political and economic considerations. The economic component of this decision presently is not encouraging to nuclear power advocates because new nuclear power plants presently cost more to build than do fossil fuel plants. This includes fossil fuel plants such as those fired by natural gas, a fuel that carries lower environmental costs than does the other significant alternative fuel, coal.

If nuclear power is to improve its advantages in mitigating greenhouse and other power plant emissions, the industry will have to lower its costs further than it already has. How far these costs will have to be reduced is uncertain. Because few modern nuclear power plants have been built, it is not entirely clear what building such plants now costs. Nuclear power also has some market advantages that make it more suitable for supplying base load power in some cases. There is thus no certain requirement that nuclear power must exactly match the costs of alternative fuels to become competitive. A recognition of environmental benefits would also make presently high nuclear power construction cost targets less onerous.

The inclusion of nuclear power as an option for mitigating greenhouse gas emissions also provides a nation with a tool that is not presently available under the Kyoto Agreement and subsequent arrangements. The availability of the nuclear options simplifies a nation's tasks. Many options now imposed under the Kyoto and subsequent arrangements such as emissions trading and a more restricted array of clean development mechanisms might divert nations from chosing the most effective array of mitigating options.

Any discussion of nuclear power today must acknowledge the impact of the now active war on international terrorism. Nuclear plants have specifically been enumerated among the potential targets of terrorists. This probably does not mean the abandoning of nuclear power, but it might mean a shift in the choices of what conditions are acceptable for nuclear power. For example, some designs that either do not have containment or that were not intended to have containment, might face reconsideration. Such views would raise the costs of nuclear power production and construction. In contrast, energy security is certainly due to receive higher evaluations in nations that depend on fossil fuel imports. Nuclear power is beyond question one of the most readily available sources of energy independence in the important power generation arena.

Bibliography

Energy Information Administration, "Annual Energy Outlook 2001" (December 2000)

Energy Information Administration, "Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants: Sulfur Dioxide. Nitrogen Oxides, Carbon Dioxide, and Mercury and a Renewable Portfolio" (July 2001).

Energy Information Administration, "Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants with Advanced Technology Scenarios" (October 2001); see website at http://www.eia.doe.gov/oiaf/servicerpt/eppats/pdf/sroiaf(2001)05.pdf.

Appendix

The Kyoto Protocol

Study Results in Light of U.S. Policy and Kyoto Protocol Attainment

Given the increasing level of carbon emissions in the world and the United States, the Kyoto Protocol challenges the United States to meet a specific target. The most fundamental feature of the Kyoto Protocol (agreed to on December 11, 1997) is a set of quantified greenhouse gas emissions targets for Annex I countries, which collectively are about five percent lower than the 1990 emissions of these countries taken as a group. Each Annex I signatory has a quantified emissions reduction limitation commitment.[17] The protocol examines GHG emissions based on six specific cases. The reduction targets for the United States are seven percent, relative to 1990 emissions.[18] Since the United States has not signed the Kyoto Protocol, no specific policies for carbon reduction have been enacted. Voluntary procedures have been implemented, however.

Absent significant changes in energy usage patterns, energy-related carbon emissions will be about 550 million metric tons above the Kyoto target in 2010 and nearly 680 million metric tons above it in 2020. A 500-megawatt coal plant produces nearly a million tons of carbon per year. To meet the target in 2010, the United States would have to achieve a reduction equivalent to the retirement of 550 similarly sized coal plants or almost 80 percent of existing coal capacity.

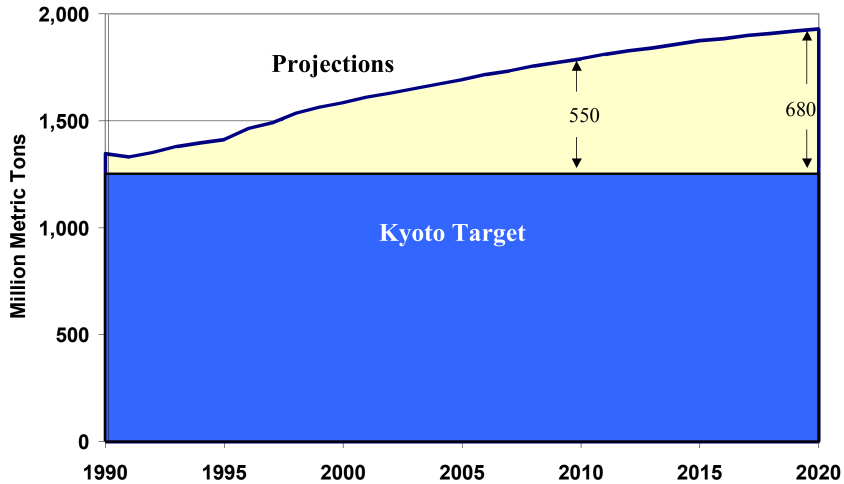
A reference case represents the projections of energy markets and carbon emissions without enforced reductions and is presented as a baseline for comparisons of the impacts in the six reduction cases. Six other cases assume different levels of emissions reductions. In the reference case, carbon emissions from energy increase to 33 percent above 1990 levels in 2010, reaching 1,791 million metric tons.

Although this reference case was based upon a similar case from the *AEO99*, small differences exist in order to permit additional flexibility. This allows for response to higher energy prices or the inclusion of certain analyses previously done offline directly within the modeling framework, such as nuclear plant life extension and generating plant retirements. Also, some assumptions were modified to reflect more recent assessments of technological improvements and costs. As a result of these modifications, the projection of energy-related carbon emissions in 2010 was slightly reduced from the *AEO98* reference case level of 1,803 million metric tons to 1,791 million metric tons. The projected level for 2020 in this reference case is 1,975 million metric tons of carbon and represents an increase of 47 percent relative to 1990.

[17] United States Department of Energy, Energy Information Administration, *Emissions of Greenhouse Gases in the United States 1997*, p. 9.

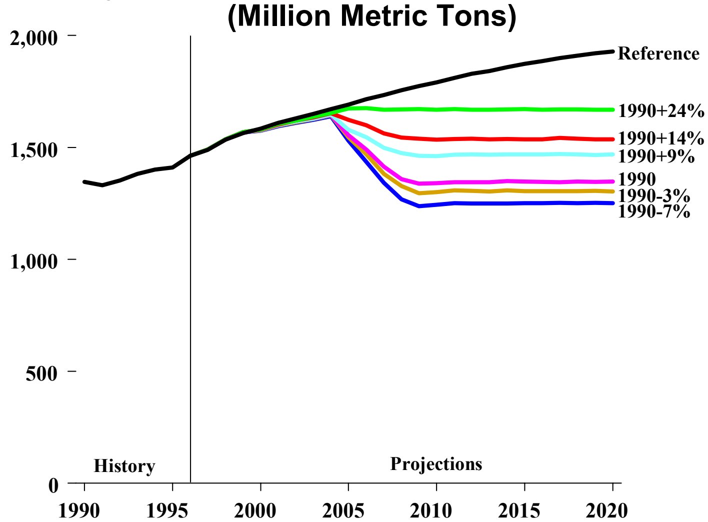
[18] United States Department of Energy, Energy Information Administration, *Annual Energy Outlook 2000*, p. 40.

The Challenge of the Kyoto Protocol



The implementation of each of the six possible reduction targets is assumed to occur over a three-year period, beginning in 2005. This allows for incremental implementation of measures necessary to meet the targets and, therefore, the ability to adjust and match those measures to unforeseeable market developments. It is possible, although not investigated here, that an even longer or more delayed phase-in process could lower the costs associated with meeting the reduction targets. Incorporated in this analysis is the likelihood that some carbon reductions will be realized even before the start of the phase-in period. Such early reductions will be the result of the incorporation of expected future energy price increases in capacity expansion decisions made prior to the phase-in period.[19]

Projections of Carbon Emissions, 1990-2020
(Million Metric Tons)

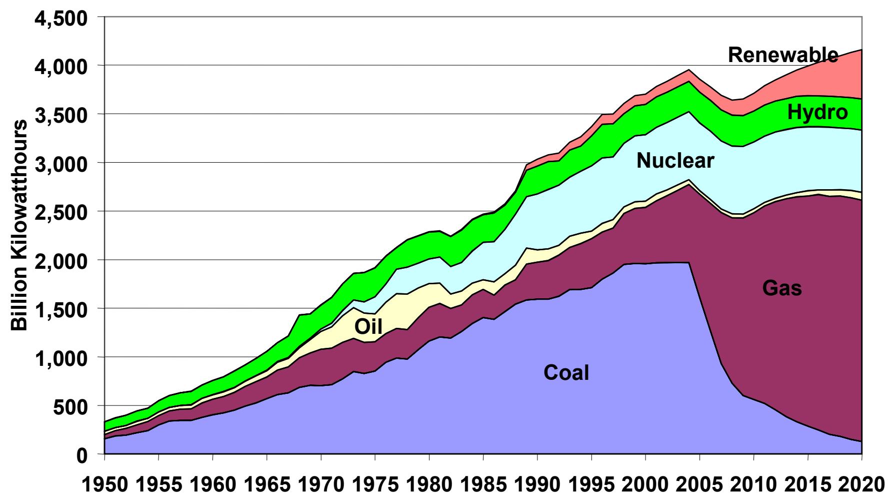


[19] United States Department of Energy, Energy Information Administration, *Impacts of the Kyoto Protocol on the U.S. Energy Markets and Economic Activity*, p. xiii.

Kyoto Impacts: Results

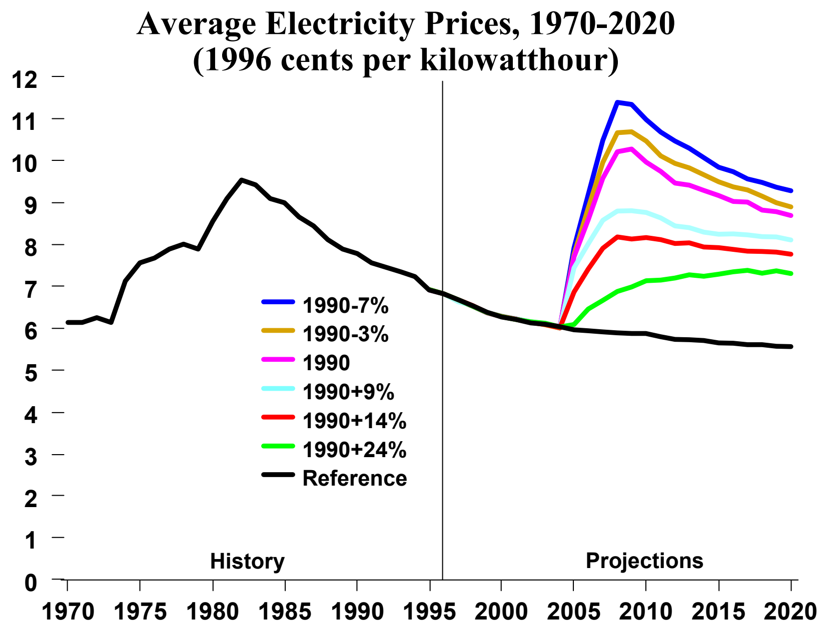
There are several anticipated impacts from the Kyoto Protocol. In one analysis, a carbon price is applied to each of the fuels at its point of consumption relative to its carbon content. Electricity does not directly receive a carbon fee, but the fossil fuels used for electricity generation do receive the fee. This cost is reflected in the delivered price of electricity. In 2010, the carbon price necessary to achieve the targeted reductions ranges from $67 per metric ton in the 1990 +24 percent case to $348 per metric ton in the 1990 -7 percent case. All prices are in 1996 dollars. In the more restrictive cases, the carbon price escalates rapidly to achieve the more stringent reductions but then declines. Cumulative investments in more energy-efficient and lower carbon equipment, particularly for electricity generation, reduce the cost of compliance in the later years. The carbon prices represent the marginal cost of reducing carbon emissions, reflecting the price the United States would be willing to pay to purchase carbon permits from other countries or to induce carbon reductions in other countries. Since this is not an analysis of international trade, these prices do not attempt to represent an international market-clearing price for carbon permits or a price at which other countries would be willing to offer such permits.

1990 -3% Case Electricity Generation By Fuel



18

The United States expects that the major source of carbon reductions in the electricity sector will be the process of switching from relatively high carbon fuels to lower or zero carbon fuels - mainly from coal to natural gas, and to a lesser extent, to renewables. The move towards advanced gas-fired combined cycle plants also leads to a significant increase in average generator efficiency. In the carbon reduction cases, the commercial, industrial, and residential sectors account for most of the carbon reductions, and the transportation sector the least. Most reductions in the non-transportation sectors are due to lower electricity consumption. Very little attention is paid to reducing carbon emissions from personal automobiles. The basis of this lack of attention is the general resistance of the individual to modify personal energy consumption, even in response to drastic price change. However, large central producers and large consumers, such as utilities and industry, do pay close attention to price fluctuation and are more likely to adjust consumption or production technology accordingly.



An examination of the fuel mix in the reference case demonstrates that coal is expected to continue to dominate, but gas will capture the lion's share of the growth. Nuclear will decline, as older plants retire; hydro and other renewables will change very little. This scenario changes dramatically in response to a carbon fee, as seen in the 1990 -3 percent case. The market for coal drops away very rapidly. The relative carbon intensity of existing coal plants (571 pounds per megawatt versus 200 pounds per megawatt for a natural gas combined cycle) makes them very uneconomical. Gas displaces most of the coal. It becomes economical to maintain the operating lives of most existing nuclear plants. Non-hydroelectric electric renewable capacity grows significantly, especially in the later years.

In 2010, carbon reductions from electricity generation will account for between 68 and 75 percent of the total carbon reductions across the various cases. As energy prices increase, electricity consumption is reduced and more efficient, less carbon-intensive technologies are used for electricity generation. On average, electricity prices in 2010 are higher by between 20 and 86 percent compared to the reference case. By 2020 the range narrows to 31 and 67 percent.

Unlike fossil fuel power generation sectors, generation from nuclear plants is expected to decline in the reference case, in which over half of the existing nuclear capacity is expected to retire by 2020. Most of these retire at the end of their 40-year operating licenses; only a few are expected to retire early. In the Kyoto study analysis cases, the economics of maintaining the lives of these plants beyond the end of their original license period is evaluated against the option of building a new plant to replace them. When the carbon fee is added to the cost of fossil fuels, maintaining the life of existing nuclear plants becomes more economical. In the most stringent cases, it appears that it would be economical to maintain almost all of the existing nuclear plants.